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Sea Water Quality and Processes in Simon's Bay

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"Along only 3km of unique idyllic coastline, yachtsman sail past subsistence trek-net fisherman, while naval vessels are refitted close to pristine penguin beaches.

Simon's Town is dependent upon the surrounding seas for, inter alia,amongst others tourism, recreation, industry and naval activities.

The health of the sea is therefore critical if the area is to maintain or improve this quality diverse lifestyle"

"Simon's Bay is a unique quality coastal environment which has thus far escaped excessive development. For this jewel of False Bay to be maintained with increasing influxes of tourists and residents, it is vital that its current diverse quality lifestyle be maintained. This can only happen if all users of the sea and coastline in the area and surrounds take proud ownership"

Carl Wainman – Public Feedback Meeting, Simon's Town, 14 December 1999.

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Scope

The continued sustainable beneficial use of the sea, and in particular Simon's Bay, as an important industrial Naval Harbour, beach and recreational retreat, tourist destination, penguin haven, trek-net fishery, maritime archeological area and research zone has been highlighted. If these benefits are to be maintained or in the context of expanded future use, then the quality of seawater in the region is seen as a key maritime health indicator of this interdependent system. Information about near-shore interaction with False Bay and beyond is important for good management.

This work is primarily concerned with the marine coastal region defined by the port limits of Simon's Bay. Simon's Bay cannot, however, be studied, without consideration of the external influences of the greater False Bay and, still further afield, from the South Atlantic Ocean and the Agulhas bank

The primary area of interest includes the port limits of Simon's Bay as defined by the South African Navy, depicted on the SAN 1017, 1998 Simon's Bay hydrographic chart.

This work aims to provide an initial understanding of the spatial and temporal environmental dynamics of Simon's Bay and establish baseline values.

The South African Navy has always been a major beneficiary and by implication custodian of the sea in Simon's Bay. The equipment, funding and contracting of this work by the South African Navy thereby provided a logistical background that made this work possible.

Rationale and Hypothosis

The recent flourish of South African legislation concerning coastal marine and environmental issues, will assist in the preservation of the area. However, the nature of these laws renders them dependent upon scientific information that can distinguish between pollution and naturally occurring norms. Although the area has been impacted upon by man, measurements taken during this work can provide a baseline against which further degradation or improvement can be compared.
This work sets out to define and quantify the major processes and water quality issues on a spatial and temporal scale relating to Simon's Bay, with particular reference to the greater False Bay.

The complex and extremely varied intensive usage of Simon's Bay when compared with other South African coastal areas has remained sustainable and apparently healthy since human settlement, posing a number of questions :-

1. How has such a confined sea and coastline been able to maintain it's apparently good water quality with such an array of diverse impacts, or have these benefits instead become unsustainable, threatening to create an environmental disaster ?
2. How do physical processes govern water quality in Simon's Bay, and to what extent are the dynamics influenced by the greater False Bay processes?
3. Although humans have impacted the region, could baseline variables and procedures be established as guidelines for other similar harbours ?

It is hypothesized that:

Sufficient larger False Bay scale dynamics and forcing mechanisms exist to flush Simon's Bay, assisted by wind mixing and vertical current shear. These surrounding flushing waters from False Bay are sufficiently healthy to maintain a biologically healthy natural system such as exists in Simon's Bay. However water quality in specific parts of Simon's Bay are negatively influenced by anthropogenic inputs. These are point source pollutants which, at present, become sufficiently diluted to background levels within the surrounding bay waters.

Chapter 1 – Introduction and Background

False Bay is the largest bay in South Africa's 3000 km of coastline. The Bay contains 44.6 km^3 of seawater with a mean depth of 40.9 m (Spargo 1991), covering an area of 1082 km^2 (Spargo 1991).

Simon's Bay is a deep-water half-heart shaped bay located in the North Western corner of False Bay (Figure 1, 3 and 5), offering many social and economic opportunities.

Figure 1 Photo showing Simon's Town, the Small Craft Harbour and the Naval Harbour

Like most of South Africa's coast, it is an asset that depends on continued marine health for sustainable usage and development.

Simon's Bay Setting and Overview

The Simon's Bay coastline defined by the port limits occupies 14.504 km (determined from Geographic Information System [GIS] measurements), 7.4 % of the Cape Metropolitan coastal region (195 km) (Largier 1998). The coastline of the area can be conveniently classified (Figure 2) as 48 % artificial/anthropogenic structures, 21 % beaches and 31 % rocky shores (GIS measurements). In the south is a scenic scuba dive site, close to beaches inhabited mainly by a large penguin colony. This colony shares beach space with beach users and is as an important tourist attraction in the Peninsula. Nearby, the Institute for Maritime Technology (Pty) Ltd. (IMT) overlooks the sea, along a protected stretch of reclaimed coast that is home to a pair of Cape Clawless otters. In the sea in front of this building, gear trials and various applied naval technology projects are undertaken. Next to IMT is South Africa's only Naval Harbour. This is the base for a number of naval ships, submarines and port support services.

Alongside the Naval Harbour is the False Bay Yacht Club (Figure 4). It has a slipway, moored boats and a number of floating mariners. Opposite the yacht club is a public town jetty from where charters, kayak trippers and fisherman operate along side the East Dock yard. The East Dockyard (the original Naval Harbour), is owned by the SA Navy, and some small boat activities take place, supported by a wide slipway. It is from here that small fast naval patrol and diver's boats operate (Figure 4). Navy diver sea training is also undertaken and general naval sea survival courses are given in the open sea. The Harbour is an industrial area used and controlled by the South African Navy. It consists of two smaller older inner basins (East Dockyard and West Basins) and a larger deeper more recent (1910) Outer Basin, with a dry dock and syncro-lift. The harbour has a total coastal wet length of 5008 m, occupying 35% of the entire length of the coastal port limit. No significant freshwater runoff enters the harbour although 14 stormwater outlets enter the harbour. Traditional shipwright and naval activities are undertaken such as chemical cleaning of ships, dry-docking , electro-plating and galvanising. Running through naval property in the north is a seasonal stream (Baviaanskloof river) that represents a primary fresh water source into the Bay.

