Executive Summary

The Australian Geological Survey Organisation (AGSO) has carried out a literature review for the Australian Quarantine Inspection Service (AQIS) to compile environmental data for 66 Australian ports. The data will be used in a risk analysis to assess the survival potential of marine pest organisms introduced via ships ballast water.

A risk assessment framework was designed by the CSIRO Centre for Research on Introduced Marine Pests (CRIMP), includes degrees of detail for each environmental parameter that will be required for the risk analysis at five different levels of complexity. The level of the assessment depends upon the availability of sufficient data, and hence the need for this report, to assess the data available for each port.

This report gives information on the availability of water temperature, bathymetry & layout, dredging activities, surficial sediments, sediment stratigraphy, current and wave measurements and modelling results, habitats, water quality and introduced pests. Since even at the very lowest level of the risk analysis, it is necessary to have monthly mean, maximum and minimum temperature and salinity values, it is clear that the availability of temperature and salinity data is the limiting factor in the risk analysis process. For this reason, extra effort was focussed towards acquiring this information for as many ports as possible. Port sediment maps, bathymetry, dredging activity and habitat information is needed for a “level 2” analysis and hence this information was also given a high priority in our search.

The search methods used included conventional library searches, and the examination of over 1,400 references, World Wide Web search engines (Alta Vista, Blue Pages, etc.) and telephone/facsimile contact with the relevant organisations. A major discovery in the course of this review was that the Australian Marine Safety Authority (AMSA) have created an ARCINFO database for Australian ports and shipping focal areas for use in predicting the dispersal and drift trajectories of oil spills. The database includes bathymetry, sensitive habitats and current modelling routines.

Out of the 66 port studied, 30 are located in estuaries or deltaic distributary channels, subject to seasonal freshwater discharge and episodic flood events. The results of the present literature survey indicate that sufficiently detailed temperature data are available for 39 ports, salinity data for 33 ports, surficial sediment distribution maps for 27 ports and detailed grain size data for 15 ports.
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Part 1. Introduction and Summary of Results

This report was compiled as partial fulfilment of a contract agreement between the Australian Geological Survey Organisation (AGSO) and the Australian Quarantine Inspection Service (AQIS). The aim of the project is to compile environmental data for Australian ports that will be used in a risk analysis computer program which is currently under development by AQIS, in collaboration with the CSIRO Centre for Research on Introduced Marine Pests (CRIMP). CRIMP have defined a risk assessment framework, including the environmental parameters as well as degrees of detail for each parameter that will be required for the risk analysis at five different levels of complexity (Hayes and Hewitt, 1998). The level of the assessment depends upon the availability of sufficient data, and hence the need for this report, to assess the data available for each port.

*Types of information sought*

In the compilation of this report, a number of individual port authorities, commercial organisations and government agencies were contacted to request access to data that could be used in the risk analysis. It was realised that the data will eventually be needed in a Geographic Information System (GIS) to facilitate manipulation, so digital copies of appropriate coverage’s were collected where possible. A list of ports that were included in the survey are shown in Table 1. The major data types that were sought are as follows:

1. Water temperature - Preferably time-series measurements over 12 months with vertical profiles from as many sites as possible. Ideally, the data would be from the ship berths themselves as well as from surrounding harbour areas. Monthly mean, maximum and minimum values are required for the risk assessment at the lowest level.
2. Salinity - Preferably time-series measurements over 12 months with vertical profiles from the same locations as temperature (above). Monthly mean, maximum and minimum values are required for the risk assessment at the lowest level.
3. Bathymetry & Layout - AUS Charts plus maps were sought, in digital format if possible, of channels, berths, wreck locations and spoil grounds complied by port authorities.
4. Dredging activities - As part of the port bathymetry data, descriptions of regular maintenance dredging and any planned capital dredging.
5. Surficial Sediments - Grain size data preferably as frequency histograms and statistics but otherwise, descriptions of sediment texture were recorded. Where it was available, data on heavy metals and other contaminants were also noted.
6. Sediment stratigraphy - information on sediment stratigraphy (age, lithology, depositional history) in the port area was recorded where it was available, particularly for ports which have dredging operations where different sedimentary units have been exposed along the shipping channel.
7. Current and wave measurements and modelling results were summarised from available published information.
8. Habitats - maps showing locations of mangroves, seagrasses, salt marshes, intertidal flats, sandy beaches, rocky shorefaces, etc.
10. Introduced pests - Any studies on the distribution of introduced organisms in the port or even their presence or absence would be important. Higher level risk assessment uses site specific information. Any information on when pests such as toxic algal blooms first appeared would also be useful.

From the review of Hayes and Hewitt (1998), it is evident that even at the very lowest level of the risk analysis, it is necessary to have monthly mean, maximum and minimum temperature and salinity values. These are required for levels 0 to 3 and so it is clear that the availability of temperature and salinity data is the limiting factor in the risk analysis process. For this reason, extra effort was focussed towards acquiring this information for as many ports as possible. Port sediment maps, bathymetry, dredging activity and habitat information is needed for a level 2 analysis and hence this information was also given a high priority in our search. The presence/absence of introduced pests is an area where CRIMP has a special expertise and hence our survey effort was not in this direction.

Search methods and information sources used

The following search methods and important information sources were used in the compilation of this report:

- AGSO library search facilities located the following numbers of references for each state: NSW = 157, NT = 84, QLD = 367, TAS = 60, SA = 129, WA = 396 and VIC = 207. In many cases, references lead to one or more other related papers, which allowed the search to expand as it progressed. In total, over 1,400 references were examined.

- World Wide Web search engines (Alta Vista, Blue Pages, etc.) were used to locate the web pages of relevant port authorities, commercial organisations and government agencies that hold environmental information on ports. In many cases, relevant data were located on the web and the URL for these have been recorded for each port.

- Direct telephone/facsimile contact was made with 29 different port authorities and about 40 other organisations.

- Temperature/salinity/water quality data - a separate sub-contract was let to Earth Oceans and Space Pty Ltd, Sydney, to locate oceanographic data for the ports.

- Sydney Herbier & Botany Bay - a separate sub-contract was let to Sydney University Ocean Sciences Institute to locate data for these ports.

- A report prepared by Harris et al. (1991) which summarises some environmental data for 32 Australian ports, formed the initial basis for the assessment of these ports. This report focussed mainly on sediments, currents and turbidity and did not tabulate temperature or salinity statistics.
A report prepared by Hyder Consulting (1997) which summarises some environmental data for 26 Australian ports, is an important information source. This report did not tabulate monthly temperature-salinity statistics and many other data types do not meet the minimum requirements for the AQIS Ports Database. The ports assessed in the Hyder (1997) report are indicated on Table 1.

A report prepared by Hilliard et al. (1997) which summarises some environmental data for 12 Queensland ports, is an important information source. This report includes only mean, min and max water temperature and wet season and dry season min & max salinity, whereas the minimum requirements for the AQIS Ports Database are monthly statistics. Other data types, such as habitats, currents, sediments and water quality are well covered by the report. The ports assessed in the Hilliard et al. (1997) report are indicated on Table 1.

Table 1. Australian ports, listed by state and alphabetically, and indication of data availability. For the EO&S study, symbols used are as follows: X = Port covered by this study and with at least monthly statistics of temperature and salinity data available; X(S, T) = Port covered by this study and with some data available, at least monthly statistics of temperature (T) or salinity (S) data; x = Port covered by this study but no useful data are available; x? = Port covered by this study but data availability not clear.

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Major data sources

AMSA Database - A major discovery in the course of this review was that the Australian Marine Safety Authority (AMSA) have already created an ARCINFO database for Australian ports and shipping focal areas for use in predicting the dispersal and drift trajectories of oil spills. The database includes bathymetry, sensitive habitats and current modelling routines for simulating the movement of surface water layers for defined input parameters (mainly wind and tidal factors). Coverage's are not at the high resolution for some port areas that might ultimately be required. Nevertheless, the AMSA database provides an excellent starting point for any future ports databases and it is strongly recommended that an agreement between AQIS, AMSA and AGSO be reached, whereby data could be contributed by each organisation as may be required for the mutual benefit of all parties.

EO&S data report and CD-ROM attached herewith gives available temperature and salinity data from several ports, which can be used to derive monthly statistical values as required for levels 0 to 2 risk analyses.

NSW Coastal Resource Atlas - CD-ROM attached herewith, this document includes detailed information on habitats, bathymetry and digital coastline for New South Wales, prepared for the State Marine Pollution Committee as a supporting document for the National Plan to Combat Pollution of the Sea by Oil.

WWW Connections - Listed in Table 2 are some of the most important web URL’s for ports and port environmental data. Information available over the web includes water depths in port approaches and berths, the number of ship berths and their primary uses, weather statistics, tidal data and for some ports real-time wave climate and tidal data are available.
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<th>Table 2. Web servers holding information relevant to the ports environmental database.</th>
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<td>The Association Of Australian Ports And Marine Authorities Incorporated. A list of ports and web page entries is maintained by the AAPMA at these addresses:</td>
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<td>Ports Corporation of South Australia <a href="http://www.portscorp.sa.gov.au">http://www.portscorp.sa.gov.au</a></td>
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<td>Tidal information is available for all Australian ports from the Flinders University National Tidal Facility (NTF): <a href="http://www.ntf.flinders.edu.au/TEXT/TIDES/aust.html">http://www.ntf.flinders.edu.au/TEXT/TIDES/aust.html</a></td>
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<td>Oceanographic data from many ports and coastal areas can be found at the RAN Oceanographic Data Centre (AODC): <a href="http://www.aodc.gov.au/AODC.html">http://www.aodc.gov.au/AODC.html</a></td>
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<td>BHP have lists of port operations and shipping information on their web page: <a href="http://www.bhp.com.au/bhphome.htm">http://www.bhp.com.au/bhphome.htm</a></td>
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</table>
Geomorphology of port environments

An important controlling factor in the context of the hydrography and circulation of individual ports is the geomorphic setting. Ports that are situated in estuaries, (Hobart or Sydney, for example) or that are adjacent to river deltas, will be subject to extreme variations in salinity during peak discharge events. Ports that are located in sheltered embayments, where fluvial input is low and water circulation is restricted, may be subject to extremely high surface water temperatures, as well as evaporation-driven salinity maxima (e.g. Spencer Gulf ports).

A summary of port geomorphic setting is given in Table 3. In general, it can be seen that 30 ports are located in estuaries or deltaic distributary channels, subject to seasonal freshwater discharge and episodic flood events.

Summary of available port information

Table 4 gives a generalised guide to the status of data availability for each of the 66 port studied. For salinity and temperature data, the availability of monthly statistical information is indicated and for sediments data the availability of surface distribution maps and detailed grain size measurements (frequency histograms) for the harbour are indicated. The results of the literature survey indicate that sufficiently detailed temperature data are available for 39 ports, salinity data for 33 ports, surficial sediment distribution maps for 27 ports and detailed grain size data for 15 ports (see Table 4).

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NEW SOUTH WALES PORTS

Botany Bay

The port of Botany Bay is managed by the Sydney Ports Corporation [http://www.sydports.com.au/] and port layout and other shipping information can be found on their web page. The principal imports to the port are crude oil, bulk liquids and containers and exports are petroleum products and containers.

Scientific studies of Botany Bay date back to the voyage of Capt. Cook and his companion, the naturalist Joseph Banks. Banks collected interesting botanical specimens along the Bay's foreshore in 1770 (hence the name Botany Bay). Since European settlement, Botany Bay has been subjected to a series of investigations, in most recent times related to the construction of a third runway at Mascot Airport. The Bay was partly infilled to build Mascot and partly for port reclamation along its northern shoreline, and it has been dredged in several places to allow access for large ships. In the course of all this activity, a considerable volume of environmental data has been collected, which is summarised here.

Botany Bay is another example of a NSW drowned river valley type estuary (Roy et al., 1980; Roy, 1984a). The Bay is generally shallow, less than 10m deep in most areas, except at the Bay entrance and where dredging has been carried out in the north and east. A maximum depth of 21m occurs in the entrance. The isobaths depict a smooth gently sloping surface apart from the area adjacent to Dolls Point, which is the ebb tidal delta derived from George's River.

Hydrography

Bay water is normally marine in salinity, although during flood events the water may become stratified, via input from George's River. Water quality data collected by the Federal Airports Commission (FAC) between December 1996 to June 1997 at several sites is included with this report. Real time ocean surface temperature data is collected at a buoy located offshore Port Jackson and can be viewed on the web: [http://www.mhl.nsw.gov.au/www/real_quick.html](http://www.mhl.nsw.gov.au/www/real_quick.html)

Tidal range in the Bay is 1m on neaps and 1.9m on springs. Maximum tidal current velocities are 40 cm/sec in George's River channel (Roy and Crawford, 1981). Oceanic swell waves penetrate into the Bay and though much dissipated, impact on beaches. Dredging for the Australian Oil Refinery jetty in the 1960's (near Kurnell) changed the wave refraction pattern in southern Botany Bay which lead to erosion of the foreshore at Kurnell; the erosion was subsequently stabilised by the construction of rock groynes (Lord and Nielson, 1989). Such events demonstrate the importance of swell waves on sand mobility within the Bay as well as the far-reaching impact of human activities.
Bathymetry

As part of a project to assess the impact of further dredging in 1970, Roy and Crawford (1981) examined historical charts and air photographs to determine depositional and erosional zones within the Bay. The central Bay floor is considered by these workers to have undergone erosion over the past 150 years, with a net loss of about 110,000 tonnes/year of sand. The rate of shoreface erosion at Towra Point increased as a result of the dredging. Storm events exacerbate erosion rates. Much of this sand has been transported landwards to supply Lady Robinson's Beach and peripheral embayments, with the growth of a new spit on the northwestern side of Towra Point (Roy and Crawford, 1981).

A grided bathymetry map for Sydney Harbour and Botany Bay is available from the Sydney Ports Corporation, which is used to run a tidal model of the port environment.

Sediments

Roy and Crawford (1981) recognized several depositional environments with Botany Bay. Two of these environments are of particular importance to the present study: (i) Bay sediments; and (ii) tidal deltaic sediments. The sand is composed mostly of fine to medium grained, moderately well sorted, rounded to sub-angular quartz with generally less than 5% lithic fragments. This is supplemented with calcareous molluscs (intact and fragments), with minor amounts of foraminifera, ostracods, calcareous algae and echinoid spines (Roy and Crawford, 1981). Mud is derived from fluvial supply of fine terrigenous grains and organic material. Muddy sediment is typically coloured dark grey or brown-black by decaying organic matter. Sediments in Botany Bay are a mixture of these three sediment types (quartz sand, calcareous sand-gravel and mud), in which different deposits reflect their environment and proximity to source.

Well sorted, clean sand with a grain size of 1.8 to 2.0ø covers a large portion of central Botany Bay (SPCC, 1978). Mud content of the sediments is high within the dredged basin west of the runway and within natural basins off Ramsgate and in Woolooware Bay. The deposition of mud in the northern part of Botany Bay appears to be mainly a consequence of dredging and bay infilling activities (Jones, 1981). Detailed statistical analysis of 174 samples collected on the northern margin of the bay, adjacent to the Sydney Airport, are provided by SPC (1993). The effects of substratum on growth of oysters and barnacles in Botany Bay was investigated by Anderson and Underwood (1994).

Waves, Currents and Sand Transport

Statistics on the wave climate inside and outside of the entrance to Botany Bay have been collected by the Sydney Ports Corporation for the period 1971 to 1998. The statistics are monthly values of wave height and period. Over the recording period, the highest maximum wave height for the offshore buoy was 14.12 m (Mar., 1998) when the maximum wave period was 9.44 seconds. For the same month in the Bay itself, the equivalent values are: 1.89 m and 5.33 seconds. These waves are certainly able to mobilise coarse sand and gravel in shelf
water depths of 20 to 50 m. Real-time wave data is collected by the Manly Hydraulics Laboratory and can be viewed on the web:

Data from sand tracer experiments (Goodwin, 1970), current meters and bedform orientations (Roy and Crawford, 1981) have been used to deduce sand transport paths in Botany Bay. Maximum tidal current velocities are 40 cm/sec in George's River channel (Roy and Crawford, 1981). Sand is transported northeasterwards out of the channel and it is deposited forming an ebb tidal delta, located north of Towra Point. Southward transport along the littoral zone of Lady Robinsons Beach contrasts with northward movement in the subtidal zone and hence a general pattern of sand movement into the embayment along the sides and seawards down the centre of the bay is exhibited.

Late Quaternary evolution of Botany Bay

Hann (1986) described late Quaternary deposits in Botany Bay from drill and vibrocore data. Four broad units were identified corresponding with major depositional events: (i) estuarine muds and sands; (ii) Pleistocene aeolian dunes; (iii) transgressive marine sand; and (iv) Holocene marine bioturbated sand and mud. These deposits overlie a fluvially incised bedrock surface (Albani, 1981). It has been generally accepted among workers (eg. Albani, 1981; Roy and Crawford, 1981; Hann, 1986; SPC, 1993) that the sedimentary sequences in Botany Bay correlate with Pleistocene sea level fluctuations.

In the last marine flooding of Botany Bay (about 120,000 years BP) estuarine sands and muds were deposited to a thickness of about 50m (Albani, 1981). These estuarine sediments overlie bedrock and channel gravels. This "estuarine" interval was followed by a period of subaerial exposure during which aeolian sand dunes occupied the coastal area and migrated inland. The dunes piled up against the cliff faces to form ramps which allowed sand to be deposited on top of and beyond the present cliff face (Cowell, 1986; Hann, 1986). Sea level fluctuations during this time allowed some estuarine sediments to be deposited, which became interbedded with dune sands during lower sea level stands.

In the Holocene, sea level transgression between 8,000 to 6,000 years BP caused reworking and landward transfer of sand towards the present entrance of Botany Bay. This sand is thought to have formed a barrier across what is now Bates Bay, such that Port Hacking and Georges River emptied into a larger Botany Bay. The entrance to the Bay was at its present location. By 6,000 years BP sea level reached its present position and the Bay bed was in disequilibrium with prevailing wave and current conditions (Hann, 1986). Thus transgressive estuarine sands and muds were eroded from the Bay bed, exposing Pleistocene sands. Sediment was transported landward onto Lady Robinson's Beach, forming beach ridges prior to 4,000 years BP. In the late Holocene, sediment has continued to be eroded from the bed of Botany Bay and redistributed with the Bay; some sand may exit onto the shelf.

References
Port Jackson (Sydney)

Port Jackson (Sydney Harbour) is the premier port of Australia. An estimated 11 commercial vessels (over 10,000 tonnes gross) enter or leave the harbour every day, in addition to numerous yachts, small craft and ferries; an average of 700 boat movements occur every day on Port Jackson (Cameron-McNamara, 1986). Sydney Harbour contains the RAN Fleet Base at Garden Island and several other RAN facilities are found around the port. The Sydney Ports Corporation [http://www.sydports.com.au/] web page has maps of berth layout in Port Jackson. Also, P&O Ports [http://www.poal.com.au/] have lists of port operations, port maps, and information on their web page.

General Physiography
The harbour is a drowned valley type estuary (Roy, 1984a) comprised of three valley systems: Middle Harbour, Lane Cove River and Parramatta River (Roy, 1983). The fluvial systems forming the valleys eroded down into bedrock (Hawkesbury Sandstone) and the valleys have been infilled to a significant degree in the late Quaternary; the thickness of sediments is about 80m at the entrance and averages about 20 to 30m over much of Port Jackson (Emerson and Phipps; 1969). Inside the entrance there is a flood tidal delta which was at a depth of 6m below the surface, but this was dredged to a depth of 13m between 1869 and 1924. That little maintenance dredging has been required since the channel was dredged attests to minimal sand input to the entrance from the adjacent shelf (Roy, 1983).

The seabed of Port Jackson comprises several deep "holes", rocky islands, shoals and basins separated by sills. The deepest hole is 46m in depth, located upstream from the Sydney Harbour Bridge. Typical holes are about 35m in depth, located on the landward edge of steep sided tidal delta sands; a sill only about 3m in depth occurs over the Middle Harbour tidal delta located near Clontarf (refer nautical chart AUS 200). The entrance to Port Jackson is about 1.5 km in width and 20m in depth; this morphology is in contrast to Botany Bay and Jervis Bay in which the deepest part of the embayment is at the entrance. Such a pattern indicates Port Jackson is at a comparably less mature stage of infilling and estuary evolution (Roy, 1984).

**Bathymetry**

In December 1997 a high resolution swath mapping survey of Sydney Harbour was undertaken by a consortium lead by Sydney University. The digital bathymetry and backscatter data are available and provide the basis for an accurate bathymetric map of the port area (see web page):


A gridded bathymetry map for Sydney Harbour and Botany Bay is also available from the Sydney Ports Corporation, which is used to run a tidal model of the port environment.

A CD-ROM copy of the Coastal Resource Atlas for oil spills in New South Wales (June, 1998) has been obtained and this contains further geographic information including the location of habitats and sensitive environments.

**Hydrography**

Oceanographically, Port Jackson is a partially mixed (occasionally stratified) estuary, with a well defined freshwater plume present after intense rainfalls in the Parramatta River (Wolanski, 1977). Temperature stratification may also occur in summer. During rainfall events, density currents are superimposed on the tidal currents to accelerate the landwards near-bed (cold-saline) flow and the seawards surface (warm-fresh) flows. Under prevailing conditions of low to minimal rainfall, the estuary becomes homogeneous and the system returns to this state within 4 or 5 days of major storm events (Wolanski, 1977). A table listing water quality data collected by Sydney Water between September 1995 and December 1997 at a number of sites is attached to this report. Real time temperature and salinity data
are collected by Manly Hydraulics Laboratory at a buoy located offshore the harbour entrance and can be viewed on the web:

Although tidal range is microtidal (1m on neaps and 2m on springs) tidal currents dominate in the mixing and circulation of estuarine water. Typical current speeds are of the order of 30 to 50cm/sec although surface current speeds up to 100cm/sec are known in the narrow, constricted channels. Little data are available on bottom currents in Sydney Harbour (Irvine, 1980). However, the estuary waters appear quite turbid, which is thought to be caused by sediment erosion and reworking. Irvine (1980) measured suspended sediment concentrations of between 16.1 and 52.4 mg/l at 11 stations and found the highest levels were associated with zones of strong tidal current flow in the narrow channels of central Port Jackson (i.e. in the vicinity of the Harbour Bridge). The occurrence of the scoured deep hole (to 46m depth) in this same area is suggestive of tidal current scouring.

As a result of the construction of the Sydney Harbour tunnel, the seabed will be slightly elevated at the northern end where the rock armour protrudes above the level of surrounding seafloor. Tidal currents may scour around the rocks and cause some localised erosion (Cameron-McNamara, 1986).

Oceanic swell waves are refracted through the "Heads" and are thought to have affected beach development at Chinaman's Beach, Clontarf and The Spit (Roy, 1983). However, waves are diffracted by the complex bathymetry and shoreline configuration such that most of Port Jackson is affected only by locally derived wind- and ship-generated waves (the latter probably being of greatest energy inside the harbour). Sea level in Sydney Harbour is elevated by 0.48cm for every m/sec wind speed blowing from 162° and by 0.74cm for every mb of atmospheric pressure (Thompson, 1983). This "set-up" of the Harbour causes changes in sea level at sub-tidal frequencies with attendant circulation patterns.

Approaches to Port Jackson

Sydney's ocean frontage extends for 80.9km from Broken Bay in the north to Bates Bay (Port Hacking) in the south. Of this frontage, 23.7km is sandy beach, 48.5km is rocky headland and the other portion is comprised of estuary and harbour entrances (Gordon, 1989). The coastal geography is thus dominated by rocky cliffs. Such a pattern is reflected in the seabed morphology of the approaches to Port Jackson, which exhibits large areas of exposed bedrock. Any vessel approaching Port Jackson from the north to northeast must cross an area of exposed bedrock ~5km in width, adjacent to the Port entrance (Roy, 1983). Vessels approaching from the southeast, however, cross sandy areas of seabed.

Sydney Harbour Sediments

Inside the "Heads", the entrance to Port Jackson is floored with a clean, flood delta sand, containing less than 10% mud, which extends ~2km into the embayment from the entrance. This gives way further inside the harbour to areas of mud, muddy sand and sandy mud, interspersed with rocky outcrops. A detailed description of sediment types based on 354
surficial grab and 36 core samples was provided by Irvine (1980) and results from other studies have been summarised Roy (1983). Sediments are derived from three main sources: marine, fluvial anthropogenic sources.

Fluvial sediments dominate the deep holes and shallow bay environments. They are comprised of muds and freshly weathered sand. The fresh sands are eroded from outcrops of Hawkesbury Sandstone and comprise very coarse, subrounded to angular white, clear or brown quartz grains, sometimes stained with iron oxide. Shale siltstone and feldspar are also present. The mud is mostly detrital but it also contains a large organic component together with authigenic iron sulphides. Irvine (1980) examined the clay fraction using X-ray diffraction and found clay minerals are chiefly kaolinite (60%) vermiculite/chlorite (10%) illite (11%) and mixed-layer clays (19%). The surface layers of the muddy deposits as seen in core samples are intensely bioturbated with occasional faint colour laminae and shell layers (Irvine, 1980).

Marine sediments dominate the entrance, Rose Bay and exposed oceanic environments. They are chiefly sands and shelly gravelly sands, similar to those described above for Botany Bay. The quartzose sands are fine to coarse grained, subrounded to subangular moderately to well sorted sand. The grains exhibit a morphology indicative of several cycles of aeolian and marine reworking. The calcareous material comprises both relict (iron-stained) and recent bioclastic material, derived mainly from bivalves and foraminifers with minor amounts of bryozoans, echinoid spines, gastropods and sponge spicules (Irvine, 1980). Core samples from this environment exhibit wave and current ripple cross lamination, planar lamination and burrowing.

A third category are the so-called anthropogenic sediments. Industrialisation in the Sydney area has led to marine pollution (eg. Swane and Irvine, 1987; Birch, 1995; Birch and Davey, 1995; Birch et al., 1996; Birch and Irvine, 1998). Anthropogenic sediments comprise all the different types of refuse introduced by humans into Sydney Harbour, including broken glass, plastic, metal, wire, rubber tyres, tar, paper, slag, coke and coal. Anthropogenic sediments range in size from gravel to silt. The depth at which they occur in cores can be utilized as a chrono-stratigraphic indicator (for determining accumulation rates, depth of mixing, etc.).

Late Quaternary History

The sediments infilling the fluvially incised valley forming Sydney Harbour were deposited in Pleistocene episodes of marine flooding and aeolian sedimentation. In most seismic sections and drill holes obtained, stiff clay and sandy clay layers are interbedded with thin peat, shell and sand layers forming a basal sequence overlying bedrock. These layers are interpreted as representing estuarine sedimentation punctuated by episodes of freshwater swamp development. Erosion of the upper surface of this unit probably occurred during the last interglacial sea level minimum and resulted in the uppermost clays being leached, iron-stained and mottled. On the eastern side of Garden Island and in the Rose Bay area, aeolian sands were transported northwards from Botany Bay (see above) by prevailing winds, infilling part of the basin. Bondi Beach sand is probably the reworked remains of this aeolian dune sand (Roy, 1983).
The next major stage was the flooding of the embayment towards the latter part of the post glacial transgression, about 10,000 years BP. The transgression caused the reworking and erosion of the older Pleistocene estuarine and aeolian deposits. Holocene sedimentation occurred in three depositional environments: marine tidal delta, mud basin and channel.

The tidal delta sands were pushed landwards during the last phases of post glacial transgression and early Holocene and they infill the mouths of Middle Harbour and Port Jackson (west of South Head). Tidal delta sands are 30m thick in Middle Harbour and exhibit landward dipping foreset beds, indicative of the sand transport direction. Tidal delta sands have been dredged from the opening of Port Jackson (see above). Deep basins partially infilled with estuarine mud lie upstream of the tidal deltas. These mud deposits are generally less than 15m in thickness in Port Jackson but in Middle Harbour they are 30m thick (Roy, 1983). Estuarine channel shelly sand and muddy shelly sand occur in the upper reaches of Middle Harbour and in Lane Cove River. These deposits are 5 to 7m thick and appear to have prograded over fluvial mud, with some interbedded sand and mud being evident in the Lane Cove River channel (Roy, 1983). Local dredging operations have affected the separation and deposition of shell and fine muds and sands in different locations.

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**Coffs Harbour**

*Hydrography*

The annual sea surface temperature ranges from 25° in February to 19° in August. Salinity varies only slightly over the course of a year, from 35.2 to 35.5 ppt (Rochford, 1975). The harbour itself is an artificial structure and does not have a significant fluvial influx, hence oceanic water properties prevail throughout the harbour environment. Monthly or weekly values of temperature, salinity and nutrients were collected between 1948 and 1960. Data are held by the CSIRO Marine Research Data Centre and a copy has been obtained for the present study (EO&S report, this study).

*Bathymetry*

Apart from the AUS Chart, no data have been identified for Coffs Harbour. A CD-ROM copy of the Coastal Resource Atlas for oil spills in New South Wales (June, 1998) is available, and this contains further geographic information including the location of habitats and sensitive environments.
Sediment transport

At Coffs Harbour, two islands (Muttonbird and South Coffs Islands) were joined to the mainland prior to 1940 in order to provide a safe port facility (Lord and Van Kerkvoort, 1981a&b; Lord and Nielson, 1989). As a result, the littoral drift of about 75,000 tonnes/yr was blocked. Sand has accumulated on the southern side of the harbour and beach erosion occurs on the northern side (at Park Beach). Also, sand is trapped within the artificial harbour itself at a rate of about 25,000 tonnes/yr. The effects of waves and currents keep sand clear of the bedrock surface which is exposed to a depth of 10 m to sometimes 20 m adjacent to the rocky shorelines to the north and south of the harbour (Millar, 1990). McMonagle and Fidge (1981) have reported extreme wave heights, storm surges and wave setup for the Coffs Harbour area.

References


Lord Howe Island

Lord Howe Island is a volcanic island, about 11 km in length and 2 km in width, located in the northern Tasman Sea at 31° 35’S, 159° 05’E. It is fringed by coral reefs, which are notable given the southern latitude of the island (Veron and Done, 1979). A summary of the islands physical features and submarine environments is provided by the LHIB (1985).

Provisions are landed on Lord Howe Island by a small ship, the Island Trader, which is beached at high tide along side of the island's single wharf.
**Bathymetry**

The available source of bathymetry data is the AUS Chart and some transects across Prince William Henry Bay collected by Veron and Done (1979). Water depths are less than 5 m in the lagoon and the bathymetry is complex in vicinity of the numerous coral reefs. A natural > 15 m deep channel (North Passage) leads through the reef to the boat landing area in North Bay.

**Hydrography**

The CSIRO DMR has Coastal Station temperature, salinity and nutrients data collected between 1976-1985 (data included on EO&S CD-ROM). Lord Howe Island has no major rivers. According to LHIB (1985), in the coral reef lagoon (Prince William Henry Bay) temperature ranges from 21° to 27.5° and the surrounding ocean exhibits variability due to the east Australian Current, which influences this region.

**Sediments and habitats**

Broad characteristics of seabed types in Prince Wiliam Henry Bay have been mapped by Veron and Done (1979) who differentiated reef flat, sandy floor, dense algal mats, intertidal groynes and beaches, lagoon coral zones and a channelled zone. The jetty for ships is in Hunter Bay (LHIB, 1986), where the bottom is mainly sand (Veron and Done, 1979). The habitats around the remaining sections of Lord Howe Island have been mapped by the LHIB (1985).

**References**


**Port of Newcastle**

The Port of Newcastle is located on the Hunter River estuary, about 120 km north of Sydney. Its main use is (inbound) raw materials for steelworks, fertiliser and aluminium industries and (outbound) coal, grain, steel products, mineral sands and woodchips. P&O Ports [http://www.poal.com.au](http://www.poal.com.au/) operate some facilities at the port. The harbour is well protected from SE swell waves by Nobby's Headland and a sand barrier extending northwards from the entrance. The Hunter River channel divides and flows around Kooralgang Island and another branch leads into Fullerton Cove, which is a mud basin trapped behind the coastal barrier spit (Stockton Beach).
Bathymetry

Water depths in the existing port have been increased by dredging operations to allow access to larger vessels (nominal depth of 13m). Some of the dredge spoil was used in the past to reclaim land on Kooragang Island (Roy, 1977). Dredge spoil is also dumped on the inner continental shelf adjacent to the Hunter River mouth. Digital bathymetry data are available for the port and have been provided as compressed DXF files.

Dredge spoil removed from Newcastle harbour and dumped offshore, built up over the years and influenced wave refraction patterns. This lead to wave focussing and an increase in wave conditions at the harbour entrance. The changed wave patterns affected navigation and also lead to coastal erosion at the southern end of Newcastle Bight (Treloar and Abernethy, 1977; Lord and Nielson, 1989).

A CD-ROM copy of the Coastal Resource Atlas for oil spills in New South Wales (June, 1998) has been obtained and this contains further geographic information including the location of habitats and sensitive environments.

Hydrography

As a part of dredging operations, temperature, salinity, dissolved oxygen, pH and suspended sediment concentrations are monitored by the Newcastle Port Authority at selected sites within the harbour environment at the time of each dredge operation. These data include surface and bottom water temperature, salinity, dissolved oxygen, pH and turbidity, collected at approximately weekly intervals, and have been compiled for the time period of 1992-1996 attached to this report. In 1995, surface water temperature in the port ranged from 11.8° (August) to 24.5°C (November) and salinity ranged from 21.5 (June) to 35.2 (May). Water properties are influenced by river discharge from the Hunter River.

Water movements and turbidity

The mean spring tidal range in the harbour is 1.2m. Tides are mixed with a distinct diurnal inequality. Suspended sediment measurements in the Hunter River around Kooragang Island obtained by the NSW Public Works Department (1981) are relatively low (30 ppm). Current metering at 7 locations in the Newcastle Docks area has demonstrated the occurrence of two-layer estuarine flow in this area; maximum near bottom currents were generally directed up-channel whilst surface currents were directed down-channel (Public Works Department, 1981). Such a pattern explains accounts for the retention of marine sand in the harbour mouth plus the offshore removal of fine grained sediments transported in suspension.

Harbour sediments

Roy (1977) examined sediments in the Hunter River estuary and determined that sand is not supplied to the coast of the Newcastle Bight by the fluvial system. Terrestrial (fluvial) sand is not transported beyond Kooragang Island. Sand presently found in the Hunter River...
channel near Newcastle is derived from the reworking of relict marine and aeolian dune sand deposits; sand is not considered to be supplied to the harbour from the adjacent shelf at the present time. Fine sediments transported by the river system are trapped in Fullerton Cove (mud basin) and are removed offshore, probably to become deposited on the middle shelf mud belt (Roy, 1977).

The Newcastle area is heavily industrialised; Roy and Crawford (1984) discussed heavy metal pollution in sediments of Lake Macquarie (a large lagoon adjacent to the southern side of Newcastle) emanating from Newcastle industry. Heavy metal and organochlorine concentrations in dredged harbour sediments have been reported by Batley and Brockbank (1992), and by Matthai and Birch (1997). A report by Ajani and Wansbrough (1996) gives details of an oyster bioaccumulation study as well as further information on contaminants in estuarine sediments. Furthermore, the response of biot to pollution and changes in other environmetal factors have also been investigated (Hodda, 1986; 1990; Hodda and Nicholas, 1985; Walsh et al., 1994, 1995).

*Sediments in the harbour entrance and adjacent shelf*

The continental shelf adjacent to Newcastle comprises an inner shelf plain to a depth of about 45m. Bedrock outcrops occur on the plain in association with headlands and with two groups of offshore rocks (Pinnacles and Rock Peaks). Offshore from the 45m isobath, the shelf slopes relatively steeply down to 120m depth where a second plain, the Outer Shelf Plain, is found. Sediments on the inner continental shelf in the approaches to Newcastle were studied by Gordon and Roy (1977), Roy and Crawford (1980) and Colwell (1982). The latter workers found the shelf sediments to be muddy sands on the inner shelf slope (containing generally <10% mud) and to be gravelly sands on the inner shelf plain. The *inner shelf slope muddy sands* contain poor to very well sorted, fine to medium grained, grey quartzose marine sand and terrestrial mud with 10-30% carbonate (mainly whole and fragmented bivalves and foraminifera) with less than 5% iron-stained grains. The *inner shelf plain gravelly sands* contained poor to well sorted, medium to coarse grained orange-brown quartzose sand, with 5-70% relict, iron-stained rounded quartz and carbonate debris. *Nearshore and beach sands* were well to very well sorted, fine to medium grained quartzose marine sands with typically 7% carbonate content and 5-15% relict iron-stained grains (both quartz and shell).

*Quaternary evolution of the Hunter Estuary*

The evolution of the Hunter River estuary is considered by Roy (1984a) to have occurred in a manner similar to other barrier type estuaries found in NSW. The river mouth was partially blocked by a wave- and aeolian-built barrier system towards the end of the post glacial transgression. This leaves a mud basin behind the barrier which is gradually filled with fluvial sediments. The present configuration of Newcastle Harbour and Fullerton Cove (the remains of the mud basin) are suggestive of stage "C" in Roy's (1984a) model. Boyd and Penland (1984) compared stratigraphic sequences left by shoreface translation at Newcastle Bight with other locations from around the world.

*Introduced pests*
The port has been investigated by CSIRO’s Centre for Research on Introduced Marine Pests (CRIMP) [http://www.marine.csiro.au/CRIMP](http://www.marine.csiro.au/CRIMP) A report in CRIMP’s “Port Survey Report Series” introduced species survey for the port is available.

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Port Kembla (Wollongong)

Managed by the Port Kembla Port Corporation [http://www.kemblaport.com.au](http://www.kemblaport.com.au) this harbour is a commercial port for importing iron ore, dolomite, limestone, sulphur, copper, phosphate rock and petroleum products and exporting iron and steel, coal, coke, tinplate and copper cables. The port is built on the lagoon behind a drowned barrier spit. Allan's Creek emptied into what used to be "Tom Thumb's Lagoon" but which has now been converted into the inner harbour of the Port, dredged to a depth of 11m. A small boat harbour, used mainly for yachts and fishing vessels, has been constructed on the northern side of Wollongong Head.

**Hydrography**

Sea surface temperature data are collected by the the National Tidal Facility in conjunction with the tide gauge operated at the port (data from 1992-98 are included on the EO&S CD-ROM). Monthly oceanic T&S statistics are available for the Port Kembla region. According to the Victorian EPA (1996) harbours report, Albany port sea surface temperatures range from 15 to 21°C and seasonal salinity values are: 35.525 (summer) 35.547 (autumn) 35.544 (winter) and 35.567 (spring).

**Sediments**

Apart from the general data presented above and bathymetry available in nautical charts (AUS 195), data on surficial bottom sediments are available from Bosher (1973; 1977). Bosher (1973) obtained 51 samples from the shoreface to 70m depth and analysed them for grain size, carbonate content and heavy mineral content. The distribution patterns of the poorly to very poorly sorted, coarse grained sediment [slightly gravelly sands (g) S and gravelly sands gS] is affected by the presence of large amounts (up to 80%) of calcium carbonate. The carbonate is derived from coralline algae (up to 50% but typically ~10% of the sample), molluscs (up to 70% but typically ~30%) and bryozoa (up to 40% but typically ~10%). The bioclastic material was concentrated around the Red Point area, in the nearshore...
east of Wollongong Head and in the east of the study area, in depths >40m. Whereas the
inshore bioclasts are associated with a modern source (autochthonous and local supply from
rocky areas), the offshore bioclasts contain a high percentage of relict (rounded, pitted and
iron-stained) material. Mean grain size ranged between 0 to 4ø.