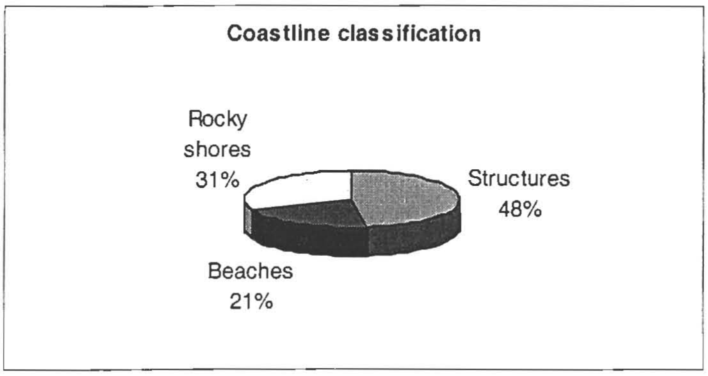


Figure 2 Pie chart of proportional coastline types in Simon's Bay

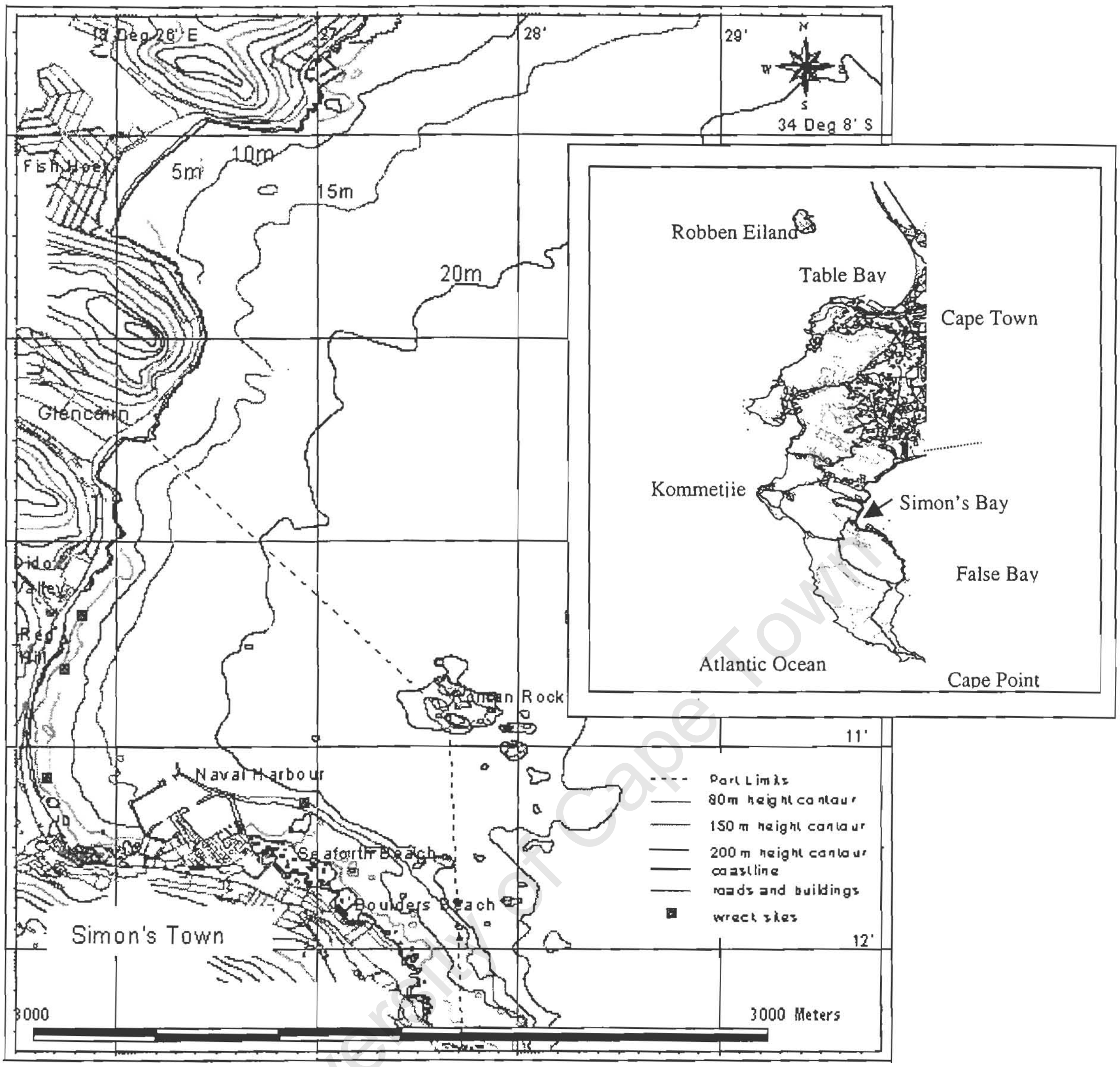


Figure 3 Simon's Bay, depth contours, height contours and the harbour limits.

The town's sewage network is at its lowest point here, with a pump barely above the spring tide level. A disused jetty marks one end of the private, Admiral's beach. This and the Admiral's jetty are situated in naval property. The southern-most railway station in Africa is found in Simon's Town. It is located alongside a sandy beach that ends in the north where an offshore sewage outfall is located. This is adjacent to a Naval Battery at a rocky outcrop (Figure 4). Just to the north of this is a geologically unique beach called Mackerel Bay, the only known local beach where sand overlays granite rock (personal communication A Terhorst). This small beach is also home to a small group of subsistence trek fisherman whose traditions and techniques have been passed down through the years.

A marine oil refinery, which provided employment for a few hundred people as a long-term industrial site for a ¼ century, has disposed of its effluent onto Mackerel beach (Figure 4). At the northern limits of the port, a second small seasonal river (Elsies River) which flows into the sea across Glencairn beach. The river drains a catchment area of about 18 km^2 (Taljaard S, van Ballegooyen R.C and Morant P.D. 2000). Currently the river carries storm water from Da Gama Park (above DidoValley) and Glencairn residential areas (Figure 4). Previously, effluent from the Simon's Town Waste Water Treatment Works was discharged into the river, but has since been diverted to sea. (See Urban and Industrial effluent). "*In earlier studies it was noted that the steepness of the topography of the catchment makes the river, and particularly the valley-bottom, liable to short duration flooding during periods of high rainfall*" (Taljaard S, van Ballegooyen R.C and Morant P.D. 2000).

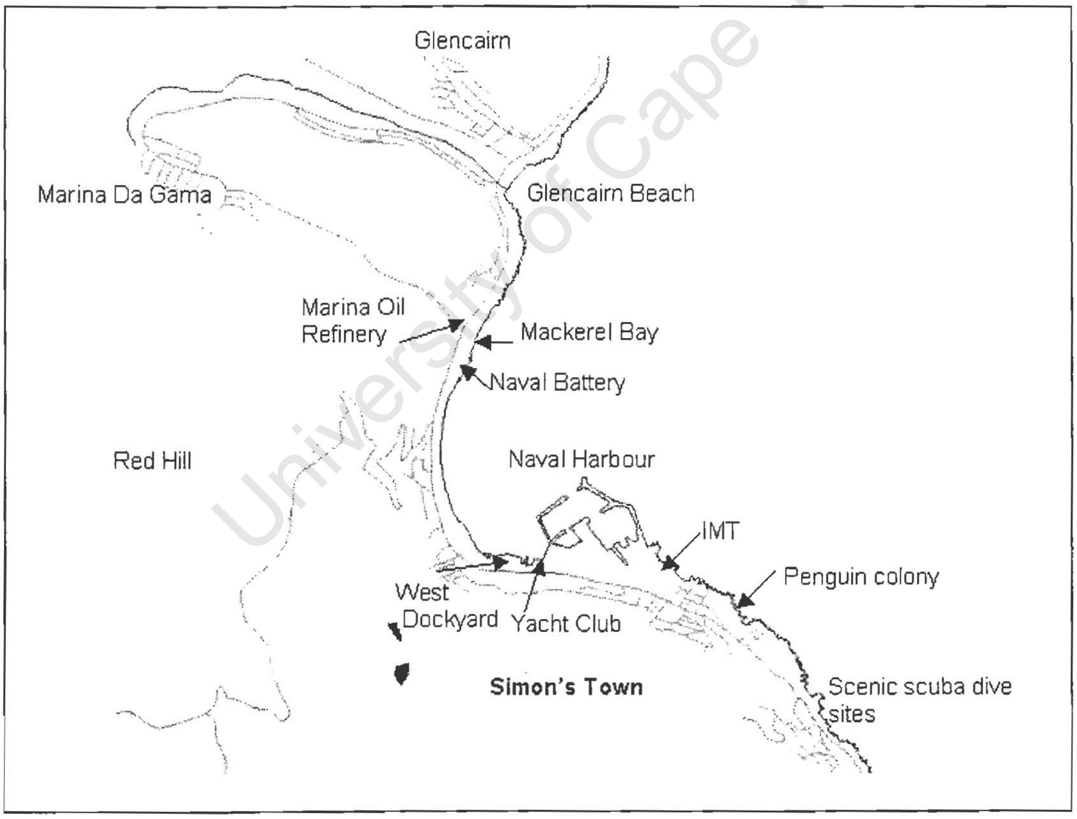


Figure 4 Map of Simon's Bay

Three historic maritime wreck sites exist in shallows waters of the bay. The area is generally classified as south west coast due to its weather patterns and oceanic setting. It is characterised by dry south-easterly winds in summer and rain-bearing north

westerly winds in winter, typical of a mediterranean climate. The oceanic region is exposed to cool nutrient rich water from the southern region of the Benguela system in summer, and thereby enjoys enhanced biological activity.
Historically the bay has served as a safe haven for ships during violent winter storms, housed a whaling station and has a number of maritime archeological sites. It is South Africa's largest naval base and the area has a proud history of naval custodianship and recently, South Africa's first Maritime school. Activities such as tourism, shore-based whale and penguin watching, recreation, subsistence treknet fishing, industry (oil refinery) and harbour activities all seem to coexist relatively harmoniously. The area provides refuge for sub-Antarctic animals such as whales and penguins. Physically, the surrounding False Bay provides the coast with protection from high-energy waves from the west. The coastline is composed of sandy, shale and course grained white pocket and large beaches, rocky granite shores, reclaimed areas, harbour walls, slip-ways and jetties. Limited coastal dunes have long since been stabilised by coastal roads, buildings, rail development and vegetation. Sand however continues to accumulate on the summer leeward wind beaches and was relocated on Simon's Bay beach by municipal workers during the 1960/70s (Brown 1971). Kelp beds, with associated urchin and abalone, are found south of the harbour. In the north, a small wetland ecosystem exists near Glencairn beach.

The area in general is coast-dependent, thereby gaining from its coastal location as a small economic and infra-structural nodal development of the greater Cape Metropole that is one of four major coastal population concentrations in South Africa (Largier 1998). Simon's Bay has so far escaped the threat of rapid population growth.

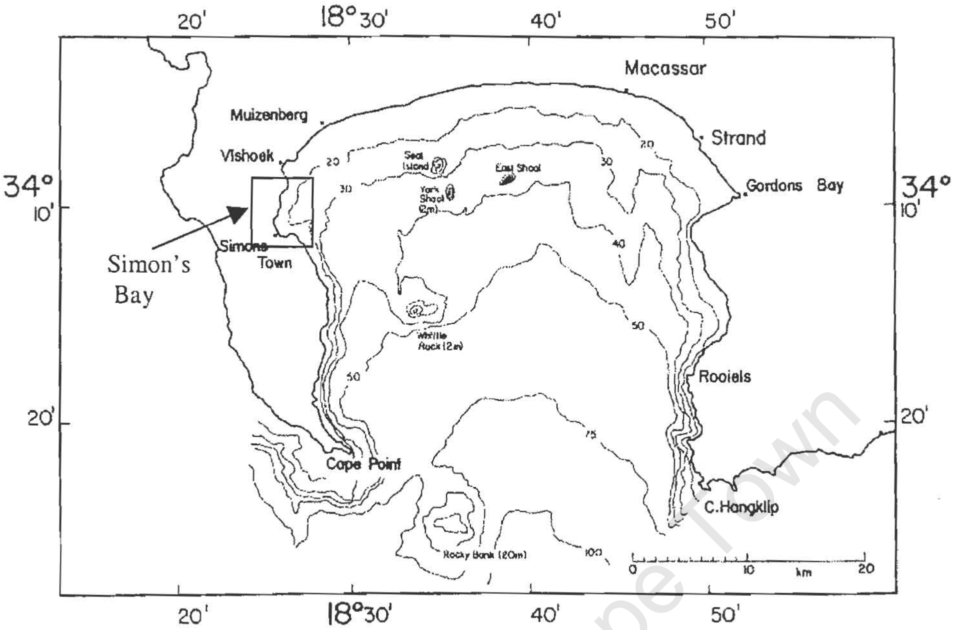


Figure 5 Chart of False Bay showing depth contours. From Gründlingh and Largier (1991) The insert block indicates the locality of Simon's Bay.