*Bathymetry*

The shelf bathymetry off Port Kembla is complicated by the presence of rocky islands which
act to reflect, refract and diffract waves into complex interference patterns. The occurrence
of mud patches (one sample contained 85% mud) on the shelf is believed by Bosher (1973,
1977) to be related to 'stilling' zones where interference patterns cause wave energy to be
locally suppressed. Mud concentrated in a patch directly adjacent to the entrance of Port
Kembla may have been derived from harbour dredging operations.

A CD-ROM copy of the Coastal Resource Atlas for oil spills in New South Wales (June,
1998) has been obtained and this contains further geographic information including the
location of habitats and sensitive environments.

*Sand transport*

In the nearshore zone Healy and Lee (1975) carried out a fluorescent sand tracer experiment
to determine net littoral transport rates. Beach sand is extremely well sorted quartzose sand
with a mean diameter of 1.32ø (0.4mm). The results of the tracer experiment indicated a
northward annual sand flux of about 35,000 tonnes. However, Healy and Lee (1975) consider
this value to be somewhat low and suggested a northward rate of about 100,000 to 150,000
tonnes.yr as a more realistic value.

Statistics on the wave climate at Port Kembla have been provided by the Sydney Ports
Corporation for the period August 1987 to May 1994. The statistics are monthly values of
wave height and period. Over the recording period, the maximum wave height was 10.93 m
(April, 1988) when the maximum wave period was 9.3 seconds.

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Port of Eden (Twofold Bay)

Location and port layout

The fishing town and Port of Eden http://www.eden.nsw.gov.au/ is at the head of Twofold Bay, which is some 4.5 km wide and 36 metres deep at its entrance. Imports include frozen fish and petroleum oil and the major export is woodchips. The woodchip loading berth is privately owned by Harris Daishowa. It is 11.3 m draught and can handle a vessel of up to 50,000 grt and 230 m long. A tanker terminal mooring buoy allows discharge by submarine pipeline for vessels up to 183 m long and 10.3 m draught. There are two smaller jetties: Eden jetty 183 m in length, with a depth of 7.3 m to 4.9 m and a maximum vessel size of 2,500 grt; and Breakwater wharf (extended in 1987) which is 100 m in length and 3.5 m to 8.8 m in depth.

Hydrography

Monthly and some weekly values of temperature, salinity and nutrients were collected between 1954 and 1985. Data are held by the CSIRO Marine Research Data Centre and a copy has been obtained for the present study (EO&S report, this study).

Waves, currents and flushing time

Wave data were collected near the Eden breakwater and a report published by the Maritime Services Board (1982). The mean tidal range of Twofold Bay is 1.1 m and the maximum astronomical range is 1.8 m and the associated tidal currents are probably quite weak. Wind-driven currents of up to 0.1 m/s have been estimated (Forteath, 1996) and these currents probably dominate water circulation in the bay. Flushing time was calculated by Forteath (1996) by multiplying the surface area of Twofold bay (3,300 ha) by the mean depth (18 m) to estimate the volume of 600,000 ML. Using this volume and estimated tidal and wind-driven current patterns, a flushing time of from 5 to 8 days was estimated (Forteath, 1996).

Bathymetry

Apart from the AUS Chart 191, bathymetry data identified for Coffs Harbour includes a hydrographic survey of Eden Harbour carried out by the NSW Public Works Dept (1993). A CD-ROM copy of the Coastal Resource Atlas for oil spills in New South Wales (June, 1998) is available, and this contains further geographic information including the location of habitats and sensitive environments.
Sediments

Surficial sediments have been mapped in Twofold Bay by Hudson (1991), who defined seven types based on texture and composition (lithology and calcium carbonate content). Sediments are mainly fine quartz sand in the inner bay area, with a zone of coarse sand along the southern and outer parts of the bay. There is a small patch of mud near the centre of the bay (Hudson, 1991), which may be of significance to the present study as a site for dinoflagellate spore accumulation. Several boreholes were drilled under the site of the present breakwater jetty, which was extended in 1987 to its present size (Leventhal and Wagstaff, 1988). The five boreholes penetrated up to 30 m into the seabed and described mainly as grey sand with some shelf and silty layers (Leventhal and Wagstaff, 1988).

Introduced pests

The port has been investigated by CSIRO’s Centre for Research on Introduced Marine Pests (CRIMP) http://www.marine.csiro.au/CRIMP A report in CRIMP’s “Port Survey Report Series” introduced species survey for the port is available.

References


Port of Yamba (Clarence River)

Location

The Port of Yamba http://www.yamba.nsw.gov.au/ is located on the Clarence River estuary, on the NSW coast. It is principally a holiday resort, fishing and prawning town with a population of 3,600. Work on a breakwater at the entrance to the river began in 1862. Yamba is Australia's easternmost port, approximately 310 nautical miles north of Sydney. The Clarence River is 380 kms in length and is navigable by vessels of 4 metres draught to Grafton, 65 klms upstream of the entrance at Yamba. The entrance is protected by two breakwaters. One nautical mile eastward of the ends of the North and South breakwaters defines the seaward limits of the port.
Bathymetry

Port access is limited to vessels which draw less than 4.0 metres plus height of tide (ie about 5.4 metres on spring tides). A CD-ROM copy of the Coastal Resource Atlas for oil spills in New South Wales (June, 1998) has been obtained and this contains further geographic information including the location of habitats and sensitive environments.

Hydrography

The Clarence River is the largest catchment area on NSW Tasman Sea coast, covering an area of 21,900 km² (Virgona, 1992). The NSW Environment Protection Authority carried out a survey of the Clarence estuary in July 1993 and collected temperature and salinity data at this time. The Manley Hydraulics Laboratory have collected tide gauge data, with surface water temperature and salinity, and the available data are copied onto the attached EO&S CD-ROM.

The tidal range and times of high and low water at Yamba are identical to Sydney. Tidal range is 1 m on neaps and 2 m on springs. Tide gauge data are available from the AODC at this web address:

Sediments

Britton and Lord (1984) provide descriptions of local history, geology, coastal processes, sediment movement and mining in the Yamba area. These workers also provide a conceptual model of sediment transport paths, incorporating northward longshore drift, coastal erosion and seaward advection from the river mouth. Smith (1996) studied sediments collected from from aquaculture (prawn) pens and found they had similar chemical and physical properties to those found in some natural mangrove deposits found along the estuarine margins.

Water movements and biota

Fluvial discharge from the Clarence River has been significantly altered from its natural flow pattern, as the result of flood mitigation works and agriculture in the catchment. Changes to the natural fluvial system may have affected the river’s ability to episodically flush-out sediments from the estuary. Such changes have also been implicated in the outbreak of “red-spot” disease in the local sea mullet population (Virgona, 1992).

References


**QUEENSLAND PORTS**

**Abbot Point**

Abbot Point is the location of a coal loading facility managed by the Ports Corporation of Queensland (http://www.pcq.com.au/). Established in 1984, the Port of Abbot Point (http://www.pcq.com.au/abbot.htm) is situated 25 kilometres north of Bowen at the northern edge of the Bowen Basin coalfields. It has a coal handling terminal, two stockpiling areas, an offshore wharf and shiploader. The wharf projects offshore into unprotected waters, and it is thus influenced mainly by open marine processes.

*Hydrography*

According to the report of Hilliard et al. (1997), there are no temperature or salinity data specifically recorded for the port of Abbot Point. Their best estimate of the range of sea surface temperatures is 19.3 to 32.4°C and extreme salinity values are 24.3 to 36.5. The Don River mouth is located only a few km southeast of the jetty and probably lowers surface salinity values during peak discharge and flood events.

*Tides and tidal currents*

The maximum spring tidal range is 2.4 m and tides are mixed semidiurnal. Maximum spring tidal currents adjacent to the wharf are reported by Hilliard et al. (1997) to be of the order of one knot (0.5 m/s). Wind-driven currents of up to 0.2 knots (0.1 m/s) flow parallel to the coast, towards the west.

*Sediments and seagrasses*

Sand and mud deposits adjacent to the mouth of the Don River are deposited mainly on the northwest bank, which indicates littoral drift is in this direction. An estimated 18,000 m3/a of littoral drift transport was cited by Hilliard et al. (1997). Offshore subtidal sediments are described by Hilliard et al. (1997) as broad and gently sloping sheets of silty sand, interspersed with coarse sediments, low rocky outcrops and reefal shoals.

Lee Long et al. (1993) reported 33.35 km² of sea grass beds in the Abbot Bay area.

*References*
Port of Brisbane

The Port of Brisbane is managed by the Port of Brisbane Corporation [http://www.PORT-OF-BRISBANE.QLD.GOV.AU/] and is located on the Brisbane River which empties into Moreton Bay. Ships entering the harbour are obliged to follow a complex route between numerous tidal sand banks at the northern entrance to the Bay. Moreton Bay is about 55km in length (N-S) and up to 35km in width (E-W) but is constricted at its entrance to a width of about 16km. The main shipping channel into Brisbane is dredged at the southern end of Ridge Shoal to a depth of 13m. The main berthing area for ships is near the mouth of the river, and includes large, man-made jetties built by excavation and land-fill along the margins of Fisherman’s Island.

Hydrography

Hydrographic studies in the Brisbane River and Moreton Bay areas have been conducted over a number of years and an extensive and comprehensive data base now exists for the port. Water quality data have been compiled by and for two major government-sponsored programs: the Brisbane River and Moreton Bay Wastewater Management Study (Abal et al., 1998) and the Queensland Department of Environment and Heritage [http://www.env.qld.gov.au/environment/coast/]. The Brisbane River and Moreton Bay Wastewater Management Study has a web site ([www.brmbwms.qld.gov.au]) that leads into a database that can be searched and the data down-loaded as required. Data collected by Queensland Department of Environment from near the mouth of the Brisbane river (adjacent to the berth mooring area) has been provided and is attached to this report.

Mosich (1993) reported on the distribution of two taxa of red alga in relation to salinity variations along the lower reaches of the Brisbane River.

Currents and sediment transport

Moreton Bay is a mesotidal embayment with a maximum predicted tidal range of 2.8m (Department of Harbours and Marine, 1984). Tides are semidiurnal with a distinct diurnal inequality. Ebb and flood currents (flowing north and south, respectively) have formed ebb and flood tidal deltas (Stephens, 1978) comprising numerous channels and sandbanks. On the deltas, currents of up to 200cm/sec have been recorded (Church, 1977, 1979). Although many of the sandbanks are found in depths of less than 10m, the tidal channels in places...
exceed 40m in depth. To the north of the Bay entrance, ocean generated swell waves impact upon the exposed sandbanks and wave transport of sand becomes dominant over tidal current transport (Davison, 1984). The constricted northern entrance to the Bay is sheltered by Moreton Island from ocean generated swell and tidal currents are consequently the dominant sand transport agent. Waverider buoy data collected along the shipping channel between 1980-84 indicates that the probability of exceedence of waves having a significant height of 1m and a period of 9 sec is less than 1% and that the mean wave is only 30cm in height and about 3 seconds in period (Lawson and Treloar, 1985).

Current meter data has been obtained at several locations within Moreton Bay by Church (1977, 1979) and by Harris et al., (1990, 1991), with particular reference to the dredged section of the main shipping channel adjacent to East Channel. Bedload transport vectors estimated from the current meter data vary depending upon location with respect to tidal sand banks. Comparison of a time series plot of bedload transport with corresponding tidal height curves shows that significant transport rates occur only during spring tides and that almost all of the transport occurs during one flood tidal stage in each diurnal cycle. This pattern may be attributed to the mixed tidal regime (Harris et al., 1991). Computer modelling work has investigated the tidal regime of Moreton Bay (Church, 1979; Truscott and Steele, 1991), including wind-driven circulation and the dispersal of floodwater plumes emanating from the Brisbane River (Townson, 1989).

In the Brisbane River, tidal currents are produced by the progressive tidal wave propagating across Moreton Bay; mean spring tidal ranges are of the order of 1.8m at Brisbane River mouth. Tidal currents reach spring tidal speeds of up to 70cm/sec in the lower reaches of the river (Steele, 1990). Sidescan sonographs indicate that several "bedrock reaches" of the river which are scoured free of surficial deposits and the bedrock is exposed (Sargent, 1978). Tidal excursion in the lower River is about 10km and the water is well mixed except during flood events (Steele, 1990).

Sediments of the Brisbane River Channel and Delta

Commercial sand and gravel extraction from the main channel of the Brisbane River has been in progress for the last 100 years. Total reserves are estimated to be about 100 million tonnes and 40 million tonnes has been extracted as of 1990 (Malempre, 1990). The sediments extracted range in size from 1mm to 300 mm and are composed of 13% quartzite, 22% chert and jasper, 26% andesite and volcanics, 11% quartz, and 28% metasedimentary and sedimentary rocks. According to Malempre (1990), the percentage of coarse aggregate that is recovered has fallen in recent years, such that at present only 10% of the mined material is "coarse" (> 5mm). Dredging and tidal current mixing in the lower reaches of the Brisbane River causes water to be relatively turbid, with average Secchi disk readings of ~0.2 m along the section where dredging operations are carried out and <1 m elsewhere (Mosich, 1993).

The Brisbane River delta covers an area of approximately 300 km², which comprises an extensive submerged prodelta, characterised by fine grained mud and muddy sand. The surface and shallow subsurface sediments on the Delta were mapped by Herdy (1997), which show that adjacent to the Fisherman’s Island berthing area, sediments are mainly poorly
sorted, fine grained muddy sand and sandy mud, with a mean grain size of around 0.25 to 0.15 mm. The deltaic sediments infill palaeo-drainage channels exceeding 15 m in thickness locally (Evans et al., 1992), and exhibit a seismic character that has been interpreted by Evans (1991) as indicative of the presence of biogenic gas. Heavy metals associated with the sediments of the supratidal delta have been investigated by Arakel and Hongjun (1992) and the occurrence of ploycyclic aromatic hydrocarbons in sediments and water in the Brisbane River channel have been investigated by Kayal and Connell (1989, 1990). Mackey and Hodgkinson (1995) reported a moderate level of pollution based on measured heavy metal concentrations in 50 surface sediment samples collected 1 km upstream of the Port of Brisbane in an intertidal mangrove swamp.

**Sediments in Moreton Bay**

Data sets compiled on the beds of the Brisbane River and Moreton Bay are as comprehensive as for any port in Australia. Sidescan sonar surveys have been carried out in the Brisbane River (Sargent, 1978) and in the northern approaches (Stephens, 1978; Harris et al. 1991). Detailed sediment mapping and coring programmes have also been carried out (Jones et al. 1978). The following is a brief summary of the available data. Heavy metals in the sediments of the Brisbane River have been measured by Moss and Costanzo (1998).

Sediments in Moreton Bay occur as four major types: (i) fluvial delta quartz and lithic sand; (ii) prodelta mud; (iii) muddy sand; and (iv) tidal delta quartz sand. All four sediment types occur along the main shipping route. The delta is composed of fine grained quartz and lithic sand and is about 2.5m in thickness at its seaward margin (Jones and Stephens, 1981). The prodelta muds are fluvially derived. The muds are subject to resuspension by large surface waves, which results in the dispersal of the muds over a wide area. The intermediate sandy-muds represent distal deltaic sedimentation and mixing with relict quartzose sand deposits.

The tidal deltas are the best studied sedimentary facies in Moreton Bay, mainly because of their significance to shipping and as a supply of quartz aggregate to the building industry. In 1983, 14 million tonnes of sand was dredged from the Middle Banks to supply material for the construction of Brisbane Airport. The tidal deltas are composed of quartzose, fine to medium sand with a modal grain size of about 2.2ø (Jones and Stephens, 1981). The sands are thought to be supplied partly by the reworking of a Pleistocene tidal delta or coastal barrier substrate (Maxwell, 1970; Jones et al. 1978). The present day supply of sand to the Bay is chiefly the result of northward littoral drift along the eastern coastlines of Moreton and Stradbroke Islands (Stephens et al. 1983). The rates of sand transport along this stretch of shoreline are likely to be similar to those found along the nearby Gold Coast, where it has been estimated at about 450,000 tonnes/yr (Pattearson and Patterson, 1983).

Other sand sources of sand to Moreton Bay include southward littoral drift along the coast of Bribie Island and supply from the erosion of the western shore of Moreton Island (Ward, 1982). Fluvial sources supply only fine grained suspended sediments to pro-delta mud deposits in the western side of Moreton Bay and do not contribute sand to the tidal delta system (Jones et al. 1978).
The tidal deltas of the Bay are formed by a complex series of sandbanks which range in height from 7 to 20m and have crestlines from 3 to 9km in length (Stephens, 1978). The crestlines of the sandbanks are sinuous and three-dimensional in character, as delineated by the 5 and 10m isobaths. The mobility of and dynamics of sandbanks has been studied by means of successive aerial photographs spanning a 26yr time period (Harris and Jones, 1988). Comparative photographs have demonstrated that: (i) some of the sandbanks migrate whilst for others no movement was detected; (ii) migration is non-uniform along some sandbank crests causing them to become distorted into complex S-shapes; (iii) two areas of rapid sandbank change correspond with areas offshore from promontories, suspected of being sand depocentres; and (iv) morphological examples of the sequential development of sandbanks occur as described by Caston (1972). Dune and sandbank morphologies were interpreted from aerial photographs to represent mutually evasive ebb- and flood-dominated zones of net bedload transport (Harris and Jones, 1988).

In a recent programme, the Ocean Sciences Institute has carried out an intensive field programme over the East Channel area of Moreton Bay (Harris et al. 1990; 1991). Data included surficial grab samples and vibrocores obtained along one east-west transect. Plotting the grain size data obtained from the top 0-2cm of cores and from surficial grab samples along an east-west trending cross-section shows that mud concentration is highest in the deeper water channels, particularly in Main Channel, where mud content of sediments reaches 29%. In terms of the sand grain size characteristics, there is an apparent fining towards the west. Sorting, on the other hand, becomes poorer in a westward direction although there is much variation between stations located upon the sandbanks. Skewness of grain size populations is nearly symmetrical to fine skewed throughout the study area.

**Bedforms**

Harris et al (1990) obtained sidescan sonar and high resolution seismic data along 250km of survey track line. Bedform wavelengths, crestline strikes and lee slope orientations were measured from the sonographs (Harris et al., 1991). Geometric corrections were applied to derive crestline strikes and lee slope orientations for dunes identified in sidescan sonar images. The results indicates a predominantly southward transport of sand in the area studied. Repeated observations and available current meter data indicate that bedform orientations do not reverse over tidal cycles. Localised areas of northward (ebb) transport were found in the crestal areas of Middle Bank, Dring Bank and Ridge Shoal. Harris and Jones (1988) mapped zones of net ebb and flood dominance on the basis of dune and sandbank morphology, and identified much larger areas as being flood or ebb dominated.

Sets of parallel lines, separated by 15-20m, were observed in some sonographs, which intersect each other and curve across sonographs. These are interpreted as fishing trawler marks, created probably as trawl boards are dragged along the seabed. The marks are characterised by a light tone on the sonographs, seen more clearly on the 100kHz as compared with the 500 kHz images, which suggests they are 2m wide grooves (i.e. localised depressions) partially infilled with unconsolidated sediment. Where they occur, their preservation is an indication of relatively low bedload transport rates.
Dune wavelength exceeding 20m are restricted spatially to the western slopes of larger scaled sandbanks. These large dunes invariably have smaller scaled dunes superimposed. Both 2-D and 3-D dune crests were observed. The boundary delimiting the areal extent of dunes is readily identified on sonographs. The most common wavelength for dunes appears to be in the 10-20m bracket and these dunes did not have smaller forms superimposed. Dunes having a wavelength of less than 10m occur in bathymetric depressions and occur as a fringe along the edges of the dune field.

Sedimentary structures and sequences

Boreholes obtained from Four Fathom Bank and Middle Bank as described by Coffey and Hollingsworth Pty Ltd. (1972), penetrated up to 15.7m into the sandbanks. One borehole, obtained upon Four Fathom Bank (no. 4), encountered an indurated sand at 2.7m. At about 6m depth below the seabed, boreholes from Four Fathom Bank (no.s 4 and 5) encountered a "clay of medium to high plasticity" (Coffey and Hollingsworth Pty Ltd.; 1972). All of the other boreholes penetrated into loose sand with varying amounts of clay occurring as lenses and, at one site (no. 9), an organic rich layer containing "decayed wood and roots" was encountered at 10.7m below the seabed. No radiocarbon dates were obtained from any of the borehole samples.

Seismic profiles obtained by Harris et al. (1990; 1991) show fluvial cut and fill features and deeper relatively smooth surfaces. The data confirms the existence of sub-bottom reflectors beneath the Holocene-Pleistocene sand deposits, as proposed by Jones et al. (1978). However, the banks appear to be structureless in the seismic data, indicating the lack of any acoustically reflective surfaces within the banks.

One vibrocore obtained by Harris et al. (1990; 1991) contained 140cm of shelly muddy sand overlying a cohesive Pleistocene clay (VC2). The other cores penetrated only into sand, with slightly higher mud in the deeper water cores. Mean grain size was typically constant through the cores at around 2ø, with slight coarsening upward trends being evident in VC2 and VC8. Sedimentary structures observed in the cores include foreset beds and burrows. All of the cores showed indication of intense bioturbation as indicated by a mottled appearance to the cores; bioturbation is linked with an increase in shell and mud content. Forests occur as solitary sets bounded by bioturbated units, and are delineated by coarse shell-hash layers in which the shells are aligned with the bedding plane. Variation in the thickness of the foreset beds is attributed by Harris et al. (1991) to changes in transport rate over spring-neap tidal cycles. Thus, they are a type of "tidal bundle", in which the character of the laminated sequence is related to tidal cyclicity. Furthermore, Harris et al. (1991) have related the alternating bioturbated - foreset sequence to the passage of a climbing dune, in which bioturbation destroys the upper part of the foreset beds but leaves the lowermost sections undisturbed; the passage of many dunes results in the alternating sequences observed.

References


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**Bundaberg**

The Port of Bundaberg is located about 4.5 km upstream from the mouth of the Burnett River. The township of Bundaberg is located 12 km upstream of the river mouth. Two commercial wharves in the port are used mainly to export bulk sugar and molasses and import petroleum products. The shipping channel is dredged to a depth of 7.3 to 7.6 m. The dredge spoil is dumped 3 km offshore of the river mouth in >10 m water depth.
Hydrography

According to the report of Hilliard et al. (1997), there are no temperature or salinity data specifically recorded for the port of Bundaberg apart from a two week survey conducted in February, 1995. Based on these and other unpublished data, their best estimate of the range of sea surface temperatures is 15.7 to 29.2°C and extreme salinity values are probably 25 to 35.5 °/oo. Surface salinity values may be much lower during peak discharge and flood events.

The Burnett River has a catchment area of approximately 30,300 km² and has had 20 dams or weirs constructed on it to facilitate irrigation. These dams have reduced the rivers discharge at the mouth and only large rainfall events can flush through the entire length of the river system. Pollution problems related to inputs from two sugar refineries and a distillery were exacerbated by the construction of a tidal barrage on the Burnett River just upstream from Bundaberg, which reduced the rate of mixing and dispersal of effluent discharged into the river (Miller, 1985). Modelling work on the river by Miller (1985) showed that only relocation of the effluent point source discharge further downstream would resolve this problem. Lupton et al. (1995) conducted a study to document fish species in the Burnett River, in relation to the impact of the tidal barrage which had caused fish kills and algal blooms on the river.

Overuse of groundwater caused the watertable to be lowered by about 6 m and about 45 km² of coastal land to become degraded due to saltwater intrusion between 1968 and 1971 (Hillier, 1993). Subsequent management of groundwater resources has seen usage reduced to equate to the safe yield of the aquifer, although continued groundwater resource management is required (Hillier, 1993).

Tides and currents

The tides are mixed semidiurnal in character and have a maximum spring range of 2.35 m. Currents at the mouth of the Burnett may attain 2 knots (1 m/s) on spring tides. Flooding tidal flows are reduced during periods of high river discharge.

Sediments and habitats

Sediments sampled on the river bed are mainly sands and silts, reworked by the strong tidal flows (Hillier et al., 1997). Seagrasses colonise the channel floor that is not dredged routinely and turbidity levels in the river are generally low. Mangroves colonise much of the river bank area and the low lying deltaic islands at the mouth of the river. Lee Long et al. (1993) reported 2.07 km² of sea grass beds in the Burnett River area.

References

The Port of Cairns is located on Trinity Inlet and close to the Barron River that empties into Trinity Bay. Access to the port is via a shipping channel dredged to 8m, which leads across the shallow muddy bottom of Trinity Bay. The port hosts a RAN Base plus 11 commercial berths used to export bulk sugar and import petroleum and containerised freight. P&O http://www.poal.com.au/ have lists of port operations, port maps, and information on their web page.

**Hydrography**

Trinity Inlet receives freshwater runoff from the Barron River (catchment area of 2,200 km² and mean annual flow of 1.02 km³; Johns et al., 1994) and a small contribution from Smiths Creek, the location of the Port of Cairns. Rainfall is seasonal, with 80% of the 2005 mm average falling during the monsoon (December to April). This gives rise to a seasonal discharge pattern which effects both surface salinity and turbidity in the port area.

Hilliard et al. (1997) cites an unpublished report by Dames and Moore to the Queensland Bulk Sugar Organisation, and gives sea surface temperatures ranging from 20 to 32°C. Extreme variations in surface salinity occurs in the port during flood events which forms a ~1m thick layer of brackish surface water, having a salinity of 5 to 25‰. At other times, salinities are in the normal range for the adjacent waters of Trinity Inlet, from 34.4 ‰ (summer) to 35.2 ‰ (winter). More detailed T&S information will become available in the

**Tides, currents and suspended sediments**

Mean spring tidal range in Cairns is 1.8m and the tides are semidiurnal with a large diurnal inequality. Spring tidal flows in the entrance and along the approach channel may reach speeds of 3 knots. Strong currents are also common in the narrow channels associated with the inner estuary (Hilliard et al., 1997) although Furukawa et al. (1997) measured currents of
only 0.2 m/s in a channel draining a mangrove swamp. Tidal current scour has formed local ~10 m deep holes in Smiths Creek.

Suspended sediment concentrations vary seasonally, reaching their maximum levels during flood events. Typical (winter) dry season background levels average around 7.8 mg/l (range from 0.6 to 17.8) but typical summer monsoon turbidities average 35.5 mg/l and high river discharge can increase concentrations to as high as 280 mg/l (Hillier et al., 1997). This sediment appears to largely remain trapped in the mangrove swamps and tidal flats surrounding estuary. A study of sediment transport in mangroves in Middle Creek showed that about 80% of the suspended sediment brought in from coastal waters at spring flood tide was trapped in the mangroves (Furukawa et al., 1997). Hamilton (1994) found that inner shelf sediments having a high mud content also give rise to regions susceptible to high turbidity levels, caused by wave resuspension.

**Sediments**

Bottom sediments in the port berthing area are mainly clays, silts and fine sands, containing high levels of organic matter and sulphide (Hilliard et al., 1997). Sediments in a transect of cores collected from Cairns harbor across Trinity Bay contained 60% mud and 1.5% total organic carbon (TOC) in the harbour and over 90% mud and 1.1 to 1.5% TOC at 10 km distance from the harbour entrance (Johns et al., 1994).

The offshore surficial sediments of Trinity Bay were examined by Jones (1985), who obtained 181 grab samples in the Bay. The sediments are well to poorly sorted clean to muddy sands. The clean sand is 80% quartz with up to 20% felspar, 10% rock fragments and 4% mica with generally less than 20% carbonate. Sand content varies over the area but is concentrated in the shallow nearshore zone (to a mean depth of 0.8m below LAT) where surface wave reworking winnows the fine fraction for offshore deposition. The water content of the surficial sediments is mostly in the 40-50% range although it does exceed 50% in places. Water content correlates with the muddier sediments, and is particularly high in the dredged shipping channel and in two large patches off Cape Grafton and Yorkey Point. Low water content correlates with the well sorted clean sand shoreface deposits. It may be expected that high frequency sonar backscatter would vary over Trinity Bay as a function of these changes (in water, sand and mud content).

Sand content is directly related to bathymetry. Mud content is highest in the central part of the bay and in association with the dredged shipping channel, where it exceeds 90%. The terrigenous mud and sand forming the surficial sediments are derived almost entirely from the Barron River, with little if any sediment entering the bay along the coast around Cape Grafton (Jones, 1985). Brady et al. (1994) examined the heavy metal concentrations in marine sediments, and suggested that iron content could be used as a tracer for the dispersal of river-derived sediments along the inner shelf. Johns et al. (1994) reported on a geochemical discontinuity in a sediment core collected in 20 m water depth (11 km distance offshore) in Trinity Bay, which they interpreted in terms of terrigenous input during a cyclone or flood event.
Papers by Jones and Stephens (1986) and Murray and Ford (1983) discuss the coastal evolution and littoral drift processes operating in the area. Jones (1985) compiled available seismic data and constructed an isopach map for deposits of Trinity Bay, overlying a reflector termed S-3 (equivalent to reflector "A" as defined by Johnson and Searle, 1984). The sediment thickness is greater than 10m in the central part of the bay where old river channels have been infilled with sediment. The age of this infilling material is unknown and may have been deposited by the river system in the Pleistocene or as a backfilling of the channel during the postglacial sea level rise (in the context of Johnson et al., 1982). The remaining material appears to represent deltaic infilling of the bay under the Holocene sea level still stand. The muddy sediments are transparent to seismic energy, allowing good definition of the Pleistocene unconformity (Jones, 1985). They reach a maximum thickness adjacent to Cape Grafton on the southeastern side of the bay. The similarity between this depositional pattern to that of Cleveland Bay (Port of Townsville) is noteworthy. The Holocene muddy sands thin both northwards and eastwards (offshore) with increasing distance from the Barron River fluvial point source.

**Seagrasses, mangrove habitats and biota**

Seagrasses in Cairns Harbour have been studied by Coles et al. (1993), McKenzie et al., 1994) Coles et al (1993) used aerial photography and diving surveys to map 8 species of seagrasses, covering an area of 876 ha in Cairns Harbour. Over the Cairns Harbour Mission Bay areas, Lee Long et al. (1993) reported 21 km² of sea grass beds. Seagrasses were found only between 0.5 and 5.0 m below mean sea level. Commercially important prawn species were significantly greater on seagrass-covered substrata than on non-vegetated substrata.

Mangroves cover an area of 860 ha in Cairns harbour, although dieback has occurred (Weste et al., 1982), possibly due to accelerated sedimentation since European settlement. von Westernhagen, H and Klumpp (1995) measured the concentrations of pesticides in ovaries and livers of Queensland marine and estuarine fish species and found the highest values were in waters adjacent to the main sugarcane growing areas of Ayr, Mackay and Cairns.

**References**


receiving ports (EcoPorts Monograph Series No. 10). Ports Corporation of Queensland, Brisbane, 71 pp.

Cape Flattery

The Port of Cape Flattery (http://www.pcq.com.au/capef.htm) exports very fine-grained pure silica sand from a 350 m long jetty which has a single-berth. The jetty extends into the open marine waters of the Great Barrier Reef lagoon and it does not require any maintenance dredging. Water depth of the berth is 15 m.

Hydrography

According to the review conducted by Hilliard et al. (1997), no water salinity or temperature data have been collected at the port. Best estimates using regional information are that the sea surface temperature ranges from 22 to 32°C and salinities range between 35.3 (summer) and 34.4 (winter). Only local runoff from the adjacent coastal area will effect surface salinity values; there are no large rivers in the region, the nearest being the Normanby which enters...
the sea at Cooktown, 60 km to the south of the port. Hilliard et al. (1997) cite unpublished data for Secchi disk depths (4m) and suspended sediment concentrations (1.7 mg/l) which indicate that waters in the area can be relatively clear.

No measurements of currents are available for the jetty area. Modelling work conducted in coastal areas of the Great BarriRed Reef have been summarised by Wolanski (1994) and these generally show that the inner shelf coastal flow is northwards during the SE trade wind season (May to November) and is weak or southward during the northerly monsoon (December to April).

**Sediments and seagrasses**

Much work has been carried out on the subaerial dunes (Pye, 1982a, 1982b) and lakes (Hawkins et al., 1988) of the Cape Flattery area. Unpublished grain size information (PTH) is available from a sample of beach sand taken near the jetty. The sample was composed of very well sorted aeolian >99% quartz sand having a mean grain diameter of 120 µm. This sand is probably representative of that found in the subtidal berth area, although some in situ biogenic carbonate may be mixed with it in the offshore environment. The subtidal sand sheet is colonised by seagrass meadows (Hilliard et al., 1997) but the area is heavily used by prawn trawlers, and the sparse cover of seagrasses initially reported in the area is attributed to this activity (Coles et al., 1984). Lee Long et al. (1993) reported 10.67 km² of seagrass beds in the Cape Flattery area.

The destruction of seagrass beds in shallow waters along the Queensland coast can be caused by cyclone and flood events, which both physically uproot the seagrasses and bury them under sediment. In Hervy Bay, such processes have been documented in the destruction of 1000 km² of seagrass beds, and the problem is considered to be exacerbated by prawn trawlers (Preen et al., 1995). Recovery may be slow but substantial regrowth (especially in deeper water, below 10 m) appears to have occurred after two years in the Hervey Bay case. More recent studies cited by Hilliard et al., (1997) have shown that the seagrass cover at Cape Flattery is large and diverse. Hence there appears to be considerable temporal variability in the density of seagrass beds, resulting from the interplay of these processes.

**References**


Port of Gladstone

The Port of Gladstone (http://www.gpa.org.au/) receives about 8 million tonnes/a bauxite shipped around Cape York from Weipa via the GBR Inner Route. Exports include coal, alumina, grain and livestock. During 1983-84 the harbour handled 510 ships carrying 23.4 million tonnes of bulk cargo (O'Keeffe and Harding, 1985); by 1996/97 this has risen to 770 ship visits and 39 million tonnes per year.

A report was provided by the Gladstone Port Authority (GPA, 1998) which summarises the available information on port water temperature, salinity dissolved oxygen, pH, port sediments, habitats, occurrence of algal blooms, waves, tidal currents, meteorology, water and sediment toxicants, freshwater inflow, fishing uses and dredging/engineering activities. The following is extracted mainly from this report plus other references found in the literature survey.

Hydrography

According to the Victorian EPA (1996) ballast water study, sea surface temperatures range from 20 to 28°C and seasonal salinity values are: 35.279 (summer) 35.325 (autumn) 35.527 (winter) and 35.359 (spring). The Gladstone Port Authority (GPA, 1998) have installed in January, 1998, two Aqualab systems which automatically collect and analyse water samples daily at Clinton and Boyne Is. Wharves. The systems monitor water temperature, pH, dissolved oxygen, electrical conductivity (salinity), turbidity and available phosphate.

Port water temperature is affected by cooling water discharge from Gladstone Power Station into the Calliope River. Ross and Curtis (1989) reported on measurements obtained during the period 1975-85 from short and long term monitoring, remote sensing and studies of tidal conditions. The studies found that water temperatures had increased by more than 2 degrees C above natural levels, with greatest temperature rises during winter (15-25% above average annual figures). Tidal range has an effect on the dilution and advection of the thermal...
discharge, with warm water discharge extending from the outfall across to the other side of the river at slack tide. Significant thermal stratification occurs near the outfall during the incoming and high stages of the tide.

Freshwater runoff from the Calliope and Boyne Rivers and Raglan Creek may effect port salinity values only during rare flood events. The total catchment area of the three systems is 3827 km² and the mean annual discharge is 683,000 ML (GPA, 1998). Discharge is seasonal, with 75 to 90% of occurring in the monsoon season, November to April.

Turbidity

The turbidity of harbour waters adjacent to reclamation and dredging works is continuously monitored using nephelometers (GPA, 1998). Levels monitored by the Aquatrack system at Clinton and Boyne Island wharves in Feb. 1998 showed a neap-spring variation, ranging from 30 to 40 NTU’s during springs and from 0 to 5 NTU’s on neaps (GPA, 1998).

Tidal regime

Mean spring tidal range at Gladstone is 3.3m. Tides are semidiurnal with a small diurnal inequality. Strong tidal currents in the harbour have caused problems with the berthing of ships, and a numerical model has been prepared by O’Keeffe and Harding (1985). Examples of model output provided by GPA (1998) show spring current speeds of 1.75 m/s are attained in the main shipping channel in the port area.

Sediments and bedforms

Surficial sediments within 10km of Gladstone are characterised by quartzose benthic foram (10-30% carbonate), moderate to poorly sorted sand, having a mean size of 2-3ø (fine sand; Marshall, 1977). The sands are high in feldspar and rock fragments (greater than 20% in each case; Marshall, 1977).

Bedforms are likely to be common in Curtis Channel due to the strong tidal currents. Dunes 4 to 10m in height and 250 to 1200m in wavelength, with crestlines trending northwest, occur in a association with Herald Patches (24°13’S 152°42’E). At the northern end of Curtis Channel, Marshall (1977) described a field of large dunes in 70 to 80m water depth. The dunes are 2 to 20m in height (significant wave height of 11m) and most have a wavelength of between 200 to 500m. Dune asymmetries indicate east-west transport. Marshall (1977) suggests that the dunes are moribund (formed in relation to a lower sea level and no longer active) based on hydrodynamic evidence and as sediments from the adjacent reefs appear to be prograding over the dune deposits.

In the harbour itself, GPA (1998) gives the results of a surficial sediment mapping study in relation to dredge spoil dumping in the approaches to Port Curtis. The dumped material is coarse to fine sand, with <6% mud and <7% gravel. Aerial photographs show dunes associated with East Bank extending offshore from Gascombe Head, and superimposed on an ebb tidal delta extending about 3 km offshore from Colosseum Inlet. The banks may provide
a source of sediment to the dredged section of the shipping channels. In 1982 18.1 million tonnes of clay and sand was dredged from the approach channel to Gladstone to allow access to 17.5m draught vessels (Crabb, 1986; Carter, 1986).

**Seagrasses and biota**

Lee Long et al. (1993) reported 17.17 km² of seagrass beds in Gladstone Harbour. Port Curtis is also fringed by intertidal zones with mangroves and saltflats, having areas in 1989 of 3264 and 2824 ha, respectively. These areas have been reduced by about 21% since 1941 by coastal development (QDEH, 1994). Saenger et al. (1980) studied the macrobenthos of the Calliope River. A similar study on the macrobenthos of Port Curtis by Walker and McNamara (1998) tabulated the abundances of polychaetes, crustaceans, bivalves, gastropods and other taxa. Generally, the muddier, fine-grained sediments were found to support the greatest diversities of macrobenthic invertebrates (Walker and McNamara, 1998).

**References**


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GPA (1998). *Ballast Water Management - background information for decision support system* Report provided by the Gladstone Port Authority, 21 pp. (with numerous supporting documents)


**Hay Point**

The port of Hay Point ([http://www.pcq.com.au/haypt1.htm](http://www.pcq.com.au/haypt1.htm)), located 38 kilometres south of Mackay, is Queensland's largest port in terms of trading volume. The port has two coal-loading terminals administered by the Ports Corporation of Queensland (PCQ) [http://www.pcq.com.au/](http://www.pcq.com.au/). The terminals comprise jetties which extend offshore from Hay Point and into Dalrymple Bay, approached via a channel dredged to a depth of 13.2 m. Depths of 16.7 to 19.6 m are also maintained at the two terminals by dredging operations.

The port can provide vessels with real-time measurements of tides and wave height to maximize loads.

**Hydrography**

According to the review conducted by Hilliard et al. (1997), few water salinity or temperature observations have been collected at the port. Best estimates using regional information are that the sea surface temperature ranges from 20 to 30°C and salinities range between 34.9 (summer) and 37 (winter). Hay Point projects offshore into the marine environment of the Great Barrier Reef lagoon, and only local runoff from the adjacent coastal area will effect surface salinity values. There are no large rivers in the region, the nearest being the Pioneer River which enters the sea at Mackay, 30 km to the north of the port.

**Tides, currents and turbidity**

Hay Point is located on the mainland coast at the northern end of the macrotidal regime of Broad Sound (Cook and Mayo, 1978). Mean spring tidal rages are 4.9m and the tides are semidiurnal with a small diurnal inequality. Strong currents flowing parallel to the coast may reach speeds of up to 2 knots on springs. Hilliard et al. (1997) cite unpublished measurements of suspended sediment concentrations that were collected in association with dredging operations; the background levels in Sandringham and Dalrymple Bays were between 2 to 7 mg/l.
Lessa and Masselink (1995) investigated the transport of sediment by tidal currents into the Louisa Creek estuary, located about 3 km west of Hay Point. They found that the estuary has been infilled with up to 3 m thickness of mainly marine sand derived from the adjacent shelf area, due to flood tidal asymmetry. However, once the estuary had become infilled, the expanded intertidal area generated strong ebb-flows and the estuary is now ebb-dominated throughout (Lessa and Masselink, 1995).

**Sediments**

Sediments on the seabed adjacent to the port are terrigenous sands. Strong tidal currents have produced linear sand banks and dunes throughout the area, with notable complexes being the Blackwood Shoals (at the southern end of Whitsunday Passage) and the Viscount Shoals, which extend northward to a latitude of 21° 20'S. Such features occur along the coast between the Whitsunday Islands and Broad Sound (Cook and Mayo, 1978) to a depth of about 20m.

Crabb (1986) noted that dredging operations, associated with the construction of a jetty facility at Hay Point in 1981, required the removal of a "stiff clay". Such observations indicate that Holocene unconsolidated deposits form a mobile, thin patchy veneer over cohesive-clayey Pleistocene sequences on the inner shelf (to 20m depth).

**References**


**Karumba**

The Port of Karumba [http://www.pcq.com.au/karum.htm](http://www.pcq.com.au/karum.htm) is located at the mouth of the Norman River in the southeast corner of the Gulf of Carpentaria. Karumba is used mainly by commercial fishing vessels and by smaller trading vessels forwarding general cargo to Weipa and other Gulf communities. The port handles general cargo, livestock, seafood and petroleum.

**Norman River**
The Norman River has a catchment area of 40,000 km² and experiences a highly seasonal rainfall pattern, with 95% of precipitation occurring during the summer monsoon (December to March). The rivers which adjoin the Norman, such as the Gilbert, have built a huge fandelta complex along this portion of the Gulf of Carpentaria. Studies of the hydrology and sedimentology of these rivers shows that during winter, discharge may reduce to zero for several months, whereas summer monsoon rains cause large volumes of sediment and water to be discharged (Jones et al., 1993). Flow measurements of the Gilbert River show that its catchment area of 32,000 km² discharges about 5.8 ML/a (Jones et al., 1993); extrapolating this figure to the Norman suggests that its discharge may be of the order of 7 ML/a.

**Hydrography**

Hilliard et al. (1997) cite an unpublished report of Poiner et al. (1994) which reports data from spot measurements collected during the 1991 and 1992 wet and dry seasons, for five stations in the lower 8 km of the Norman River. Also, mentioned in the report are the results from a mooring located 5 km offshore from the river mouth collected data from 1975 to 1979. These offshore data suggest that sea surface temperatures range from 15 to 32°C and salinity ranges from 0 to 39‰. Hilliard et al. (1997) also cite another unpublished report in which brackish (0 to 5 ‰) surface waters were described as being present in the port for several days in January, 1996.

Ridd et al., (1988) reported on the results of two current meter mooring deployments, one located about 2 km upstream of Karumba, and another from a small tidal creek draining the mangroves and salt flats. The time series of the data show the influence of saline tidal flat runoff, which was in the range of 40 to 46‰, compared with the main river channel in which salinity oscillated with the tidal flow between 36 and 37.5 ‰. Due to the vigorous tidal exchange, turbulence causes the water to be well mixed.

**Sediments and habitats**

Progradation of the Gilbert River fandelta complex has been described by Jones et al (1993) as having deposited a Holocene lensoidal body which is 25 km wide and 8 m thick. Channel evulsion and a succession of strandline beach ridges characterise the prograding sequence. Pulses of sediment discharged in the summer monsoon are reworked during the low-flow periods, leaving sorted beach sands and muds are trapped in the tidal portions of the river channels. Point bars and intertidal flats contain sand-mud couplets which record this seasonal pattern (Jones et al., 1993). A similar depositional pattern may be expected for the adjacent Norman River system.

No precise descriptions of the sediments in the vicinity of the port area are available. Hilliard et al. (1997) describe the subtidal sediments as sand and silt, which supports an abundant benthic community. The deltaic nature of the environment explains why there are no bedrock outcrops and all of the beaches and coastal areas are formed of unconsolidated sediments.

The river channel in flanked by 40.86 km² of mangroves (Long and Skewes, 1996) and broad, intertidal salt flats, covering an area of 250 km², which are immersed only on spring high
tides (Ridd et al., 1988). Evaporation results in saline spring tidal runoff from the salt flats which drain into the lower parts of the Norman River in the vicinity of Karumba. Seagrasses are absent in the port area and subtidal zone offshore from the river mouth due to high turbidity, but the mangroves of the Norman River provide an important habitat for juvenile prawn species (Staples and Vance, 1987). Away from the river mouth (and turbid water) there are extensive seagrass meadows (Hilliard et al., 1997).

**Currents and turbidity**

The mean spring tidal range at Karumba is 3.3 m and the tides are predominantly diurnal. A consequence of the broad intertidal salt flats is that once spring tidal levels are high enough to flood them, the volume of water which enters (and exits) the river mouth increases dramatically and tidal current speeds accelerate. The stronger currents resuspend bottom sediments and turbidity increases rapidly on spring tides. Turbidity in the river increases from around 50 to 100 mg/l on neap tides to over 400 mg/l on springs at the station 2 km upstream of Karumba (Ridd et al., 1988).

**References**


**Lucinda**

The Port of Lucinda http://www.pcq.com.au/lucin.htm exports raw sugar grown in the Ingham district. There is a single jetty which is 5.75 kilometres long. The port is situated on
the Herbert River delta, adjacent to the river’s main distributary channel, and is accessed via Hinchinbrook Channel, a narrow, 44km long tidal channel between Hinchenbrook Island and the mainland.

**Hydrography**

The Herbert River has a catchment area of 10,130 km², a mean annual discharge of 98 cumec based on 40 years of records collected at Ingham (Hilliard et al. 1997) and an estimated annual sediment load of about 180,000 tonnes (Mitchell et al., 1997). The flow is highly seasonal with most discharge occurring during the summer monsoon (December to March) when brief periods of high discharge rates (a maximum rate of 12,940 cumecs has been recorded) may occur (Hilliard et al. 1997).

According to Hilliard et al. (1997), there are no reliable temperature or salinity records for the port of Lucinda. Sea surface temperatures in the region range between 21 and 31°C. Salinity observations have been made sporadically and indicate the range is between 30 and 35.2‰ (Hilliard et al., 1997). CTD data presented by Wolanski et al (1990) shows that water introduced into Hinchinbrook channel by a flood event remained stratified during neaps but was rapidly vertically mixed by spring tidal currents. Wolanski et al.'s (1990) station “C” was closest to the port entrance and this showed surface salinity after the flood was around 27‰. Hence, flood episodes probably cause port waters to become brackish at times.

**Currents and water circulation**

Wolanski et al (1990) studied the dynamics of the Hinchinbrook Channel. Spring tidal currents attain speeds of up to 2 m/s in the channel and the waters are vertically well mixed (see also report of Murray, 1989, cited by Hilliard et al., 1997). According to Hilliard et al. (1997) the channel is floored with sandy sediments. Wolanski et al. (1990) showed that during periods of low river discharge, net residual currents in Hinchinbrook Channel are negligible even in the presence of wind and the residence time of water is about two months.

**Sediments and habitats**

Since nearly 80% of the Herbert River catchment has been cleared for agriculture (Hilliard et al., 1997) there is concern over the impact that the export of nutrients and sediments may be having on the health of the Great Barrier Reef. Mitchell et al (1997) made measurements of water chemistry of the Herbert River (northern Queensland) during a flood event that followed Cyclone Sadie in January 1994. Minimum estimates of flood-related export are 600 tonnes of N, 65 tonnes of P and 100,000 tonnes of suspended sediments over seven days, with most transport (85%) occurring within the first two days.

An air photograph on the Port of Lucinda web page shows the occurrence of numerous bedforms lying sub-normal to the shoreface. The bedforms demonstrate the nearshore wave and current processes which rework the shallow subtidal sediments. The shallow subtidal sandbanks adjacent to the port of Lucinda have a long documented history of movement since the port was first surveyed in 1887 and a jetty was constructed in 1896. Movement of the
sandbanks and tidal channels has caused some inconvenience to port managers, and dredging operations have been and will continue to be required. The southward migration of the main channel in the vicinity of the wharf averaged about 3 m/a over the past century, and the channel has generally become progressively more shallow and narrow (Murray, 1989).

About 164 km² of mangrove swamps border along the margins of Hinchinbrook Channel and the Herbert River delta (Wolanski et al., 1990). Lee Long et al. (1993) reported 30.38 km² of seagrass beds in the Hinchinbrook Channel area to the north of the harbour, as well as 3.48 0.38 km² of seagrass beds adjacent to Palm Island (located offshore of the harbour entrance).

References


Mackay

The Port of Mackay is located on the mainland coast at the northern end of Broad Sound. It comprises an artificial harbour constructed on the northern side of the Pioneer River mouth (see Nolan et al. 1986, for a history of Mackay harbour). It is used mainly for the export of sugar products, meat and grain and for the import of petroleum and fertiliser (see P&O port operations http://www.poal.com.au/). Imported ballast water is discharged alongside berths 1, 3, 4 and 5 (Hilliard et al., 1997).

Bathymetry

The shelf area adjacent to Mackay is a broad, gently sloping surface such that the depth is 20 m at a distance of 15 km offshore. The port approach channel is dredged to a depth of 8.3 m and depths at the berths are maintained at 10.4 to 12 m. The dredged material is dumped about 3.5 km offshore from the harbour in 11 m water depth.

Hydrography
Hilliard et al. (1997), cites unpublished data collected by the Mackay City Council which shows that the harbour water temperature ranges between 18 and 30°C. There are no estimates of salinity for the harbour.

**Tides and currents**

Mean spring tidal rages are 4.9m and the tides are semidiurnal with a small diurnal inequality. Modelling work in the Broad Sound Mackay area has been carried out by Bode and Stark (1983), who investigated the effects of tides and cyclone storm surge along the coast. The model predicts that northward flowing coastal currents with speeds of up to 1 m/s could be generated by the passage of a 940 mb low pressure system. Storm surge associated with the passage of a cyclone was modelled by Love (1988) who found that the recurrence of a cyclone low pressure system of 962 hPa is about 20 years which would generate a storm surge of about 2.7 m.

**Sediments**

Sediments on the seabed adjacent to the port are terrigenous sands. Strong tidal currents have produced linear sand banks and dunes throughout the area, with notable complexes being the Blackwood Shoals (at the southern end of Whitsunday Passage) and the Viscount Shoals, which extend northward to a latitude of 21° 20'S. Such features occur along the coast between the Whitsunday Islands and Broad Sound (Cook and Mayo, 1978) to a depth of about 20m. A group of subtidal dunes known as Downward Patches, is located about 10km due east of Mackay Harbour. The dunes average 600m in wavelength with a maximum wavelength of about 1km. Crestlines are orientated at about 110°, sub-normal to the direction of coast-parallel flowing tidal currents. Eddies formed of turbid water flowing along the coast are formed also, where flow separates in the vicinity of islands and adjacent to the breakwater of Mackay Harbour.

Hacker (1988) examined the sedimentology of the Pioneer River, which is the principal source of sand to the Mackay area. The river has a catchment area of about 1,500 km² and a natural sediment load of about 50,000 - 90,000 tonnes/yr. Clearing in the catchment for agricultural purposes has caused the sediment load to increase to about 200,000 tonnes/yr. Discharge occurs in the form of extremely variable flood-events resulting in currents strong enough to transport cobbles (250mm) into the estuary. One flood in 1958 is thought to have achieved a peak discharge rate of 9,439m³/s which was capable of transporting around 1 million tonnes of sediment (Hacker, 1988). There is evidence that marine pollution has occurred based on the report of von Westernhagen and Klumpp (1995) who measured the concentrations of pesticides in ovaries and livers of Queensland marine and estuarine fish species and found the highest values were in waters adjacent to the main sugarcane growing areas of Ayr, Mackay and Cairns.

The sand delivered to the coastal bar by the Pioneer is angular, 60-70% quartz, 30% felspar, a mean size of 0.90mm and a sorting of 0.78 (coarse, moderately sorted sand; Hacker, 1988). This sand is deposited onto the delta and some may make its way into the inner shelf zone.
The thickness of the deltaic deposits is estimated to be about 30m at Mackay (Hopley, 1982, p. 32). The thickness of deposits on the inner shelf is unknown, although Nolan et al. (1986) described sequences of interbedded clay, clayey sand, silty clayey sand and sand extending below 5m water depth in the vicinity of Mackay Harbour. The material appears to be permeable, since groundwater seeps have been documented to outcrop on the intertidal zone in the Mackay area (Turner, 1993).

**Biota and habitats**

Within the port limits, 52 species of benthic fauna were sampled in the subtidal zone according to an unpublished report cited by Hilliard et al. (1997). These species are typical of soft-sediment areas, and included polychaete worms, bivalves, gastropods and crustacea. Lee Long et al. (1993) reported 7.11 km² of seagrass beds in the Mackay harbour area and Hilliard shows areas of mangroves within the estuarine embayments located to the north and south of the artificial harbour.

**References**


**Mourilyan**

The port of Mourilyan [http://www.pcq.com.au/mourl.htm](http://www.pcq.com.au/mourl.htm) established in 1892, is set within a sheltered natural harbour. It is the export outlet for bulk sugar and molasses produced in the Innisfail and Babinda district. The port is situated on the Moresby River estuary, the entrance
to which has been dredged to a depth of 8.5 m. The main harbour has depths of 7 to 22 m and is used for anchorage and a single main berth has a depth of 9.6 m (Hilliard et al., 1997).

**Hydrography**

According to Hilliard et al. (1997) the Moresby River has a catchment area of 126 km$^2$ and the catchment lies within the area of Queensland having the highest rainfall in the region (3,552 mm). The seasonal rainfall pattern results in high river discharge during the summer monsoon months (Dec. to April) with lower discharges during the winter months.

Temperature and salinity data were collected by Larcombe and Taylor (1997), to document the seasonal variation in the Mourilyan harbour area. Surveys were conducted at several stations in the harbour in January, May and October, 1995 and the results show that temperature and salinity in the port range from 24.7 to 32.9°C and 0.84 to 34.6‰, respectively.

**Tides, currents and turbidity**

The mean spring tidal range at Mourilyan is 1.82 m and tidal currents in the harbour entrance may reach 2 to 3 knots. Hilliard et al. (1997) reports that flood current speeds exceed those on the ebb in the harbour entrance, and flood currents generate an eddy within the central harbour basin. Flood currents are reduced in duration during peak river discharge. Onshore (easterly) winds may cause a rise in local sea level, and when this is combined with highwater on a spring tide, can cause flooding of cane fields adjacent to the river banks (Hilliard et al., 1997).

During high discharge events, the Moresby River provides fine grained mud and sand to the estuary and adjacent offshore environments. When high discharge is combined with spring tidal flows turbid waters are produced, having up to 200 mg/l of suspended solids in the upper estuary, and up to 50 mg/l adjacent to the ships berth (Larcombe and Taylor, 1997). Lower discharge rates and neap tides result in lower turbidity in the harbour (5 to 15 mg/l). Offshore of the harbour entrance, turbidity is controlled by surface wave activity; large swell waves may induce turbidity levels of >60 mg/l (Larcombe and Taylor, 1997).

**Sediments and habitats**

Sediments in the harbour entrance comprise calcareous (~50% carbonate) gravelly silty sand (Larcombe and Taylor, 1997). Two samples were collected adjacent to the dredged ship berths (M-09 and M-10) were described as clay and silty clay, with a high organic content, H$_2$S odour and mean grain sizes of 10 to 18 µm (based on laser particle sizer measurements). Another sample collected adjacent to the mooring-pilings on the south side of the harbour (M6) was a poorly sorted, calcareous silty sand, with a mean grain size of 300 µm and a clear bimodal size distribution, with peaks in the fine silt and medium sand size ranges (Larcombe and Taylor, 1997, Appendix 15).
Lee Long et al. (1993) reported 1.31 km² of seagrass beds in the Mourilyan harbour area and a map published by Hilliard et al. (1997) shows the estuarine intertidal zone contains extensive mangrove swamps. The coastline in the harbour entrance and in the port area is rocky, with sandy beaches on the seaward coastal margin.

Cyclones and shelf sediment dispersal

Gagan et al., (1987, 1988, 1990) obtained short sediment cores immediately before and after the passage of Cyclone Winifred in February 1986, a "severe" tropical cyclone, with a 50-70 year return interval. Winds gusting up to 55 m/s induced strong currents affecting sediment movement to a water depth of at least 43m near Mourilyan. The thickness of the storm beds was greatest on the mid shelf, where it exceeded 10cm in thickness. The sediment transported during the storm was derived from reworking of shelf deposits (eroded to over 14.4 cm at one location) together with input of terrigenous sediment supplied in buoyant freshwater plumes Gagan et al., (1990). It is inferred that sediment excursion distances were as much as 15km along the shelf (from south to north).

The storm layer contained graded, fining-upward sequences consisting of: (1) terrigenous medium sand to silty clay (inner shelf, 0-25m depth); and (2) well sorted relict quartz and skeletal gravelly sands capped in places by a thin mud veneer (Gagan et al. 1990). One year after cyclone, the same section of shelf was resampled again. It was found that bioturbation had obliterated the graded storm beds in mid- to outer shelf sediments (>30m depth) but that storm beds were well preserved in the inner shelf (<30m; Gagan et al., 1988). Thus bioturbators are more effective (more numerous?) at mixing sediments over the middle shelf in comparison with the inner shelf.

References


Port Alma (Rockhampton)

Port Alma is located on the Fitzroy River Delta, on the west side of Raglan Creek. Ships approaching the port transit through Keppel Bay and a dredged channel with a minimum depth of 7.9 m. The three berths have depths of 9.5 m. Exports are mainly salt (50% of trade), beef, tallow, explosives and scrap metal. Imports are petroleum products, ammonium nitrate, gypsum and containers.

Hydrography

According to the report of Hilliard et al. (1997), water temperature and salinity were recorded monthly by the Rockhampton Port Authority at several locations around the port area (within 1-2 km of the berths) over a two-year period (6/88 to 6/90). Over this time the range of sea surface temperatures was 19.5 to 28.7°C and extreme salinity values are 27.9 to 29.2 ‰. (data are available from the Port of Rockhampton and the Queensland Department of Environment and Heritage http://www.env.qld.gov.au/environment/coast/). River input during summer probably lowers surface salinity values during peak discharge and flood events to less than 20 ‰ (Hilliard et al., 1997).

Tides and tidal currents

The maximum spring tidal range is 4.0 m and tides are mixed semidiurnal. Fluvial currents adjacent to the wharf may be of the order of one knot (0.5 m/s) that would add to the ebbing tidal flow (Hilliard et al., 1997). No current measurements have been collected in the port.

Modelling work in the Broad Sound Mackay area has been carried out by Bode and Stark (1983), who investigated the effects of tides and cyclone storm surge along the coast. The model predicts that northward flowing coastal currents with speeds of up to 1 m/s could be generated by the passage of a 940 mb low pressure system

Sediments

The Fitzroy River supplies about 1.774 x 10⁶ tonnes/a, which is elevated above the natural sediment load of the river by agriculture and deforestation in the catchment (Hilliard et al., 1997). Its catchment area is 142,645 km² and its maximum discharge occurs in summer, between November and April. Water turbidity in the port area is usually high due probably to strong tidal mixing. Secchi disk depths (taken in conjunction with the monthly T&S readings, described above) ranged from 0.1 to 0.7 m (mean of 0.4 m)

Maintenance dredging of the port area is required about every five years and the spoil comprises “clay and silt” Hilliard et al. (1997). The literature search did not locate any seafloor sampling studies in the port area or its approaches, although the port was included in

**Cyclones**

Cyclone generated wind waves have been modelled by Gourlay and McMonagle (1989). Wave observations related to the passage of Cyclone David in 1976, which crossed the southern GBR shelf over the Capricorn Channel area, were obtained near Great Keppel Island. The data showed an increase in significant height of from a background reading of about 0.5m to a maximum of 4m and a corresponding increase in wave period of from 4 seconds (background) to 8 seconds. Gourlay and McMonagle (1989) point out that the stage of the tide at the time of maximum wave amplitude will partly determine the cyclone's impact on the coast (a more severe impact would occur when maximum wave energy is delivered to the coast at high spring tides).

**References**


**Thursday Island (Torres Strait)**

Located at the northern end of the GBR, Torres Strait is a major shipping focal point for vessels bound around the northern section of Australia. Thursday Island is the largest human settlement in the area and provides harbour facilities for prawn trawlers, RAN patrol boats, coastal trading vessels and the Torres Strait Pilots.

Torres Strait has a sill depth of about 12 m (Harris, 1988) and many large bulk carriers discharge ballast water in order to pass through the strait. Hence, although Thursday Island is not itself a large commercial port, the area may be influenced by significant ballast water discharges.

**Environmental considerations**
Torres Strait is bordered by three separate nations; Australia, Papua New Guinea and Indonesia. It also forms a biogeographical boundary, in which the carbonate coral reef province of the Great Barrier Reef abruptly changes into the terrigenous deltaic mud province of the Gulf of Papua. The environmental impact of this sediment and its associated heavy metals on the Torres Strait marine environment has been the centre of controversy and much debate (Dent, 1985; Lawrence and Cansfield-Smith, 1990). Heavy metals were reported from measurements of bottom sediments by Baker and Harris (1991) and Schneider (1989) reported that some heavy metal concentrations (specifically cadmium) in commercial prawns taken from Torres Strait were above natural background levels and comparable to those found in some polluted areas. These and other reports led to the Federal Government funding the Torres Strait Baseline Study, the results of which have been published by the Great Barrier Reef Marine Park Authority (Dight and Gladstone, 1993; Gladstone, 1996; Evans-Illidge, 1997). These later studies confirmed Schneider’s (1989) observation of high cadmium levels in commercial prawns, but Evans-Illidge (1997) concluded that this is a natural phenomenon, characteristic of carbonate depositional environments and unrelated to pollution from the Fly River.

Hydrography

An estimate of the monthly averaged sea surface temperature is provided by the US Navy Marine Climatic Atlas of the World CD-ROM which can be extracted from the AODC Web site http://www.aodc.gov.au/information/sstdata/sst.html The values range from 24.5 to 28.4 (mean is 26.7), and monthly mean values are:

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For comparison, Harris et al (1991) measured water properties at 80 stations in Torres Strait in September 1991 and found temperature ranged from 25 to 27.4°C and salinity ranged from 22.30 to 35.75‰. In April 1990 Harris et al. (1990) recorded water properties at 31 stations in central Torres Strait and found that surface temperature values ranged from 29.4 to 30.0°C and salinity ranged from 29 to 34‰. Waters in southern and central Torres Strait were consistently high (>33) whereas the lower salinity values were recorded adjacent to the southern coastline of Papua New Guinea, which is influenced by freshwater input of the Fly River system.

Waves, tides and currents

Most of Torres Strait is protected from surface waves generated in the Coral Sea by the northernmost extension of the Great Barrier Reef, which serves to block long period swell. The result is that only locally produced gravity waves are found in the "GBR lagoon". In contrast, the Fly Delta is exposed to Coral Sea generated swell produced during the southeasterly trade winds. Satellite altimetry data used by McMillan (1982) to estimate global surface wave heights over the year suggests that, in Torres Strait, significant wave
heights rarely if ever exceed 3.5m and during the northwesterly Monsoon they are nearly always less than 1.5m.

Mean spring tidal ranges are 2.4 m at Thursday Island and 3.6 m at Booby Island (located 30 km west of Thursday Island in the Gulf of Carpentaria). Storm surges of up to 40 cm have been measured at Booby Island by Amin (1978). The tides in Torres Strait are forced by different systems to the east and west, originating in the Coral Sea and Arafura Sea, respectively. Thus the tides may by out of phase form one side to the other such that sea level varies by up to 6m, which induces strong tidal currents (Wolanski et al., 1988). Only about 30% of a tidal wave approaching from the east or west is able to propagate across the strait. Bode and Mason (1994) used current meter and tide gauge data as the basis for a modelling of the surface tidal currents in Torres Strait. The maximum observed current strength has components related to different driving forces (tides, wind-shear, etc.). The low-frequency (mainly wind-driven) currents in the Strait are generally less than 0.10 m/sec, though they may attain 0.2 to 0.3 m/sec for periods of up to several days. Such wind-driven currents reverse in sign over periods of days to weeks, but flow generally westward through the Strait during the southeast trades (April to November) and eastwards during the monsoon (December to March). Sandwaves (subtidal dunes), with heights of 4 to 5 m above the sea bed, also reverse their migration direction on a seasonal basis (Harris, 1989; 1991).

Current meter data reported by Harris (1989) in Adolphus Channel measured speeds of up to 1.3 m/s. Clarke (1990) developed a linear equation to predict current speed for the Prince of Wales Channel and found that depth averaged currents in the channel reach a peak of 2 m/sec. About 5 kilometres west of the Prince of Wales Channel, Harris et al. (1991) reported that tidal currents observed during September, 1991 comprised westward-flowing ebb currents peaking at about 0.70 m/sec and weaker, eastward-flowing flood currents attaining a maximum speed of about 0.4 m/sec. Observations from near Booby Island reported by Harris (1993) recorded speeds of up to 0.58 m/s. In general, the available data define a zone within which maximum current speeds exceed 0.8 m/sec, encompassing the Torres Strait Islands (including Thursday Island), Adolphus Channel and waters north of Cape York, and waters around the Warrior Reef complex (Harris, 1995).

Bathymetric zones

The Torres Strait comprises three north-south trending bathymetric regions. The shallow, central Torres Strait basin is characterised by depths of typically less than 15m; the sill depth of Torres Strait is 12m. This region extends 130 km from Cape York to the PNG coast and it is bounded to the east by the Warrior Reefs, and to the west by the Torres Strait islands and shoals. These islands are peaks of a range of hills extending northward from Cape York (Willmott et al., 1973) and in combination with a series of elongate coral reefs of tidal current origin (Jones, 1995), form a dense matrix such that shipping is forced to navigate the Prince of Wales Channel which is just 2.5 km across at its narrowest point. Adjacent to the Cape York Peninsula lies Adolphus Channel, 20 to 25 m in depth, located at the northern end of the Great Barrier Reef inner route and the main shipping route out of the southeastern corner of Torres Strait. The northwestern sector of the strait contains >3,600 km² of subtidal sandbanks.
and dunes that have been mapped using LANDSAT imagery (Rennie et al., 1997; Harris, in press).

The eastern bathymetric region contains the Great North East Channel which forms the shipping channel leading out of northeastern Torres Strait. It has depths typically of 20 to 30 m, with several high islands of volcanic origin (Willmott and Powell, 1977) and is bordered by the vast eastern patch reef complex and further east by the shelf edge barrier reefs. Depths increase eastwards into the patch reef province averaging around 30 m but may drop to 50 m or greater in places. A 60 m deep channel trends discontinuously within 20 km of the southern coastline of Papua New Guinea, probably the product of fluvial erosion during Pleistocene low sea level periods, and subsequent tidal current scour in the Holocene (Harris, 1994).

Finally, the western bathymetric region is formed by the Gulf of Carpentaria. This is a broad, gently sloping surface which gradually deepens to the west. The gradient of this vast submarine plain is of the order of 1:10,000, such that the 20 m contour of the Gulf of Carpentaria is located 75 km west of Thursday Island.

**Surficial sediments**

The distribution and the nature of surficial sediments in Torres Strait have been investigated by Maxwell (1968), Harris (1988, 1989, 1991) and Harris et al. (1988, 1989, 1990). Surficial sediments are a mixture of terrigenous and carbonate material, the former being derived from reworked relict quartzose sand deposits in the vicinity of Endeavour Strait, relict and modern sand in Newcastle Bay and terrigenous mud derived from the Fly River of Papua New Guinea. Such is reflected in the carbonate distribution pattern which is highest in a north-south trending belt of the Torres Strait basin, particularly in association with the Warrior Reefs, and the Torres Strait islands. The carbonate becomes "impure" (using Maxwell's, 1968, facies names) in the Great North East Channel and in the vicinity of Cape York. Foraminiferal sands are reworked and polished by the continuous tidal currents, and their taphonomic and grain size properties can be used to infer dispersal patterns and facies (Cole et al., 1995).

In terms of grain size, mud distribution in Torres Strait shows high levels (over 40%) are located in the patch reef province to the east of the Great North East Channel, and on the Fly Delta. The sources of the mud are quite different between these two areas, however, the former being derived from reworked and degraded bioclastic sediments and the latter Fly Delta muds being wholly of terrigenous origin (Harris and Baker, 1991). The carbonate muds of the eastern patch reef province of Torres Strait are thus a northern GBR analogue to those found in the southern GBR in Capricorn Channel (Harris, 1994). These muds both owe their origins to the strong tidal currents and high energy regime which breaks down carbonate grains into silt sized particles for deposition in low energy zones. The muds are not inorganically precipitated as occurs in other carbonate provinces. The mean grain size of the mud fraction increases from 7µm on the terrigenous Fly Delta to about 20µm in the eastern patch reef area. The percentage of clay-sized particles varies between 10 and 40% of the mud fraction (Harris et al. 1990).
The carbonate sands and gravels which characterise most of the rest of Torres Strait reflect the high energy conditions found here by the occurrence of tidal dunes and sand banks (Harris, 1988). These are located around the rim of the Torres Strait basin, near Cape York, the channels between the Torres Strait Islands, the southern coastline of Papua New Guinea and the passes of the Warrior Reefs. Seismic, cores and sidescan sonar data suggest that the central Torres strait basin is scoured free of sediment, such that lag gravels and thin (<50 cm) patchy layers of muddy gravelly sand overlie the cohesive clay and limestone characteristic of the regional unconformity. Mobile dunes may exceed 4m in height and they rest unconformably upon the cemented limestone. Holocene deposits in the Great North East Channel are up to 2.5m in thickness. Fluvial channels, some partially infilled, some buried and others exumed and perhaps enlarged by tidal current scour, are found along the southern coast of Papua New Guinea in an east-west trending belt that does not extend very far south of Saibai Island. In some locations, such as north of the Warrior Reefs, the channels are up to 65m in depth (Harris, 1994).

**Turbidity**

Suspended sediments in Torres Strait form a turbidity maximum that can bee seen in satellite images (Harris and Baker, 1991). This suspended sediment is composed of reworked calcareous sediments, which are produced by the physical and biological destruction of larger carbonate grains (see above).

Measurements of suspended sediment concentration in the surface 1m of water at 102 stations in Torres Strait in April 1990 (the northwest Monsoon season) had a mean of 9.14 mg/l and ranged between 2.2 and 36.6 mg/l whereas measurements at 78 stations in September 1991 (southeast Trade wind season) had a mean of 5.4 mg/l and ranged between 0.90 and 35.2 mg/l (Harris et al., 1990; Harris in press). Although the two data sets are not directly comparable since different stations were occupied during the two surveys, the data probably represent the typical range of surface water turbidity occurring in Torres Strait. Baker et al. (1990) investigated the heavy metals associated with suspended sediments in Torres Strait.

**Substrate types, biota and habitats**

Vessels traversing the Torres Strait area will encounter a number of different sedimentary environments and habitats. Starting from the soft, laminated terrigenous muds adjacent to the Fly Delta (which extend to within 10 km of Bramble Cay) a vessel proceeding down the Great North East Channel will encounter carbonate muddy gravelly sands giving way to mobile sand dunes in places adjacent to the Warrior Reef passes and finally to scoured limestone and lag gravel pavements in the narrow inter-reef channels and the Torres Strait basin.

Vessels entering the area via Adolphus Channel will traverse a rocky and dune covered seafloor. Lee Long et al. (1993) reported 0.98 km² of seagrass beds in the Adolphus Island area and Long et al (1995) have shown that seagrasses are widespread and particularly abundant in the shallow northwestern section of Torres Strait. In south-central Torres Strait, Bridges et al (1982) attributed the high species diversity but low abundance to strong, erosive tidal flows and high turbidity.
Finally, as all vessels must pass through the Prince of Wales Channel, where they will traverse the rocky and dune covered seabed which leads westward towards the Gulf of Carpentaria. The high rocky islands of central Torres Strait are fringed by intertidal mangrove swamps in many locations, including the Thursday Island port area. These swamps are traps for fine-grained sediments, derived from local runoff and from the marine environment, and which accumulate in the intertidal, low current energy regime.

References


Harris, P. T. (in press). Environmental Management of Torres Strait: a Marine Geologist's Perspective. In V. A. Gostin (Eds.), *Gondwana to Greenhouse: environmental geoscience - an Australian perspective* Adelaide, Geological Society of Australia,


Lawrence, D., & Cansfield-Smith, T. (Ed.). (1990). *Sustainable development for traditional inhabitants of the Torres Strait region; Proceedings of the Torres Strait Baseline Study*
Townsville is Queensland's second largest city and the port provides an outlet for sugar, minerals and meat produced in the region. Petroleum products, steel, iron, automobiles and fertilizer are the major imports. The port provides 8 commercial berths protected behind an artificial breakwater. Townsville is host to three important marine research institutions, each of which has conducted research programs in the Cleveland Bay area. These are: James Cook University (CRC For Reef Research) http://www.gbrmpa.gov.au/~crcreef/ , Australian Institute of Marine Science (AIMS) http://www.aims.gov.au/ , and the Great Barrier Reef Marine park Authority (GBRMPA) http://www.gbrmpa.gov.au/
prograding bay fill and this slopes slightly more steeply offshore at around 1.25m/km, merging with the mid-shelf surface at about 20m depth. West Channel, on the west side of Cleveland Bay, separates Magnetic Island from the mainland.

Hydrography

Studies of temperature and salinity variations in Cleveland Bay and the Port of Townsville locality have been published by Kenny (1974) and Walker (1981). Kenney (1974) recorded 212 sea surface temperature observations at the Townsville breakwater between 1961 and 1971, and recorded a low of 20.0° in July and a high of 32.4°C in January, 1962. Mean monthly values are as follows:

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Walker (1981) recorded surface temperature and salinity at a station in central Cleveland Bay (19° 11’S, 146° 56’E) over a 55 month period. The results showed that temperature varied from 19.3 to 30.9°C and salinity ranged from as low as 24.0‰ following a flood in February 1978, to as high as 36.2‰ in October at the end of the dry, southeast trade wind season.

Surface salinity minima of 22‰ were recorded closer inshore in Cleveland Bay by Ngan and Price (1980), and salinity variations in the port may be extreme due to the close proximity of the Ross River. The Ross River is has a catchment of 1,700 km² and a seasonal discharge pattern, in which >80% of mean annual rainfall (1109 mm) occurs in the summer monsoon season, from December to March (Hilliard et al., 1997).

Regional studies of seasonal variability and the influence of flood-derived freshwater plumes have been presented by Wolanski & Jones (1981), Wolanski et al. (1981) and Wolanski and van Senden (1983). Weekly measurements from a transect across the shelf from Cleveland Bay to Keeper Reef indicate that the waters are well mixed during the southeast tradewind season (Wolanski et al., 1981). Under dry conditions evaporation forms a saline inner-shelf water mass that sinks under mid-shelf waters. In summer, rainfall and runoff produce a low-salinity buoyant surface layer and the water column becomes stratified. The freshwater plume emanating from the Burdekin River following one flood event in January 1981 was tracked by Wolanski and van Senden (1983) as it migrated northwards along the coast. Sixteen days after the event, a significant lowering of surface salinity values in the Townsville port area was recorded as the plume entered Cleveland Bay.

Corals collected from Pandora Reef, 50 km north of Townsville, exhibit seasonal density banding as observed X-ray photographs of coral drill-cores. The bands appear to be related to seasonal variations in coral growth, similar to tree rings (Isdale, 1984). Gagan et al. (1994) have extracted a 6 year record with near-weekly sample intervals (1978-84) from one such coral, which provides an accurate estimate of sea surface temperature.

Waves, tides and currents
Waverider buoy data shows that waves between 0.5 and 1.2m height and 4-6 seconds in period occur for 60% of the time. Maximum wave heights are associated with the passage of cyclones; a height of 4.7m was recorded in 1979 by Cyclone Peter. However, wave heights inside Cleveland Bay are less than these because the Bay is protected from southeasterly swell by Cape Cleveland and from northeasterly swell by Magnetic Island.

Mean spring tidal range in Townsville is 2.5m and tides are semidiurnal with a large diurnal inequality. Tidal currents in Cleveland Bay, measured along Platypus Channel, are of the order of 15-30cm/sec on spring tides. Weaker currents are found on neaps but also, in West Channel, it was found that currents of 5-10cm/sec towards the NE persist over both flood and ebb tides, in the absence of any wind-driven circulation (Carter and Johnson, 1987). Northward wind-driven flow along the coast sets up an anticlockwise gyre within the Bay with a northward flow through West Passage.

Dredging operations and surface sediments

Sidescan sonographs and vibro-cores indicate that at least 25% of surficial sediments in Cleveland Bay have been affected by dredging and spoil dumping operations (Carter and Johnson, 1987; Carter et al., 1993). The cores indicate dredged sediments form a layer 10-30cm in thickness and a maximum thickness of 50cm was observed. Pringle (1989) presented a review of dredging operations in the approach channel. Large amounts of sediment have been dredged; during 1973/74, for example, 2,112,879 tonnes were removed in 12 months. On average, about 200,000 tonnes/a are dredged from Platypus Channel and Townsville harbour (Pringle, 1989). Much of this sediment has been dumped in 10-15 m water depth to the southeast of Magnetic Island. Wolanski et al. (1991) examined the effects of dredging and spoil dumping on turbidity in the Bay and described the formation of fluid muds in the bottom of Platypus Channel.