Historic Viewpoint

On 29th May 1671 a round sterned ship-rigged Dutch merchant ship by the name of Isselsteijn '..... *had by contrary winds been obliged to anchor in False Bay for fresh water and cattle refreshment'* .

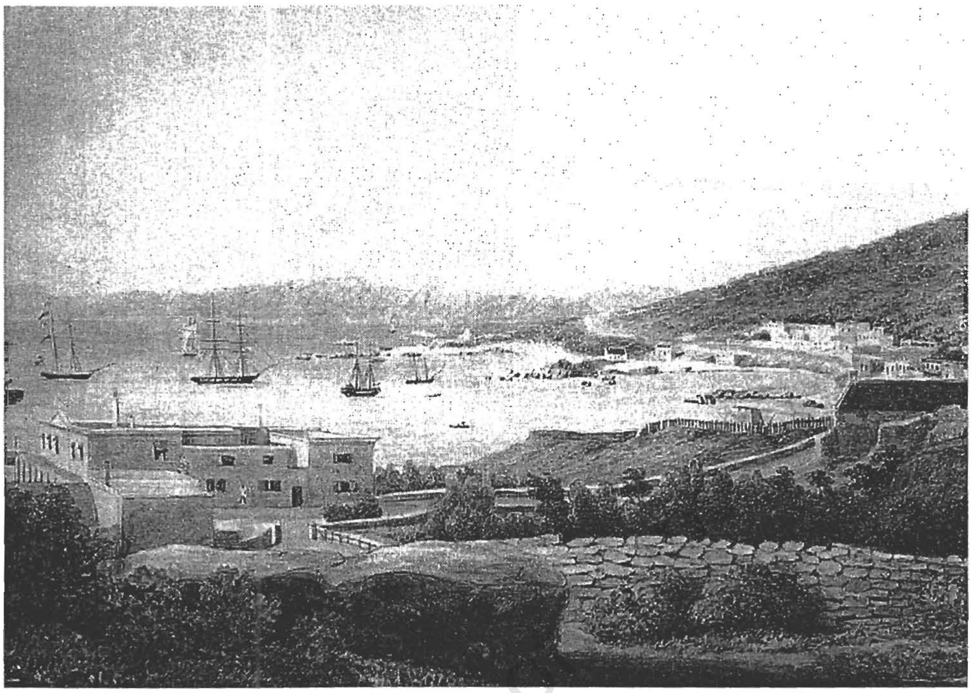


Figure 6 Water colour picture of Simon's Town pg 99 (Christopher Webb Smit c1838.)

This event set a precedent, and from favourable impressions passed on to the authorities in Batavia, a resolution was passed to take possession of the area referred to as '... *where the "Yselsteyn" anchored in June last'*. For a number of years, the area was known as "Yselstein Bay" until Governor Simon van der Stel visited the bay in 1687 and renamed it after himself (Simon's Town Historical Society 1976). During the same year, he conducted a bottom feature and coastline survey of Simon's Bay (Gründlingh 1991). The bay became a popular winter anchorage for ships (Figure 6 and 8) and before suitable roads were constructed, the preferred journey from Simon's Bay to Kalk Bay was by sea. (Simon's Town Historical Society 1976.)

An early ship's record describes the area as follows '*...In Simon's Bay, 13 or 14 sail of ships may be moored in safety. The new moon makes high water there at half past 3 p.m. The tide seldom rises more than 3 feet, except after a storm, or some other circumstance. There is no current to be perceived all over the bay; the soundings are* *also regular, with a clear sandy bottom.'*. The depth between Noah's Ark and Roman rocks was given as *'... from 10 to 15 and 16 Fathoms water'*, this is comparable to present day soundings of the area (Simon's Town Historical Society 1976).

Fishing was plentiful with reference to Steenbras and other fish often quoted in ships' records, and whaling was described as *'flourishing'* in Simon's Bay.

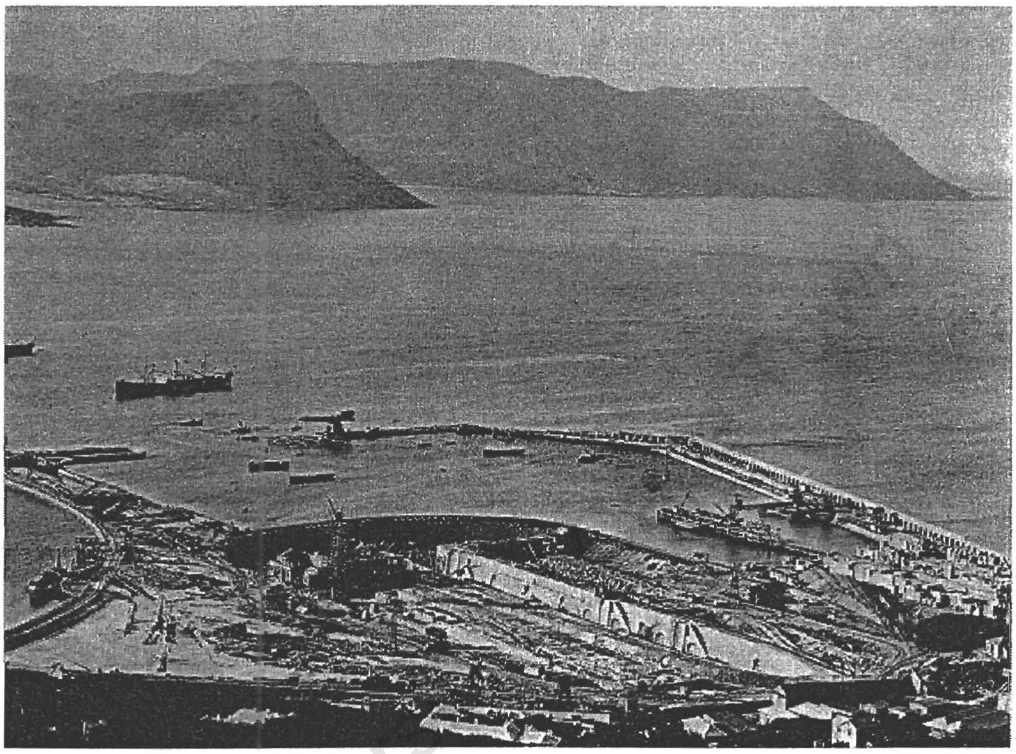


Figure 7 Photo showing the construction of East Dockyard and Selbourne Dry Dock c1908.

The Dockyard in Simon's Town is an important focal point of the town and has always been the major reason for the town's existence. The west Dockyard covered 13 acres and provided for all ships' facilities until about 1895 when it became too small to cope with increased demand. After 9 years of intensive work the East Dockyard and Selbourne dry dock were opened in 1910 (Figure 7). The dry dock was quoted as holding 22,000,000 gallons of water and was pumped dry in approximately 4 hours (Simon's Town Historical Society 1976).

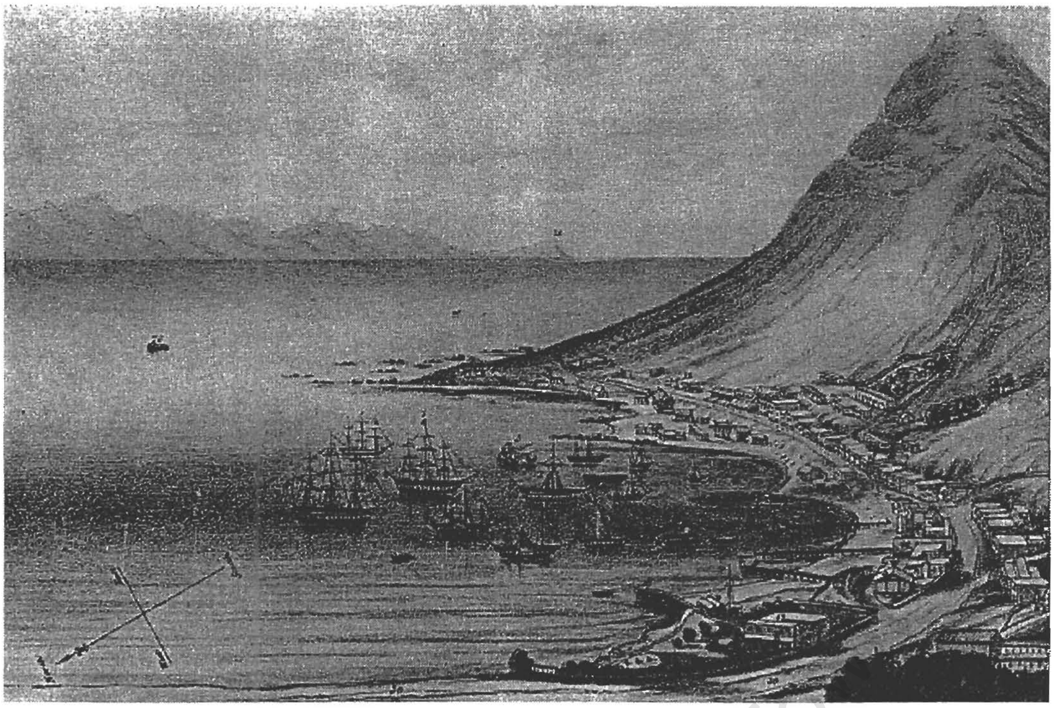


Figure 8 Sketch showing Simon's Town & Bay with the West Dockyard, before construction of the East Dockyard, viewed from above Waterfall 1899.