The dredged spoil blanketing the Cleveland Bay seabed is poorly sorted quartzose sand and shell gravel mixed with terrigenous mud. Sediment in Platypus Channel is sandy mud (~23% sand, ~77% mud) and particle size analysis indicates the mud is typically 40% clay, 10% fine silt and 30% coarse silt (Carter and Johnson, 1987). Belperio (1983) presented maps showing details of sediment constituents in the surficial deposits for the inner shelf. Wave reworking and suspension of the dredge spoil causes it to be spread over the Bay and, as a consequence of the anticlockwise gyre, to be relocated on the eastern side of the bay. Such a pattern appears to have affected sediment dispersal in Cleveland Bay throughout the Holocene, as the Holocene deposits are thickest (averaging about 4m) on the eastern side of the Bay as determined from the coring/seismic survey of Carter and Johnson (1987).

Turbidity and sediment transport

Sediment transport in Cleveland Bay is predominantly controlled by wave stirring of the seabed; tidal flows appear to be an important factor in West Channel, as indicated by the presence of a scoured bed with subtidal dunes, derived from current reworked dredge spoil, and coral reefs (Carter et al., 1993). Spring tidal current speeds range from 15 to 30 cm/sec.
Belperio and Searle (1988) showed that sediment resuspension in Cleveland Bay waters is related to surface wave climate. For slight seas, with wind speed at 5-7m/s and a wave height of 0.8m, turbidity exceeds 10 mg/l only in the shallow intertidal flat area; for moderate to rough seas, with winds 7.5-9.5m/s and wave heights 1.0-1.8m, the coastal turbid zone extends to the middle of the Bay, and for rough seas, with winds of 10-12.5m/s and waves 1.9-2.5m in height, the whole Bay becomes turbid. Larcombe et al. (1995) deployed nephelometers on fringing reefs near Magnetic Island and at the dredge spoil dump site in outer Cleveland Bay for a 4 month period, recording turbidities of up to 200 mg/l.

Cleveland Bay receives sediments derived from wave-reworked offshore deposits and from Burdekin River freshwater plumes (Using a modelling approach with field validation to account for waves and currents, Lou and Ridd (1997) calculated a net sediment deposition rate of 0.1 mm/a for Cleveland Bay. Larcombe and Ridd (1996) studied sediment transport in a mangrove swamp adjacent to the Ross River and reported a net seaward transport of sand and a net landward transport of suspended fine-grained sediment during the dry season.

**Biota and habitats**

Eutrophication of Great Barrier Reef shelf waters is a major environmental concern to the region and there is evidence of increased phytoplankton concentrations over the past 65 years (Bell and Elmetri, 1995). Lee Long et al. (1993) reported 12.88 km² of seagrass beds surrounding Magnetic Island as well as 60.17 km² in Cleveland Bay. These are unevenly distributed in patches around the margins of the bay, generally in water <5 m in depth (Hilliard et al., 1997). Mangroves occur in the Townsville area, extending southeastwards from the Ross River along the intertidal zone of Cleveland Bay.

**Late Quaternary sedimentation**

Carter and Johnson (1987), Carter et al (1993) and Larcombe and Carter (1998) have carried out extensive coring and seismic survey work in Cleveland Bay, and Belperio (1983), Johnson and Searle (1984) and Harris et al (1990) completed coring and seismic transects across the shelf from Cleveland Bay. During the last glacial maximum sea level was ~130 m below its present position and the palaeo-Burdekin River joined the Ross River and flowed seawards across what is now Cleveland Bay. The climate was drier (Kershaw, 1987) and river discharge was probably much less than at present. Nevertheless, a palaeo drainage channel was formed and this has been mapped across Cleveland Bay (Carter et al., 1993) and the offshore region (Belperio, 1983; Johnson and Searle, 1984).

Rising sea level saw this channel backfilled with sediment derived from fluvial input and intercepted from littoral drift along the palaeo coast (unit A of Carter et al., 1993). The channel fill forms a crossbedded and draping unit in seismic section. Cores show that the Holocene bioturbated muddy sand (unit A) overlies interbedded mangrove sand and mud layers forming a unit 1-2m thick (unit B). This unit, in turn, overlies a cohesive, weathered, Pleistocene clay which is known also from onshore drilling and excavations (Carter and Johnson, 1987). The maximum thickness of units A-C is up to ~10 m where the fluvial channels have been infilled, but is commonly ~ 5m thick. Even though more than 20 cores
have been collected and tied to a single seismic traverse across Cleveland Bay, the exact timing of deposition for each unit and intervening diachronous facies boundaries, cannot be resolved by radiocarbon dating (Larcombe and Carter, 1998).

References


**Weipa**


The ports major facility is the Lorim Point Wharf and there are two other smaller wharves (Evans Landing and Humbug Wharf). About 9 million tonnes of bauxite are exported each year, 6.5 tonnes going to Gladstone for processing and the rest overseas. The approaches to the port are via Albatross Bay and the 15 km long South Channel, dredged to a depth of 11m.

**Hydrography**

Cyrus and Blabber (1992) studied the distribution of fish in relation to turbidity and salinity variations in the Embley estuary. These workers conducted seven field trips between November 1986 to May 1989, during which longitudinal transects, with ~2 km spaced stations, from Albatross Bay to a point 31 km upstream of the estuary mouth were completed. In the lower reaches of the estuary, temperature was found to range from 24.8 to 31.8°C and the longitudinal gradient in temperature never exceeded 2.5°C. Salinity was found to range from 6.5 to 36‰ with a marked longitudinal gradient, such that salinity was around 25 to 30‰ in the estuary mouth but ~0‰ at a distance of 23 km upstream during March, 1989 (Cyrus and Blabber, 1992).

In a study of estuarine seagrass distribution, Haywood et al (1995) collected seasonal temperature, salinity and sediments data from 23 sites in several estuaries in the vicinity of Weipa, including 18 observations spaced over a 2 year period from one site located adjacent to the Weipa port area. Temperature at this site (SG1) ranged from 26.6 to 31.4°C and salinity ranged from 10.6 to >35‰ over the sampling interval (August 1990 to July, 1992).

**Tides and currents**

The mean spring tidal range at Weipa is 2.2 m and the tides are mixed semi-diurnal with a very pronounced diurnal inequality. At certain times the inequality results in only one tidal cycle per day.

Strong ebb tidal currents in Jackson Channel have resulted in the formation of linear tidal sandbanks on both flanks of the channel, probably by the “tidal jet” mechanism described by Ferentinos and Collins (1979). Surface radar current work carried out in Albatross Bay shows ebb current plumes forming a clockwise rotating eddy with currents of up to 0.8 m/s (Heron et al., 1994). Ebb flows dominate along the northern shore of the harbour area and adjacent to the ship berths, where peak spring currents are up to 4 knots (2 m/s). This ebb dominance
persists through the Jackson Channel, and gives way laterally to a mutually-evasive ebb/flood dominance pattern over the tidal sandbanks. The flood-dominance of currents in South Channel is expressed by flood current velocities of up to 0.5 m/s, which exceed ebb currents by 20 to 30% (Larcombe, 1994).

Current meters moored at 1, 2 and 9 m above the bed in 10 m depth in the Hey River (just upstream of the Embly-Hey confluence) show that spring-tidal near-surface flows are up to 0.8 m/s. The residual currents recorded at this site are consistent with evaporation-driven negative (reverse) estuarine circulation, in which weak surface flows (0.03 m/s) are landward and near-bottom residual flows are seawards (Wang and Craig, 1993).

\[ \text{Dredging and turbidity} \]

Around 400,000 to 600,000 m³ of sediment is dredged per year from the South Channel, to maintain its depth (Collins et al., 1993). The dredge spoil has been dumped at a spoil ground in central Albatross Bay since 1966, although dumping the spoil in Jackson Channel, which is the natural entrance to the estuary, has been carried out since 1989 (Collins et al., 1989). Considerable effort has been made to analyse the fate of dredged spoil and the dispersion of the fine grained sediments (mean size about 0.02 mm) from the channel (eg. McAlister and Stokoe, 1990). Sediment resuspension and siltation of the channel is most rapid during the cyclone season (Patterson and Ford, 1988). Dispersion of the dumped dredge spoil may impact on seagrass beds and hence the prawn industry, because juvenile prawns rely on adequate seagrass beds for their nursery areas.

According to Hilliard et al., (1997), surface water turbidity in the harbour area ranges from 25 to 55 mg/l, and near-bottom values are 30 to 90 mg/l. In Jackson Channel, post dredge spoil dumping turbidity values are 55 to 90 mg/l and in South Channel turbidities of 80 to 850 mg/l may occur in relation to dredging and/or rough sea conditions. For comparison, Cyrus and Blabber (1992) report turbidity levels in the lower reaches (Weipa Port) area are from 1.2 to 10.5 NTU (= 29 to 58 mg/l using the conversion equation presented by Hilliard et al., 1997). An aerial photograph on the Port web page http://www.pcq.com.au/weipa.htm shows turbid waters in the nearshore area, with flood currents forming eddies adjacent to Duyfken Point.

\[ \text{Sediments,} \]

Sediments at the lower estuarine site (SG1) of Haywood et al. (1995) were 14% mud, 78% sand and 8% gravel. Mud content generally increases up the estuary. At the (dredged) ship berths, sediments have been described by Larcombe and Taylor (1997) as follows. Four repeat grab samples collected adjacent to Evans Landing (site W1) were mostly gravelly, sandy, silty clay, composed of calcareous sand, oyster shell, terrigenous mud and bauxite. The grain size distributions (based on laser particle sizer measurements) were bi-modal for three samples and polymodal for one, with modal peaks at around 8, 100 and 1,000 µm and mean grain sizes of 17 to 31 µm.

Two repeat grab samples collected adjacent to Humbug Wharf (site W15) were mostly terrigenous (60 to 90%) silty clay, and gravelly sandy clay, composed of terrigenous clay, fine
quartz sand, carbonate and minor organic matter. The two samples had quite different frequency distributions, with one almost unimodal grain size distribution having a peak at 7 µm (mean size of 11 µm) and the other sample exhibiting a bimodal distribution with peaks at around 7 and 800 µm (mean size of 35 µm).

Four repeat grab samples collected adjacent to Lorim Point (site W5) were mostly a gravelly silty clay, composed of lithic gravel fragments, quartz sand, minor carbonate sand and terrigenous clay. The samples all had distinct grain size frequency distribution peaks at 7 µm, but three samples exhibited much poorer sorting, with long tails to their distribution curves and minor peaks at around 1000 µm. Mean grain sizes ranged from 10 to 19 µm (Larcombe and Taylor, 1997).

Seafloor sediments offshore from the port have been described by Jones (1986) based on samples collected by the CSIRO. Nine samples were collected along a 27 km traverse extending westwards from the coast and were used to identify three sedimentary units. In 0-6m water depth is a nearshore sand, 2.6 ø in grain size and comprised of up to 100% quartz. In 6 to 18m depth is a muddy sand (3.3ø mean grain size) changing to a sandy mud with increasing depth and containing up to 70% mud. In water deeper than 18m there is a relict quartzose sand which transforms into the carbonate rich (15-40% carbonate) Gulf of Carpenteria muddy sand below about 20m depth. Secondary modes in the muddy sand and sandy mud units at 1 to 2ø are made up of quartz grains similar to those of the coarser relict sand unit, suggesting deposition of these units on top of the relict sand, in which bioturbation mixed the relict quartz into the overlying modern sediments (Jones, 1986).

**Seagrasses and mangroves**

The Embley Estuary contains several seagrass beds over 3 ha in area which were studied by Haywood et al (1995). Mangroves cover the intertidal flats, particularly in the middle to upper estuarine environment. Smaller patches of mangroves may be found in the lower estuary, particularly in the tidal creeks which drain into the harbour opposite to the ship berths (Hilliard et al., 1997).

**Coastal dunes**

Coastal dunes on the Peninsula which forms Albatross Bay were studied by Lees et al (1993). These workers identified two early phases of dune emplacement prior to the modern foredune, at 11,200 and 8,300 years BP. The timing of these dune emplacement events is suggested to be related to times of slow-downs or pauses in the rate of post-glacial sea-level rise.

**References**


**NORTHERN TERRITORY PORTS**

**Darwin**

The Port of Darwin [http://www.nt.gov.au/dpa/](http://www.nt.gov.au/dpa/) is the principal port of the Northern Territory, situated on the southern coast of Beagle Gulf. It is used for importing petroleum and timber and for exporting live cattle, frozen meat, fish and prawns and mineral concentrates (see P&O have port operations [http://www.poal.com.au/](http://www.poal.com.au/)). Darwin hosts an important RAN base. The approaches to the Port are via Dundas and Clarence Straits (approaching from the east) and from Beagle Gulf (approaching from the west).

**Hydrography**
The port receives runoff from two river catchments, the Elizabeth River which empties into the northern branch of the harbour (North Arm) and the Blackmore-Darwin Rivers, which empty into Middle Arm. A dam has been built on the Darwin River to provide a water supply; the remaining catchment area of the Elizabeth-Blackmore-Darwin river systems is about 900 km\(^2\) (Fogarty et al., 1984).

Seasonal variation in freshwater discharge into the harbour causes a lowering of salinity to less than 29ppt adjacent to the mouth of Elizabeth River (Mitchie, 1987). Given that the Elizabeth River has a very flashy discharge rate, a long-term monitoring program is needed to build up a reliable T&S database for the port area. For example, Woodroffe (1995) notes that salinity varies from at least 6 to 41\(^o\)oo in many of the tributaries to Darwin Harbour. Taylor and Tulloch (1985) examined rainfall in Darwin from 1870-1983 and noted the extreme episodic character of Darwin’s rainfall pattern. Modelling work on the dispersion of introduced effluent has shown that river channels are purged of accumulated waste during flood events (Wallis and Soroczynski, 1987).

Available data are provided on a spreadsheet (EO&S CD-ROM attached to this report) which provides an average of 6 different sites measured in Darwin Harbour, collected by the Northern Territory Department of Lands, Planning and Environment (Water Quality Branch). Vertical profile measurements were made at least every month at the 6 sites over a one-year period. The general location of these sites is: 12° 30’S, 130° 50’E.

**Currents**

In Port Darwin, tides have a mean range of 3.7m and a maximum range of 8m giving rise to strong tidal currents in the harbour entrance. Nautical charts (AUS 27) show that rectilinear tidal currents in the harbour entrance reach peak speeds of about 3.2 knots (160cm/sec) such that peak flood currents exceed slightly peak ebb currents in velocity (thus explaining the landward transport of foraminifer sands into the harbour, noted by Michie, 1987). Storm surge associated with the passage of a cyclone was modelled by Love (1988) who found that the recurrence of a cyclone low pressure system of 965 hPa is about 20 years which would generate a storm surge of about 1.7 m.

**Sediments:**

Sediments in Port Darwin are known from one study by Michie (1987), whose interest was in the foraminifera contained in the bottom sediments. This worker described the main approach channel to Port Darwin as tidally scoured, where "fast tidal currents scour and rework the sediment" which is redeposited on adjacent sandbanks. Three depositional zones described by Michie (1987) included a lime sand and gravel zone, to the north of the harbour entrance (Beagle Gulf), a terrigenous sand containing mica and mud flats comprised of fine sands and muds. Michie (1987) also noted that tidal currents affect a net transport of tests from open marine species of foraminifera (derived from the adjacent shelf) into Port Darwin estuary. Baseline data on heavy metals associated with the harbour sediments are reported by Esselmont (1997).
In the deeper waters of the harbour entrance and in Clarence Strait, Mulhearne and Cerneaz (1994) mapped the grain size, carbonate content, porosity, grain density and angle of initial yield of surficial sediments. The approach channel was found to be floored by hard-packed, calcareous sandy gravel, having a mean size of -1.78ø.

Tidal sandbanks and eddies of turbid water are visible in aerial photographs. Sandbanks, up to 2km in crestline length, have formed in association with headlands. Dunes occur in association with the sandbanks and as a large dune field, independent of any sandbanks, located in the outer harbour entrance (north of Middle Ground sandbank). Dunes may be present also at other locations in the harbour but could not be detected in aerial photographs owing to the high level of turbidity there.

**Mangroves and heavy metals**

Darwin harbour’s coastal area is characterised by two large estuarine systems of the Darwin and Elizabeth Rivers, which have deposited tide-dominated deltas that are stabilised by mangroves. Studies of the zonation of the mangroves and their possible response to sea level change have been investigated by Semeniuk (1985), Woodroffe et al. (1988) and Woodroffe (1995). Fogarty et al. (1984) assessed the land types in North and Middle arms and surface areas covered by different habitats. They found that bare, salt-encrusted, intertidal mud flats cover an area of 347 ha, mangroves cover 7,072 ha and a 60 ha patch of calcareous, sandy, beach dunes occur in Middle Arm.

Heavy metals accumulate in the mangrove mud deposits reported by Peerzada and Rohoza (1989) and metal levels in biota established (references of Peerzda and others). The impacts of coastal development and industry are of concern to environmental managers (Hanley and Couriel, 1992).

**Clarence Strait**

Access to the Port of Darwin is via Clarence Strait, and the main shipping routes pass close to several tidal sand banks, notably Marsh Shoal. No information has been published in the scientific literature concerning seabed properties in Clarence Strait, although some information is available on nautical charts (AUS 20) and aerial photographs. Tidal currents in Clarence Strait are highly rectilinear, reaching peak speeds of about 4 knots (200cm/sec) on spring tides. The direction of peak velocity is reversed from one side of Clarence Strait to the other, such that the strongest tidal currents flow to the west near Marsh Shoal and to the east on the eastern end of Howard Channel. The bathymetry of Clarence Strait suggests that tidal currents have scoured out a depression up to 70m in depth in Howard Channel and similar deeps are exhibited in the bathymetry of the other channels of Clarence Strait. The eroded sediment is probably deposited in Beagle Gulf to the west and in Van Diemans Gulf to the east. Thus an area of erosion and scour is found in much of the central part of Clarence Strait (i.e. within the narrow tidal channels) exposing bedrock and possibly exsuming sections of Pleistocene drainage channels leaving lag gravel deposits. Sediments would be expected to cover much of the seabed along the shipping route extending west from Marsh Shoal. Such a
divergent bedload transport pattern is caused by the acceleration of water flowing through the constricted channels of Clarence Strait.

References


Peerzada, N; Watson, D, and Guinea, M. Mercury concentrations in oysters from the coastline of Northern Territory, Australia. Bulletin of Environmental Contamination and Toxicology. 50 (1), P158-163. 1993.
Gove

The port of Gove is located on the northwestern corner of the Northern Territory, bounded by the Gulf of Carpentaria to the East and the Arafura Sea to the North. The Harbour is operated by NABALCO PTY Ltd. [http://www.nabalco.aust.com/home.htm](http://www.nabalco.aust.com/home.htm) and is primarily used for the export of bulk alumina and bauxite.

**Bathymetry and layout**

The bulk cargo wharf is located at the end of a 900 m long jetty which projects SW into Gove Harbour from Dundas Point. According to a web page maintained by Bridgewater Chartering, [http://www.dryoil.com.au/drycargo/ports/nt/gove/](http://www.dryoil.com.au/drycargo/ports/nt/gove/) there are four berths in Gove Harbour: No. 1 is 275 m in length, 12.2 m depth alongside and used for loading alumina and bauxite; No. 2 is 275 m in length, 13.6 m depth alongside and used for oil products and caustic; No. 3 is 94.0 m in length, 10.0 m depth alongside, used for limestone, general cargo and acid No. 4 94 m in length and 11.6 m depth alongside.

**Ballast water**

According to Bridgewater Chartering, there are no ballast water reception facilities at Gove.

**Hydrography**

According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures in Gove Harbour range from 23 to 30°C and seasonal salinity values are: 34.217 (summer) 33.563 (autumn) 34.32 (winter) and 34.398 (spring). NABALCO Pty Ltd hold
digital information on temperature and salinity for Gove Harbour and have a “reasonable”
time series for the bulk cargo berths which shows strong seasonal effects (EO&S Report).

*Tides and currents*

The mean spring tidal range of Gove is 2.2 m and tides are mixed-semidiurnal with a
pronounced diurnal inequality. No current information is noted on AUS Chart 715, and no
other data on currents are available.

*Sediments and Habitats*

According to AUS Chart 715 the outer harbour bottom is mud with broken shell, and south of
Dundas Point the bottom is rocky, with a number of rocky reefs, close to the sea surface. The
coast of Dundas Point is fringed by intertidal sand flats, 100 to 300 m wide. The coast of the
inner harbour is mainly mangrove swamps, and the nearest mangroves are 2.5 km east of the
jetty in Inverell Bay.

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**Milner bay (Groote Eylandt)**

At Milner Bay, Groote Eylandt, a manganese mine and ore export facility were constructed
by BHP and started exporting ore in 1966. The jetty is located in Milner Bay, which lies on
the east side of Groote Eylandt, south of Connexion Channel, which separates the island from
the mainland.

*Hydrography*

The National Tidal Facility tide guage has collected sea surface tempertaure data, from 1992
to the present (EO&S data report). Temperatures and salinities measured in the Gulf of
Carpentaria at a depth of 10 m by Rothlisberg and Jackson (1987) ranged from 23.1 to 29.9°C
and from 31.6/o/o (in March) to 33.8/o/o (in November), respectively. There are no major
rivers in the vicinity of Milner Bay and so the normal oceanic salinity regime probably
prevails at the port.

*Currents and waves*

Sediment distribution patterns in the vicinity of Groote Eylandt are affected by tidal currents
inshore from the Moresby Rock area and extending through the channel (Emerald Sea)
between Groote Eylandt and the mainland. The results of an extensive study using 8 current
meters in this area were reported by Radok (1978). Speeds of up to 1.34 m/s were recorded in
Connexion Channel. At the Milner Bay jetty, net flow was towards the north over both wet
and dry seasons, but in Connexion Channel the direction of wind-driven flow was southwards in June and July, but northwards during February. Although tidal height at Milner Bay exhibits a diurnal cycle with a maximum range of 1.2 m, tidal currents in the Emerald Sea reverse direction semidiurnally, driven by the sea levels which are out of phase from the northern to southern ends of the island. The currents are strongly modified by wind-driven circulation, which induce flows of the order of 0.2 m/s (Radok, 1978).

Waves propagating across the Gulf of Carpenteria are known to reach maximum significant wave heights of up to 4.5 m in the centre of the gulf (Lawson et al., 1994).

**Sediments**

Groote Eylandt is a very ancient landform which has undergone little erosion in the Quaternary (Nott, 1996) and hence it supplies little sediment to the surrounding seas. According to the maps of Jones (1987) and Somers and Long (1994) sand and gravel comprise up to 80% of the sediment adjacent to Milner Bay. The coarse sands and gravels are low in organic carbon (Burford et al., 1994). Sediment grain size has also been correlated with macrobenthic communities in the Gulf of Carpentaria (Long et al., 1995) and with the distribution of commercial prawn species (Sommers et al., 1987).

Aerial photographs show the occurrence of dunes and tidal sandbanks adjacent to Moresby Rock and at the entrance to Port Langdon, at the northern end of Groote Eylandt. The dunes are 80 to 200m in wavelength, occurring both in association with sand banks and as separate dune trains such as in the channel between Groote Eylandt and Morseby Rock, at a depth of 15 to 20m. Offshore (north and east) from Moresby Rock, the bathymetry shows a relatively steep slope, in which the depth increases from 20 to 45m over a distance of about 10km; no dunes are visible at these depths in the aerial photographs examined. Sediment types are not well correlated with bathymetry in this area.

**References**


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WESTERN AUSTRALIA PORTS

Albany

The port of Albany is located on the northern shore of Princess Royal Harbour, a nearly land-locked and very protected harbour adjacent to King George Sound. The port has an access channel that is dredged to a depth of 10 m. Oyster Harbour is adjacent to the northern part of King George Sound and is used as an anchorage and boat harbour. P&O have lists of port operations, port maps, and information on their web page: http://www.poal.com.au/

Hydrography

There appears to be an excellent database of Albany harbour temperature, salinity and nutrients data, from the CSIRO Marine Research Data Centre datasets which contain a record of T, S, and N observations obtained monthly or every two weeks over the period 1952 to 1983 (see EO&S CD-ROM). According to the Victorian EPA (1996) harbours report, Albany port sea surface temperatures range from 16 to 22°C and seasonal salinity values are: 35.568 (summer) 35.720 (autumn) 35.619 (winter) and 35.684 (spring). Hodgkin and Lenanton (1981) note that Oyster Harbour remains marine throughout the year.

Sediments and seagrasses

Heavy metals in harbour bottom sediments have been studied by Talbot (1983, 1990). These studies investigated the input of waste that is high in mercury from a fertilizer plant. Concern in the community has been raised by reports of 80 and 90% losses of seagrass beds in Oyster Harbour and Princess Royal Harbour, respectively. The dieback is attributed by the WA Environment Protection Authority to increases in nutrient loads from runoff which has
resulted in macroalga proliferation. Hodgkin and Lenanton (1981) note that there are 112 species of molluscs in Oyster Harbour.

Currents

Talbot (1990) cites oceanographic and current modelling studies that have been carried out in the harbour which show that a strong flood current tidal jet having speeds of up to 0.5 m/s is established in the harbour mouth. Ebb flows draw water from a wider area and are less directional in the harbour. Flushing time is estimated to be of the order of 14 days.

Introduced pests

The port has been investigated by CSIRO’s Centre for Research on Introduced Marine Pests (CRIMP) http://www.marine.csiro.au/CRIMP A report in CRIMP’s “Port Survey Report Series” introduced species survey for the port is available.

References


Barrow Island (Tanker Mooring)

Barrow Island is located about 80 km offshore of Onslow on the Northwest Shelf of Australia. Production platforms around this area are operated by Shell Australia http://www.shell.com.au/index.htm The Barrow Island tanker mooring has a maximum spring tidal range of 3.4 m.
Hydrography

There appears to be an excellent database of Barrow Island temperature, salinity and nutrients data collected by the CSIRO Marine Research Data Centre datasets. This file contains a record of T, S, and N observations obtained monthly or every two weeks over the period 1977 to 1979 (see EO&S CD-ROM). The tanker mooring is not influenced by any significant fluvial runoff, so the oceanic data compiled on the US Navy - Marine Climatic Atlas Of The World CD-ROM may be fairly accurate. It shows the sea surface temperature ranges from 23.1 to 28.0, and has the following monthly values:

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<td>24.0</td>
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Broome

Broome is a small port located on Roebuck Bay. It exports mostly beef and meat products and also handles drilling supplies, fuel oil and general cargo (see P&O port operations http://www.poal.com.au/). The town was once famous as being the pearl industry capital of the world and today is a major centre for the cultured pearl farming industry. In 1998 the WA Government was considering whether to build a floating breakwater pontoon off the Broome Port Jetty.

Hydrography

A tide gauge is maintained at Broome by the National Tidal Facility, which also collects sea surface temperature data for the port (see EO&S CD-ROM). According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 22 to 31°C and seasonal salinity values are: 35.301 (summer) 34.929 (autumn) 34.916 (winter) and 35.149 (spring). Other data sets have been reported by Furnas and Steinberg (1997).

Sediments

Data on sediments and transport processes in the approaches to the Port of Broome were derived from a study by Wright (1981), by Mulhearn and Cerneaz (1994) and from nautical charts (mainly AUS 50). Sedimentary deposits include two tidal sandbanks in the vicinity of the harbour, an un-named shoal 8km to the south of the harbour and the large Middle Ground sandbank, which is connected to intertidal flats at its eastern end. An eddy, formed by flood tidal currents entering the Bay, is likely to be responsible for the formation of Middle Ground bank. At the western end of Roebuck Channel, the chart indicates that sediments are gravel, sand and shell and at the eastern end of the Channel, gravel, mud and shell are deposited.

Mulhearn and Cerneaz (1994) mapped the grain size, carbonate content, porosity, grain density and angle of initial yield of surficial sediments in the port approaches. Carbonate content was found to decrease in a seawards direction from nearly 100% to less than 40% carbonate about 24 km offshore of Ganheuame Point. This is weakly correlated ($R = 0.52; n = 25$) with mean grain size, with grains less than 2.5ø (177 µm) corresponding to the low
carbonate sediments, and coarser sizes (> 1 mm) corresponding to sediments having a higher carbonate content.

**Currents & sediment transport**

The harbour is located on the protected side of a headland which forms the northern end of Roebuck Bay. Adjacent to the headland, tidal currents have scoured a hole in Roebuck Channel delimited by the 50m isobath, wherein depths reach 96m. Spring tidal ranges are 8.5m and tidal currents reach peak spring speeds of 250cm/sec in the incised Roebuck Channel, which is denoted as being a rocky bottom on the chart. Thus there is evidence of localised scour and erosion within the shipping channel leading into Broome harbour. Compared with the semidiurnal constituents, the diurnal components of the tides are very small. Consequently, Broome tides are truly semidiurnal, with a negligible diurnal inequality.

Wright (1981) examined tidal sand transport off Cable Beach, in Ganteaume Bay. The beach is comprised of fine sand (0.135mm), 60-75% carbonate. Whilst sand is transported towards the north by the action of tidal currents, finer grained sediments are influenced by waves and tidal currents such that they are transported in suspension load to the south (i.e. into the vicinity of the shipping channel).

Further offshore, between the 15 and 20m isobaths, the bathymetry indicates a series of elongate ridges with log axes trending NNE-SSW; this appears to be an extensive field of subtidal sand dunes, which may be part of a larger dune field covering much of the inner continental shelf in this area. The dune features have a wavelength of 400 to 800m and rise to within 10m of the surface from a depth of 20 to 25m (i.e. the dune-like features are as high as 10 to 15m). Individual crestlines are up to 10km in length. Further studies are required to determine whether these ridges are active dunes or relict features.

Mulhearn (1993) measured Secci disk depths (SD, a measure of water turbidity) in the harbour approaches to Broome and found that relatively turbid water (SD < 5 m), whereas within about 10 km of Ganheume Point SD was > 5 m.

**References**


**Bunbury**

P&O have lists of port operations, port maps, and information on their web page: http://www.poal.com.au/


*Hydrography*

The data search carried out by EO&S found that WNI Science and Engineering http://www.wni.com have collected a Currents / Temperature dataset between August 1982 to February 1983. According to the Victorian EPA (1996) harbours report, Bunbury port sea surface temperatures range from 17 to 23°C and seasonal salinity values are: 35.652 (summer) 35.618 (autumn) 35.595 (winter) and 35.638 (spring). Hearn and Pearce (1985) used satellite remote sensing techniques to map a plume of cool (22.2 °C) lagoon water that is injected into Koombana Bay by tidal currents (see below).

*Sediments*

Sediment on the seafloor is scarce in the vicinity of the cut and the seabed is characterised by a hard calcrete surface over which a thin mobile sand layer rests. Further south, in the vicinity of Bunbury Harbour, the seabed is a flat, smooth pavement of fresh to weathered basalt covered locally by sand, gravel or mud (Semeniuk and Meagher, 1981).

Semeniuk (1985) investigated the stratigraphy and Holocene history of the sand spit (Leschenault Peninsula) which forms the Leschenault lagoon. The stratigraphic sequence is 20 to 30 m in thickness and consists of (in upwards vertical succession) Pleistocene limestone and quartz sand, estuarine muds, beach sands and aeolian dune sands. Semeniuk (1985) concludes that sea level fluctuation of ~ 2 m was caused by local tectonism between 4,800 and 2,800 years before present (BP).

*Currents*

A detailed study of tidal currents in Koombana Bay was presented by Hearn *et al.*, (1985). Tides are microtidal (MHHM - MLLW = 0.5m) and diurnal. Adjacent to Koombana Bay is the Leschenault Estuary, which is a shallow lagoon connected to the sea by an artificial channel known as "The Cut". Prior to the construction of "The Cut" in 1951 and a reduction
in freshwater input from the Collie and Preston Rivers (subsequent to development of Bunbury), the Leschenault was brackish during late winter and marine at other times. At present, salinity in this lagoon is essentially marine year-round (Semeniuk and Meagher, 1981). Wind-related sediment resuspension patterns, as described for the Peel Inlet by Gabrielson and Lukatelich (1985), would probably apply also to the Leschenault Estuary.

Hearn et al., (1985) and Hearn and Pearce (1985) examined the formation of a tidal jet which forms seawards of The Cut. The jet is about 200m in width and has maximum current speeds of about 50 cm/sec. The jet induces a west flowing current which affects an eddy system in the port approaches and embayment. Offshore, tidal currents flow north-south parallel with the coast and at speeds of about 5 cm/sec (Hanrahan, 1987). Axial current speed drops off rapidly away from The Cut due to bottom friction and entrainment. The jet is slightly buoyant during winter freshwater discharge events, but mainly it is vertically mixed and remains attached to the bed for its length. Cooling of the lagoon water in winter enables satellite sensors to detect the plume of water which forms at the seaward mouth of The Cut (Hearn and Pearce (1985).

Introduced pests

The port has been investigated by CSIRO’s Centre for Research on Introduced Marine Pests (CRIMP) http://www.marine.csiro.au/CRIMP A report in CRIMP’s “Port Survey Report Series” introduced species survey for the port is available.

References


Dampier

Dampier is a major iron ore export facility and the port is utilised by the petroleum industry; salt and general cargo are also handled. Gas and condensate produced from Woodside
Petroleum’s [http://www.woodside.com.au/index.html](http://www.woodside.com.au/index.html) offshore facilities are piped ashore via a 135 km long subsea pipeline to a onshore gas processing plant on the Burrup Peninsula, near Dampier. The steel pipeline is one metre in diameter, coated with reinforced concrete and is partially buried in a trench for its entire length and some sections of it are entirely covered with rock to protect it from strong tidal currents and cyclones. The King Bay Supply Base, is 2 km from the plant and it comprises cyclone-proof pens for four tugs to service the LNG, condensate and LPG ships. P&O have lists of port operations, port maps, and information on their web page: [http://www.poal.com.au/](http://www.poal.com.au/)

**Dredging Operations**

Data on sediments and transport processes in the approaches to the port of Dampier are derived from Semeniuk *et al.*, (1982) and from nautical charts. The approaches lead through the shallow waters of Mermaid Sound, which is mainly between 10 to 15 m in depth but which has been dredged to 12-15 m depth in the main shipping channel. About 8.4 million tonnes of sandy clay and calcarenite has been dredged from the channels (Crabb, 1986; Stejskal, 1992). Maintenance dredging has been carried out and will probably be ongoing in the future.

Stejskal, (1992) investigated the effects of these dredging operations on coral communities and concludes that impacts are most severe within about 1.5 km of the dredged channel. Damage to reefs by tropical cyclones is more severe than the dredging operations, and Stejskal (1992) noted that chronic dosing of the corals with sediment that is resuspended by ships propellor wash may be more significant in effecting the reefs than dredging operations.

**Hydrography**

The data search carried out by EO&S found that Lawson & Treloar collected vertical temperature profiles off Parker Point Jetty from 22-10-82 to 5-11-84, available as daily averages. According to the Victorian EPA (1996) ballast water study, sea surface temperatures range from 20 to 31°C and seasonal salinity values are: 35.126 (summer) 34.977 (autumn) 34.939 (winter) and 35.023 (spring).

Data on tides, waves and other oceanographic parameters are monitored at Woodside Offshore Petroleum's condensate facility (Lovell and Harper, 1989). Woodside has also obtained current meter data at four locations in Mermaid Sound, used to calibrate dredge spoil plume dispersion models (Winton *et al.*, 1986) as part of an LPG plant feasibility study to investigate the dispersion of cooling-water plumes (Treloar et al. (1985)).

**Sediments**

Semeniuk *et al.*, (1982) quoted an unpublished report of Woodside Offshore Petroleum which described the seafloor physiography as comprising "flat, featureless limestone pavements, terraces and sand/gravel veneers". It is unclear from the nautical charts which of the elongate shoals extending from the islands of the Dampier Archipelago are coral reefs and which are sandbanks. Both are probably present. The chart indicates sandy intertidal flats adjacent to many of the islands but shows the seabed to be rocky at the northern entrance to Mermaid
Sound in depths greater than 10 to 20m. Offshore from the 30m isobath, the chart (AUS 57) indicates the seabed to be comprised of sand and broken shell with some fine sand and mud also present locally.

The Maitland River Delta is a drowned sand plain system which has been overlain by alluvial sediments and tidal muds and sand ridges, locally. The Delta is thought to be underlain by a sheet of Pleistocene limestone (Semeniuk et al., 1982). Water turbidity was described by Semeniuk et al. (1982) as being due to suspended particulate matter, organic detritus and plankton, the relative importance of each varying spatially and depending upon tidal cycle, wave action and season. Turbid water may be exported from the Maitland River during flood events and from Nicol Bay during spring tides.

**Tides and waves**

Tides in Mermaid Sound are semidiurnal with a mean spring range of 5.6m. Tidal currents are relatively weak, the strongest (up to 75 cm/sec) occurring in the narrows of Mermaid Strait, adjacent to East Lewis Island. In other areas, maximum speeds are up to about 50cm/sec. Wind-generated waves are generally less than 1.3m in height (Semeniuk et al., 1982; wave data is also presented by Buchan and Russell, 1989) and wind-driven currents can be significant; AUS 57 notes that rates of up to 2.5 knots (125 cm/sec) may occur in Mermaid Strait after "prolonged blows".

Hamilton (1997) studied the wave climate at Dampier to generate monthly wave spectra for the port. Hamilton (1997) found that the wave climate was strongly seasonal, influenced by cyclones in summer months. Cyclone-generated swell, having a period of 8 to 12 seconds, is differentiated from local wind-waves that have periods of from 4 to 8 seconds.

**References**

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Derby (King Sound)

Port Approaches

The approaches to the port of Derby lead through Sunday Strait and King Sound. These waters experience the strongest tidal currents found along shipping routes anywhere in Australia; in Sunday Strait, spring tidal current speeds of up to 9 knots (450 cm/sec) are noted on AUS Chart 733. To the north and south of Sunday Strait, numerous tidal sandbanks have formed, mainly in association with headlands and islands. Tidal currents appear to have scoured deeply into the seabed within the constricted section of Sunday Strait, where water depths exceed 100 m, in contrast with depths of about 40 m away from the channel.

The major commercial shipping facility in the area is located at Yampi Sound (16° 08' 123° 38') at the entrance to King Sound. This facility is owned by BHP for the sole purpose of iron ore export. Small volumes of general cargo is transported into Derby.

Hydrography

According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 20 to 33°C and seasonal salinity values are: 34.88 (summer) 34.682 (autumn) 34.612 (winter) and 34.897 (spring). However, the port is located at the mouth of the Fitzroy River, which although does not discharge to the sea during the dry season, it does “pump large volumes of freshwater into the estuary” during the rainy monsoon season (Jennings and Coventry, 1973). Hence the river discharge must influence surface salinity values during peak runoff periods, when the above seasonal salinity values probably are not accurate.

Sediments and bedforms

Although there have been no observations of subtidal seabed or sediment properties published in the scientific literature, the intertidal mudflats of King Sound have been described by Semeniuk (1980, 1981, 1982), and the internal structures of some intertidal bedforms have been described (Gellatly, 1970). The interfingering of desert dunes and tidal flats in the
Fitzroy River estuary has been described by Jennings (1975) and the gravelly barrier forming Point Torment was described by Jennings and Coventry (1973). The mean spring tidal range at Derby is 9.4m (National Tidal Facility). Surface waves are negligible in terms of sediment transport, due to limited fetch and wind driven circulation is probably unimportant in relation to the tidal flow; thus King Sound is a tidally dominated estuarine-embayment system.

Semeniuk (1980, 1981, 1982) described the occurrence of low amplitude dunes composed of gravel and sandy gravel in the lower part of intertidal flats in the vicinity of Derby (submerged 95-97% of the time). The sediments are cleanly washed sand, gravelly sands and gravel. Plane beds and gravel (shell) pavements are developed locally. Intertidal dunes are 0.3 to 1.0m in height, 2-10m in wavelength and have angle of repose lee slopes (Gellatly, 1970). The sediments are mainly laminated and cross-laminated medium and coarse quartz sand (mean size of 1mm) with shell and lithoclast gravel located along laminae. Sorting is poor to moderate. Because of the intense tidal current reworking of sediments, biota are not abundant. *Scopimera* (sand bubbler crabs), sand-tube building polychaetes, bivalves and vagile gastropods are present, locally. It may be anticipated that similar bed types extend to the subtidal zone.

*Net erosion of King Sound tidal flats?*

An unusual aspect of sedimentation in King Sound is that its mud flats and mangrove coastline are in overall retreat (Semeniuk, 1982). Thus it would appear that King Sound is a source, rather than a sink, for sediment, with respect to the adjacent continental shelf. Such a pattern is contrary to that normally associated with sedimentation in macrotidal estuaries (which are typically a sediment sink; Harris, 1988). It is not true, however, that the entire coastline of King Sound is presently eroding away, since some areas may be undergoing erosion whilst elsewhere, sediments are accreting (i.e. as in the case of a meandering channel). As a result of net erosion in King Sound, however, coastlines in the vicinity of Derby are retreating by as much as 20m per year, and tidal creeks are observed to widen and extend landwards in sequential aerial photographs spanning many years. The deposition of the Doctors Creek formation (tidal sand and mudflat deposits) in the early Holocene (about 5 kyr b.p.) has been followed in subsequent years by its net erosion in the areas studied by Semeniuk (1982). The change from net accretion to net erosion in King Sound during the early Holocene is attributed by Semeniuk (1982) to a reduction in fluvial sediment input at around this time (which in turn suggests a regional change to a more arid climate). That net erosion is not occurring over the entire King Sound area can not be entirely discounted, since the area studied by Semeniuk (1982) was restricted to a 60km length of coastline centred around Derby; a complete sediment budget for King Sound is yet to be constructed. The explanation that the King Sound area has undergone subsidence, causing a relative rise in sea level and hence net erosion in the late Holocene, is not substantiated by observations near Fitzroy River reported by Nakada and Lambeck (1989; see Fig. 1.19). However, as sediment partially infilled King Sound in the early Holocene and was subsequently removed, the volume (tidal prism) of King Sound changed and hence a change in tidal regime may have been affected; present erosion may be simply a form of "loose boundary" adjustment towards hydraulic equilibrium. Further investigation into the intriguing phenomenon of King Sound sediment erosion is warranted.
Semeniuk (1982) considers that net erosion results in the turbid waters of King Sound which supply mud to offshore deep water environments. The high degree of turbidity was noted also in aerial photographs examined as part of the present study. Fluid muds no doubt occur in the shallow approaches to Derby as well as in the main river channels which empty into King Sound, although it is unlikely that they would be found offshore (below a depth of 20m?). Sand is thought to be trapped within the subtidal zone of King Sound, forming a vast residual sheet of sand and lithoclast gravel (Semeniuk, 1982). Some may also be exported to the northern mouth of King Sound to form the subtidal sandbanks found north of Sunday Strait. The export of mud from King Sound might explain the patch of silty sand on an otherwise sand covered shelf, as observed in sediments at this location.

References


Esperance

Located on the southern coast of WA in the Great Australian Bight, the port of Esperance lies on Esperance Bay. Esperance exports grain and ore, and imports mainly petroleum products. P&O have lists of port operations, port maps, and information on their web page: http://www.poal.com.au/

The port is dredged to 11 m, and is located behind a rocky headland inshore of the Archipelago of the Recherche. These islands of crystalline rock (Conolly et al., 1970; Conolly and Von Der Borch, 1967) give this shelf area a rugged bathymetry, compared with the smooth shelf characteristic of the Great Australian Bight (James et al., 1994). Bird, (1979), describes the Recherche Shelf as having an inner zone of scoured rock platforms dotted with islands, and further towards the shelf edge there is a cover of shelly sand.
Hydrography

According to the Victorian EPA (1996) ballast water study, sea surface temperatures range from 16 to 23°C and seasonal salinity values are: 35.339 (summer) 35.759 (autumn) 35.645 (winter) and 35.671 (spring). The port is not influenced by any major fluvial inputs.

References


Exmouth (Point Murat)

Port location

The port of Exmouth is located on the western coast of North West Cape on Exmouth Gulf. The tides are micortidal, as MHWS-MLWS is only 1.8 m (see NTF web page). Exmouth Gulf is host to a sizable prawn fishery (>1,000 tonnes pa) and the oil and gas industry (McCook et al., 1995). The WA governmnet has designated fishing areas and restricted use zones around the port (see this URL: http://www.wa.gov.au/westfish/rec/broc/ff/ffmap7.html).

Hydrography

According to the Victorian EPA (1996) ballast water study, sea surface temperatures range from 20 to 30°C and seasonal salinity values are: 35.164 (summer) 34.999 (autumn) 35.009 (winter) and 35.047 (spring). The port is not influenced by any major fluvial inputs. Indeed, the southern portion of Exmouth Gulf may achieve high salinities (up to 390/oo) due to high evaporation and low runoff rates (Brown, 1988). The eastern shore of the Gulf in particular is characterised by a narrow fringe of mangroves which give way landwards to drying salt pans. Saline waters could thus also be introduced into the Gulf by runoff from these salt pans. Hence, the above salinity values may be exceeded episodically.

Sediments
Clifton (1974) and Murray (1976) discussed tidal flat sedimentation and the Pleistocene geology in the Bay of Rest in southern Exmouth Gulf. The tidal flats, tidal channels and beach ridge deposits flanking the Gulf have also been summarised by Brown (1988).

The review of Brown (1988) covers the Holocene sediments and depositional environments of Exmouth Gulf based on several previously unpublished theses and reports of the University of WA Geology Department. The subtidal environment in the northern part of Exmouth Gulf and in the vicinity of the port of Exmouth, is floored by bare or encrusted (limestone?) rock, with discontinuous patches of mixed carbonate and quartzose sand with gravel sized skeletal (mollusc, foraminifer and echinoid) fragments and lithoclasts (Brown, 1988). Strong tidal flows occur in the relatively deep (>20 m) area adjacent to Point Murrat, and give rise to subtidal dunes, up to 4 m in height and 200 to 400 m in wavelength. Mud content is up to 30% in the central and southern Gulf, where currents are weaker, and unconsolidated sediment thickness above pre-Holocene bedrock exceeds 1 m and may be up to 2 m thick, locally. Much of this central Gulf area has been disturbed by the activities of Prawn trawlers. Bioturbation rates are also high and sediment cores collected here are mixed and structureless throughout (Brown, 1988).

Seagrass beds in the Gulf are neither extensive or abundant (McCook et al., 1995) and hence un cemented sediments are freely available for transport by waves and currents.

References

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Fremantle (Perth)

The Port of Fremantle http://www.freport.wa.gov.au/ is the principal port of Western Australia. The port includes an inner harbour and outer harbour, having a combined area of
The northern approaches to Fremantle harbour includes the Warnbro-Cockburn Depression between Rottnest Island and the mainland. The Depression extends northward from Rockingham Sill and is divided into a north-south trending chain of three, 15-20m deep basins: Cockburn Sound, Owen Anchorage and Gage Roads. Each basin is divided from the others by a bank: Parmelia Bank, Success Bank and Fairway Bank. On the seaward side, the chain of basins is bordered by the semi-continuous Garden Island Ridge (submerged aeolianite system), which extends from Rockingham Sill to Rottnest Island. Further seaward the Ridge is bordered by another 20m deep depression (Sepia Depression) and another offshore ridge (Five Fathom Bank). The entire ridge and basin system lies inshore of the inner shelf plain. The main shipping channel crosses Fairway Bank, Gage Roads and Success Bank.

Hydrography

Routine oceanographic surveys, including vertical salinity–temperature-density (STD) profiles and contour plots from the region between Fremantle, south Rottnest and Garden Island have been collected by the WA Department of Environmental Protection every three weeks since 1984 (D’Adamo et al., 1995a&b). These transects have been used to calibrate satellite estimates of surface water temperature (Pearce et al., 1989). Water quality studies in Cockburn Sound have also included measurements used to calibrate satellite images for surface water chlorophyll and Secchi disk depth (Pattiaratchi et al., 1994). An interesting process identified in association with small lagoons that border on eastern Cockburn Sound, north of Perth, is the influx of groundwater high in nitrate and silicate; a salinity front (halocline) can sometimes be distinguished in the nearshore zone (Johannes and Hearn, 1985). Coastal waters in this region are well mixed and exhibit a summer phosphate and salinity maxima and winter silicate and nitrate maxima (Johannes et al., 1994).

The Swan River has a catchment area of 122,960 km2 and a mean flow of 624 million m³/a, with 80% of the flow occurring during June to October (Hodgkin and Hesp, 1998). The river water is itself saline, with the first winter discharge of the Swan typically around 7‰, falling to 2‰ by October (Hodgkin and Hesp, 1998). Hyder Consulting have carried out a study of “physical chemical and biological characteristics of the port environment” and Steedman Ltd. have studied river and tidal flow regimes in the Fremantle inner harbour (EO&S Report). According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 18 to 24°C and seasonal salinity values are: 35.744‰ (summer) 35.648 (autumn) 35.651 (winter) and 35.695 (spring). These values do not agree with the results of Hodgkin and Lenanton (1981), however, who published a monthly time series of sea surface salinity values, spanning three years (1965, 1969 and 1970) along a transect of the
Swan River, from the estuary mouth to 60 km upstream. At the estuary mouth, these workers found that surface salinity was generally ~35 from October to June. During July to September, however, surface salinity was less than 5‰ in 1965 and was between 20 and 25‰ during 1969-1970 (Hodgkin and Lenanton, 1981).

Stephens and Imberger (1996) reported on an estuarine modelling program based on a series of 18 CTD transects conducted on the Swan River during December 1991 to November 1992. The Swan estuary has deep basins (20 m) that are separated from Cockburn Sound by sills, which restrict circulation and causes bottom waters to become anoxic. If summer floods are too weak, they will not flush out this anoxic bottom water. The results of some more recent studies carried out by the Centre for Water Research (UWA) are given on their web page http://www.cwr.uwa.edu.au/cwr/research/projects/

*Sediments in Cockburn Sound*

Surficial sediment deposits were described by Searle and Logan (1979) as comprising sand bank units and an inner shelf veneer sedimentary unit as well as various onshore units. Fairway Bank is a homogenous body of grey sand composed largely of carbonate lithoclasts (80%), mainly molluscan skeletal fragments (10%) and quartz-feldspar lithics (10%). Gravel sized sediments are common on the western side of the Bank adjacent to Garden Island Ridge. The top of Fairway Bank (7m depth) is flat and composed of rippled mobile sands with sparse burrowing pelecypods and echinoderms. These sands are well sorted with a mean size of about 0.4mm. The southwestern flank of the Bank is about 50% covered with seagrass *Amphibolus* which inhibits sediment mobility in that area. The eastern flanks of the Bank slope gently down into deeper waters of Gage Roads (20-22m depth) at a gradients of between 0.3° - 1° (Searle and Logan, 1979).

Success Bank extends across the Warnbro-Cockburn Depression to form a sill dividing Owen Anchorage from Gage Roads. A channel has been dredged (to a depth of 13.7m) across the bank to join these two basins. The top of Success bank lies in depths of between 3 and 7m and the sides slope to the north and south at a gradient of up to 1.7°. Seagrass (*Posidonia*) meadows cover the top of the bank interspersed with areas of mobile (rippled?) sand. Sediments are moderately to well sorted grey carbonate sands with a mean size of 0.3mm. The sediments are derived from carbonate lithoclasts (45%), skeletal fragments (45%) and quartz sand (10%). The skeletal fragments are derived from molluscs, alga, foraminifera and echinoids (Searle and Logan, 1979).

Along the inshore section of the seaway lies the Cottesloe Fringing Bank, which is a shoreface attached bank, 2 to 3 km from the beach, in a depth of between 5 to 12m. The Bank is composed mainly of quartzo-feldspathic sands with typically 5% carbonate in surficial layers but up to 39% in deeper subsurface layers. The carbonates are mainly molluscan skeletal fragments and carbonate lithoclasts. Sand may be exchanged between the beach and offshore bank in relation to minor sea-level fluctuations, which results in periods of beach erosion/accretion in response to relative rise/fall in mean sea level (Clarke and Eliot, 1983).
The inner shelf sediment veneer lies in depths below 15m. It is characterised by rocky surfaces of Pleistocene limestone and patches of quartzo-feldspathic sands that form a thin layer (to about 0.5m thickness) overlying the rocky pavement. The relative proportion of quartz-feldspar and carbonate lithoclasts in bottom sediments indicates high quartz-feldspar content sands over much of the nearshore and inner shelf areas and an increase in carbonate lithoclast content over Fairway bank (Searle and Logan, 1979).

Sediments in Fremantle harbour and the Swan Estuary

The Fremantle inner harbour is dredged to a depth of 11 m, intersecting Holocene coastal sand, which is up to about 30 m in thickness in the outer harbour area (Hodgkin and Hesp, 1998). Eyre and McConchie (1993) reported on measurements of heavy metals in bottom sediments from the inner Swan Estuary (Perth and Melville Waters) and found evidence for anthropogenic input and suggest that other processes such as currents and bioaccumulation may also be important factors. The dynamics of sediment transport in the estuary is driven mainly to winter rainfall and river flow (Cameron and Ho, 1985).

Two short sediment cores collected from the Swan River by Gerritse et al. (1998) show that the concentration of phosphorus in sediments has risen by a factor of 3 between 1940 and 1990, and other trace metals (Pb, Zn, Cd and Cu) are also significantly elevated in surface sediments above pre-European settlement background levels.

Waves and Currents

Wave energy impacting the inner coastal areas (i.e. in the Fremantle area) is mostly sheltered from the ocean swell due to offshore ridges and islands. Locally generated waves are small and have a minimal effect on the eastern shores of Garden Island (i.e. in the vicinity of HMAS Stirling; Treloar et al., 1989).

The maximum spring tidal range at Fremantle is 1.2 m and tidal currents are not significant in terms of sediment transport processes in much of Cockburn Sound. Water circulation patterns in the Fremantle - Cockburn Sound area were studied by Steedman and Craig (1983) using current meter data and numerical modelling. Currents in the northern part of Cockburn Sound are weak, being 0-5cm/sec for 83% of the time (tidal influence) but speeds of up to 25cm/sec occur in relation to storm-wind events. The numerical model shows that under the influence of SW sea breezes, northeastward flowing currents are accelerated in the channel north of Garden Island and over Parmelia Bank. A reversed pattern occurs when strong NE gale force winds occur. Field investigations into the effects of sea breezes (up to 15 m/sec) have shown a rapid response in Cockburn Sound, with higher wave energy (swash oscillations) and increased wind driven current speed from 0.05 to 0.8 m/s (Pattiaratchi et al., 1993).

Sediment Transport and Depositional History

Searle and Logan (1979) have stressed the importance of surface swell waves in transporting sediments over the Cockburn Sound area. In their model, sand is moved northward in littoral drift along the Garden Island Ridge and enters the Warnbro-Cockburn Depression via a series
of narrow entrances. The origin of Parmelia Bank and Success Bank is thought by these workers to be caused by wave diffraction patterns which interfere in the regions behind the offshore ridges causing a reduction in energy and sediment deposition.

The unconsolidated bank deposits unconformably overlie a foundation of Pleistocene limestone, based on unpublished vibrocore data (Searle and Logan, 1979). Fairway Bank has a maximum thickness of 11m. The history of the development of the banks partially infilling the Warnbro-Cockburn Depression can be viewed, according to Searle and Logan (1979), as representing various stages of extension and shoaling towards a mature structure that extends across the Depression. Those banks furthest to the south began forming first and so the southernmost banks are older than the northern banks (Fairway Bank is the youngest in the series). In this context, Rockingham Sill is a mature structure, Parmelia and Success Banks are in intermediate stages toward maturity and Fairway Bank is in an early stage of development. The source of the sediment forming the banks is mainly erosion of older Pleistocene limestone, reworking of relict quartz sands, supplemented by modern biogenic sediments. All of this material is moving northwards in littoral drift.

References


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Geraldton


Hydrography

There appears to be an excellent database of Albany harbour temperature, salinity and nutrients data. this is from the CSIRO Marine Research Data Centre datasets which contain a record of T, S, and N observations obtained monthly or every two weeks over the period 1978 to 1985. Furthermore, WNI Engineering hold 10 years of tide guage and sea surface temperature data (see EO&S CD-ROM). According to the Victorian EPA (1996) ballast water report, port sea surface temperatures range from 19 to 25°C and seasonal salinity values are: 35.612 (summer) 35.379 (autumn) 35.402 (winter) and 35.526 (spring). Further studies have been carried out on water quality in association with port development activities (Walker et al., 1993; Walker and Penifold, 1995).

Sediments
The port of Geraldton is located inshore of the Houtman Abrolhos Reefs on an 80km wide section of the continental shelf between 28° and 29°S. In 1985, HMAS *Moresby* completed a detailed bathymetric survey of the Houtman Abrolhos shelf and a cruise of RV *Rig Seismic* conducted a sidescan sonar survey of the shelf in July 1986 (Harris, 1986). Consequently, there exists a large data base regarding shelf morphology in this area. However, very little data on the harbour area itself was located in the literature search.

The existence of coral reefs in the Abrolhos group has provoked much speculation over the past 100 years, regarding the possibility of a warm southward flowing current. It is known that coral growth is limited to water temperatures >17°C, and the western coasts of continents normally experience a cold, equatorward flowing current (eg. the California, Humbolt and Benguela Currents). The poleward flowing Leeuwin Current thus plays a key role in providing warm tropical waters to the Abrolhos promoting the growth of corals. A detailed study of shelf currents in the area by Cresswell et al. (1989) and Creswell (1991) showed the influence of the Leeuwin Current spreading out onto the shelf. A mean southerly flow of about 20 cm/sec in April to August with weaker northerly flow in November to March was found.

Little terrigenous sediment is thought to be deposited on the Houtman Abrolhos shelf as only a few intermittent streams are found along the coast and these supply sediments only to drowned river valley type estuaries which serve as effective sediment traps (Carrigy and Fairbridge, 1954). Several recent detailed studies have focussed on the geology of the Abrolhos Reefs (eg. Collins et al., 1991, 1993, 1996, 1997), but few workers have studied sediments inshore and adjacent to the Geraldton port area. France (1985) carried out an examination of the southernmost Abrolhos reefs and analysed 47 grab samples from the shelf area. This worker identified 3 main shelf sediment facies and five sub-facies as outlined in Table 1.

Table 1  Shelf facies defined by France (1985).

<table>
<thead>
<tr>
<th>FACIES:</th>
<th>Packstone</th>
<th>Packstone- Boundstone</th>
<th>Grainstone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Unit 5</td>
<td>Unit 6</td>
<td>Unit 7</td>
</tr>
<tr>
<td>Location Shoreface</td>
<td>Upper Slope</td>
<td>Outer Shelf</td>
<td>Reef/Reef Lee</td>
</tr>
<tr>
<td>Depth</td>
<td>&gt;100m</td>
<td>50-100m</td>
<td>20-50m</td>
</tr>
<tr>
<td>Sediments*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bryozoans</td>
<td>30%</td>
<td>D</td>
<td>2-10%</td>
</tr>
<tr>
<td>Coralline Algae</td>
<td>m</td>
<td>D</td>
<td>25-35%</td>
</tr>
<tr>
<td>Molluscs</td>
<td>m</td>
<td>m</td>
<td>25-35%</td>
</tr>
<tr>
<td>Echinoderms</td>
<td>m</td>
<td>t</td>
<td>2-10%</td>
</tr>
<tr>
<td>Sponges</td>
<td>t</td>
<td>t</td>
<td></td>
</tr>
<tr>
<td>Foraminifera</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Benthic</td>
<td>t</td>
<td>t</td>
<td>10-20%</td>
</tr>
<tr>
<td>Pelagic</td>
<td>m</td>
<td>m</td>
<td></td>
</tr>
<tr>
<td>Quartz 3-15%</td>
<td>50%</td>
<td>Lithoskels t t t t t t - 34% t - m</td>
<td>D50 (φ) 0.3 - 0.68 0 - 1.3 1.23 - 2.11/2 - 4 0.39 - 2.44 -0.3 - 2.81 0.2 - 3.3</td>
</tr>
</tbody>
</table>

* D = dominant, m = minor, t = trace (average percentages given where available)

**References**


Walker, D I, Morrison, P F, and Brearley, A, 1993, Geraldton foreshore and marina development monitoring programme report 1993: water quality, heavy metals and biota: University of Western Australia, Department of Botany, Nedlands WA. 33p, 14 Tables, 8 Figs, Refs.

Walker, D I, and Pennifold, M, 1995, Geraldton foreshore and marina development: water quality, heavy metals and biota: University of Western Australia, Nedlands WA. 26p, 7 Tables, 13 Figs, Refs.
**Koolan Island (Yampi Sound)**

The major commercial shipping facility in the area is located at Yampi Sound (16° 08' 123° 38') at the entrance to King Sound, along the macrotidal coastline of the Kimberly region of Western Australia. This facility is owned by BHP [http://www.bhp.com.au/](http://www.bhp.com.au/) for the sole purpose of iron ore export from mines at Cockatoo Island (established in 1950) and Koolan Island (1964).

*Hydrography*

According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 23 to 32°C and seasonal salinity values are: 34.88 (summer) 34.682 (autumn) 34.612 (winter) and 34.897 (spring). These are identical values for those given for the port of Derby in King Sound. However, as Yampi Sound is located outside the entrance to King Sound and is not directly influenced by any significant fluvial input, these salinity values may be realistic.

*Tides and currents*

This port is located in Yampi Sound, along part of Australia’s coast that experiences the largest tidal ranges in the country. The spring tidal range (MHWS-MLWS) at Koolan Island is 8.9 m (see NTF web page), and very strong currents are found around the islands offshore. Remotely sensed imagery from the Admiralty Gulf region (located about 350 km east of Yampi Sound) illustrates the interactions between currents and topographic features such as reefs and islands in the dispersal and mixing of coral spawn and other buoyant material (Pattiaratchi, 1994).

*References*


**Onslow**

The port of Onslow is located on a locally straight section of coastline about 100 km east of Exmouth. Barrow Island is located about 80 km offshore, across Mary Anne Passage, to the northeast of Onslow. The approaches to the port lead across a broad, shallow shelf, where water depths are less than 20m up to 35km offshore.

*Hydrography*
Onslow experiences semidiurnal tides with a mean spring tidal range of 1.8m; tides are thus microtidal in this area, in contrast to the macrotidal tidal ranges found over most of the North West Shelf. Dix (1989) noted that the daily wind pattern is bi-modal, with strong afternoon west to northwest winds and weaker easterly to southeasterly morning breezes being characteristic.

According to the Victorian EPA (1996) ballast water study, information for Exmouth (the nearest coastal Port to Onslow) shows that sea surface temperatures range from 20 to 30°C and seasonal salinity values are: 35.164 (summer) 34.999 (autumn) 35.009 (winter) and 35.047 (spring). However, Onslow is located adjacent to the mouth of the Ashburton River, which may discharge seasonally (episodically) and hence influence the surface salinity in the port area.

Sediments and inner shelf coral reefs

A descriptive account of the reefs and sandbanks in Mary Anne Passage was presented by Dix (1989), who examined the Mary Anne Group, located about 27km northwest of Onslow. There are no published accounts of shelf sediment properties in the area directly offshore from Onslow. In the Mary Anne Group, Dix (1989) reported 50 to 100cm thick coarse-grained sands and gravels deposited on and adjacent to a submerged rock platform. Subtidal sandbanks are up to 10m in thickness and 4km in length, often attached at one end to rocky headlands or reefs. The sandbanks are produced by strong tidal currents which locally reach up to 170cm/sec but which decrease in speed rapidly with increased distance from constricted channels. Subtidal sediments are comprised of skeletal (molluscs, foraminifera, bryozoans, corals and calcareous red algae) and rock fragments, with the gravel fraction (< -1phi) comprising up to 90% of the sediments adjacent to coral reefs; mud is an important component in only a few restricted locations, along the sheltered eastern margin of the platform chain.

References


Port Hedland


Port Hedland exports of the order of 70 million tonnes of iron ore each year to Asia and Europe (Stacy and Currey, 1986); salt, fuel oil, petroleum products cement and drilling
equipment are also handled by the port with over 600 ship visits per year (see Port Web Page).

Port development and dredging operations

Processes affecting sediment movement in Port Hedland harbour and the dredged channel leading offshore have been examined by Paul and Lustig (1975). The harbour was constructed between 1965 and 1970; it was extended in 1984-86 to provide berths in the harbour for iron ore bulk carrier vessels of up to 270,000 dead weight tonnes (dwt). About 12.6 million tonnes of sediment was dredged to create the channel and harbour basin and dumped on a spoil bank to the east of the channel (LeProvost, 1986). A further 9 million tonnes was dredged over two years in 1984-86 (Crabb, 1986). The spoil bank extended landwards after 1975 and was joined to the mainland in 1985 (LeProvost, 1986). By 1989 the spoil bank was a peninsula of dry land and dredge spoil is now dumped offshore of the 10m isobath. Comparison of older nautical charts with the present ones shows that considerable shoaling has taken place on both the east and west sides of the dredged channel inside of the 10m contour over the last 10 to 15 years.

Recent drilling operation have been carried out for the construction of a tunnel under the harbour to carry fine-grained iron ore via conveyorbelt (Nutt et al., 1996). The transect across the harbour was drilled to a depth of 40 m and encountered calcarenite, red beds (reddish-brown clayey sandstone), conglomerates and sandstone (Nutt et al., 1996).

Hydrography

Very little data are available on water properties in Port Hedland. According to a report on ballast water and hull fouling compiled by the Victorian EPA (1996), sea surface temperature ranges from 20 to 31°C in the port, and quarterly salinity values are: 35.265 (summer), 35.018 (autumn), 34.956 (winter) and 35.169 (spring).

Tides, waves and currents

Tides in Port Hedland have a mean spring range of 5.5m. Tidal currents reach speeds of up to 95cm/sec in the outer shipping channel, with ebb velocities exceeding slightly those of flood currents. At the harbour entrance, Paul and Lustig (1975) estimated spring tidal current speeds of up to 90 cm/sec occur in the constricted section of the channel off Airy Point with lesser speeds in the turning basin (current speeds may have been affected by the 1984-86 dredging operations). Current speeds of up to 100cm/sec are noted on AUS Chart 54, with a distinct tidal asymmetry such that flood currents are only about half the speed of ebb currents.

Ocean swell approaches the coastline from the northwest and has a significant height less than 1.5m 70% to 90% of the time. The area is influenced also by tropical cyclones which pass within 166km of Port Hedland every 2 years, on average. During the passage of cyclone Chloe in 1984, surface waves with a significant height of 5.4m were measured and a storm surge of 1.25m was measured inside the harbour (Rice, 1987). Hamilton (1997) studied the
wave climate at Port Hedland to generate monthly wave spectra for the port. Hamilton (1997) found that the wave climate was strongly seasonal, influenced by cyclones in summer months. Cyclone-generated swell, having a period of 8 to 12 seconds, is differentiated from local wind-waves that have periods of from 4 to 8 seconds. Storm surge associated with the passage of a cyclone was modelled by Love (1988) who found that the recurrence of a cyclone low pressure system of 950 hPa is about 20 years which would generate a storm surge of about 4m.

**Harbour sedimentation**

In Port Hedland harbour, maximum siltation rates are about 0.6m/yr (Fig. 5.34a), located at the eastern end of the turning basin. Correlations between grain size, current speed and rate of siltation within the harbour shows that maximum sedimentation coincides with silt-clay sized sediments and maximum currents of about 25 cm/sec; the lowest rates of sedimentation correlate with sand and gravel sized sediments (mean size about 1mm) and maximum spring tidal currents about 100cm/sec. Section number 31 does not require dredging, the depth being maintained by tidal currents. In fact, Paul and Lustig (1975) reported that a local bathymetric "hole" to a depth of 20m was located in this section of the channel (the bathymetry of AUS Charts 52 and 54 do not show details of this area). Also, in the outer part of the approach channel, sections 9/10, 11/12 and 13/14 from the dredged channel showed indications of erosion rather than siltation which Paul and Lustig (1975) attributed to tidal current scouring. The highest rate of deposition in the outer channel occurred at section 17/18 and was 0.12 m/yr.

The source of the sediments to the inner harbour is thought to include the tidal creeks which drain into it. Sediment may also be transported into the harbour from the dredged channel via flood tidal currents; however, as the strongest currents are ebb directed, it seems likely that the harbour is a net exporter of coarse sand-sized sediments with fine muds and muddy sands being retained within the adjacent tidal flats. Paul and Lustig (1975) discussed the possibility of blocking off the tidal creeks (or diverting their flow) to reduce the rate of sedimentation in the harbour. The outer dredged channel is infilled with reworked shelf sediments, transported into the channel by tidal currents. Aerial photographs show the occurrence of dunes and tidal sandbanks associated with the outer bar but there were no bedforms observed in the outer sections of the approach channel. Paul and Lustig (1975) noted that measurements of channel cross sectional area before and after one cyclone did not change significantly, and these workers concluded that "it is probable that cyclonic disturbances do not significantly influence sediment movements (in the approach channel)".

Mulhearn and Cerneaz (1994) mapped the grain size, carbonate content, porosity, grain density and angle of initial yield of surficial sediments in the port approaches. Muddy sediments were found to have accumulated in patches within the dredged channel, interspersed with muddy sand and sandy gravels. A generally poor correspondence was found between the results of Mulhearn and Cerneaz’s (1994) survey compared with the earlier one of Paul and Lustig (1975), possibly due to the transport and redistribution of sediments between 1973 and 1990. In several locations a hard bottom was indicated by sample non-recovery or recovery of only gravelly sediment in the Birge-Eckman grab and Van Veen grab.
This absence of sediment was thought to be probably caused by current winnowing (Mulhearn and Cerneaz, 1994).

References


Port Walcott

Port location

Port Walcott is an important iron ore export facility; scrap iron, fuel oil and petroleum products are also handled. The harbour is comprised of a jetty located on a headland which extends about 4km offshore to a channel dredged to a depth of 16m. Mean spring tidal ranges are 4.6m and tidal currents reach peak spring speeds of 70cm/sec adjacent to the jetty (AUS 55). The tidal ellipse indicates highly rotary tidal currents, reflecting the non-channelised nature of flow. Peak current speeds coincide with the ebb flow (towards 330°) at the end of the jetty.

Hydrography
According to the Victorian EPA (1996) ballast water study, sea surface temperatures range from 21 to 32°C and seasonal salinity values are: 35.126 (summer) 35.023 (autumn) 34.939 (winter) and 35.023 (spring).

*Sediments*

Data on sediments and transport processes in the approaches to the Port Walcott are derived from nautical charts (mainly AUS 55) and air photographs. Sedimentary deposits include tidal sandbanks which are plentiful between the 10 and 20m isobaths and which rise to within 2m of the surface in places (typically to within 7m of the surface). Sandbank crests trend east-west subparallel to the direction of peak tidal flow. The shipping channel threads its way through Bass Pass, located between a set of un-named offshore banks and the Tessa Shoals, located inshore from them. The sandbanks provide some protection to Port Walcott from swell waves approaching from offshore.

In addition to the sandbanks are numerous bathymetric features interpreted to be subtidal dunes. The dune-features are distinguished from the sandbanks by their shorter crestlines, smaller amplitude and by the trend of their crests which is SW-NE and thus sub-normal to the direction of currents. They are found at depths greater than 15m and their crests seldom rise to within 10m of the surface.

Aerial photographs of Port Walcott reveal the occurrence of dunes associated with a sandbank adjacent to Bezout Island; these bedforms are located inshore of the 10m isobath (which is typically the depth limit in which bedforms are visible on air photographs). The shallow water of less than 10m depth is marked also by the presence of turbid water plumes which depict eddies associated with headlands in the Port Walcott area.

*References*


**Wyndham (Cambridge Gulf)**

Wyndham is a regional outlet for meat products derived from the Ord River development scheme. P&O have lists of port operations, port maps, and information on their web page: [http://www.poal.com.au/](http://www.poal.com.au/)

*Port approaches*

The approaches to the port of Wyndham lead through Cambridge Gulf and the West Arm of Cambridge Gulf. One report by the Wallingford Hydraulics Research Station (1971; cited in Wright et al., 1973) describes tides and current patterns in the context of a siltation study for the port of Wyndham.
Hydrography

According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 22 to 33°C and seasonal salinity values are: 34.91 (summer) 34.722 (autumn) 34.795 (winter) and 35.072 (spring). However, surface salinity values at Wyndham are influenced by the seasonal fluvial discharge from the Pentecost, King and Forrest Rivers and it may also be influenced by the Ord River. Discharge of the Ord River reaches a peak in January-February when maximum discharge rates are 730 m³/sec; during September the discharge is zero. During discharge events a brackish surface layer is present at the port of Wyndham (S. Forrest, Port of Wyndham).

Sediments and currents in Cambridge Gulf

The area is known in the scientific literature from the studies by Wright et al. (1973, 1975) which were carried out in conjunction with the Ord River dam construction and irrigation scheme. These studies were concerned mainly with the Ord River estuary and its dynamic tidal regime and provide some insight into the processes active in the area, though not directly related to the situation near Wyndham. Tides are amplified in Cambridge Gulf by the coastal geometry. At LaCrosse Island in the northern entrance to the Gulf, the average spring tidal range is 5.15m and at Wyndham the range is 6.6m. The Ord has an average sediment load of 22 million tonnes/year and this sediment is largely responsible for the extensive tidal flats and fluvial deposits found around Cambridge Gulf (Wright et al., 1973).

Tidal currents are accelerated in the constricted channels connecting Cambridge Gulf with the Ord River and West Arm. In the narrows at the north of West Arm, currents of up to 5 knots (250 cm/sec; noted on nautical chart AUS 32) are associated with a local deep of 67m. This is in comparison with surrounding levels of the seabed at 10 to 30m. Although it may be speculated that such a bathymetric deep is evidence of local tidal current scouring, nothing is actually known of the sediments or seafloor morphology in this area.

A recent study by Clarke and Ringis (2000) documents low sea level fluvial channels and Quaternary deposits in relation to exploration for economic detrital diamond deposits in the inner Bonaparte Gulf region.

References


South Australian Ports

Port of Adelaide


**Bathymetry**

A marked channel from Fairway Buoy to Outer Harbour is dredged to 12.0 m. Outer Harbour swing basin width 420 m has a depth of 10.1 m. Container Berth swing basin width 460 m, depth 12.0 m. The dredged channel to Inner Harbour has a minimum width 152 m, and depth of 9.1 m generally limited to vessels of 206 m in length.

**Hydrography**

Water temperature is effected by cooling water discharge from the Torrens Island power station into the port area via Angas Inlet (Thomas et al., 1986). Sea surface temperatures in Angas Inlet were 2 to 4°C warmer than in adjacent harbour waters over 9 years of summer measurements taken between 1972 to 1985 and reported by Thomas et al. (1986). During the sampling program, the ambient Port River water temperature ranged from 21.5 to 28.1°C, whereas temperatures in Angas Inlet were as warm as 40°C. Steffensen and Walters (1980) reported water conductivity, but no corresponding temperature readings were made so the conversion of the data to salinity will not be accurate.

The best available water temperature and salinity data for the Port River are those reported by Jones et al. (1996) based on monthly observations taken at 5 stations between January 1986 and May 1987. Over the sampling period, water temperature near Angas Inlet (Stn 4 of Jones et al., 1996) ranged from 19.8 to 33.2°C and salinity ranged from 36.7 to 40.5‰. For comparison, temperature measured at the station located at the harbour entrance (Stn 1 of
Jones et al., 1996) ranged from about 12.5 to 26°C and salinity ranged from about 36.3 to 39.9 o/oo. Sea surface salinity increases northwards in Gulf St Vincent and may reach 42 o/oo in summer when runoff is low at the northern end of the Gulf (deSilva Samarasinghe, 1998).

Prior to European settlement the Port River comprised an extended catchment area of 1,440 km² which fed into a large freshwater swamp on the Cowandilla Plains (Holmes and Iversen, 1976). Water trapped in the swamp was lost mainly by evaporation and discharge into the sea was small. Most of the Cowandilla Plains has now been developed into the Adelaide suburbs, so that the present catchment area is now only 131 km² (Torrens Catchment Management Board) http://www.cwmb.sa.gov.au/torrens/extension/index.htm  and freshwater inflow from the Port River averages 15 GL per year, but may be zero in some years. Rainfall and runoff in the Adelaide region is highly seasonal, with >80% occurring between June and September (Holmes and Iversen, 1976).

Stratification of the water column is seen as a factor that enhances blooms of toxic dinoflagellate algae (Alexandrium). Diffusers have been installed by the Department of Engineering and Water Supply (EWS) at the Jervoise Bay Bridge to destratify the water column. However, studies by the Centre for Water Research (UWA) http://www.cwr.uwa.edu.au/cwr/research/projects/ have shown that these have not been effective.

Tides and currents

The tides in the Gulf of St Vincent exhibit a mixed semidiurnal cycle, and in the Adelaide inner harbour the mean spring range is 2 m. On lowest neap tides, sea level may remain nearly stationary for a ~24 hour period, known locally as a “dodge” tide (Bye, 1976). Tidal currents at a station in 19 m water depth in St. Vincent's Gulf near Adelaide attained a maximum speed of ~0.3 m/s, whilst wind-driven currents at this station were found to reach 0.2 m/s (Provis and Lennon, 1983). Tidal mixing during spring tides causes an increase in the eddy viscosity and reduces the efficiency of wind-induced energy transfer through the water column. Hence, wind-driven currents of the order of 0.2 m/s are most pronounced during neap tides in the gulf (Provis and Lennon, 1983).

Computer modelling of tides and circulation in the Port River estuary by Teubner (1976) shows that the thermal plume emanating from the Torrens Island power station, in which elevation of water temperatures are >4° above background levels, extends about 5 km downstream of the effluent pipe in Angas Inlet during a spring tidal cycle (15 hrs).