Physical Processes

Chemical, physical and biological characteristics of water determine water quality. These are acted upon and modified by certain physical factors and processes such as topography, climate, tides, water depth, water circulation, sediment or substrate, the amount of suspended particles and human activities which occur above and below sea level and in the entire watershed region. In order to understand changes that may occur, it is necessary to be knowledgeable of the physical forcing mechanisms and understand how they might influence water quality.

Bay and Coastal Circulation

Drift cards recovered between Simon's Town and Strandfontein by Sea Fisheries during the '60s suggested that during summer conditions, westward flowing currents enter the bay near Cape Point. Later, Atkins (after Gründlingh and Largier 1991) tracked drogues at 2 m below the surface throughout the bay and concluded that four current types could be characterised.

"Type 1 circulation is the dominant current (70% occurrence on occasions) that develops from south-easterly winds. The wind drives surface water in from Walker Bay (50 km SSE from False Bay entrance) past Cape Hangklip, which, when it enters the bay, forms a large clockwise circulation. Its large onshore component and persistence result in shallow, slow, wind driven currents in the gentle sloping bayhead region. A small clockwise or anti-clockwise vortex may develop off Gordons Bay in the north-eastern corner of False Bay" (Figure 9).
"Type 2 develops with a north-westerly wind. An easterly current enters the bay near Hangklip and follows the coastline of the bay in an anti-clockwise pattern until influenced by local winds" (Figure 9).
"Type 3 & 4 develop after calm periods. These slow-moving currents are probably tidal, although in deeper water, velocities are higher than would be expected from calculations" (Gründlingh and Largier 1991) (Figure 9).

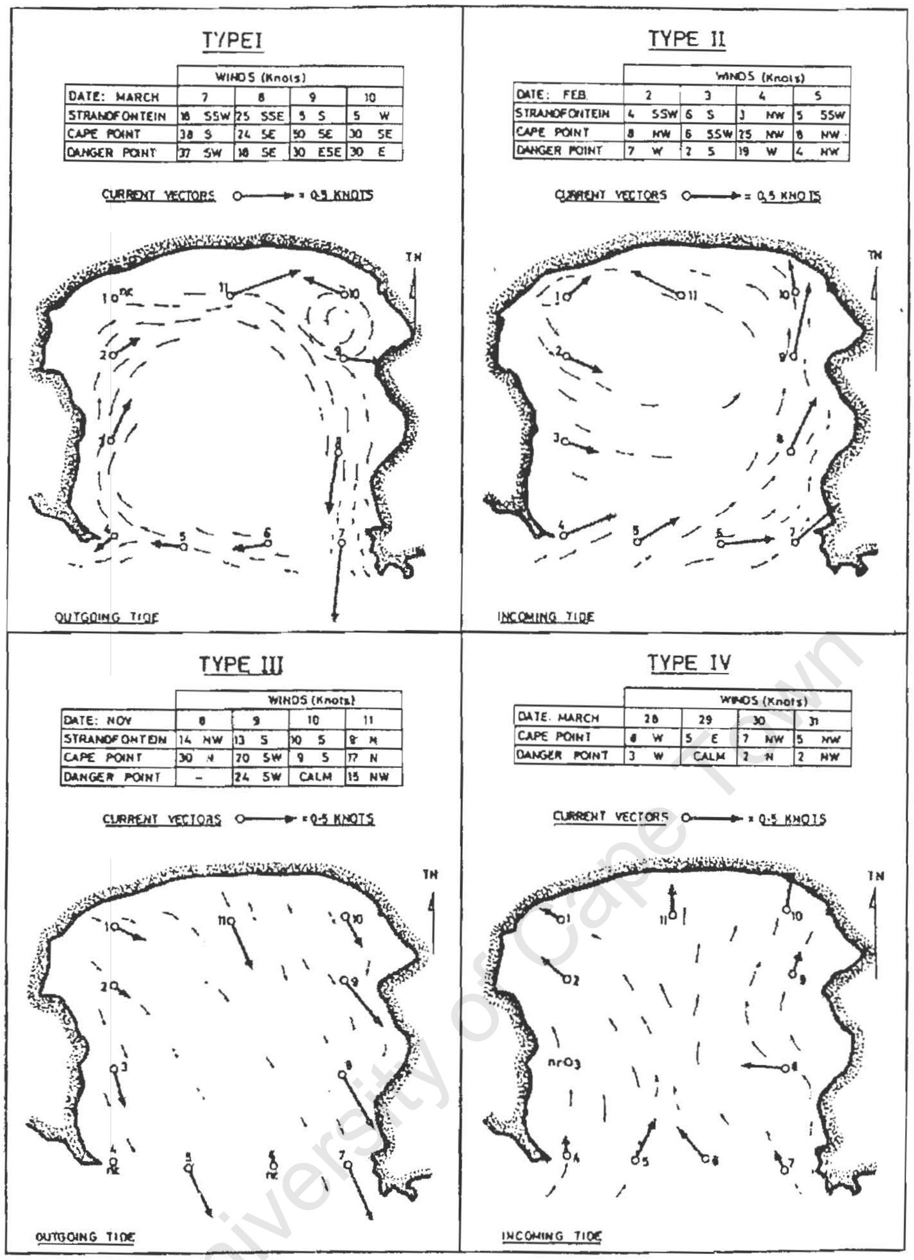


Figure 9 Typical flow patterns in False Bay (Atkins 1970).

During this early work of Atkins referred to by Gründlingh and Largier (1991), dye experiments were also used as an indication of the short-term flow. Although mention is made of readings collected in Simon's Bay, no specific results are presented for that region. Results for the entire northern False Bay revealed (a) clockwise currents under south-easterly or easterly winds occurring 50% of the time; (b) anti-clockwise currents under north-westerly winds, less than 10% of the time; (c) tidal currents dominating during calm wind conditions, setting mainly northward during flood and southward during ebb; (d) smaller eddies (e.g. at Gordon's Bay) that may have a circulation independent of that of the bay (Gründlingh and Largier 1991).

During south-easterly wind conditions and type 1 circulation which Gründlingh and Largier (1991) refer to work by Atkins, estimated a residence time in False Bay as 4-6 days and considerably longer for winter. During summer the northern part of the False Bay coast was chiefly affected by warmer water (Brown 1971), and (Isaac 1937) reported 15.3°C as tne mean annual temperature of the water off Simon's Town.

Studies undertaken by Atkins (1970) in False Bay are being refined and improved upon by varying spatial scales of oceanographic research. This study represents an important filling gap of information not previously studied in this context before in the north-western corner of False Bay.

Improved understanding resulted from the more recent study of Wainman (1987) who reported from four current meter moorings deployed within the bay that a significant proportion of the flow in the bay contained a southerly component. This implied that water enters in the centre of the bay and exits on the either or both sides. At Seal Island in the north, the upper water layer was seen to flow predominantly north eastwards while the lower layer flowed southeast.

Gründlingh and Largier (1991) refer to work by Botes (1988), described the coastal inshore currents as mainly clockwise along the northern perimeter of the bay. Flowing eastward and turning southwards along the eastern coast as a narrow band of flow.

The currents in Simon's Bay are generally weak, especially in the protected Small Craft and the Naval Harbour, making the area particularly vulnerable to effluent disposal and coastal structures. No rip-currents have been observed to occur in the area. "*Surface slicks, presumably caused by internal waves, have been observed to propagate far into the bay e.g. into Simon's Bay*" (Gründlingh and Largier 1991).

Three factors were identified as important transport mechanisms in False Bay (van Ballegooyen 1991):

(a) The morphology of the bay

(b) Water stratification

(c) The nature of the forcing mechanism

It is likely that these factors also apply to water transport in Simon's Bay.

Van Foreest and Jury (1985) refer to work by Shannon et al (1991) suggested that under persistent southeast wind of 9 m/sec, clockwise flow developed in the bay after 3 days.

The large southern opening of False Bay, exposes the basin to external influences such as sub-tidal sea level fluctuations and current reversals that occur in the south eastern Atlantic Ocean. Previous studies in False Bay have produced sufficient data to investigate the occurrence of remote wind forcing but insufficient data to observe the exact response to this remote forcing (van Ballegooyen 1991).

Prominent colour fronts develop in False Bay, and Shannon et al (1991) concluded that near shore and bay waters generally function as separate systems, with considerable interchange at times.

Thermal structure of the Water Column

Gründlingh and Largier (1991) characterised the water column in the western False Bay according to spatial and temporal variations. They found that significant thermal stratification occurred during summer (Figure 10). This was consistent with the temperature record from current meter time series data of Wainman (1987).