Water Quality

In the Port River Steffensen and Walters (1980) measured nitrogen, phosphorus, conductivity, turbidity, suspended solids, heavy metals, nutrients, and bacterial levels at 13 locations downstream of the West Lakes outlet to Torrens Island at ~3 monthly intervals from 1975 to 1979. Turbidity in the harbour ranged from 1 to 130 mg/l, with the lowest values (1 to 7 mg/l at all stations) in April, 1978 and the highest values (9 to 130 mg/l) in October 1978.
Measurements of turbidity taken by Phillips and Scholtz (1982) across Gulf St. Vincent from Port Vincent, Stansbury to Adelaide, ranged from 0.12 and 2 m$^{-1}$, but mostly were between 0.2 and 0.7 m$^{-1}$. The units of Beam Attenuation Coefficient do not discriminate between suspended inorganic matter versus plankton, although Phillips and Scholtz (1982) noted higher turbidity values correlated with swell wave height, which suggests that resuspension of bottom sediments is an important source of these higher turbidity levels.

**Harbour sediments**

Geological studies in the Adelaide harbour area date back to the last century, with the observations of Howchin (1890) on the distribution of estuarine foraminifera in the Port Adelaide River and his description of limestone beds that were excavated during harbour construction works (Howchin, 1886).

Belperio (1985a,b) presented the interpretation of drill cores and surface sediment mapping work in the harbour area and this has been synthesised into a regional facies model for sediment-organism zonation by Belperio et al. (1988). Belperio (1985a) describes the succession of units encountered in the drilling program, which includes Pleistocene Hindmarsh clay and Granville formations. The latter Granville formation is a coastal, intertidal sequence that has undergone pedogenesis, cementation and calcretesation. It underlies and crops out between deposits of Holocene deposits. The Holocene, St Kilda Formation is an unconsolidated bioclastic sand, with abundant seagrass fibre in the subtidal zone. The St Kilda Formation is 2 to 3 m thick near St Kilda, on the north side of the estuary, and it is up to 10 m thick in the outer harbour. Holocene deposits are absent within the incised channels of the Port River and Barker Inlet, where the Pleistocene Hindmarsh clay and the Granville biocalcarenite crop out (Belperio, 1985a). On a local scale there has been a change in the pattern of sediment movement as a result of development along the Adelaide shoreline and the consequent degradation of the stabilising seagrass beds (Thomas, 1983). Sediment on the dredged channel bottom is mainly clay and silt.

As part of their survey of intertidal fauna, Thomas et al (1986) collected sediment samples at 46 locations around Torrens Island and found sizes ranged from medium sand (26 sites), to fine sands (16 sites) and coarse sands (7 sites). No relationships between grain size and depth or with fauna types were observed (Thomas et al., 1986). Tiller and Zarcinas (1976) reported that levels of Cd, Pb, Co, Ni, Cu and Zn in harbour sediments are all above background levels and Pb was highest near a stormwater outfalls where levels reached 460 µg/g. In Barker Inlet (northern side of Torrens Island) Harbison (1986) reported on the heavy metal content in water and sediments at 8 stations collected from mangrove intertidal mudflats (69 to 97% mud) in a longitudinal transect up the estuary, in relation to tidally induced variability associated with the dodge tides (when water movement is negligible).

**Coastal and inner shelf sediments**

Its position within the protected environment of the gulf means that the coast experiences low wave energy. Tidal currents are accelerated locally by constrictions in the coastline, but storm waves and currents are the major factors causing the transport of sediment and
influencing the development of seagrass beds (Hails et al., 1982). Waves created by the southwesterly wind induce a net northerly littoral sand transport which has resulted in the recurve spit of Lefevre Peninsula at Outer Harbour (Thomas, 1983). This peninsula is formed of a complex of beach ridges that have been prograding continuously over the past 7,000 years, with ridge formation being a response to pulses of sediment delivered via longshore drift (Bowman and Harvey, 1986). Sediment is moved offshore during storms by return flow currents moving along the seafloor, and is trapped by the proximal-offshore seagrass beds.

Hails et al. (1982) studied nearshore sediment dynamics and described the sediments and shoreface processes near Adelaide, (from Port Gawler to Port Noarlunga). This coast forms a partially enclosed sedimentary basin with a restricted quantity of relict terrigenous and biogenic sediment. Most sediment is supplied from offshore, augmented by beach and coastal cliff erosion. The sediments are mainly fine grained sand, with a general pattern of fining towards the north and also fining landward. The finest sediments are found just south of Outer Harbour. Hails et al. (1982) conclude from their study that the Outer Harbour -Port Gawler section of coastline acts as a sediment sink, with sediment being supplied from a number of sources. They also note the important role the seagrasses play in supplying sediment and stabilising sandbanks. Based on studies of grainsize distributions, bedform morphologies and current patterns, Hails et al. (1982) proposed that sand moves northward in littoral drift and is transported offshore during storm events.

Seagrass beds and shoreface erosion

Thomas (1983) suggests that disturbance of the seagrass beds and developments over the last 100 years or so have resulted in extensive erosion of the seagrass beds and consequently the beaches exposed to greater wave energy. The loss of seagrass as reported in Thomas (1983) is significant in the zone from Glenelg to Outer Harbour where the beds have receded 1,350 m offshore and an overall total loss of 10% of the original complete seagrass cover has been noted over a 50 year period. As a consequence there has been net vertical erosion of 1 m, with the sand moving slowly off shore as the seagrass is no longer available to stabilise the sandbanks. The lowering of the seafloor associated with the erosion of the beds and the deepening of the nearshore profile has meant that higher wave energy has resulted in beach erosion in the Adelaide area (Thomas, 1983).

Biota and habitats

Thomas et al (1986) recorded intertidal fauna along 8 transects (49 sites) in the vicinity of the Torrens Island power station, to determine whether the impact of cooling water on intertidal communities. The abundance of bivalves and worms characteristic of undisturbed areas have decreased from 1972 to 1985 as discharge from the power station increased, to be replaced by opportunistic worm species. Similarly, the heated water is related to a decrease in estuarine seagrasses and fish species (Jones et al., 1996). However, experiments into the effect of the discharge on epifauna conducted by Host (1977) found that the effluent had little effect on the total production of the epifauna.
The shoreline of the Adelaide region is sandy with extensive seagrass beds (Thomas, 1983) which extends to a depth of about 15m offshore from Adelaide in Gulf St. Vincent (Shepherd and Sprigg, 1976). A seagrass area of 1,900 ha adjacent to the Adelaide sewage outfall were reduced by 365 ha between 1978 and 1982, but had stabilised by 1983-85 (Neverauskas, 1987a). Dieback is attributed to the added nutrients (sewage) causing a proliferation of epiphytes (comprised of a complex assemblage of algae) on seagrass leaves, which blocks out the sunlight and eventually kills the plant (Neverauskas, 1987b).

The growth and retreat of mangroves along a 38 km section of the coast extending northwards from Adelaide was described by Burton (1982). Landward migration and colonisation of mangroves occurred in the port area at rates of up to 17 m/a between 1935 and 1982 as a result of local subsidence (Belperio, 1985). Mangroves occur on Torrens Island, adjacent to the main shipping channel leading into the inner harbour, and in Angas Channel, which receives the cooling water discharge from the Torrens Island power station. Comparisons of mangroves growing on the intertidal margins of Angas Inlet and influenced by cooling water, with those of an control (cool) area on the main shipping channel, showed that the cool area had a higher leaf/shoot growth rate, faster rates of leaf-litter decomposition and lower in situ nutrient (N, P, K, Mg, Mn) levels, in comparison with the thermally influenced mangroves of Angas Inlet (deGuia, 1982).

Toxic dinoflagellate blooms

The first documented bloom of the toxic dinoflagellate *Alexandrium minutum* occurred in October 1986, and was described by Hallegraeff et al. (1988). This dinoflagellate was probably introduced to the Adelaide area via discharges of ships ballast water. Cannon (1990) speculated that effluent discharge sites would favour the occurrence of *Alexandrium minutum* blooms since the freshwater / sewage mixture would promote a stratified water column and provide nutrients, both factors being conducive to cell growth.

References


Ardrossan

Ardrossan is located on the east of the Yorke Peninsula facing the Gulf St Vincent. Major exports are wheat and dolomite, mined south of the town by BHP. P&O have lists of port operations, port maps, and information on their web page:


According to a web page maintained by Bridgewater Chartering Pty Ltd. http://www.dryoil.com.au/drycargo/ports/sa/ardrossan/ardrossan.html, the dredged exit channel at Ardrossan has a bottom width of 125 m and a depth of 9.3 m, the length of the berth is 409 m and the depth at the berth is 9.2 m at MLWS. The channel bottom is mud.

Hydrography

According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 13 to 21°C and seasonal salinity values are: 36.223 (summer) 36.278 (autumn) 36.187 (winter) and 36.185 (spring). However, according to maps published by deSilva Samarasinghe (1998), surface salinity adjacent to Ardrossan was between 37.4 to 37.6 in April 1982, and hence the seasonal range in salinities reported by the EPA (1996) appears to be too small.

Tides and currents

The mean spring tidal range at Ardrossan is 2.5 m. Offshore from the port modelling work carried out by Bye (1976) shows a weak clockwise rotating gyre is present in the northern
gulf, under most wind conditions. Inshore currents adjacent to the port facilities will be even weaker. The results of bottom-stress modelling work carried out by Waters (1982) showed this area to be a low energy zone, as is also indicated by the accumulation of muddy sediment here. Tidal mixing during spring tides causes an increase in the eddy viscosity and reduces the efficiency of wind-induced energy transfer through the water column. Hence, wind-driven currents of the order of 0.2 m/s are most pronounced during neap tides in the gulf (Provis and Lennon, 1983).

Turbidity

Measurements of turbidity taken by Phillips and Scholtz (1982) across Gulf St. Vincent from Port Vincent, Stansbury to Adelaide, ranged from 0.12 and 2 m⁻¹, but mostly were between 0.2 and 0.7 m⁻¹. The units of Beam Attenuation Coefficient do not discriminate between suspended inorganic matter versus plankton, although Phillips and Scholtz (1982) noted higher turbidity values correlated with swell wave height, which suggests that resuspension of bottom sediments is an important source of these higher turbidity levels.

Sediments and habitats

According to the geological summary of Burne and Colwell (1982), the Yorke Peninsula is part of the Gawler Block, which is Lower Proterozoic quartzite, schist, amphibole, granite that is overlain by Permian sedimentary rocks (sandstones, siltstones and tillites).

Surficial sediment maps of the Gulf St Vincent constructed by Waters (1982) show that the area adjacent to Ardrossan is >50% terrigenous, poorly sorted fine sand with a mean grain size of 0.25 mm. Seawards of the 10 m isobath, the carbonate content rapidly increases to ~90% (Waters, 1982). Substrate types adjacent to Ardrossan are characterised by Posidonia seagrass meadows in shallow depths and by a Pinna-holothurian assemblage in deeper waters (Shepherd and Sprigg, 1976). This latter assemblage is characteristic of the muddy sediments found in the northern gulf, and is comprised of the razor shell Pinna at densities of up to 5 m⁻² (Shepherd and Sprigg, 1976).

References

Kangaroo Island
(Kingscote, Penneshaw, Ballast Head)

The ports of Kingscote and Penneshaw are managed by the Ports Corporation of South Australia [http://www.portscorp.sa.gov.au/index2.html] and Ballast Head is a private facility operated by CSR Building Materials.

Kingscote is located on Nepean Bay and is the largest town on Kangaroo Island. The Island is separated from the mainland by Backstairs Passage, which is about 16km wide. Penneshaw is situated on the northeast coast of Dudley Peninsula, about 30 km east of Kingscote, and Ballast Head is located approximately midway between Kingscote and Penneshaw. Penneshaw is primarily used by vehicle and passenger ferries with daily services to Cape Jervis, on the mainland.

Neither Kingscote or Penneshaw have bulk cargo facilities and hence the volume of ballast water discharged there is not great.

Hydrography

According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 13 to 21°C and seasonal salinity values are: 35.687 (summer) 35.776 (autumn) 35.801 (winter) and 35.71 (spring).

Tides and currents

The maximum spring tidal range at Kingscote and Pesseshaw is 1.4 and for American River (Ballast Head) it is 1.2 m. Tides are mixed-semidiurnal with a distinct diurnal inequality. According to Radok and Raupach (1977), tidal currents recorded at a station located offshore of Penneshaw, in Backstairs Passage, flow east-west and reach maximum speeds of up to 0.68 m/s.

Nepean Bay beach ridges

Short et al. (1989) described a series of five, low, shelly beach ridges at Brownslow, whose uniform elevation suggests that no significant changes in sea level have occurred during the late Holocene.
Port Augusta

Port Augusta is located on the train line from Adelaide to Perth across the Nullarbor, which served to make the port an important outlet for wool, wheat and minerals from the east and north of the Flinders Ranges earlier this century. However, the major post-war industrial developments in Spencer Gulf have bypassed Port Augusta, and it is no longer a major port for commercial shipping.

The harbour has a single 350 m long berth, dredged to a depth of 6.1 m. The approach channel is dredged to a depth of 5 m, is 6 km long and not less than 80 m wide. There is also a jetty at the Thomas Playford Power Station, which has depths of 7 to 10 m alongside (AUS Chart 778).

Hydrography

Spencer Gulf is well known oceanographically as a negative or inverse system, in which evaporation exceeds runoff forming a dense saline bottom-water mass to flow seawards under certain conditions (Noye, 1984; Nunes and Lennon, 1986; Nunes-Vaz et al., 1990). Bye (1981) predicted that the yearly-averaged surface salinity in the vicinity of Port Augusta should be around 45 to 49‰, and seasonal variations should follow an annual sinusoidal cycle, with a low of ~44‰ in August-September and a high of ~48‰ in February-March. Burne and Colwell (1982) collated minimum and maximum temperature and salinity values for several locations in the gulf; for Port Augusta Bridge (adjacent to the berth area), the relevant values are 11 to 26°C and 44 to 49.6‰.

The study of Nunnes and Lennon (1986) was based on 14 CTD surveys conducted in Spencer Gulf between July 1982 and January 1985. One station located 10 km down-channel from Port Augusta showed salinity ranging from a high of 47.3‰ in January 1983 to a low of 43.5‰ in August 1983. Based on a CTD survey conducted in March 1984, Nunnes and Lennon (1986) reported a depth-averaged temperature of 25°C and a salinity of 48‰. in the vicinity of Port Augusta.

According to Harbison (1986), the two power generation stations at Port Augusta discharge 4.02 x 10⁶ m³/day of cooling water. Noye (1984) cites predictions made that water in an 8
km² area adjacent to the outfall would be elevated in temperature by about 1°C. Tidal mixing will reduce any impacts on the biota in the vicinity of the outfalls but during neap tides the impact might be more localised and severe (as in the case of Adelaide harbour). Salinity in upper Spencer Gulf may be effected by saline water runoff and groundwater seepage (Gostin et al., 1984; Bye and Harbison, 1991), and hence is not dependant completely upon evaporation rate. Salinity in intertidal ponds may be as high as 100‰ under certain conditions (Burne and Colwell, 1982). Authigenic minerals including gypsum and dolomite are deposited in the supratidal evaporite flats.

_Tides and currents_

The upper reaches of Spencer Gulf form a hypersynchronous tidal system, in which the tidal wave is amplified by the geometry of the northward-converging coastline. The extreme spring tidal range at Port Agusta, is 4.32 m (Noye, 1984), which makes Spencer Gulf a macrotidal system, the only example in southern Australia. The diurnal inequality is very large in the southern Gulf, such that at Port Lincoln and Wallaroo the tides exhibit a nearly diurnal cycle on neaps, and some spring tides may have one large diurnal cycle at times (Easton, 1978). At Port Augusta the diurnal inequality is much less and the tides are more uniformly semidiurnal.

Between November 1976 and October 1977, Noye (1984) reported that at Port Pirie (about 60 km south from Port Augusta), there were 7 negative storm surges that lowered sea level by ~0.5 m and 17 positive surges that raised sea level by more than 1 m. These storm surges are produced by atmospheric pressure gradients and wind-stress which piles up water on one side of the gulf (Noye, 1984).

Currents in the vicinity of Port Augusta are driven mainly by the tides, and speeds of up to 0.75 m/s occur in the central Flinder’s Channel, with weaker flows occurring along the channel margins (AUS Chart 778). Noye (1984) reported maximum tidal currents at Port Augusta were up to 0.5 m/s, and the tidal excursion length is about 18 km. Superimposed on these tidal flows are weaker wind-driven currents with speeds up to 0.17 m/s, and density-driven currents with speeds of up to 0.1 m/s (Noye, 1984; Nunes and Lennon, 1986; Nunes-Vaz et al., 1990).

_Sediments_

Hails et al (1984) collected 330 cores and 365 km of boomer seismic profile data in the upper section of Spencer Gulf. In cores collected in the vicinity of Port Augusta, these workers described the bottom sediments as a poorly sorted mixture of shell sand and gravel, quartzose sand and mud, with variable amounts of seagrass fibre. This sediment type forms a layer up to 10 m thick near Point Patterson and associated with the linear sandbanks which occupy the upper reaches of Spencer Gulf. Thicknesses in the interbank-channels are of the order of 1 m. These sediments overlie “Mambray Formation” Pleistocene weathered clays with calcareous horizons that was subaerially exposed during the last glacial maximum (Hails et al., 1984). The review of regional heavy metal concentrations in bottom sediments of Harbison (1984) suggests that sediments in the Port Augusta region are close to background levels in lead, zinc.
and cadmium. McLaren and Wiltshire (1984) note that the concentrations of heavy metals discharged from the power station are small compared with the heavy industrial plants at Port Pirie and Whyalla.

The tidal channels leading to Port Augusta are thus very dynamic, since nearly 33% of the surface area of upper Spencer Gulf is intertidal in nature (Gostin et al., 1984). Strong tidal currents give rise to a suite of tidal bedforms that have been studied in some detail.

Bedform movements in the approach channel

Dune movement was studied on Middle bank, located in Flinders Channel, by Shepherd and Hails (1984) using metal reference stakes hammered into the seabed to measure dune movements. This is similar to the methods employed by Langhorne (1982) in his detailed study of one dune, except that Shepherd and Hails (1984) did not obtain the number or frequency of measurements from their stakes, and neither did they obtain simultaneous current meter data.

The dunes studied by Shepherd and Hails (1984) are located in the northern part of Spencer's Gulf in Flinder's Channel, the approaches to Port Augusta. Sediments are medium to coarse sand, 30-95% calcium carbonate. The dunes are located on a sandy mid-channel area adjacent to one side of a sand bank (Middle Bank). They range in size from smaller forms, 20-30cm in height and 5-6m in wavelength, to larger forms, up to 3m height and 18m wavelength. Shepherd and Hails (1984) examined dune movement at six locations; dunes at each location differed in terms of cross-sectional profile, height, geometry, grain size and seasonal/annual migration rate.

Observations were obtained on five occasions over a 12 month period. No reversals in dune asymmetry were observed. Dune crests were noted to migrate in a non-uniform manner, giving rise to curved dune crests, dune bifurcation and merging. Migration direction of the dunes was dissimilar from one side of the dune field to the other, giving rise to an overall pattern of net shear such as is commonly noted for linear sand banks (eg. Harris, 1988).

Migration rates vary between summer and winter, with winter rates being up to 6 times larger than summer rates and the northward orientated (flood-dominated) dunes experience the greatest seasonal change in migration rate, whereas the southward facing dunes are virtually unaffected by seasonal variations. Evaporation-driven circulation currents are strongest in the summer (Nunes et al., 1990) and peak speeds are thought to be of the order of 0.1 m/s. If flood (northward-flowing) currents are reduced in summer by southward-flowing near-bottom density currents, it would reduce bedload transport rates and the northward migration of dunes. This seems to be the best available explanation for the bedform data compiled by Shepherd and Hails (1984).

Habitats

The coastal habitats adjacent to Port Augusta include large intertidal sand and mud flats and low red cliffs composed of Pleistocene Hindemarch Clay (Gostin et al., 1984; Hails et al.,
The upper Spencer Gulf area covers about 1,960 km$^2$ of which about 9% is intertidal mangroves, 17% is bare sand flats, and 18% of the subtidal area includes extensive *Posidonia* seagrass beds which are distributed over the subtidal channel area to a depth of about 10 m (Gostin et al., 1984).

In the deep water channels, between 10 and 15 m, the razor shell *Pina bicolor* dominates the benthic community and occurs at densities of up to 5 m$^{-2}$. This community includes other molluscs, bryozoans, soft corals, ascidians and sponges (McLaren and Wiltshire, 1984). The epifauna which inhabit the migrating dune fields of the gulf have been described by Shepherd (1983a) and the seagrass community in a 30 km$^2$ area adjacent to Redcliff Point was mapped by Shpheard (1983b).

References


Port Bonython

Port Bonython is situated near Lowly Point on the western shore of upper Spencer Gulf, about 9 nm (17 km) from the port of Whyalla and about 160 nm (294 km) from the entrance to the Gulf. The port includes a new liquids terminal which extends ~2 km southwards from Lowly Point. Port Bonython jetty, operated by Santos Pty Ltd., has been designed to load refrigerated LPG products, crude oil and condensate.

Water depth adjacent to the jetty is about 16 m and the depth of the approach channel west of Fairway Bank is 11.2 m and east of Fairway Bank the depth is 18.4 m.

Ballast Water

According to a web page maintained by Bridgewater Chartering Pty Ltd http://www.dryoil.com.au/drycargo/ports/sa/portbonython/portbonython.html ships may not discharge ballast water into the harbour at Port Bonython. Treated ballast from shore tanks only may be discharged into the harbour, during daylight hours, subject to strict restrictions and conditions. One receiving tank is available with a normal working capacity of 15,000 m³.

Hydrography

Spencer Gulf is well known oceanographically as a negative or inverse system, in which evaporation exceeds runoff forming a dense saline bottom-water mass to flow seawards under certain conditions (Noye, 1984; Nunes and Lennon, 1986; Nunes-Vaz et al., 1990). Based on a CTD survey conducted in March 1984, Nunes and Lennon (1986) reported depth-averaged temperatures of between 22 to 22.5°C and salinities of between 41 and 41.5‰ in the vicinity of Port Bonython. Bye (1981) predicted that the yearly-averaged surface salinity in the vicinity of Lowly Point should be around 42‰ and seasonal variations should follow an annual sinusoidal cycle, with a low of ~41‰ in August-September and a high of ~43‰ in February-March. Burne and Colwell (1982) collated minimum and maximum temperature and salinity values for several locations in the gulf; for Lowly Point, the relevant values are 11 to 24°C and 40.2 to 44.8‰.

Tides and currents

The upper reaches of Spencer Gulf form a hypersynchronous tidal system, in which the tidal wave is amplified by the geometry of the northward-converging coastline. The extreme spring tidal range at Port Bonython is 3.06 m but the range at Port Agusta, 50 km further north, is 4.32 m (Noye, 1984). The diurnal inequality is very large in the southern Gulf, such
that at Port Lincoln and Wallaroo the tides exhibit a nearly diurnal cycle on neaps, and some spring tides may have one large diurnal cycle at times (Easton, 1978). At Port Augusta the diurnal inequality is much less and the tides are more uniformly semidiurnal.

Between November 1976 and October 1977, Noye (1984) reported that at Port Pirie (about 27 km from Port Bonython on the opposite shore of Spencer Gulf), there were 7 negative storm surges that lowered sea level by ~ 0.5 m and 17 positive surges that raised sea level by more than 1 m. These storm surges are produced by atmospheric pressure gradients and wind-stress which piles up water on one side of the gulf (Noye, 1984).

Currents in the vicinity of Port Bonython are driven mainly by the tides, and speeds of up to 1 m/s may occur adjacent to Fairway Bank in the main channel, with weaker flows occurring along the channel margins. Noye (1984) summarised the available current meter data adjacent to Lowly Point, which shows that the ebb currents were up to 0.71 m/s whereas flood currents were only 0.43 m/s. However, in the lee of Lowly Point, an eddy is formed during the ebb tide such that an eastward flowing inshore current occurs; the eddy dissappears during the flood tide and so the eastward-flowing inshore currents persists (see Noye, 1984, Fig. 5). Superimposed on these tidal flows are weaker wind-driven currents with speeds up to 0.17 m/s, and density-driven currents with speeds of up to 0.1 m/s (Noye, 1984; Nunes and Lennon, 1986; Nunes-Vaz et al., 1990).

Because of the heavy industry carried out in the upper sections of Spencer Gulf, a number of modelling studies have been published on oil spill slick trajectories (Beer et al., 1983) and water-pollutant movements (eg Tronson, 1974; Green, 1984; Nunes-Vaz et al., 1990). A problem with the negative circulation exhibited by the estuary, in which a net landward flow of surface water is required to offset the seaward flow of dense saline bottom-water, is that the circulation acts to transport any pollutants in surface waters landwards towards Port Augusta. This may be an important factor to consider in the context of the fate of discharged, normal-salinity, ballast water.

**Sediments**

Hails et al (1984) collected 330 cores and 365 km of boomer seismic profile data in the upper section of Spencer Gulf. In cores collected offshore from Lowly Point, these workers described the bottom sediments as a poorly sorted mixture of shell sand and gravel, quartzose sand and mud, with variable amounts of seagrass fibre. This sediment type forms a layer 0 to 1m thick near Lowly Point, but may reach ~ 4m thickness in a small patch south of the point where water depths exceed 20 m. These sediments overlie a mottled greyish yellow brown (oxidised red), laminated and gypsiferous clay, estimated to have been deposited ~80,000 years BP during a previous sea level high stand. The clay was subaerially exposed and weathered during the last glacial maximum (Hails et al., 1984). Heavy metal concentrations in the intertidal flats to the west of the Port Bonython jetty were reported by Harbison (1984); the sediments are enriched above background levels in lead, manganese, zinc and cadmium.

**Habitats**
The coastal habitats adjacent to Lowly Point include low rocky shores comprised of Precambrian sedimentary rocks around the point itself (Gostin et al., 1984), with intertidal sand and mud flats and beach ridges located 5 to 10 km to the west of the jetty (Hails et al., 1984). McLaren and Wiltshire (1984) described the distribution of seagrasses offshore from Redcliff in upper Spencer Gulf, which they consider to be representative of the upper gulf. There is a succession of seagrass species with increasing depth and distance from the intertidal zone. The most extensive and widespread is the *Posidonia australis* seagrass beds which are distributed over about 18% of the subtidal channel area to a depth of about 6 m (Gostin et al., 1984). Fairway Bank, located offshore from the port, supports another large seagrass meadow. Below 6 m depth, the seabed is characterised by coarse gravelly sand and bedforms (Gostin et al., 1984). Some deeper (up to ~9 m), lower current energy areas away from the main tidal channels may support *Posidonia sinuosa* and *Heterozostera tasmanica* seagrass communities (McLaren and Wiltshire, 1984).

In the deep water channels, between 10 and 15 m depth, the razor shell *Pina bicolor* dominates the benthic community and occurs at densities of up to 5 m⁻². This community includes other molluscs, bryozoans, soft corals, ascidians and sponges (McLaren and Wiltshire, 1984).

**References**


**Port Giles**

Port Giles, located on the eastern side of Yorke Peninsula at Giles Point, is managed by the South Australia Ports Corporation [http://www.portscorp.sa.gov.au/](http://www.portscorp.sa.gov.au/) and was established in 1970 to export bulk grain from the lower section of the peninsula. The port consists of a single jetty which extends about 600 m offshore into Gulf St Vincent at the eastern end of Investigator Strait. Depth at the end of the jetty is 11.6 m, with 200 m length of jetty available for berthing.


**Hydrography**

According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 13 to 20°C and seasonal salinity values are: 36.223 (summer) 36.278 (autumn) 36.187 (winter) and 36.185/o/oo (spring). However, according to maps published by Bye (1976) and deSilva Samarasinghe (1998), surface salinity in the upper gulf exceeds 37/o/oo, and hence the seasonal range in salinities reported by the EPA (1996) is too small. I conclude that there are no reliable hydrographic data available for this port.

**Tides and currents**

The mean spring tidal range at Wool Bay (nearest tidal reference to Port Giles) is 1.6 m. Offshore from the port lies the Troubridge Shoals, which is a zone of high tidal and wind-driven current energy dissipation, according to Bye (1976). Tidal currents over the shoals exceed 1 m/s on springs, but inshore currents adjacent to the port facilities will be weaker. Tidal mixing during spring tides causes an increase in the eddy viscosity and reduces the efficiency of wind-induced energy transfer through the water column. Hence, wind-driven currents of the order of 0.2 m/s are most pronounced during neap tides in the gulf (Provis and Lennon, 1983).

**Sediments and habitats**
According to the geological summary of Burne and Colwell (1982), the Yorke Peninsula is part of the Gawler Block, which is Lower Proterozoic quartzite, schist, amphibole, granite that is overlain by Permian sedimentary rocks (sandstones, siltstones and tillites).

Surficial sediment maps of the Gulf St Vincent constructed by Waters (1982) show that the area adjacent to Giles Point is >50% terrigenous, moderately to poorly sorted fine sand with a mean grain size of 0.125 mm. Seawards of the 10 m isobath, the carbonate content rapidly increases to ~ 90% (Waters, 1982). Substrate types adjacent to Giles Point is characterised by Posidonia seagrass meadows (Shepherd and Sprigg, 1976).

References


Port Lincoln

Port Lincoln is located on the Eyre Peninsula and is managed by the Ports Corporation of South Australia http://www.portcorp.sa.gov.au A natural deepwater harbor (Boston bay) makes Port Lincoln attractive to large bulk grain carriers for topping up loads from shallow ports in South Australia and Victoria. Principal exports from this port are grain and phosphate. The port is also utilised by the South Australian fishing fleet.


Hydrography

According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 13 to 19°C and seasonal salinity values are: 35.933 (summer) 36.001
(autumn) 35.921 (winter) and 35.884 (spring). Depth averaged temperature in Spencer Gulf just outside of Port Lincoln measured in April, 1964, was 17°C and salinity was 36/oo according to Bullock (1975). Nunes Vas et al. (1990) reported a salinity of 36.1/oo outside Port Lincoln based on observations made in June, 1986. There is minimal freshwater discharge into the harbour, and its close proximity to the entrance to Spencer Gulf suggests that these oceanic salinity values are representative of the harbour conditions. Nunes Vas et al. (1990) provide a summary of seasonal data obtained outside the port area adjacent to Cape Donnington, and show that a temperature front may occur across the gulf entrance due to summer heating.

Tides and currents

The extreme spring tidal range at Port Lincoln is 1.76 m (Noye, 1984). The diurnal inequality is very large in southern Spencer Gulf, such that at Port Lincoln and Wallaroo the tides exhibit a nearly diurnal cycle on neaps, and some spring tides may have one large diurnal cycle at times (Easton, 1978). No information of currents in Port Lincoln harbour is available.

Sediments and habitats

The nautical chart (AUS 776) shows Boston Bay is 10 to 15 m deep and has a bottom of fine sand and mud, with coarse sandy beaches and rocky shores around the harbour area. Short et al (1989) described low beach ridges which formed in relation to northerly wind waves in Proper Bay, near Port Lincoln.

References


Port Pirie
Port Pirie is situated on the eastern side of upper Spencer Gulf and is principally a bulk port, handling lead and zinc ores and concentrates, also grains from the northern agricultural areas of the State. The port is home to what is reputedly the world’s largest lead smelter (annual output of 9.6 million tonnes) run by PASMINCO. The port is managed by South Australia Ports Corporation [http://www.portscorp.sa.gov.au/](http://www.portscorp.sa.gov.au/)

The dredged channel is 6.4 m in depth, with a minimum width of 91 m, and it follows a circuitous route for about 15 km across the extensive shoal area of Germein Bay (AUS Chart 778). The 10 berths all have a dredged depth alongside of 8.2 m and can accept vessels of up to 193 m x 32 m in size.

**Ballast water**


**Hydrography**

Spencer Gulf is well known oceanographically as a negative or inverse system, in which evaporation far exceeds runoff, which results in the formation of a dense saline bottom-water mass that flows seawards under certain conditions (Noye, 1984; Nunes and Lennon, 1986; Nunes-Vaz et al., 1990). Rainfall at Port Augusta is 236 mm/a which is less than 10% of the “pan” evaporation rate of 2507 mm/a. Whereas rainfall is fairly uniform throughout the year, evaporation peaks in January (371 mm/month) and falls to a low in June (71 mm/month; Bye, 1981). There is no fluvial input of freshwater to upper Spencer Gulf at any time (Gostin et al., 1984). Hence, there is a seasonal pattern to the formation of dense, saline water produced by evaporation.

Based on a CTD survey conducted in March 1984, Nunnes and Lennon (1986) reported depth-averaged temperatures of between 22 to 22.5°C and salinities in excess of 42‰ in the vicinity of Port Pirie. Bye (1981) predicted that the yearly-averaged surface salinity in the vicinity of Lowly Point should be around 42‰ and seasonal variations should follow an annual sinusoidal cycle, with a low of ~41‰ in August-September and a high of ~43‰ in February-March. Burne and Colwell (1982) collated minimum and maximum temperature and salinity values for several locations in the gulf; for Port Pirie channel, the relevant values are 10 to 26°C and 41.2 to 47.2‰.

**Tides and currents**

The upper reaches of Spencer Gulf form a hypersynchronous tidal system, in which the tidal wave is amplified by the geometry of the northward-converging coastline. The extreme spring tidal range at Port Pirie is 3.44 m but the range at Port Augusta, 60 km further north, is 4.32 m (Noye, 1984). The diurnal inequality is very large in the southern Gulf, such that at Port Lincoln and Wallaroo the tides exhibit a nearly diurnal cycle on neaps, and some spring
tides may have one large diurnal cycle at times (Easton, 1978). At Port Pirie the diurnal inequality is present but not as extreme as in the southern gulf.

Between November 1976 and October 1977, Noye (1984) reported that at Port Pirie there were 7 negative storm surges that lowered sea level by ~ 0.5 m and 17 positive surges that raised sea level by more than 1 m. These storm surges are produced by atmospheric pressure gradients and wind-stress which piles up water on one side of the gulf (Noye, 1984).

Currents in the vicinity of Port Pirie are driven mainly by the tides. A maximum speed of around 0.5 m/s adjacent to Ward Spit was reported by Noye (1984) and currents of up to 1 m/s occur near Eastern Shoal at the entrance to Germein Bay (AUS chart 778). However, tidal flows inside the bay itself are likely to be much less than this. Superimposed on these tidal flows are wind-driven currents with speeds up to 0.17 m/s, and density-driven currents with speeds of up to 0.1 m/s (Noye, 1984; Nunes and Lennon, 1986; Nunes-Vaz et al., 1990).

Because of the heavy industry carried out in the upper sections of Spencer Gulf, a number of modelling studies have been published on oil spill slick trajectories (Beer et al., 1983) and water-pollutant movements (eg Tronson, 1974; Green, 1984; Nunes-Vaz et al., 1990). A problem with the negative circulation exhibited by the estuary, in which a net landward flow of surface water is required to offset the seaward flow of dense saline bottom-water, is that the circulation acts to transport any pollutants in surface waters landwards towards Port Augusta. This may be an important factor to consider in the context of the fate of discharged, normal-salinity, ballast water.

Sediments

Hails et al (1984) collected 330 cores and 365 km of boomer seismic profile data in the upper section of Spencer Gulf. In cores collected offshore from Germein Bay, the Holocene bottom sediments are a poorly sorted mixture of shell sand and gravel, quartzose sand and mud, with variable amounts of seagrass fibre. The carbonate content exceeds 60% in the outer bay but this decreases southwards towards the port (mangrove swamp) area. This sediment type forms a uniform, ~2 m thick drape over the area surveyed in Germein Bay. These sediments overlie “Mambray Formation” Pleistocene weathered clays with calcareous horizons that was subaerially exposed during the last glacial maximum (Hails et al., 1984).

Intertidal and supratidal sedimentary facies were mapped by Depers (1974) on the bases of 66 surface and core samples and aerial photograph interpretations. The channel bottom and floor of Germein Bay are classified by this worker as Posidonia gastropod-foram skeletal packstone. It is a grey, poorly-sorted, muddy gravelly sand, containing 60 to 90% carbonate which is composed of 10-30% coralline algae fragments, 10-30% foraminifera, 15-20% gastropods and 5-15% undifferentiated skeletal debris. The terrigenous component is comprised of quartz sand and clay. Organic matter content was as high as 30% composed mainly of decaying Posidonia leaves and fibres. This subtidal facies is flanked along the channel margins by shallow subtidal to intertidal Zostera gastropod-foram skeletal packstone (Depers, 1974), characterised by prolific growths of Zostera seagrass. It is composed of sediment apparently transported landward from the subtidal Posidonia gastropod-foram
skeletal packstone facies, because although grains are of similar origin, they appear more fractured and rounded.

Because of the zinc smelter at Port Pirie and its impact on the local environment, a large number of studies into the heavy metal concentrations in marine sediments (Depers, 1974; Dossis and Warren, 1981; Ward and Young, 1981; Harbison, 1984; Norrish et al., 1986; Lent et al., 1992), seagrasses and benthic organisms (Ward and Young, 1984; Ward et al., 1986) have been carried out. One sediment core sample collected 8 km downwind from the smelter by Lent et al. (1992) from supratidal sediments adjacent to intertidal mangroves, contained extremely high concentrations of lead, zinc and cadmium (2960, 5390 and 120 µg/g, respectively). In subtidal muddy sediments, adjacent to the shipping channel (Stn. D of Norrish et al., 1986) concentrations of lead, zinc and cadmium were found to be 970, 1850, and 14 µg/g, respectively. Although lead and zinc concentrations decrease with distance from the smelter, cadmium is more mobile and appears to be associated with seagrass detritus (Ward and Young, 1981). Hence, the port area is highly polluted with industrially-derived heavy metals, although metal levels are much lower in bottoms sediments deposited outside Germein Bay in the central gulf (Harbison, 1984).

Barnett et al. (1997) studied Holocene sea level change at Port Pirie based on a coastal sedimentary succession.

Habitats

The coastal habitats adjacent to Port Pirie are predominantly the extensive intertidal mud flats (1 to 2 km wide) backed by mangrove swamps (2 to 4 km wide). The dredged shipping channel follows an ancient drainage channel which is flanked on both sides by mangrove swamps. Subtidal habitats include extensive Posidonia seagrass beds which are distributed over about 18% of the subtidal channel area to a depth of about 6 m (Gostin et al., 1984). The density of fauna in the unvegetated intertidal flat area of Germein Bay was >280 m⁻² and was as great as 2,612 m⁻² in the intertidal seagrass habitat (Hutchings et al., 1993). In the subtidal channels, between 10 and 15 m, the razor shell Pina bicolor dominates the benthic community and occurs at densities of up to 5 m⁻². This community includes other molluscs, bryozoans, soft corals, ascidians and sponges (McLaren and Wiltshire, 1984).

References


**Port Stanvac**

On the eastern shore of St. Vincent Gulf, 35 km south of Port Adelaide, Port Stanvac is an open oil harbour operated by Petroleum Refineries (Aust.) Pty. Ltd.

The port provides one single buoy mooring berth for crude discharging and one berth for shipment of refined products at the head of an L-shaped jetty which projects 650 m WNW from the shore at Curlew Point. The berth has a max. draft of 10.7 m alongside. Berthed vessels must keep the main engines ready for immediate use on very short notice. The berths are approached directly from Gulf St. Vincent and there is no dredged channel.

**Ballast water**


**Hydrography**

According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 13 to 20°C and seasonal salinity values are: 36.483 (summer) 36.522 (autumn) 36.467 (winter) and 36.428 ‰ (spring). However, according to maps published by Bye (1976) and deSilva Samarasinghe (1998), surface salinity in the upper gulf exceeds 37 ‰, and hence the seasonal range in salinities reported by the EPA (1996) may be too small. The National Tidal Facility maintains a tide guage at the port which has collected sea surface temperature data since 1992.

**Tides and currents**

The mean spring tidal range at Adelaide outer harbour (nearest tidal reference to Port Giles) is 2.1 m, but the range at Port Stanvac is probably only about ~1.1 m or so, because tidal amplification occurs in a northwards direction in Gulf St. Vincent (Bye, 1976). Furthermore, the tidal range at Port Noarlunga (6 km south of Port Stanvac) is only about 50% of that for the Adelaide outer harbour, according to data presented by Smith (1985).

Tidal current energy is at a minimum along the Port Stanvac area, according to the modelling results presented by Waters (1982). Similarly, wind-driven currents are also weak in the vicinity of the port (Waters, 1982) and most wind conditions result in a weak, northward drift
through the area (Bye, 1976). Tidal mixing during spring tides causes an increase in the eddy viscosity and reduces the efficiency of wind-induced energy transfer through the water column. Hence, wind-driven currents of the order of 0.2 m/s are most pronounced during neap tides in the gulf (Provis and Lennon, 1983).

*Sediments and habitats*

Surficial sediment maps of the Gulf St Vincent constructed by Waters (1982) show that the area adjacent to Port Stanvac is <50% terrigenous, poorly sorted fine sand with a mean grain size of ~0.25 mm. Seawards of the 30 m isobath, the carbonate content rapidly increases to ~90% (Waters, 1982). Substrate types adjacent to Port Stanvac is characterised by aeolianite reef interspersed with *Posidonia* seagrass meadows (Shepherd and Sprigg, 1976). The coastline here is comprised of steep rocky cliffs to the north (in Hallets Cove) with a rocky beach in the vicinity of the jetty (AUS 781).

*References*


**Thevenard (Ceduna)**

Thevenard is managed by the South Australia Ports Corporation [http://www.portscorp.sa.gov.au/](http://www.portscorp.sa.gov.au/), and located 3km from the town of Ceduna (pop 4,000). Major commodities handled are gypsum, salt and grain. According to P&O Ports [http://www.poal.com.au/](http://www.poal.com.au/) the shipping channel is dredged to 8.2 m depth and alongside the berth it is dredged to a depth of 9.8 m. The port is located on Murat Bay, facing the Great Australian Bight (AUS Chart 120).

*Hydrography*
According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 13 to 20°C and seasonal salinity values are: 36.130 (summer) 36.162 (autumn) 36.096 (winter) and 36.014‰ (spring). The National Tidal Facility maintains a tide gauge at the port which has collected sea surface temperature data since 1992 (EO&S Report).

**Coastal environments**

Short et al (1989) described beach ridges, chenier plain and mangrove environments in Laura and Tourville Bays, that lie adjacent to Murat Bay. In protected embayments like Tourville Bay, modern and reworked bioclastic sediment has infilled the embayment with up to 7 m thickness of Holocene sediments. Progradation of intertidal sand flats, mangroves and cyanobacterial-halophyte marsh across subtidal seagrass banks, dominated by *Posidonia australis* controls the lateral habitat zonation and the vertical facies succession (Gostin et al., 1988).

**References**


**Wallaroo**


**Bathymetry**

Wallaroo Bay is mainly 8 to 9 m in depth to within 1 km of the supratidal zone. The dredged approach channel to the jetty is approximately 7 km long, with a depth of 8.4 m (AUS Chart 777). According to Bridgewater Chartering Pty Ltd., [http://www.dryoil.com.au/drycargo/ports/sa/wallaroo/wallaroo.html](http://www.dryoil.com.au/drycargo/ports/sa/wallaroo/wallaroo.html) Wallaroo Jetty is 867 m in length and has three berths on each side dredged to depths of 7.3 to 9.5 m. The bottom of the swinging basin and berth area consists of clay.

**Hydrography**
Spencer Gulf is well known oceanographically as a negative or inverse system, in which evaporation exceeds runoff forming a dense saline bottom-water mass to flow seawards under certain conditions (Bye, 1981; Noye, 1984; Nunes and Lennon, 1986; Nunes-Vaz et al., 1990). Bye (1981) predicted that the yearly-averaged surface salinity in the vicinity of Wallaroo should be around 39%/oo. and seasonal variations should follow an annual sinusoidal cycle, with a low in August-September and a high in February-March.

The study of Nunnnes and Lennon (1986) was based on 14 CTD surveys conducted in Spencer Gulf between July 1982 and January 1985. The data showed salinity near Wallaroo ranging from a high of 39%/oo in April 1983 to a low of 37.9%/oo in September 1983 (Nunnes and Lennon, 1986, their Fig. 6). Temperature follows a sinusoidal seasonal pattern, with a low of 12.4 in July-August to a high of 22.8 in February. Based on a CTD survey conducted in March 1984, Nunnes and Lennon (1986) reported a depth-averaged temperature 21°C and salinities of between 38.5 and 39%/oo. in the vicinity of Wallaroo.

Tides and currents

The mean spring tidal range at Wallaroo is 1.1 m and the maximum range is 1.76 m (Noye, 1984). Tidal currents flow northeast-southwest into Wallaroo Bay, across the shipping channel, reaching speeds of up to 1 knot (0.5 m/s) on spring tides (AUS Chart 777). The diurnal inequality is very large in the southern Gulf, such that at Wallaroo the tides exhibit a nearly diurnal cycle on neaps, and some spring tides may have one large diurnal cycle at times (Easton, 1978).

Between November 1976 and October 1977, Noye (1984) reported that at Port Pirie, there were 7 negative storm surges that lowered sea level by ~ 0.5 m and 17 positive surges that raised sea level by more than 1 m. These storm surges are produced by atmospheric pressure gradients and wind-stress which piles up water on one side of the gulf (Noye, 1984).

In a computer model presented by Tronson (1974) surface water movements in the area of Wallaroo were towards the south under prevailing southwesterly winds, as the consequence of a clockwise rotating gyre which is established in this section of the gulf. Southerly flow was also predicted under northwesterlies (Tronson, 1974). Nunes-Vaz et al., (1990) showed that thermohaline circulation in the gulf resulted in laterally separated northward flow along the western gulf coast, with southward flow along the east coast (ie near Wallaroo). These current speeds are probably very weak (<0.1 m/s) and wind-driven currents are expected to exceed density-driven currents by an order of magnitude (Tronson, 1974; Noye, 1984).

Sediments and habitats

The coast in the immediate vicinity of the Wallaroo jetty is rocky beaches with intertidal rocky reefs 1 km to the south, giving way 1 km towards the north to a sandy beach (AUS Chart 777). In protected embayments like Wallaroo Bay, progradation of intertidal sand flats, mangroves and cyanobacterial-halophyte marsh across subtidal seagrass banks, dominated by Posidonia australis controls the lateral habitat zonation and the vertical facies succession (Gostin et al., 1988).
References


Whyalla

Whyalla is home to the BHP steel rolling mill, situated on the western shore of upper Spencer Gulf, about 17 km from Port Bonython LPG jetty and about 300 km from the gulf entrance. The port includes an ore loading jetty and a harbour wharf (known as “Blast Furnace Wharf”). The ore loading jetty is 170m long and is connected to the shore by a causeway. The berth has a length of 250m and the water depth alongside is 11.6m.

According to a web page maintained by Bridgewater Chartering Pty Ltd [http://www.dryoil.com.au/drycargo/ports/sa/portbonython/portbonython.html](http://www.dryoil.com.au/drycargo/ports/sa/portbonython/portbonython.html) Blast Furnace Wharf is a continuous land-backed wharf situated on the north side of the harbour basin. It has four berths: No. 1, used for coal, coke and tar, is 175m long and the water depth alongside is 10.7m; No. 2 used for limestone, salt and coke breeze, is 175m long and the water depth alongside is 10.7m; No. 3 used for steel and general cargo, is 167m long and the water depth alongside is 10.7m.; and No. 4 used for steel and Ro/Ro operations, is 183m long and the water depth alongside is 10.7m.

Hydrography

Spencer Gulf is well known oceanographically as a negative or inverse system, in which evaporation exceeds runoff forming a dense saline bottom-water mass to flow seawards under certain conditions (Bye, 1981; Noye, 1984; Nunes and Lennon, 1986; Nunes-Vaz et al., 1990). Bye (1981) predicted that the yearly-averaged surface salinity in the vicinity of Whyalla should be around 42/o/o, and seasonal variations should follow an annual sinusoidal cycle, with a low of ~41/o/o in August-September and a high of ~43/o/o in February-March.
The study of Nunnes and Lennon (1986) was based on 14 CTD surveys conducted in Spencer Gulf between July 1982 and January 1985. The data showed salinity ranging from a high of 41.5‰ in April 1983 to a low of 39.5‰ in November 1983 near Whyalla (Nunnes and Lennon, 1986, their Fig. 6). Temperature follows a sinusoidal seasonal pattern, with a low of 12.4 in July-August to a high of 22.8 in February. Based on a CTD survey conducted in March 1984, Nunnes and Lennon (1986) reported a depth-averaged temperature 22°C and a salinity of between 39.5 and 40‰ in the vicinity of Whyalla.

Tides and currents

The upper reaches of Spencer Gulf form a hypersynchronous tidal system, in which the tidal wave is amplified by the geometry of the northward-converging coastline. The extreme spring tidal range at Whyalla is 3.06 m but the range at Port Agusta, 50 km further north, is 4.32 m (Noye, 1984). The diurnal inequality is very large in the southern Gulf, such that at Port Lincoln and Wallaroo the tides exhibit a nearly diurnal cycle on neaps, and some spring tides may have one large diurnal cycle at times (Easton, 1978). At Port Augusta the diurnal inequality is much less and the tides are more uniformly semidiurnal.

Between November 1976 and October 1977, Noye (1984) reported that at Port Pirie (about 40 km from Whyalla on the opposite shore of Spencer Gulf), there were 7 negative storm surges that lowered sea level by ~ 0.5 m and 17 positive surges that raised sea level by more than 1 m. These storm surges are produced by atmospheric pressure gradients and wind-stress which piles up water on one side of the gulf (Noye, 1984).

Currents in the vicinity of Whyalla are driven mainly by the tides, and speeds of up to 1 m/s may occur adjacent to Fairway Bank in the main channel, with weaker flows occurring along the channel margins. Because of the heavy industry carried out in the upper sections of Spencer Gulf, a number of modelling studies have been published on oil spill slick trajectories (Beer et al., 1983) and water-pollutant movements (eg Tronson, 1974; Green, 1984; Nunes-Vaz et al., 1990). In a computer model presented by Tronson (1974) surface water movements in the area of Whyalla were towards the north under prevailing southwesterly winds. Nunes-Vaz et al., (1990) showed that thermohaline circulation in the gulf resulted in laterally separated northward flow along the western gulf coast (ie near Whyalla), with southward flow along the east coast. These current speeds are probably very weak (<0.1 m/s) and wind-driven currents are expected to exceed density-driven currents by an order of magnitude (Tronson, 1974; Noye, 1984).

Sediments

Hails et al (1984) collected 330 cores and 365 km of boomer seismic profile data in the upper section of Spencer Gulf. In cores collected offshore from near Whyalla, these workers described the bottom sediments as a poorly sorted mixture of shell sand and gravel, quartzose sand and mud, with variable amounts of seagrass fibre. This sediment type forms a layer 0 to 1m thick near Whyalla, but may reach ~ 2m thickness in small patches in False Bay. These sediments overlie the “False Bay Formation” which is a mottled greyish yellow brown (oxidised red), laminated and gypsiferous clay, estimated to have been deposited ~80,000
years BP during a previous sea level high stand. The clay was subaerially exposed and weathered during the last glacial maximum (Hails et al., 1984).

Heavy metal concentrations in the intertidal flats near Whyalla were reported by Harbison (1984) as being enriched above background levels in lead, manganese, zinc and cadmium. About 429,000 m$^3$/day of wastewater from the BHP steel works is discharged into False Bay via a settling pond. This water contains $\sim$ 5 g/l suspended solids, which in turn contains high concentrations of lead, zinc, copper and manganese (McLaren and Wiltshire, 1984).

**Habitats**

The port area is located on a rocky promontory composed of Precambrian sedimentary rocks (Gostin et al., 1984). To the north is False Bay, which is shallow with 2 to 4 km wide intertidal flats and which has undergone $\sim$ 5 km of Holocene progradation and infilling (Gostin et al., 1984). To the south, the coastal habitats include intertidal sand and mud flats, mangroves, and salt flats (Burne and Colwell, 1982). McLaren and Wiltshire (1984) note that a large mangrove forest is located just south of Whyalla. McLaren and Wiltshire (1984) described the distribution of seagrasses offshore from Redcliff in upper Spencer Gulf, which they consider to be representative of the upper gulf. There is a succession of seagrass species with increasing depth and distance from the intertidal zone. The most extensive and widespread is the *Posidonia australis* seagrass beds which are distributed over about 18% of the subtidal channel area to a depth of about 6 m (Gostin et al., 1984). Fairway Bank, located offshore from the port, supports another large seagrass meadow. Below 6 m depth, the seabed is characterised by coarse gravelly sand and bedforms (Gostin et al., 1984). Some deeper (up to $\sim$9 m), lower current energy areas away from the main tidal channels may support *Posidonia sinuosa* and *Heterozostera tasmanica* seagrass communities (McLaren and Wiltshire, 1984).

In the deep water channels, between 10 and 15 m depth, the razor shell *Pina bicolor* dominates the benthic community and occurs at densities of up to 5 m$^{-2}$. This community includes other molluscs, bryozoans, soft corals, ascidians and sponges (McLaren and Wiltshire, 1984).

**References**


TASMANIAN PORTS

Port of Bell Bay

Port description

The Port of Bell Bay is located on the Tamar River on the north coast of Tasmania. Other port facilities are provided by the port at Launceston, but this is restricted to shallow draught vessels (<5.4 m). The port includes major industrial users, including Mobil Oil, Comalco Aluminum, BHP Temco and woodchip exporting facilities.

The Tamar estuary formed during the last transgression when sea level rose, drowning the river valley. The river extends for 69.5 km from the coast to Launceston, where it joins the North and South Esk Rivers making a total catchment area of 11,590 km² (Edgar et al., 1998). A large amount of sediment (approx. 40,000 t/yr), is being deposited in the estuary, slowly infilling the channels. The majority of this sediment comes from the South Esk River (Foster and Nittim, 1987). A major environmental review of the Tamar estuary has been published recently by Pirzl and Coughanowr (1997) which confirms that few studies have been carried out into water quality or sedimentology.
**Bathymetry**

The Port of Bell Bay is naturally deep and so no significant maintenance dredging is required. Consequently, there has been no need for recent hydrographic survey work. Hand-drawn fair sheets are available from the Port Authority, but no digital bathymetry or port-layout data are available.

**Hydrology**

The estuary has a semi diurnal tidal regime, dominated by the M₂ component (Foster et al., 1986). There is an increase in mean spring tidal range from 2.34 m at Georgetown to 3.25 m at Launceston. The maximum spring tidal range recorded at Rosevears is 3.9 m, and the minimum neap range is 2.1 m. Tidal non-linearity increases upstream, with a marked distortion of the tidal curve evident at Launceston (Foster *et al.*, 1986).

The catchment of the Tamar River is approximately 9700 km². The South Esk River provides the greatest fresh water flow, with an estimated mean discharge of 62 m³/s (Newell, 1969, report to Hydro-Electric Commission of Tasmania). There is significant seasonal variation in flow, with the maximum recorded in spring and winter. Water temperature also varies, from an average of around 10°C in winter to 20°C in Summer. Secchi disk readings collected since 1971, indicate that visibility is generally low (< 1m) in the upper part of River, increasing to high (5-10m) near Bell bay at the entrance to the Tamar (Foster *et al.*, 1986).

The salinity structure of the river, during low flow and flood flow conditions has been investigated by Rochford, (1951) and Foster *et al.*, (1986). At Rosevears there is little variation in the salinity over the ebb and flood tide. However, further upstream at Freshwater Point, there is a distinct asymmetry between ebb and flood tides, with an increase in salinity stratification on the flood tide. During flooding the upper estuary is occupied completely by fresh water, while the lower estuary remains strongly stratified.

Temperature and salinity data have been collected by the Launceston City Council (1998) associated with a study of metropolitan sewer outfalls. According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 11 to 18°C and seasonal salinity values are: 35.387 (summer) 35.388 (autumn) 35.315 (winter) and 35.292 (spring).

**Sediments**

The sediments of the Tamar River are dominated by muds, although sands are present at the mouth of the estuary, down stream of Whirlpool Reach. Adjacent to the Bell Bay berthing area sediments are described as sand with bedrock outcrops adjacent to the shore (Foster *et al.*, 1986). Precise grain size data are not available.

Upstream of Whirlpool Reach the sediments are almost entirely silty mud. Sedimentation in the upper estuary has been effected by the construction, in 1955, of the Trevallyn Dam on the
South Esk River. The dam effectively traps the bed load of the South Esk River, so that no coarse fluvial material enters the estuary from this source.

A major study on siltation of the river, which has been a problem since about 1915, was carried out by Foster et al., (1986). Dredging of the river channel in the upper estuary started in 1880, and ceased in 1967, when the major port facilities were moved downstream to Bell Bay. Foster et al. (1986) determined that during periods of low flow sediment is moved upstream by the tide, and settles out in the old dredged areas within Home Reach. They estimated that the siltation rate at Home Reach is 43,300 tonnes/yr. There are two other areas of major sediment deposition in the upper estuary, the Tamar Island shoals, and the Nelson Shoal at Rosevears (Fig. 8.58). Foster et al. (1986) calculated that 1,500,000 m$^3$ of silt has been deposited on the Tamar Island Shoals in the last 96 years. Interestingly, the operation of the power station has decreased the rate of siltation by reducing the incidence of low river flows.

The estuary has extensive areas of inter-tidal mud flats which have been colonized by the exotic *Spartina anglica* (rice grass). In some areas the introduced vegetation has acted as a significant sediment trap, with up to 12 cm/yr of vertical accumulation (Pringle, 1982). This factor, in combination with increased sediment loads due to anthropogenic disturbance in the river catchment, has resulted in rapid infilling of channels and siltation, that has been identified as a problem for local environmental managers (Pirzl and Coughanowr, 1997).

Iron Barron


References:


Foster, D. N., & Nittim, R., (1987) Siltation of the Tamar River. 8th Australasian Conference on Coastal and Ocean Engineering. Launceston,


**Port of Burnie**


*Bathymetry*

The Port of Burnie is situated on the western shore of Emu Bay, which covers ~ 8 km². Depth in the bay and alongside the berths is 10 m. Digital bathymetry for the port layout and surrounding area has been provided in DXF format and is available on 3.5” floppy disk.

*Hydrography*

The only T&S data available is the global US Navy Marine Climate Atlas of the World CD-ROM Version 1.1. This provides monthly statistics for 1° squares (ie. Stanley and Burnie fall within the same square) and ignores any local fluvial input effects. According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 11 to 18°C and seasonal salinity values are: **35.335** (summer) **35.352** (autumn) **35.309** (winter) and **35.26** (spring).

*Wave model*

A wave model has been developed for the port by the Wallingford Hydraulics Research Station (1958). Wave data have also been collected over a period of three years by Lawson and Treloar Pty Ltd (1985).

*Sediments*

The harbour is dredged to a depth of 10 m and berths are dredged to 11.5m. The sediments sampled from the dredged berth areas are medium to coarse silt and frequency histograms are available (BFP Consultants, 1995). According to the Burnie Port Authority, the harbour bottom is sand and clay interspersed with patches of reef and rock particularly in the south eastern sector of the bay.
Coastal shoreface sediments along the northern Tasmanian shoreline were studied by Davies and Hudson (1987a,b). These workers found that shoreface sediments reflect mostly the influence of local point-source sediment supplies, in terms of texture and mineralogy. Littoral drift rates are low due to the lack of sufficient sediment supply along portions of this coast, and the generally low level of surface wave energy (Davies and Hudson, 1987a,b). Most of the volume of shoreface sediments were emplaced during rising sea level by around 6,500 years BP and modern rivers provide only a minor sediment source (Hudson and Davies, 1987).

References

BFP Consultants (1995) Particle Size distributions for seabed samples for Burnie Port, Burnie. Letter to Burnie Port Authority
Wallingford Hydraulics Research Station (1958). *Port of Burnie Model Investigation No. Wallingford Hydraulics Research Station, UK.*

**Port of Devonport**

The port of Devonport is managed by the Port of Devonport Corporation Pty Ltd [http://www.portdev.com.au/](http://www.portdev.com.au/) Also known as “Port Fredrick” the Port of Devonport is the home of Tasmania’s ferryboat terminal, linking the island to Melbourne and the mainland. The port is located on the northern coast of Tasmania. It has a mean tidal range of 2.2 m, maximum spring tidal range of 3.2 m and a surface area of 4.5 km². The port is located on the estuary of the Mersey River. P&O ports [http://www.poal.com.au/](http://www.poal.com.au/) operate some facilities of the port.

**Dredging operations**

The port has a long history of dredging operations which first commenced in 1882. Presently, the Port has an overall draft limit of 7.9 m and an active dredging program is being undertaken by the Port Authority to increase the port depth (Port of Devonport Authority,
Explosives have recently been used to remove bedrock outcrops from the channel bed (drill cores of the bedrock are held by the Port Authority). Between 1986 and 1994 a total of 660,000 m³ of sand, silt and shingle have been dredged from the Mersey estuary (Capt. R. O’Neill, pers. comm.).

The dredge spoil ground is located on the inner shelf in about 20 m water depth, some 3 km north from the estuary mouth. Prior to 1983 the dump site was located some 6 km northeast from the estuary mouth in a similar water depth. Current metering work has been carried out by the CSIRO, which shows that energy levels are too low to transport sand and coarser grain sizes of the dumped sediment; finer resuspended silt and clay may be advected along-shore by wind-driven flows (Environmental Management Services, 1992).

**Hydrography**

Because the ship berthing areas are within the estuary, temperature and salinity will be directly influenced by river discharge. No long-term T&S records are available for the estuary, although 5 current meter moorings and CTD profiles were collected in the vicinity of the dredge spoil dump site by the CSIRO (Environmental Management Services, 1992). The Mersey Estuary was included in Edgar et al.’s (1998) “Classification of Tasmanian Estuaries” and is specified to have a catchment area of 1753 km² with a mean annual runoff of 663 mm. According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 11 to 18°C and seasonal salinity values are: 35.387 (summer) 35.388 (autumn) 35.315 (winter) and 35.292 (spring).

**Bathymetry**

Digital bathymetry for the port layout and surrounding area has been provided in DXF format and is available on 3.5” floppy disk.

**Sediments**

The port sediments are mentioned in the study of Bolch and Hallegraeff (1990), and detailed frequency histograms are also available for the estuarine sediments that are dredged from the berthing areas (Environmental Management Services, 1992). These show that the mean grain size varies between sites from 35µm to 750 µm. The estuary exhibits attributes of a classical wave-dominated estuary, with sediments deposited in a central muddy basin, with marine sand intruding landwards from the estuary mouth and fluvial sand transported seawards at the head of the estuary (Map 2 in Environmental Management Services, 1992).

Coastal shoreface sediments along the northern Tasmanian shoreline were studied by Davies and Hudson (1987a,b). These workers found that shoreface sediments reflect mostly the influence of local point-source sediment supplies, in terms of texture and mineralogy. Littoral drift rates are low due to the lack of sufficient sediment supply along portions of the coast, and the generally low level of surface wave energy (Davies and Hudson, 1987a,b). Most of the shoreface sediments were emplaced during rising sea level by around 6,500 years BP and modern rivers provide only a minor sediment source (Hudson and Davies, 1987).
References


Hobart


Geological Description and Classification of the Port of Hobart

The Derwent has incised a valley which has been partially back-filled with sediments; fill thicknesses are about 10 m at New Norfolk, 29 m at the Bridgewater Causeway, 50 m at Bowen Bridge and 88 m at the Tasman Bridge (Fig. 1). Drilling at Bowen Bridge revealed Quaternary deposits filling a 50 m deep bedrock channel. The unconsolidated sediments described by Colhoun and Moon (1984) consist of a greenish-grey, fine sandy silt and clay unit, containing abundant, large carbonate nodules (10-15cm), and dolerite clasts. The sediments are interpreted as an estuarine facies, deposited during the last interglacial. Overlying this is a 1 m thick, transgressive, shallow-water unit, consisting of shelly sand and gravel, containing abundant fossil gastropods, barnacles, lamellibranchs, and worm tubes. These sediments are covered by a fluviatile-estuarine formation of grey silty clays, with fine sand interbeds and organic material. This deposit is characterised by the presence of enormous numbers of intact *Nothofagus cunninghamii* leaves, occasional *Eucalyptus* fruits, charcoal, twigs, fern spores and pollen, thought to have been deposited in a backswamp environment (Colhoun and Moon, 1982).
The Derwent estuary as it exists today was formed when the valley was flooded during the post-glacial sea level rise; it is thus a drowned river valley. The backswamp, fluvial-estuarine deposits described above (at Bowen Bridge) are overlain by 26 m of Holocene estuarine sediment, which consists of massively bedded, black, organic-rich mud. Radiocarbon dating of the mud suggests that it was deposited at a rate of between 0.8 to 1.2 cm/yr from 4500 yr BP (Colhoun and Moon, 1984). The estuarine sediments younger than 4500 years BP contain abundant charcoal fragments and Eucalyptus leaves, suggesting that the rapidly deposited Holocene sediment accumulations were influenced by Aboriginal disturbance of the catchment through burning (E. Colhoun, pers. comm.).

**Tides**

The Derwent River is tidal as far as New Norfolk, downstream of which the channel begins to widen, flowing through a narrow coastal plain to Old Beach (Fig. ). Downstream of Dowsings Point the channel deepens considerably and the river water is confined to a surface flow on the ocean water. The tides at Hobart are mixed semi-diurnal with a maximum astronomical tidal range (MHHW - MLLW) of 1.3 m. Tidal currents are generally weak (< 0.1 m/s) compared with fluvial and wind-driven flows (Thomson and Godfrey, 1985; Davies and Kalish, 1994).

**Fluvial input**

The Derwent River has a catchment area of 9,255 km² (Edgar et al., 1998) and an average annual water discharge of 4.28 x 10⁶ ML and supplies about 1.1 x 10⁵ tonnes/a of sediment (Olive, 1973). Fluvial sedimentation has formed flood-plain terraces and fluvial-deltaic bars between New Norfolk and Bridgewater. Based on sediment data presented by Coughanowr (1997), fine grained “sludge”, influenced by 1.5 million tonnes of wood fibre input from the Boyer paper mill over a 50 year period, is deposited mainly upstream of the Bowen Bridge (Fig. 1). Hence this marks the seaward limit of fluvially-dominated sedimentation. The sludge is described as “green to black in colour, gelatinous in texture and having a sulphurous odour” (Coughanowr, 1997).

**Waves**

Wave-formed structures include the Roaring Beach tombolo which joins South Arm to the mainland. Seismic data suggests that a bedrock channel beneath the tombolo is at a depth of > 90m. Wave action and coastal erosion has formed numerous cliffs, rock platforms and arches and blowholes along the coast (E. Colhoun, pers. comm.).

Wave climatology for the Australian region is available in digital format, and this will be representative of the wave climate in Storm Bay and deeper waters. The data is European Centre for Medium-Range Weather Forecasts (ECMWF) output derived from the US Navy Wave Model, WAM (Hasselman et al., 1988; Komen et al., 1994) which was used to yield 6-hourly predictions of significant wave height and period. The data are grided at 3° spatial resolution, for the period July 1992 to July 1994 and at 1.5° resolution for July 1994 to July
1997. The data suggest that off southern Tasmania the average significant wave height and period for both summer and winter months (Dec-Feb and June-Aug) is 3 to 4m and 9 to 11 seconds, respectively.

**Classification of the Derwent Estuary**

Based on the criteria of Dalrymple et al. (1990) the Derwent is classified as a wave-dominated estuary. Its major geomorphic features are illustrated in Figure 1. The upper portion of the estuary is supplied with fluvial sediments (and anthropogenic wood fibre) and these dominate seawards as far as Bowen Bridge. Between Bowen Bridge and South Arm the sediments are estuarine, exhibiting both marine and fluvial influences. Well-sorted sands deposited in wave-formed beaches are found along the more shallow margins of the estuary, and clean, wave-reworked sands comprise the seabed deposits adjacent to South Arm. These latter sediments are probably derived from Storm Bay and are advected landwards by storm-related currents in combination with oceanic swell. The main sediment type however, is located in the central muddy basin, which is characterised by Coughanowr (1997) as a “fine-grained, black, organic-rich contaminated sediment with H_2S odour”.

![Classification of the Derwent estuary based on the model of Dalrymple et al. (1990).](image-url)

**Bathymetry**
In addition to the published AUS charts, bathymetry data for the Port of Hobart includes some digital depth and port layout information for the commercial berth facilities. A hard copy chart showing a 1971 survey of Sullivans Cove is also available, at a scale of 1 inch = 100 ft (1: 1,200). This data was provided by Mr. Andrew Dobbie of the Hobart Ports Corporation.

Hydrography

Hydrological surveys have been carried out by Guiler (1955), Thomson and Godfrey (1985) and Davies and Kalish (1994). Ritz and Buttermore (1984) reported on salinity, temperature, dissolved oxygen and sulphide at one station in the upper Derwent just downstream from the ANM Boyer paper mill.

Guiler (1955) collected surface and bottom water samples at 60 stations and measured water temperature, salinity, pH and suspended sediment concentration. About half of the stations were visited at monthly intervals during 1949 to 1951 and mean monthly values were determined. Estuarine circulation exhibits stratified, hypopycnal flow. Over the period of observations, the salt wedge was not observed to extend as far upstream as New Norfolk; flood events appeared to favour the eastern shore and were detected in Opposum Bay in the outer estuary.

Thomson and Godfrey (1985) reported on a series of hydro-casts taken at 8 stations along a longitudinal transect of the Derwent. The casts were repeated on six occasions between 1975 and 1976. The river is strongly stratified in its upstream reaches and saltwater is flushed completely downstream as far as Bridgewater during floods which exceed 150 m$^3$ sec$^{-1}$ (N.B. the mean river discharge is about 120 m$^3$ sec$^{-1}$; Davies and Katish, 1994). Thomson and Godfrey (1985) note that the salt-wedge stratification is restored in the upper estuary about 5 to 6 days after major floods. Wind shear is more important than tides in vertical mixing processes. The propensity for flood waters to flow seawards along the eastern shore (as noted by Guiler, 1955) is attributed by Thomson and Godfrey (1985) to the Coriolis force.

Measurements of temperature, salinity DO and current speed at 19 stations are reported by Davies and Katish (1994) and used to derive a two-layer, one-dimensional box model. Water samples were also collected and analysed for pH, colour, total tannins, sulfide and non-filterable residue (NFR). Tidal current speeds of up to 20 cm/sec were measured in the upper estuary with weaker flows elsewhere. Davies and Katish (1994) observe that the construction of hydroelectric dams on the river, combined with a period of relatively low rainfall since 1977, have resulted in fewer flood events in the river.

Other unpublished modelling work has been conducted by the CSIRO Coastal Zone Program (Coughanowr, 1997) and measurements of temperature and salinity (unpublished data) have been collected as follows (Keith Hayes, pers. comm.):

Marine Board of Hobart raft data - hourly recordings at 0.5m and 7m(?) of water temperature, current speed, current direction, and tide relative to 1500mm datum. Also includes wind speed, wind direction and gusts. Data record goes back to January 1988, contact Andrew Dobbie, MBH.
CSIRO survey data - temperature and salinity measured as a function of depth at 60 stations (through-out the estuary - can supply map) on ten separate occasions between March 1992 and July 1994.

CSIRO river flow - Derwent river flow for each day on ten months between March 1992 and July 1994 (months correspond to those during which T & S surveys above were undertaken).

CSIRO current meter data - Hourly (?) current meter (x 4) readings from 2 locations in the middle of the estuary, deployed for about 100 days between October 1993 and January 1994.

Pasminco salinity data - Pasminco progress report No. 3; surface (?) salinity measurements at 24 sites (5 transects) in Ewick Bay taken on a rising and a falling tide on 26.09.78. Vertical salinity profiles measured at 7 sites in Elwick Bay on 18.12.78

CRIMP Risdon survey - vertical temperature and salinity profiles at 5 sites in the vicinity of the Risdon berth (map available) taken over a period of one tidal cycle (6 hrs) on 28.10.97.

**Introduced Pests**

In 1980, southern Tasmania experienced a bloom of the toxic dinoflagellate *Gymnodinium catenatum*, which resulted in two reported cases of mild shellfish poisoning (Hallegraff and Sumner, 1986). Subsequent toxic blooms have occurred annually, with severe impacts causing the closure of some shellfish farms in 1986, 1991 and 1993 (Hallegraeff et al., 1988; 1995). The blooms have been noted in the outer Derwent estuary, D'Encastreaux Channel and Huon River estuary. Despite having a high organic content due to industrial inputs (see below), plankton blooms are rare in the upper Derwent because of high turbidity and poor light penetration (Tagaza, 1995).

Recent studies using sediment cores and radioisotopic dating techniques, McMinn et al. (1997) have confirmed that *Gymnodinium catenatum* was introduced to Tasmanian waters in about 1972, and probably it arrived in ship’s ballast water.

In their report on the distribution and abundance of the seastar *A. amurensis*, an introduced species, Buttermore et al. (1994) consider discarded ballast water from overseas ships to be the likely cause. The species is a serious predator of bivalve molluscs and appears to be thriving in Tasmanian waters, with vast numbers having been observed in the Hobart area.

**Capital dredging works**

The dock facilities of the Port of Hobart make use of the natural harbour in Sullivans Cove and do not require maintenance dredging (Andrew Dobbie, pers. comm.). Dock construction commenced shortly after the arrival of the first settlers in 1804 and reached its present
configuration in the 1960’s. Little new harbour construction has been carried out in recent years apart from some minor dredging to increase the depth at Maquarie Wharf, which was carried out using a backhoe (Andrew Dobbie, pers. comm.).

**Sediments**

The best available information on the distribution of surficial sediments is the thesis of Pirzl (1996). This worker analysed around 40 samples over the length of the Derwent, from new Norfolk to South Arm and mapped the mud content of bottom sediments (Fig. 2).

![Figure 2 Distribution of mud content in Derwent estuary bottom sediments. The shaded area indicates the distribution of sediments containing over 90% mud (after Pirzl, 1996).](image)

Guiler (1955) observed that by 1955, there had been a change in the hydrological character of the river. He cites the example of New Town Bay, where muddy sediments are now found covering what used to be a sandy bottom. These changes are attributed to increased runoff and sediment load in the river, caused by agricultural practices in the catchment. Detailed grain size studies giving frequency curves for Derwent estuary bottom sediments are not available at present.

**Heavy metals and other toxicants**
Heavy metal pollution in the Derwent estuary has received considerable attention over the years, due to several heavy industries which have set up operations in the area, notably the Pasminco zinc refinery and the Australian Newsprint Mills (ANM) plant at Boyer. Zinc pollution appears to have reached its highest levels in about 1974; when the zinc ore carrier Lake Illawara collided with the Tasman Bridge in January 1995 and sank, it undoubtedly released a considerable quantity of zinc sulphide into the Derwent (Beckman, 1986). In bottom sediments near the Pasminco refinery, levels of copper as high as 6,000 ppm, zinc as high as 100,000 ppm, cadmium 500 ppm, mercury 450 ppm and lead 30,000 ppm were reported (Garland, 1990). Oysters containing up to 10,000 ppm of zinc were found (Beckman, 1986) and local oyster farms in Ralphs Bay were closed in 1975. The Pasminco zinc plant has been operating at its present site for 80 years. Further data may be found in Pasminco progress reports Nos. 2 and 4; Heavy metal concentrations (Zinc, Cadmium, Copper, Mercury and Lead) in Elwick Bay.

The ANM Boyer plant was established in 1941, and it discharges wood fibre and organic matter which has caused sections of the river to become anoxic. One study of benthic macrofauna found that no species were present in bottom sediments within 5 km downstream of the pulp mill (Horwitz and Blake, 1992). Effects of this input appear generally to not influence the Port of Hobart berthing areas.

The Derwent is also the topic of a major CSIRO environmental study, which can be viewed on the web: http://www.dmr.csiro.au/ResProj/CoasEnvMarPol/Derwent.html

Fluvial data

Monitoring from 1979 to 1988 showed that the Derwent had a median annual discharge of 120 cumeecs (cubic meters per second; Coughanowr, 1997). Other tributaries probably contribute less than 1 or 2 cumeecs. There are 20 storage facilities and 10 hydroelectric plants on the Derwent which modulate the natural river discharge patterns. Water is stored for use in winter months to generate electricity. Peak river discharge averaged over 10 years from 1983 to 1993 occurred in August to October, with the lowest discharge in March. Peak monthly discharges of over 250 cumeecs have been recorded (Coughanowr, 1997).

Calculation of estuary flushing rate

The surface area of the Derwent from new Norfolk to the southern end of South Arm is about 198 km² and the mean depth of the estuary is about 10 m (Coughanowr, 1997). This gives the estuary a volume of about 2 x 10⁹ m³ and, based on the median river discharge of 120 cumeecs, the average flushing time is about 190 days.

Oceanographic data (apart from sea temperature and salinity) and Oceanographic Modelling Results

Pendlebury (1987) - Three hourly wind measurements at John Garrow Light and Hobart Regional Forecast Centre for a period of one year from November 1983 to October 1984.
Pasminco current data - Pasminco progress report No. 1; unspecified number of current readings (magnitude and direction) taken in 1977 alongside the Risdon berth (purpose being to estimate water flow past Risdon due to tidal effects).

Pasminco current data - Pasminco progress report No. 5; unspecified number of current readings (magnitude and direction) taken at 1m and 10m at various locations (crude maps available) at the mouth of the Derwent, on rising and falling tides, on unspecified dates in 1979.

A three-dimensional hydrodynamical model of the Derwent has been produced according to Tagaza (1995) by the CSIRO (Reid and Walker, unpublished report).

References


Olive, L. J. (1973) *Sediment yields and stream catchment variations in southeast Tasmania.* MSc, University of Tasmania.


Port of Launceston

The Port of Launceston is located in the Tamar River on the north coast of Tasmania. The main deep water port facilities are situated at Bell Bay, Inspection Head, and Long Reach. The port at Launceston is restricted to shallow draught vessels (<5.4 m). The minimum depth of the river channel from the entrance to Long Reach is 10.4 m, and from Long Reach to Launceston is 3.0 m.