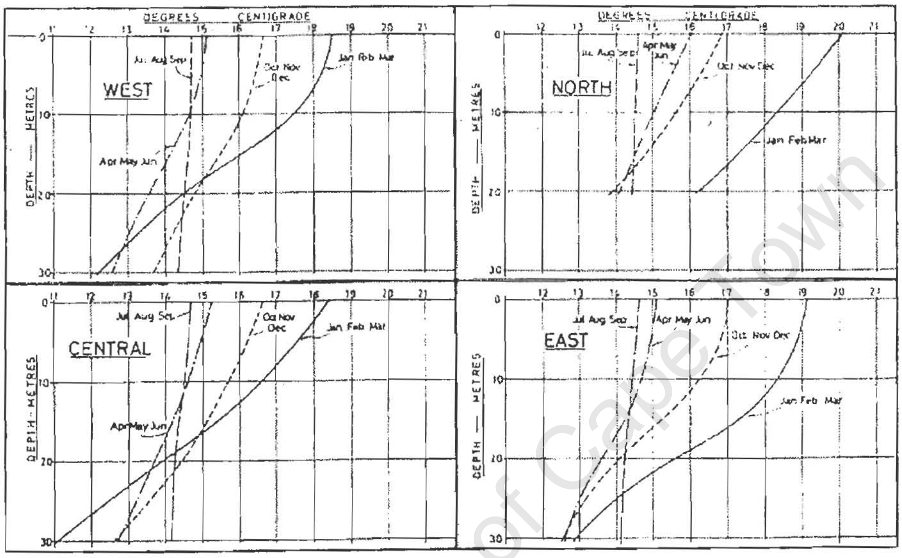


Figure 10 Seasonal temperature profiles in 4 sectors of False Bay. From Atkins (1970).

Coastal Trapped Waves (CTW)

False Bay is situated in the southern region of South Africa's west coast and forms part of the western boundary of the southern tip of Africa. The weather in the Bay is strongly influenced by larger scale synoptic variations. The existence of two semi-permanent high pressure systems over the south Atlantic and southwest Indian oceans dominates the weather, resulting in regular alongshore winds, especially during the summer months when the high pressure cells are located further north. These maritime winds in turn produce a low frequency, long wavelength, low amplitude oceanic response referred to as Coastal Trapped Waves (CTW). The existence and propagation of CTWs along the South African coastline have been reported from perturbations in sea level measurements by Brundrit (1984), Schumann and Brink (1990) and Mac Arthur (1988). Also from longshore current measurements

(Schumann 1983, Holden 1986 ,1987; Nelson 1985,1987,1989; Nelson and Polito 1987; Schumann and Brink 1990; Snowball 1996; and Wainman 1998). These alongshore currents are an important component of the upwelling process. Human benefits from such currents include waste disposal mechanisms and mariculture from the repeated flushing of embayments (Wainman 1998).

Evidence of CTWs entering False Bay was reported by Wainman et al (1987) as events lasting 2-3 days. Additional evidence of this is provided by Gründlingh (1991) from Brundrit *et al* (1987), Nelson & Polito (1987) and Nelson *et al* (1991).

From a limited dataset of water level records, Nelson *et al* (1991) concluded that CTWs, passing the mouth of False Bay influence both currents and water level between Cape Point and Simon's Bay.

Flushing and Residence Time

Simon's Bay has a wide opening to False Bay. The Naval Harbour structure would appear to increase residence time and result in reduced flushing for the Naval Harbour and the Small Craft Harbour than occurred prior to the structure. Simon's Town Naval Harbour does not have a freshwater inlet source to aid flushing, such as Durban Harbour. Residence time is probably exaggerated due to incomplete mixing and some of the water that escapes at ebb tide is returned at flood tide. Van Ballegooyen (1991) reported the flushing time of False Bay as eight days for the surface layers and 11.5 days for the deeper layers.

Tides, Water Level and Sea Level Rise

Tides in Simon's Bay have been measured by the SA Naval Hydrographic Office since 1958 (Gründlingh (1991) and SA National Tide Gauge report (10c)). Brown (1971) calculated tidal values from a 3-year period. Maximum tidal range springs range was found to be 2.13 m with a spring tide mean of 1.65 m and a neap tide mean of 0.34 m. Differences in tidal range between Table Bay and False Bay are negligible, with low water occurring approximately five minutes later than low water in Table Bay.

Brown (1971) referred to work by Atkins (1970 b), found that "*....in False Bay, oscillatory fluctuations from the predicted tidal curves occur occasionally, the average oscillatory period being 2.43 hours.*" Episodic meteorological events related to extreme pressure troughs cause water levels to be elevated above predicted heights by approximately 1 cm per 1 HPa pressure drop (personal communication, Dr Bruce Hewitson, UCT). These water level perturbations are seen in the tidal record of the area from time to time (personal communication, Capt. M Thompson (ret), tidal superintendent, SA Hydrographic office). Low Water Springs always occurs between 8.30 am and 10 am and between 9 pm and 10 pm (Brown 1971).

Upwelling

Winds blowing parallel to the coastline, such as south-easterlies along south-western coastline of South Africa, tend to displace surface, less dense, warmer water, northwards. At the same time, the Coriolis force, resulting from the earth's rotation and limited by increased distance from the earth's rotation axis, tends to deflect the surface water offshore. This results in lowered sea level at the coast, causing denser, colder, nutrient rich bottom water to be welled, replacing the surface water. This process is known as upwelling, which typically occurs as localised cells or plumes along most western boundries in the Southern Hemisphere and eastern boundries in the Northern Hemisphere.

Upwelling plumes in False Bay are known to originate via Cape Hangklip (the south-eastern corner of False Bay) from the Agulhas bank from the south-eastern Atlantic ocean (Gründlingh 1991). The recently upwelled water is known to move in a north-westerly direction, while separating from the coast. During this upwelling, the north and west coasts of False Bay remain relatively warm (Jury 1991).

Waves

False Bay is considerably less exposed to the Atlantic rollers than the west coast and Simon's Bay is further protected, resulting in waters that seldom receive significant swell. Brown (1971) referred to work by Day (1970), found that swell along Muizenburg often reached 1-2 meters high, while further westwards between Fish

Hoek and Simon's Town, they seldom reached 1 meter. Shipley (1964) reported that swells with westerly components were refracted when entering False Bay (Figure 11).

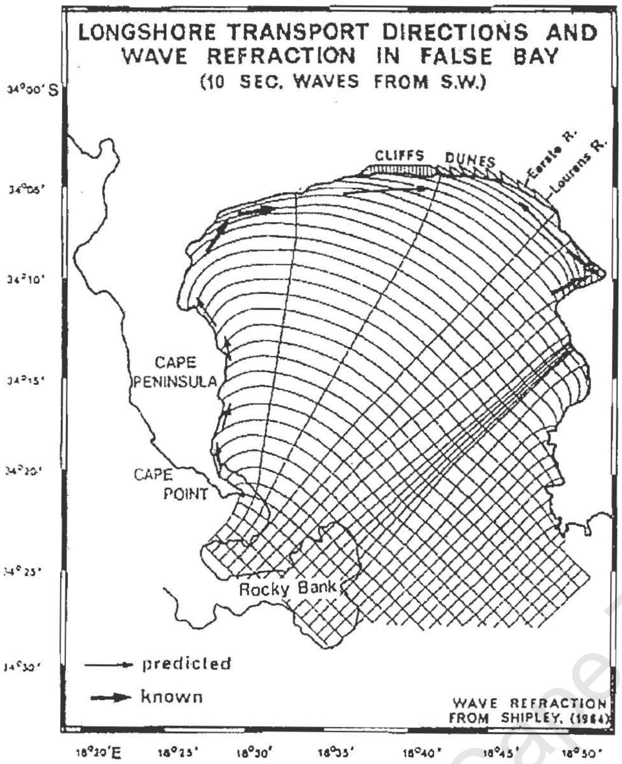


Figure 11 Longshore Transport directions and wave refraction in False Bay during 10 sec waves from the south west Shipley (1964)

The gentle sloping seabed of the northern regions (Figure 5) of the bay result in waves which break further offshore, increasing turbulent mixing. The Eastern harbour wall of the Naval Harbour offers an effective barrier from the short period south easterly wind waves, reflecting the waves back offshore towards Roman rock. It has been observed that most energy from these reflected waves are soon dissipated to within 1km from the shore. Winter northerly winds originate from across the land and are therefore fetch limited in Simon's Bay, resulting in perfect leeward protection and small waves. The easterly or north easterly wind, although rare in occurrence, blows along-shore of the northern False Bay coastal extreme with a fetch distance of approximately 30 km. After 12 hours duration, steep short period wind waves with amplitudes of approximately 1 m have been observed, that appear to focused in the Small Craft Harbour region, resulting in dangerous boating and mooring conditions (personal observation). During all other wind conditions however, the harbour is afforded suitable protection.

In describing alongshore flow, Brown (1971) used a simple method of constructing miniature breakwaters for observing how sand accumulated against these structures. At the more exposed beach such as Fish Hoek, sand accumulation was observed, while at Simon's Town, no accumulation was noticed.
This supported observations made in 1958 when sand was dumped on the 'harbour beach' artificially in such quantities that the natural inter-tidal profile of the beach was altered. The sand was not removed under normal conditions until the arrival of a particularly violent storm. This suggests that no long-shore sand movement occurs along Simon's Town beaches, due mostly to the protection offered by the harbour from the prevailing waves. These sheltered beaches represent static conditions, established by, and only altered by, abnormally heavy wave action during storms (Brown 1971).

The beaches also exhibited no variation in sand particle size. All beaches in the area exhibited the characteristic that coarsest sand was found on the 'toe' of the beach near the L.W.S level (Brown 1971).

Weather

Previous research effort was limited to the coastal weather of False Bay. Weather is known to play a prime role in processes affecting pollution dispersion, providing high-energy waves and wind driven currents, which disperse effluents. Large-scale pressure systems provide regular wind reversals and consequent changes in the weather, with a cycle of 6 to 20 days being common in the False Bay region (Jury 1991).

Jury (1991) described the climate of False Bay as follows:-

" The climate of the False Bay is pleasantly warm (mean temperature = 16.5 °C), with persistent strong winds (>15 m/sec) occurring often. These winds dominate the weather, exhibiting strong seasonal reversals, interspersed with calm conditions and moderate-light winds. The weather is influenced locally by the topographic orientation of the bay and land-sea breezes.

Four dominant wind patterns occur:-

- *Approaching low-pressure clockwise pre-frontal system results in gusty north-west winds with high wind speed. These winds occupy a deep atmospheric layer, typically more than 1500 m. With the passing of the low-pressure system, the wind always veers towards westerly winds. The mountain ranges on either side of the bay tend to compress and funnel these winds, resulting in stronger winds between Muizenberg and Strand* (Figure 12).
- *As air pressures rise with the approaching eastward movement of the South Atlantic High, this results in a divergent wind field, with south-westerly winds that increase in speed with time. Winds flow uniformly over False Bay increasing at the northern shore and light winds in the west* (Figure 12).
- *The permanent South Atlantic High (SAH) pressure system located over the southern Atlantic Ocean plays a major role in the weather over False Bay. This anti-cyclonic high-pressure system produces mainly south-easterlies, which are further categorised as: (a) Shallow south-easter*
  (b) Deep south-easter (Figure 12)

These dominant weather patterns result in wind streamlines that are steered by the local topography of False Bay (Figure 13).

(a) A shallow south-easter is caused during a period of ridging South Atlantic High, co-incident with the lowering of the subsidence inversion layer. The wind is then 'trapped' in a shallow vertical band from sea level to 300 m, the winds in this band are extremely variable and account for 40 % occurrence in False Bay. Since the vertical extent of this wind is limited, it has considerable implications for air pollution dispersion. Thickness of the shallow South Easter varies and may at times be limited to a narrow vertical band. Winds in this shallow layer are then steered by the topographic effects of the surrounding mountains.

(b) *In a deep south-easter, the subsidence inversion layer occurs at higher altitudes and the vertical extent of the wind is extended to a height of more than 1000 m (typically 1200 m) above sea level. Wind speeds are similar to those that occur* *during shallow south-easterly conditions. During these conditions, localised subsidence occurs in the lee of mountains.*

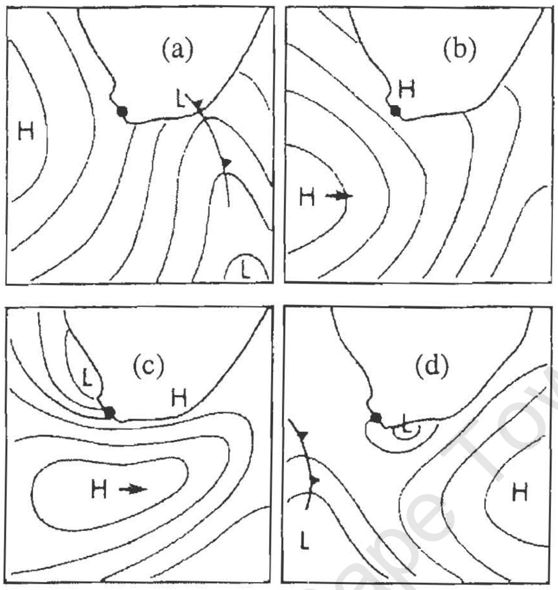


Figure 12 Synoptic weather regimes which effect the weather of False Bay, (a) Post frontal, (b) established South Atlantic High pressure system, (c) Ridging High pressure system with a coastal low and (d) approaching low pressure system accompanied by a cold front. From Jury (1991), referred to by Jury 1987

The altitude of the subsidence inversion layer is therefore the causal difference between shallow and deep South Easter."

The mean annual wind speed in northern False Bay is almost half that at Cape Point (Jury 1991). Entrainment of air on the eastern side of False Bay results in air temperatures 3 °C warmer than the west coast.

From data collected by Wainman *et al* (1987) at Simon's Town during April and May 1985, northerly winds exhibited a significant westerly component probably caused by the topographic forcing. The overall progressive wind transport was towards the north, similar to that at Kalk Bay (northeast of Simon's Bay). The progressive vectors at these sites were considerably different from those at the other 5 False Bay sites. The most marked difference was the apparent dipole flow and the absence of southerly winds. This is further evidenced by the synoptic wind field study conducted on 1 May 1985 whereby southerly winds occurred along the south-western coast of False Bay while south easterly conditions were recorded in Simon's Town. Average hourly winds speeds for the measurement period were low from midnight to 0700, increasing steadily and peaking at 1700 and steadily slowing again to midnight.

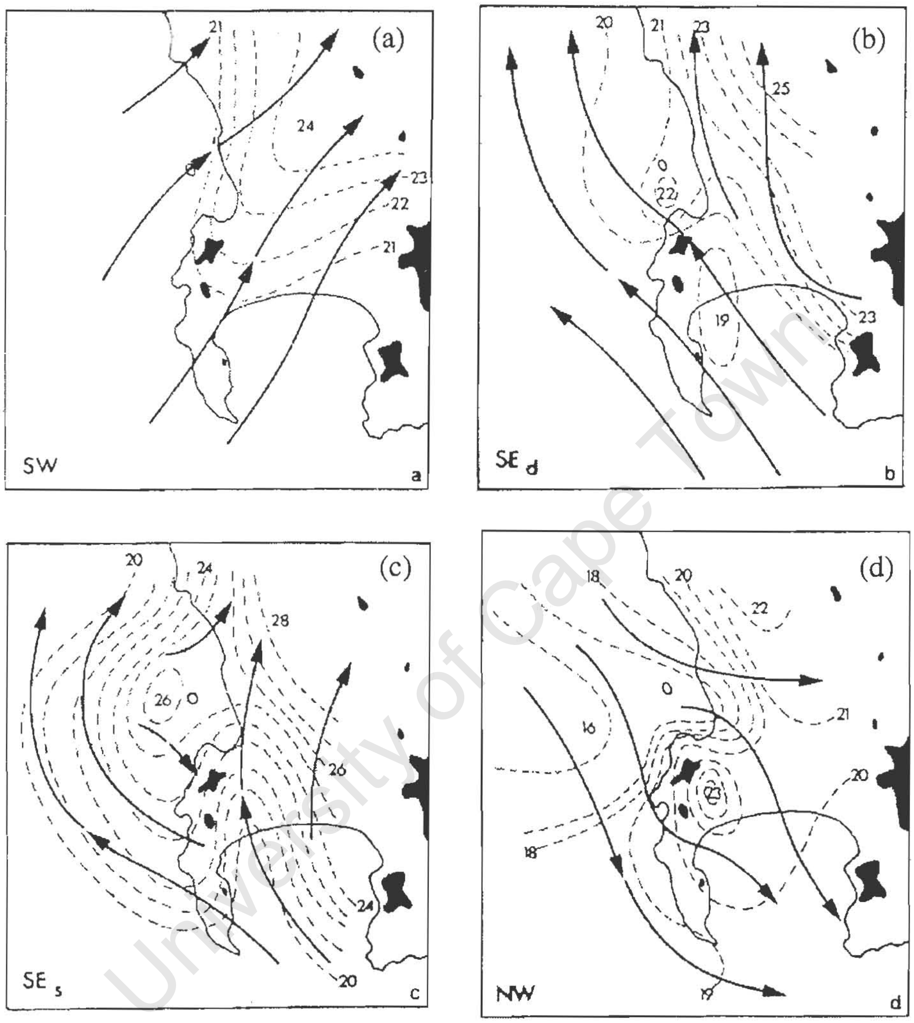


Figure 13 Mesoscale wind streamlines and air temperatures at 150 m for 4 weather phases ((a) southwest, (b) southeast – deep, (c) southeast – shallow and (d) northwest. Elevations over 600 m are shaded. From Jury (1987) referred to by Jury (1991).

Seawater Quality

The chemical, physical and biological characteristics of water determine water quality, which can be evaluated for a lake, river, estuary and the sea. The chemical variables that influence water quality include dissolved gases, minerals, nutrients, metals, toxic substances, salinity and pH. A complex interaction between these chemical components and physical and biological factors can affect water quality (Doll and Spence - no date).

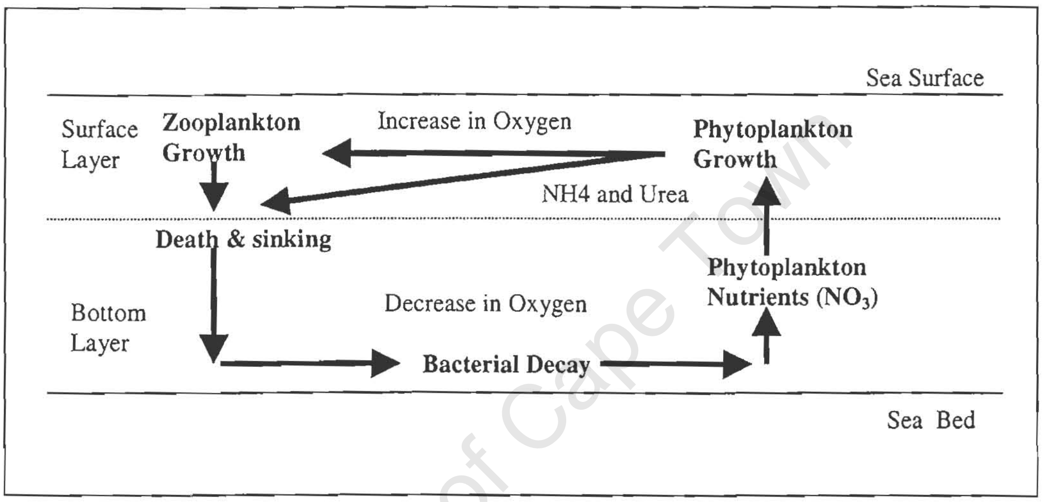


Figure 14 A Generalised Food Web

Generalised Food Web

In the Generalised Marine Food Web (Figure 14), phytoplankton or floating plantlike organisms are the primary producers, transforming nutrients, water, carbon dioxide and sunlight into plant material with oxygen and sometimes nitrites as the byproducts. Zooplankton or microscopic animal-like organisms are the primary consumers in the web, feeding on the phytoplankton, with ammonia and urea as by products. Organisms use both phosphates and nitrates to form soft tissue. Phytoplankton and hence zooplankton are dependent upon sufficient sunlight for photosynthesis and hence survival. This only occurs in the surface waters down to the base of the euphotic zone, which extends to a depth where 99% of the incoming light has been absorbed (referred to as the 1% light level).