A major environmental review of the Tamar estuary has been published recently by Pirzl and Coughanowr (1997) which confirms that few studies have been carried out into water quality or sedimentology. The available data are summarised here.

Hydrology

The catchment of the Tamar River is approximately 9700 km². The South Esk River provides the greatest fresh water flow, with an estimated mean discharge of 62 m³/s (Newell, 1969, report to Hydro-Electric Commission of Tasmania). There is significant seasonal variation in flow, with the maximum recorded in spring and winter. Water temperature also varies, from an average of around 10°C in winter to 20°C in Summer. Secchi disk readings collected since 1971, indicate that visibility is generally low (< 1m) in the upper part of River, increasing to high (5-10m) near the entrance (Foster et al., 1986).

The salinity structure of the river, during low flow and flood flow conditions has been investigated by Rochford, (1951); Foster et al., (1986). At Rosevears there is little variation in the salinity over the ebb and flood tide. However, further upstream at Freshwater Point, there is a distinct asymmetry between ebb and flood tides, with an increase in salinity stratification on the flood tide. During flooding the upper estuary is occupied completely by fresh water, while the lower estuary remains strongly stratified.

Temperature and salinity data have been collected by the Launceston City Council (1998) associated with a study of metropolitan sewer outfalls.

Tides

The estuary has a semi diurnal tidal regime, dominated by the M2 component (Foster et al., 1986). There is an increase in mean spring tidal range from 2.34 m at Georgetown to 3.25 m at Launceston. The maximum spring tidal range recorded at Rosevears is 3.9 m, and the minimum neap range is 2.1 m. Tidal non-linearity increases upstream, with a marked distortion of the tidal curve evident at Launceston.

Sediments
The Tamar estuary formed during the last transgression when sea level rose, drowning the river valley. The river extends for 69.5 km from the coast to Launceston, where it joins the North and South Esk Rivers making a total catchment area of 11,590 km$^2$ (Edgar et al., 1998). A large amount of sediment (approx. 40,000 t/yr), is being deposited in the estuary, slowly infilling the channels. The majority of this sediment comes from the South Esk River (Foster and Nittim, 1987).

The sediments of the Tamar River are dominated by muds. Sands are only present at the mouth of the river and in the lower estuary, down stream of Whirlpool Reach. The exact nature of the sand is unknown, but it is most probably relict carbonate similar to that described in Bass Strait. Upstream of Whirlpool Reach the sediments are almost entirely silty mud. Sedimentation in the upper estuary has been effected by the construction, in 1955, of the Trevallyn Dam on the South Esk River. The dam effectively traps the bed load of the South Esk River, so that no coarse fluvial material enters the estuary from this source.

A major study on siltation of the river, which has been a problem since about 1915, was carried out by Foster et al., (1986). Dredging of the river channel in the upper estuary started in 1880, and ceased in 1967, when the major port facilities were moved downstream to Bell Bay. Foster et al. (1986) determined that during periods of low flow sediment is moved upstream by the tide, and settles out in the old dredged areas within Home Reach. They estimated that the siltation rate at Home Reach is 43,300 tonnes/yr. There are two other areas of major sediment deposition in the upper estuary, the Tamar Island shoals, and the Nelson Shoal at Rosevears. Foster et al. (1986) calculated that 1,500,000 m$^3$ of silt has been deposited on the Tamar Island Shoals in the last 96 years. Interestingly, the operation of the power station has decreased the rate of siltation by reducing the incidence of low river flows.

*Introduced pests*

The estuary has extensive areas of inter-tidal mud flats which have been colonized by the exotic *Spartina anglica* (rice grass). In some areas the introduced vegetation has acted as a significant sediment trap, with up to 12 cm/yr of vertical accumulation (Pringle, 1982).

*References:*


Foster, D. N., & Nittim, R., (1987) Siltation of the Tamar River. 8th Australasian Conference on Coastal and Ocean Engineering. Launceston,
Port Huon (Hospital Bay)

Formerly a major port for timber and pulp/paper exports, Port Huon is no longer considered a significant port in southern Tasmania.

Bathymetry

Port location and bathymetry are shown on chart AUS 174. The port is located in Hospital Bay at the seaward end of the Huon estuary. While some local depth data have been collected adjacent to commercial (APM) berths in Hospital Bay, the Huon Estuary has not been surveyed since 1932. Details of the available recent bathymetry surveys are held (hard copy only) by the Hobart Port Corporation. Landwards of Hospital Bay the Huon is largely shoal with numerous intertidal mudflats and low-lying deltaic islands that restrict navigation.

Fluvial input

The Huon River falls into a class of Tasmanian rivers that have relatively high and consistent mean annual runoff (Hughes, 1988). The Huon has a mean annual discharge of 87 cumecs. Seasonal variability results in a summer low of 30 to 40 and winter high of 125 to 130 cumecs. Eleven major floods since 1920 exceeded 1,300 cumecs and the peak flood was in 1948, when discharge reached 2,223 cumecs (Gallagher, 1996).

Hydrography

Long-term monitoring of temperature and salinity has been carried out in Hospital Bay in association with the operation of the APM pulp mill (Woodward et al., 1992, their station #2). These workers used a YeoCal CTD, with pH and DO probes on 36 occasions between June 1988 and Dec. 1989 (ie fortnightly sampling) at 11 stations. Also collected were Secci disk readings, sediment and water samples. In Hospital Bay, salinity ranges from 25 to 30 ppt but surface values may fall below 5 ppt during high river discharge events (Woodward et al., 1992).
Further information on the Huon Estuary has been collected by the CSIRO since mid-1996 as part of a major estuarine study. Regular CTD measurements are made and sediment samples have been collected at 25 stations and long time series from mooring sites are available; maps showing station locations are attached. There are no publications available on the work at present (E. Butler, pers. comm.) but there is a web page with further details:


Aquaculture and introduced pests

Twenty one marine farms covering a total of 132 ha operate in the Huon Estuary area, including 11 Atlantic Salmon farms, 7 mussel farms and 3 oyster farms (Gallagher, 1996).

Water temperatures in excess of 14°C in combination with specific wind and fluvial discharge conditions appear to provide optimal growth conditions for the toxic dinoflagellate *Gymnodinium catenatum* (Hallegraeff et al., 1995). Blooms of this species caused shellfish farms on the Huon to close in 1993 (Gallagher, 1996).

The northern Pacific seastar *Asterias amurensis* has a detrimental impact on benthic ecosystems through its high fecundity and predation of invertebrate fauna. It is thought to have been introduced by ships ballast water (Morrice, 1995).

References:


Stanley and Port Latta

The small Port of Stanley is located on the northern coast of Tasmania, on a bay south of Circular Head. It is protected from the high energy swell of Bass Strait by a Breakwater pier. The approach to the port is 8.8m deep. Port Latta is approximately
five nautical miles southeast of Stanley, and has an approach depth of 15.2 m. The loading facility there was built to export iron ore pellets produced at the west coast Savage River Mine and is presently owned by Australian Bulk Minerals. The facility is fairly exposed and at times it is subjected to waves in excess of 10 m (Chappell, 1975).

Hydrography

The only T&S data available is the global US Navy Marine Climate Atlas of the World CD-ROM Version 1.1. This provides monthly statistics for 1° squares (ie. Stanley, Port Latta and Burnie fall within the same square) and ignores any local fluvial input effects (data included on EO&S CD-ROM). According to the Victorian EPA (1996) ballast water study report, port sea surface temperatures range from 11 to 18°C and seasonal salinity values are: 35.335 (summer) 35.352 (autumn) 35.309 (winter) and 35.26 (spring). The port is not located near the mouth of any major rivers, so these oceanic temperature and salinity estimates are probably representative of the port environment.

Sediments

Coastal shoreface sediments along the northernTasmanian shoreline were studied by Davies and Hudson (1987a,b). These workers found that shoreface sediments reflect mostly the influence of local point-source sediment supplies, in terms of texture and mineralogy. Littoral drift rates are low due to the lack of sufficient sediment supply along portions of the coast, and the generally low level of surface wave energy (Davies and Hudson, 1987a,b). Most of the volume of shoreface sediments were emplaced during rising sea level by around 6,500 years BP and modern rivers provide only a minor sediment source (Hudson and Davies, 1987). Sediments in Port of Stanley consist principally of quartz sand with minor carbonate, feldspar and lithic fragments (Hudson and Davies, 1987). Adjacent to the Port Latta loading jetty is a small dredged boat harbour in which sand from the local Crayfish Creek, is accumulating (Chappell, 1975).

Revegetation projects for Stanley and the Port Latta industrial plant are being undertaken by the Stanley Peninsula Land and Coastcare Group http://www.tassie.net.au/~gtaylor/index.html

References

Chappell, J. F., (1975) Siltation study, boat harbour, Port Latta, Tasmania. Australian Conference on Coastal and Ocean Engineering.
The Port of Triabunna is a commercial port dedicated to the export of woodchips, primarily to Japan. The port is owned and operated by North Forest Products http://www.nfp.com.au/triabunna.html and the operation is able to process up to 1.2 million tonnes of pulpwood each year.

Spring Bay is a marine embayment with no significant fluvial input. The bay has a catchment area of 97 km² and has a mean annual runoff of 152 mm (Edgar et al., 1998). The tidal range is mixed semi-diurnal with a maximum astronomical tidal range (MHHW - MLLW) of 1.3 m. The port is covered by AUS chart 170.

**Hydrography**

The only T&S data available is the global US Navy Marine Climate Atlas of the World CD-ROM Version 1.1. This provides monthly statistics for 1° squares and ignores any local fluvial input effects (data included on EO&S CD-ROM). However, since Triabunna is removed from any major river, this marine T&S regime may be accurate for the port. Further survey work is required to determine whether this is indeed the case. No other information on port hydrography or sediments has been located.

**Introduced pests**

In recent years there have been reports of exotic algae species in the Spring Bay area (Sanderson, 1990). The most likely vector is attributed to ballast water in the woodchip cargo vessels. Spring Bay was one of 10 Tasmanian estuaries that are identified as having been severely impacted by human activities (Edgar et al., 1998).

**References**


**VICTORIAN PORTS**

**PORT OF MELBOURNE**

Name Port of Melbourne  
Latitude 37° 50’S  
Longitude 144° 54’E  
Charts AUS 143, 154, 155

Contact Tel: 03-9628 7500  
Contact Fax: 03-9628 7510  

Customs Officer  
Quarantine Officer

**General Description**

Melbourne is the principal port of the State of Victoria. It is located at the northern end of Port Phillip Bay with Port facilities in the Yarra and Maribyrnong Rivers and at Williamstown and Port Melbourne in the bay. It is Australia’s largest mainland container port by throughput. Melbourne is host to one of Australia’s major container ports at West Swanson (see P&O Ports [http://www.poal.com.au/](http://www.poal.com.au/)).

**Port Limits.**  
The Port of Melbourne limits extend from St Kilda pier in the east to Point Gelibrand in the west. The Port boundary extends 7 km south of Point Gelibrand along the Melbourne Channel.

**Environmental Classification**

The Port of Melbourne covers three subdivisions based on morphology and hydrology:

1. Port Phillip Bay proper - The Melbourne Channel and the port spoil grounds are in the main basin of Port Phillip Bay which is a shallow marine embayment.

2. Hobsons Bay - Hobsons Bay is the northern most part of Port Phillip Bay. It is a marine embayment but is influenced by the plume of fresh water coming from the Yarra River. Port facilities in Hobsons Bay are Station and Princes Piers at Port Melbourne, commercial and recreational docks at Williamstown and Webb Dock which is an artificial basin excavated in Quaternary sediments next to the mouth of the Yarra River.
3. Yarra Delta - The Yarra River contains most of the berths in the Port of Melbourne along the river bank and in artificial basin extending from it and along its tributaries the Maribyrnong River and Mooney Ponds Creek. Australian Chamber of Shipping (1995) lists 61 berths in the Yarra and 1 in the Maribyrnong River. Swanston, Appleton and Victoria Docks are all artificial basins. The largest excavation, carried out during the late 19th century (Lucas 1887) was the Coode Canal which cut off the bend in the Yarra River from Appleton Dock to the confluence with the Maribyrnong River. Most of the port is dredged to maintain depths.

**Port Phillip Bay and Hobsons Bay Environments**

Port Phillip Bay is a semi-enclosed tidal embayment, formed in a tectonically controlled sunkland, which is bounded by two major faults, Selwyn's fault and the Rowsley fault. It is about 56 km long from north to south, and about 46 km wide, with a surface area of the 1.95x10⁹ m², and a tidal prism of 9.4x10⁸ m³ (Black et al., 1990). Corio bay, the small western arm of Port Phillip Bay is approximately 7 km long and 5 km wide. The large city of Geelong, Victoria's principle bulk port, and heavy industries line its western shore. A very narrow rocky entrance (approx 3 km), known as the Rip, separates Port Phillip from Bass Strait. Just inside the entrance there are about 280 km² of shallow sand banks. The "Great Sands" are a flood tidal delta, composed of quartzose sand derived mainly from Bass Strait and the adjacent coastline, and extending over 20 km across the bay entrance (Jones et al., 1977). Port Phillip Bay has been the subject of several major environmental studies, the latest of which reported in 1996 (Harris et al., 1996). Much of the data collected for this study are available in digital formats, including GIS presentation of spatial data.

**Geological setting**

Port Phillip Bay is part of the Port Phillip Sunkland which formed in the Cainozoic as a result of down-faulting between the Rowsley Fault and Selwyn's Fault. Non-marine limestone was deposited in the basin formed by faulting near Geelong. The late Pleistocene rise in sea level flooded the low lying region about 7,000 years ago (Rochford, 1966). Prior to the inundation the Pleistocene clays were cut by river channels. Unpublished seismic profiles have outlined a system of these channels, since infilled by mud, in the centre of Port Phillip (Holdgate et al., 1980). The channels are continuations of the present day Yarra and Werribee Rivers.

**Bathymetry**

Water depth in Port Phillip Bay ranges from approximately 10 to 26 m, but is generally deeper in the east. There is a central basin (>18m deep), of approximately 487 km² that is separated from Bass Strait by a sill near the entrance. Most of the central part of the bay is flat, with little relief. Corio Bay is very shallow, less than 9m deep, except where shipping channels are dredged to 12m. Water movement between the two bays is restricted by a sand bar that shoals at low water. At the
Entrance, tidal scouring of the Pleistocene limestone bedrock has produced a channel with a maximum depth of 94m.

Shipping enters the Hobsons Bay and the Yarra River via the Melbourne Channel which extends north from 37° 56’S and is dredged to 13.1 m until it reaches Hobsons Bay (37° 52’ 30”S) where the Williamstown Channel diverges north west into the Yarra. The Melbourne Channel continues north to Station and Princes Piers at a maintained depth of 10.9 m. Hobsons Bay has mostly undredged depths between 3 and 8 m. The anchorages area west of the Melbourne Channel entrance and south of Altona is charted as 10.6 m to 16.7 m deep. Spoil grounds in the central bay (Lat. 38° 00’S, Long 144° 53’E) are between 15.2 m and 10.6 m deep although the Australian Pilot (1982) warns of shallower depths. Virtually all cargo vessels disturb the substrate in the channels (P. Hinksman, pers. Comm.).

**Hydrography**

A study of water properties and currents in Port Phillip Bay was carried out between 1992-96 by the CSIRO [http://www.dmr.csiro.au/ResProj/CoasEnvMarPol/PPBay.html](http://www.dmr.csiro.au/ResProj/CoasEnvMarPol/PPBay.html) and the results are summarised by Harris et al. (1996). A dataset provided by CSIRO Environmental Projects Office includes monthly profiles collected at 11 sites within the Bay between May 1993 and March 1995 and is included on the attached EO&S CD-ROM.

A number of rivers flow into the bay. The largest of these is the Yarra River (catchment area of 4,000 km²) which discharges into Hobsons Bay, the northern part of Port Phillip Bay. The combined annual discharge of all rivers into the Bay during a period of flood in the early 1950s, was about 10% of the volume of water in the Bay (1507 x 10⁸ m³ at high spring tide). Therefore, even during extreme flood conditions the Bay cannot be completely flushed (Rochford, 1966).

Walker (1997) found that surface salinities in the Bay were highest near the Entrance (35 ppth) reflecting the higher salinities in Bass Strait. Most of the bay has salinities between 34.5 ppth and 34 ppth but Hobsons Bay and the eastern coast of the bay feature salinities less than 34 ppth because of runoff. Hobsons Bay, including Station and Princes Piers are strongly influenced by the Yarra River plume which extends down the eastern side of the bay producing salinities as low as 33.5 ppth (Walker, 1997).

**Tides and tidal currents**

The tides in Port Phillip Bay are predominantly semi-diurnal, with marked diurnal inequalities. The tidal wave propagating into the Bay is modified as it moves across the Sands region. It takes approximately 3 hours to travel the 18km through the Sands, and then only 12 minutes to reach the northern end of the Bay, a distance of 42km (Jones *et al.*, 1977). Black *et al.*, (1990) note that the M2 tidal amplitude of about 0.7 m outside the Entrance, is reduced to 0.44m at Point Lonsdale (just inside
the Entrance), and 0.19 m after the Sands. It rises again to 0.27 m at Geelong. Tidal velocity is fastest in the entrance, having an average speed of 1.0 ms\(^{-1}\) (max. surface velocity 4 ms\(^{-1}\)), compared to 0.05 ms\(^{-1}\) in inner Port Phillip Bay (Black et al., 1990).

The time and height of the tides is affected by the speed, direction and duration of the wind, and by changes in the barometric pressure. Prolonged southerly and southwesterly winds cause the water level in the Bay to rise, whereas easterly and northeasterly winds cause a substantial drop. An increase in sea level in the Bay can also be caused by sudden changes in the wind, which stimulate seiching. Seiches of 0.5 m with a period of about 1 hour have been recorded near the Yarra River (Black et al., 1990).

The circulation in the Bay has been investigated by the ESPPB (1973), Black et al. (1990), Walker (1997), Walker and Sherwood (1997) and the Centre for water Research (UWA) http://www.cwr.uwa.edu.au/cwr/research/projects/. ESPPB (1973) found that water movement in the region of the Sands, is along the main channels, and is little affected by the wind. In the inner part of the bay water movement is controlled by both the tides and the wind. During average wind conditions (8 km/h from the west) water moves around the Bay in a clockwise direction, from the Sands to Werribee, east to Hobsons Bay, then south towards Mornington and finally west along the northeastern edge of the Sands. Model simulations suggest that during stronger wind conditions separate circulation cells develop off the east and western shores of the Bay. Black et al., (1990) calculated the pattern of wind driven circulation in the Bay during extreme wind conditions from the south, southwest and west. Their results also suggest the development of separate circulation cells.

**Wind and Waves**

The climate in Melbourne is temperate, with an average yearly rainfall of 70cm. Wind in the Bay is predominantly from the south and southwest during the period October to March, and from the west to north from April to September (ESPPB, 1973). Waves are generated in the Bay by local winds, except at the Entrance where Bass Strait waves impinge. The shallow nature of the Bay coupled with the relatively short fetch (60km) acts to restrict wave heights. In contrast to Bass Strait, the waves in the Bay are high in comparison to their wave length, and dissipate rapidly when the wind subsides. The Bureau of Meteorology predicts that significant wave heights are unlikely to exceed 2.5m (Table 1). Waves in the Bay at any one time can show large variations in height due to such factors as wind turbulence, water depth and reflection and refraction by the coast.

**Table 1. Bureau of Meteorology wave height predictions under differing wind conditions (ESPPB,1973).**

<table>
<thead>
<tr>
<th>Wind Speed (knots)</th>
<th>Description</th>
<th>Waves Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>light air</td>
<td>0</td>
</tr>
</tbody>
</table>
4-6  light breeze  0.0.3
7-10  gentle breeze  0.3-0.6
11-16  moderate breeze  0.6-1.0
17-21  fresh breeze  1.0-1.5
22-27  strong breeze  1.5-1.8
28-33  near gale  1.8-2.4
34-41  gale  2.4-2.7
41-47  strong gale  2.7-3.7

Sediments

The sediments of Port Phillip Bay were first comprehensively described and mapped by Beasley (1966), who mapped surficial sediment grain size distribution. Greilach et al. (1996) present analyses of an additional 80 samples from the Bay and Link (1967) analysed 46 samples from the northern part of the bay. The results of these studies are consistent. The sediments of the Bay are dominated by sands, silty sands and silty clays. A general fining inwards pattern is discernible, with the coarser sands and gravels located around the shallow perimeter of the bay and at the Entrance. The sands and gravels (and the clayey sand of Swan Bay) on the western side of the bay, are composed primarily of recent carbonate skeletal material. Terrigenous sands are confined to the east of the Werribee and Little River mouths. The sandy sediments on the eastern side of Hobsons Bay and the coastal strip south to Rosebud are derived mainly from erosion of the Tertiary sediments and Palaeozoic granitic rocks that form the cliffs and shore platforms along the coast. Coring in this area revealed that these sands are generally less than 1 m thick and are underlain by non-marine clayey sands, sandy clays or clay (Jones et al., 1977). South of a line across the Bay from Rosebud to St. Leonards the sands and gravels are composed mostly of fragments of Pleistocene dune limestone, some of which has been transported into the Bay from Bass Strait. Cores of up to 4 m of fine sand have been obtained in this area (Jones et al., 1977).

The extensive northern area of the central basin is covered by silty clays, while in the south the basin sediments are mostly clay. Fine suspended material brought into the Bay by the rivers and also derived from coastal and bottom erosion is deposited here. The sediments of the western part of Hobsons Bay consist primarily of silty clay and clay. Link (1967) described the fine grained sediments of Hobsons Bay, that form the Yarra River Delta, as dark grey, poorly sorted, laminated clayey silts and silts. Beasley (1966) reports silty clays on the floor of the Melbourne Channel.

Sediment Transport

Tidal current dominate in the transport of sand at the Entrance. The series of sand banks that constitute the "Sands" are orientated sub-parallel to the current direction. The banks are up to 5 km long, separated by 1-2 km wide channels. The largest sand body, the Great Sand, surrounds Mud Island and is approximately 10 km long and 4
km wide. Large dunes with wavelengths up to 80 m, occur on some of the sand banks at the northern end of the Great Sand, and are orientated sub-normal to the flow.

The shipping channels inside the Entrance are maintained by dredging. Infilling of the channels occurs because storms in Bass Strait transport large quantities of sand via the littoral transport system, that moves from west to east along the Victorian coast. Some of this sediment is carried into Port Phillip Bay by the strong tidal currents that move through the Entrance (Riedel and Fidge, 1977). In most of the remainder of Port Phillip Bay, sediments are mobilised only by combined tidal and wind-driven flows, augmented by wind-wave stirring (Black, et al., 1990). The eastern shoreline is prone to beach erosion as a result of northerly gales.

The sediment provided by the Yarra river is predominantly deposited near its mouth in western Hobsons Bay (Link, 1967). For the rest of the Bay, the sandy marginal facies represents material eroded from the coast and winnowed by littoral processes and the central fine facies, the fine component of both coastal erosion and suspended sediment input from streams.

**Introduced Species**

Port Phillip Bay has many introduced species (Victorian Environment and Natural Resources Committee, 1997). Recognised pest species are present with abundant *Sabella spallanzanii*, patches of *Undaria pinnatifida*, *Corbula gibba* and rare *Asteria amurensis*. Three species of toxic dinoflagellates are known; *Alexandrium tamarenses*, *Gymnodinium catenatum* and *Alexandrium catanella*. *A. catenella* has been recorded as a dominant species in algal blooms in the Bay (Magro et al., 1996).

**Yarra River**

**Geological setting**

The Yarra River has formed a wave-dominated delta or infilled wave-dominated estuary with the Holocene transgression at about 8000 years BP (Neilsen, 1976). The system has been heavily modified with channels and docks excavated into the estuarine lagoon sediment (Coode Island Silt) and strand plain sands (Port Melbourne Sands) and extensive infilling of low lying areas.

**Bathymetry**

Most of the Yarra River is maintained by dredging. The Williamstown Channel and the river up to and including Swanston Dock are maintained at 13.1 m. Upstream from Swanston Dock, the Appleton Swing Basin is maintained at 12 m and Appleton Dock at 10.7 m. Most of Victoria Dock and Victoria Swing Basin are maintained at 11 m but
parts of Victoria Dock are maintained at 9.4 and 8.5 meters. North and South Wharfs are maintained at 9.7 m to 8 meters.

**Hydrology**

The Yarra is a salt wedge estuary with the salt wedge intruding well past the port facilities during all flow conditions that have been studied, including a flood event with 20 times base flow (Beckett et al., 1982). Surface salinities as low as 5 ppth extend downstream to the Westgate Bridge during high flow periods. During low flows, the surface salinities in the dock area are between 10 and 25 ppth with bottom salinities between 30 and 35 ppth (Beckett et al., 1982). Water chemistry and temperature is strongly controlled by rainfall with short term storm events providing greater influence than seasonal factors.

**Tides and Currents**

From the mouth of the river to Dights Falls, a distance of 27km, the River is subject to tidal action. Surface water flow is predominantly downstream whereas bottom flows can move upstream during the rising tides combined with moderate and low river flows. The water movement becomes more complicated in the lower reaches where Beckett et al. (1982) found downstream flow at the surface and bed but upstream water movement between depths of 1.5 and 5 m. High flows produce general downstream water movement.

**Sediments**

Most of the port facilities in the Yarra are excavated in the Coode Island silt, a Pleistocene estuarine unit mostly consisting of silty clay with some sand (Neilsen 1976). This is reflected in the river sediments transported into the Bay which are clayey silt with minor sand (Link, 1967). Fabris et al. (1995) took shallow cores from North Wharf, Victoria, Appleton and Swanston Docks and in the Maribyrnong River and at the Holden Oil wharf and reported that >95% of all samples were finer than 200 µm (Fine sand or finer).

**Sediment transport**

A considerable amount of sediment is deposited in the Yarra docks, as would be expected in an artificially deepened, tidal estuary. Fabris et al. (1995) report an annual mean volume of dredged material of 335063 m³, mostly (78%) removed from the docks and channel upstream of the Westgate Bridge.

**Port of Geelong**

Name Port of Geelong
General Description

The Port of Geelong is located on Corio Bay, the western arm of Port Phillip Bay. It is Victoria’s principal bulk port. The inner harbour in Corio Bay has 13 berths for commercial shipping and the outer harbour has two berths, one at the Point Wilson explosives jetty and one at the Point Henry oil refinery.

Port Limits

The port limits are defined by a line running from Little River (144° 35.5’E) on the northern side of the bay to Portarlington (144° 39.5’E) on the southern side.

Environmental Classification

The Port of Geelong is part of Port Phillip Bay and so the characteristics described for Port Phillip Bay proper can be applied to it, except that Corio Bay is separated from the main part of the bay by a sand bar which restricts water movements between the two.

Bathymetry

Corio Bay is very shallow, less than 9m deep, except where shipping channels are dredged to 12m. Berths are between 8 and 11 m deep, all maintained by dredging. Corio Bay is separated from the main Port Phillip Bay by the Point Henry sand bar which has small areas of intertidal sand at Point Henry and in the centre of the bay and is mostly less than 2 m deep.

Hydrology

The Point Henry and Point Wilson bars restrict circulation between Port Phillip Bay and the Outer Harbour and Corio Bay. Walker (1997) found slightly reduced salinities (<34 ppt) compared to the main part of the bay. Walker and Sherwood (1997) calculated flushing times of 315 days for Corio Bay and 291 to 301 days for the Outer Harbour compared to 210 to 270 days for most of the rest of Port Phillip Bay.
Tides and Currents

The geometry of the western arm of Port Phillip Bay results in weak tidal currents except in the dredged channel where it crosses the Point Henry bar. The Australian Pilot notes currents of 0.5 m/sec\(^1\) during part of the tidal cycle. The restricted geometry of the western arm also means that it has only limited fetch for developing waves generated by prevailing southerly, south-westerly and northerly winds. Walker and Sherwood (1997) present calculated bottom orbital velocities that indicate only the Point Henry and Point Wilson bars experience any movement of sediments by waves.

Sediments

The sediments of Corio Bay, the Geelong Outer Harbour consist primarily of silty clay and clay in the central basins with sand and silty sands around the margins and extending across the bay in separate bars from Point Henry and Point Wilson. The Australian Pilot reports a small area of rocky bottom near the Point Wilson explosives pier.

References


### Port of Hastings (Westernport Bay)

**Name** Port of Hastings  
**Latitude** 38° 21’S  
**Longitude** 145° 14’E  
**Charts** AUS 152, 156, 788, 149

Contact Tel: 03-5983 9406  
Contact Fax: 03-5983 6043  
Port Control The port is managed by Toll Westernport
General Description

Western Port is a tidal embayment, resembling a "figure-of eight" with two large islands, French Island and Phillip Island and two entrances to Bass Strait. The major port facilities are located at Crib Point and Hastings, approximately 13 to 15 nautical miles from the entrance, on the eastern side of the bay. Five berths are present, servicing the B.P. and Esso oil refineries and a steel-rolling mill. The use of the facilities by oil tankers means that substantial amounts of ballast water are introduced into the port.

Quaternary History

The Quaternary evolution of the Western Port sunkland has been extensively reviewed by Marsden and Mallett (1975), who recognised four phases in its development. Briefly, a series of faulting episodes in the Early Pleistocene established the main drainage system. This was followed by the Pleistocene deposition of the extensive Bass River flood plain. During the Late Pleistocene low sea level erosion of the channels occurred and the aeolian Cranbourne sand unit was deposited in the northwest corner of the bay. Finally, Holocene sea level rise inundated the area about 10,000 years BP.

Westernport Bay Environmental Characteristics

Bathymetry

Westernport Bay bathymetry is very complex with many sand bars and deep tidal channels (Marsden et al., 1979). The port facilities lie on the western side of the North Arm tidal channel that separates French Island from the mainland. The port is approached via a channel dredged to 14.9 and 14.3 m. The wharf areas are dredged to 14.3 m except for small areas alongside the wharves that are dredged to 15.8 m.

Hydrography

Drainage into Western Port bay is from a total catchment area of 3250 km², which rises to a (maximum elevation of 900 m in the northern highlands. Drainage patterns have been altered by land reclamation which started in the late 1800 with the filling of Kooweerup Swamp. As a result, there has been an increase in the direct input of freshwater point-source discharge to the bay, which was formerly filtered through the non-point source drainage of the swamp system (Marsden et al., 1979). Land clearing and agriculture have also resulted in increased sediment supply to the bay.

Water chemistry in the bay was studied between June 1973 and June 1977 and the results reported by Butcher (1979) and Harris et al (1979). Sampling was carried out every three weeks throughout the four-year period, with the initial 48 stations
increased to 62 stations and 26 shore locations by the end of the program. Data are held by the Victoria Department of Environment Protection http://www.epa.vic.gov.au/ and monthly averages for salinity are included in the attached EO&S CD-ROM. Over the sampling period, salinity in the bay ranged from a minimum of 31.35 in December 1974 at Corinella Segment to a maximum of 37.55 in April 1974 at the Upper North Arm of the bay.

Tides and currents

An extensive study of tides and currents was carried out as part of the Westernport Bay Environmental Study (Hinwood and Jones, 1979; Sternberg, 1979; Marsden, 1979; Harris and Robinson, 1979; Hinwood, 1979; and Harris et al., 1979). The tide in Western Port is semi-diurnal, with a dominant M2 component. Mean tidal range increases to the north, from about 1.6 m at the Western Entrance (Flinders), to approximately 2.2 m (3.3 m during spring tides) in the intertidal areas at Embayment Head (Tooradin). The high water spring tide at the Western Entrance is 2.7m and the high water neap tide is 2.1m. The maximum depth averaged tidal velocity in the channels is typically 0.6m/sec (Hinwood and Jones, 1979). Sternberg (1979), found that bottom currents measured at nine stations in the main channel system, ranged up to 0.7m/sec.

Wind speeds in the area are generally less than 10 m/sec and only exceed 15 m/sec for about 3% of the year (Marsden et al., 1979). As a result the wind exerts little influence over the flood and ebb currents, but occurrences of occasional stronger winds can be related to anomalous tides throughout the bay. Winds do have a significant effect on surface drift and also probably on net water movement (Hinwood and Jones, 1979). General features of circulation are described by Harris et al., (1979; Fig. 8.42). Approximately 95% of water movement into the bay occurs through the Western Entrance. At the Confluence zone the flood tide bifurcates with some water moving into the East Arm and some into the North Arm. As a result of tidal lags, the incoming flood tide in the East Arm is directed along Cowes Bank to the front of the Churchill tidal flats. Some of this water is known to exit the bay, via the East Entrance on following ebb tides. In the Embayment Head the phase lag causes a net movement of water across the intertidal flats, setting up a clockwise circulation around French island.

Both the Crib Point Oil terminal jetty and Long Island Point Pier are built on the edge of the main North Arm tidal channel and therefore experience significant tidal currents.

Sediments

The sediments of the bay are described in detail by Marsden et al., (1979). They are dominated by terrigenous quartz and clay with varying amounts of carbonate material. The coast of the bay is in some places erosional and in others depositional, boarded
by either cliffs, beaches or salt marsh. The intertidal areas of the bay are composed of alternating mud and sand facies.

The main entrance to the bay, the Western Entrance Channel is flanked by the Western Entrance Embayment Plain and Middle Bank. Middle Bank is the largest sand bank in Western Port. Large bedforms produced by the strong tidal currents are evident. The northern section of the bank is partially vegetated and this protected area interfingers with the mobile sands. The surficial sediments of the Western Entrance Segment are predominantly medium to fine sands, which extend to approximately the 18 m depth contour. In the deeper area there is a scoured zone covered by lag gravel. The major channel, the Western Entrance Channel, is like the majority of tidal channels in the bay, incised into the bedrock and consequently experiences little lateral migration. Marsden et al., (1979), report that the sediment in the high energy channels is composed of coarse sands, and pebble to boulder lag gravels of ironstone, rock fragments and shells.

Sediment samples collected at the wharves consist predominantly of coarse to fine sand with some silty fine sand (Currie and Crookes, 1997).

Sediment Transport

Harris et al., (1979) summarised the data on sediment transport collected by the Western Port Environmental Study group. They divided the area into four systems. Area 1. is a high-energy channel/bank sand system (Western Entrance to just beyond the Confluence Zone): this system is the most active, exposed to strong tidal currents and waves. These currents and waves combine to make the embayment plain a zone of net inward movement of sand. Broad coarse sand filled depressions may represent strong inward sediment transport pathways, providing a supply of sand for the nearby beaches and Middle Bank. Large dunes are found in the northern part of the embayment plain and Middle Bank, an area where the flood dominant flow moves southward. This pattern of sediment transport has resulted in the progradation of a spit at Sandy Point. Seismic profiles reveal the spit consists of thick Quaternary deposits underlain by basalt. Across the Confluence Zone, the strong flood tide disperses sand, which is then transported along the northern shore of Phillip Island to Cowes Bank. Marsden and Mallett (1975) observed that longshore drift (caused by waves and the weak tidal current) in the intertidal zone of the bank has resulted in the formation of eastward facing dunes. On the subtidal edge of the bank, they noted that tidal currents produce migrating mega-ripples up to 50 cm high and 10-15 m long. Harris et al., (1979) estimate that 10^3-10^4 g cm^-1 yr^-1 of sand is moved across the Confluence Zone and that during the Holocene the Bank has propagated eastward about 1.5 km from the original coastline.

Area 2. includes ebb/flood differentiated segments, with contrasting intertidal sediments (Lower North Arm; Corinella Segment): the Lower North Arm has a weak clockwise circulation caused by differences in the flood and ebb tides. Northward sand transport results in the formation of intertidal banks along the western side. At
the northern end of Lower North Arm intertidal sand deposits also occur. However, Harris et al., (1979) consider these to be mainly autochthonous Pleistocene Cranbourne Sand. On the eastern side of Lower North Arm, where the ebb and flood tidal directions converge, a series of tidal sand bars, known as the Middle Spit shoals has developed.

In the northern part of the Corinella Segment, strong flood transport has resulted in the formation of the Freeman Point Banks along the southern coast of French Island. In this area ebb flow and waves have only a limited influence. In contrast, ebb flow is dominant in the east and south of the Segment, and results in mud deposition in the subtidal Queensferry Embayment plain and the Corinella intertidal flats. Because this area is sheltered from the dominant wind direction current and wave activity are limited.

Area 3. is the subtidal, partly-enclosed, mud depositional basin (Rhyll Segment), in which there is very little sand transport (Harris et al., 1979). The counter-clockwise circulation pattern in the segment results in clay material being deposited in a central northeast trending zone, surrounded by coarser material. The sediment is derived from erosion of pre-existing substrate and discharge from the Bass River.

Area 4. is the intertidal flat system with minor channels (Embayment Head): the Embayment Head is the major depositional area for fine grained sediment in Western Port. It is the area of maximum tidal range (max. spring range of up to 3.3). The tidal flats are cut by an extensive system of dendritic channels. Draining of the hinterland swamps has resulted in discharge from the Bunyip and Lang Lang Rivers becoming an important source of sediment to the area.

Habitats

Nearly 40% of the bay is composed of intertidal flat and bank complexes, and the Embayment Head region has the most extensive intertidal area. Offshore banks and embayment plains are interspersed with channels that range in depth from 4-15 m. The deepest water is found in the Western Entrance (30m).

Introduced species

A survey of introduced species conducted in 1997 (Currie and Crookes, 1997) found 7 introduced species of which only Carcinus maenus is an identified pest species.

References


**Port of Portland**

Name  Port of Portland  
Latitude  38° 21’S  
Longitude  141° 36’E  
Charts  AUS 140  
Contact Tel: 055-250 900  
Contact Fax: 055-217 488  
Port Control The port is managed by Port of Portland Pty Ltd.

**General Description**

The Port of Portland is situated on the south-west coast of Victoria. It is a small rectangular harbour covering 101 hectares created by breakwaters on the northern and eastern sides and maintained by dredging. It has 6 commercial berths, berths for fishing vessels and a marina and slipway for recreational vessels.

**Environmental Characteristics**

**Bathymetry**

The port swing basin is maintained to 12.2 m as is No.1 berth. The remaining berths are maintained at 11 m. Away from the dredged area, the enclosed area shoals from 9 m to the shore with an extensive area less than 5 m deep.
Hydrology

Most water in the harbour is from the open shelf exchanged through the harbour entrance. Some input of fresh storm water run off is to be expected from the adjacent streets and port facilities. An unpublished report by Consulting Environmental Engineers (1991) estimated a flushing rate of 17 days. Water temperatures range from 11°C to 19°C (Walters, 1996).

Tides and Currents

Tides at Portland are diurnal with a mean spring tide range of 0.9 m. Currents are probably low considering the low tide range.

Sediment

Parry et al. (1996) analysed 14 samples from Portland harbour and found most to be fine sand but with between 8 and 35% organic matter. This high organic content may result from input of woodchips and dust from grain loading facilities.

Introduced marine pests

Parry et al., (1996) found toxic dinoflagellates (*Alexandrium* spp.), *Corbula gibba* (one specimen) and *Musculista senhousia* (one specimen).

References