In the surface layer, oxygen is at a maximum, due to the input by photosynthesis and turbulent wind induced mixing. Other essential dissolved constituents for marine life are nutrients, especially nitrates (NO_3) phosphates(PO_4) and silicates(SiO_4), which are all assimilated during phytoplankton growth. As the life cycles of the organisms are completed, they die, decompose and sink to the bottom layer. During the decomposition process, nitrates are converted to nitrites while bacteria consume oxygen as part of their decomposing process. The bottom layer steadily receives the decomposing plankton from above and as the decomposition is completed, the layer tends to have considerably less oxygen than at the surface, worsened by reduced hydrodynamic mixing . In some cases bottom water can become completely deficient of oxygen, resulting in anoxic (without oxygen) conditions. During this decay process, the same nutrients, nitrates (NO_3), phosphates (PO_4) and silicates (SiO_4) that were taken up by the organisms at the surface as part of their life cycle, are now once again returned to the water in dissolved form. A sink of nutrient rich, low oxygen bottom water exists, usually in darkness or low light levels, waiting for suitable environmental conditions such as upwelling to advect these fertile waters to the surface or mixing from episodic wind events so that food web may continue (Figure 14).

Since the constituents mentioned above play an essentual role in the marine food web, they can be used as natural indicators of the health of a marine system and will be described in more detail.

Nitrates - NO_3

Nitrate values are used as a new nutrient in primary production, with higher concentrations occuring **below** the thermocline.Vertical mixing and surface winter cooling can contribute to raised levels of nitrates. Nitrate values in the ocean range from 0.1 to 43 ug-atoms/l, while nitrite values range from 0.1-3.5 ug-atoms/l. In coastal polluted waters, sewage discharges, septic tank seepage or agriculural run-off are usually responsible for unaturally elevated levels of nitrates. The average nitrate concentrations reported for the west coast as well as those reported specifically for upwelled water is 1.17 ug-atoms/l ((Department of Water Affairs and Forestry. 1995. South African Water Quality Guidelines for Coastal Marine WatersVol 1. Natural

Environment 1995), with a range of 1.2 to 24.0 ug-atoms/l (pers. comm. Dr H Waldron), while an average of 5.79 ug-atoms/l has been reported for the south coast. As oxygen becomes depleted during the decomposition process, nitrate may be used in its place, leading to denitrification and once these have been depleted, the reduction of sulphates takes over. So it is unlikely that nitrate will co-exist with hydrogen sulphide, the byproduct of sulphate reduction. Excessive loading of nutrients in any ecosystem is termed eutrophication, which results in abnormal algal growth stimulation, general growth deficiencies and mortalities (Department of Water Affairs and Forestry. 1995. South African Water Quality Guidelines for Coastal Marine WatersVol 1. Natural Environment 1995).

Nitrites - NO_2

Natural levels of nitrite in seawater are usually low. In open waters values range from 0.1-3.5 ug-atoms/l. Thin layers of high nitrite concentrations together with low levels of oxygen (less than 0.15 ml/l) have been reported and it is thought that low oxygen concentrations favour the formation of nitrite. In upwelling regions, elevated levels (1 - 2 ug-atoms/l) have been reported and are indicative of high primary productivity. Pollution sources of nitrites and related problems are the same as for nitrates (Department of Water Affairs and Forestry. 1995. South African Water Quality Guidelines for Coastal Marine WatersVol 1. Natural Environment 1995).

Phosphates – PO_4

Phosphate is an important nutrient and originates from land weathering where it is carried to the sea in dissolved form. The mean concentration of phosphate is 2 ug-atoms/l, with a west coast average of 1.7 ug-atoms/l and 1.5 ug-atoms/l in upwelled water . The south coast is reported to have an average concentration of 1.2 ug-atoms/l. Nitrate and phosphate are used to form the soft tissue of organisms. Concentrations are similarly higher at the bottom and low at the surface, due to consumption and the steady 'rain' of organic debris to deeper water. These waste products, in the form of faecal pellets decompose, releasing phosphates into the water column. Together with nitrates, phosphates are advected to surface waters during upwelling conditions. During anoxic (denuded of oxygen) conditions in the sediments, phosphates go back into solution, particulary in the presence of iron as insoluble $FePO_4$ and $CaHPO_4$. This occurs especially during low pH and low dissolved oxygen levels.

Sources of phosphate pollution include:-

Waste products from fertilizer manufacturing as phosphoric acid.
Metal plating and processing
Household detergents in sewage discharges
Agricultural run-off from over fertilization of super-phosphates. These are usually transported to the sea by rivers.
Run-off from dairy farms and piggeries.

Eutrophication is the main problem resulting from an excessive input with consequences similar to nitrates.

(Department of Water Affairs and Forestry. 1995. South African Water Quality Guidelines for Coastal Marine WatersVol 1. Natural Environment 1995)

Silicates – SiO_4

Silicate is a nutrient used by single celled phytoplankton such as diatoms and radiolaria for their structural parts. When these siliceous organisms die, silica is released back into the seawater. Silicate is a bio-limiting nutrient in surface water, whereby availability limits biological production and is therefore often depleted in surface waters and accumulates in sediments. Silicates originate from weathering of silicate material, especially from volcanic sources. In surface waters, suspended silicon exceeds that in solution, but at depths greater than 100 m, it represents only a few percent of the total. The west coast avearge concentration is 13.6 ug-atoms/l, with approximately 15 ug-atoms/l reported in upwelled water. South coast averages are reported to be considerbaly lower, 5.2 ug-atoms/l.

Solubility of silicate in seawater is reduced by decreased temperature (30 % for Temperature drop from 25 °C to 5 °C) and increased slightly with increased pressure.

(Department of Water Affairs and Forestry. 1995. South African Water Quality Guidelines for Coastal Marine WatersVol 1. Natural Environment 1995)

Ammonium – NH_4^+

In aqueous form, ammonia exists in two forms, ionised (NH_4^+) and (NH_3)
NH_3 is toxic as it is lipid soluble and is therefore able to be absorbed into the body, by using lipids as a medium. Lipids are described as *"Any group of organic compounds that are insoluble in water but soluble in organic solvents, including fatty acids, oils, waxes, and steroids"* (Tulloch 1993). In contrast, NH_4 is non-toxic, has low plasma permeability and is a nutrient to primary producers such as phytoplankton. In unpolluted oceans, NH_4 values seldom exceed 5 ug-atoms/l, but in deep stagnant water (eg. The Black Sea), values as high as 150 ug-atoms/l have been recorded. NH_4 values in seawater are known to show considerable variation and are interdependent with pH, temperature and salinity. NH_4 and urea are excreted by animals and marine organisms such as zooplankton as part of their metabolic cycle. During decay of organisms and from those excreted by organisms, NH_4 is quickly broken down to NH_3 by bacteria.

Excessive levels of NH_4 can result in eutrophication, while excess NH_3 results in general growth deficiencies and mortalities.

(Department of Water Affairs and Forestry. 1995. South African Water Quality Guidelines for Coastal Marine WatersVol 1. Natural Environment 1995)

Nutrients in False Bay reported by Taljaard (1991), from two cruises consisting of 49 stations show that a plume of nutrient rich bottom intrudes from the Agulhas Bank in the south–east and surfaces at the centre of the Bay. These samples were taken during light southerly wind conditions. During strong south-easterly winds conditions however, nutrient rich water was upwelled within one day along the eastern boundary at Cape Hangklip (south-eastern corner of False Bay).

Temperature

As a basic property of seawater, temperature and changes thereof are important in the physiology of marine organisms. West coast seawater temperatures are largely influenced by upwelling, where temperatures range from 9-14 °C, but can increase to 16 °C or higher through sun warming. Oceanic waters have temperatures of about 20 °C. The south coast however exhibits temperatures of 20-21 °C during summer and 16-17 °C during winter.

Chlorophyll-a

Chlorophyll-a itself is not considered a water quality constituent, however it is a measure of total plant pigment produced by phytoplankton algae and higher plants. Chlorophyll-a levels are directly proportional to phytoplankton blooms and are therefore used as a method to detect and quantify these blooms or the lack thereof. Typical values in seawater range from 0.02 to more than 20 mg/m^3

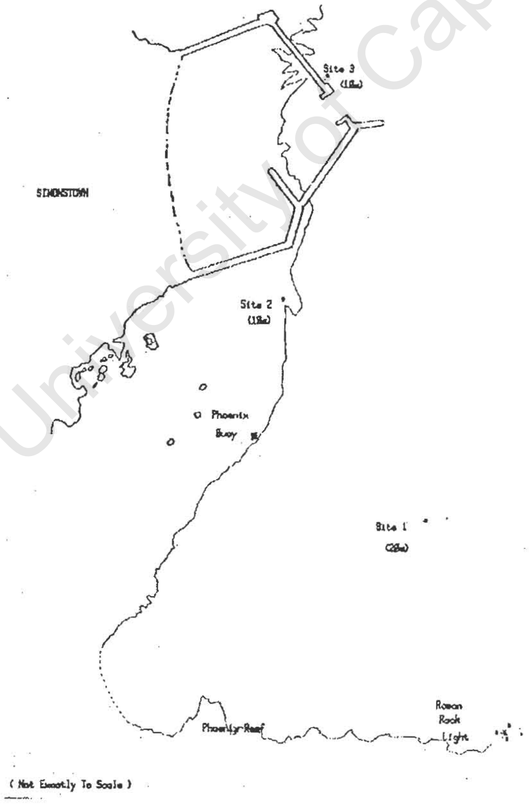
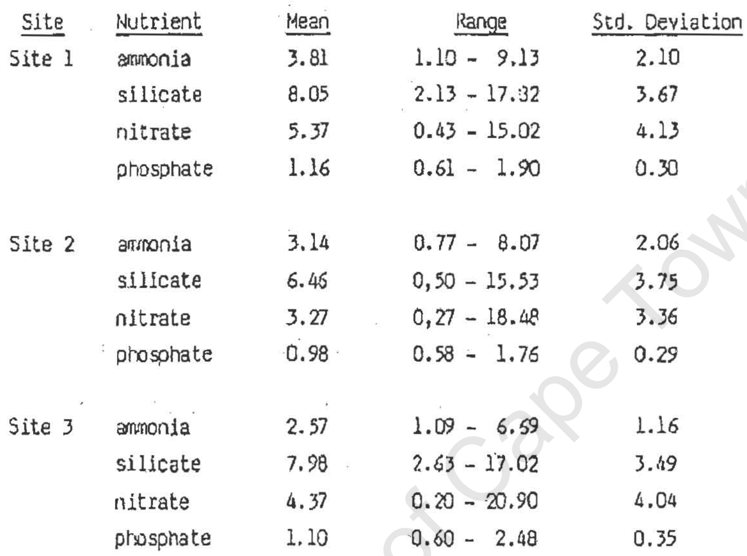


Figure 15 Stations sampled by De Chalain (1979)

De Chalain (1979) measured nutrients weekly (Figure 16) for a period of ten months, (from January 1979 to October 1979) at 1 m above the sea floor at three sites (Figure 15), during a marine fouling experiment in Simon's Bay. Copies of some of the results pertaining to this work are presented below (Table 1).



Site	Nutrient	Mean	Range	Std. Deviation
Site 1	ammonia	3.81	1.10 - 9,13	2.10
	silicate	8.05	2.13 - 17.32	3.67
	nitrate	5.37	0.43 - 15.02	4.13
	phosphate	1.16	0.61 - 1.90	0.30
Site 2	ammonia	3,14	0.77 - 8.07	2.06
	silicate	6.46	0,50 - 15,53	3.75
	nitrate	3.27	0,27 - 18.48	3.36
	phosphate	0.98	0.58 - 1.76	0.29
Site 3	ammonia	2.57	1.09 - 6.59	1.16
	silicate	7,98	2.63 - 17.02	3.49
	nitrate	4.37	0.20 - 20.90	4.04
	phosphate	1,10	0.60 - 2.48	0.35

Table 1 Nutrient results from weekly samples collected in Simon's Bay at three sites from January to November 1979. Values are quoted as µg.at/l.

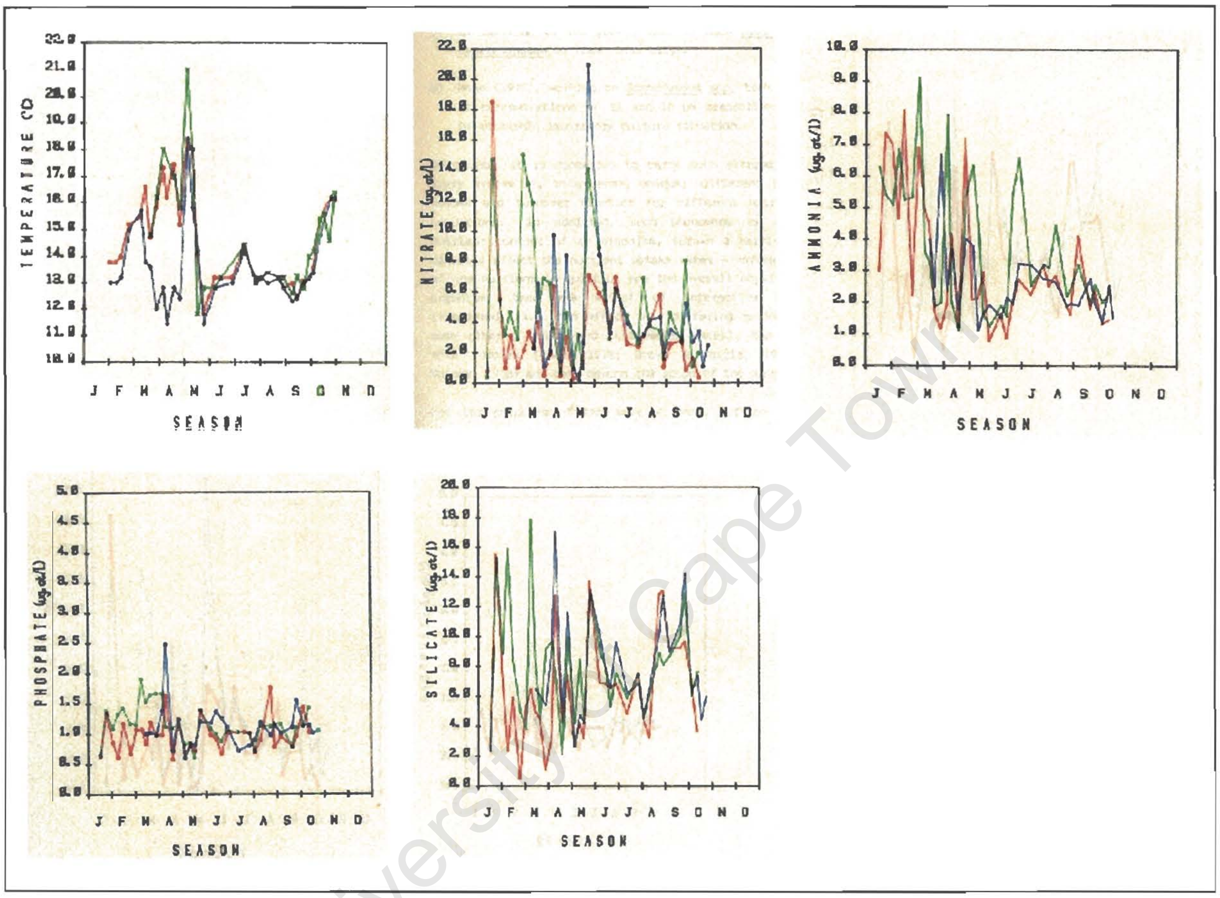


Figure 16 Plots showing weekly values of temperature, nitrate, ammonia, phosphate and silicate in Simon's Bay. Green = site 1, red = site 2, blue = site 3. Values are quoted as μg.at/l. (De Chalain 1979)

Possible pollution sources in Simon's Bay

Since most pollution runoff eventually reaches the sea, an understanding of the seawater quality in Simon's Bay requires that all pollution sources in the area be identified and understood. Pollution in Simon's Bay is thought to originate from one or more of the following sources:-

- Industrial Effluents (Oil refineries etc.)
- Pollution from ships and small craft (e.g. Sewage, hydrocarbons etc)
- Run-off from land (storm-water, storage dumps, insecticides etc)
- Harbour activities from the small craft and Naval ship works. (e.g. painting and chipping, grit blasting etc)
- Fresh water pollution (eg. Sewage, effluents)
- Air pollution (e.g. grit blasting)
- Floating matter (human presence and tourism)

It is considered that weak tidal currents, a small tidal range, wave-setup in Simon's Bay are conducive to increased residence times of pollutants in the area.

Mussel Watch Programme

Filter feeders such as mussels and clams have been used in the U.S.A as biomonitors of heavy metal concentrations in coastal waters since the late 1960s. These 'biological filters' concentrate substances in their body tissue and can therefore be used to locate and identify harmful substances, toxic levels and polluted areas and therefore provide an important element in water quality management strategies. (Downing 1996)

The South African Mussel Watch programme has been administered by Marine and Coastal Management (previously Sea Fisheries Research Institute) since 1985. A larger range of substances including PAH's, PCB, TBT, DDT, Organochlorine, Organotin are monitored in the U.S.A and certain other countries. In South Africa heavy metals eg Chromium, Copper, Lead, Zinc, Iron and Mercury are monitored. Amongst the extensive sampling sites monitored bi-annually (October and May), four are within Simon's Bay. These are Glencairn, Marine Oil at Mackerel Bay

(Marine Oil), Simon's Town Naval Harbour entrance and Boulders (Figure 17).

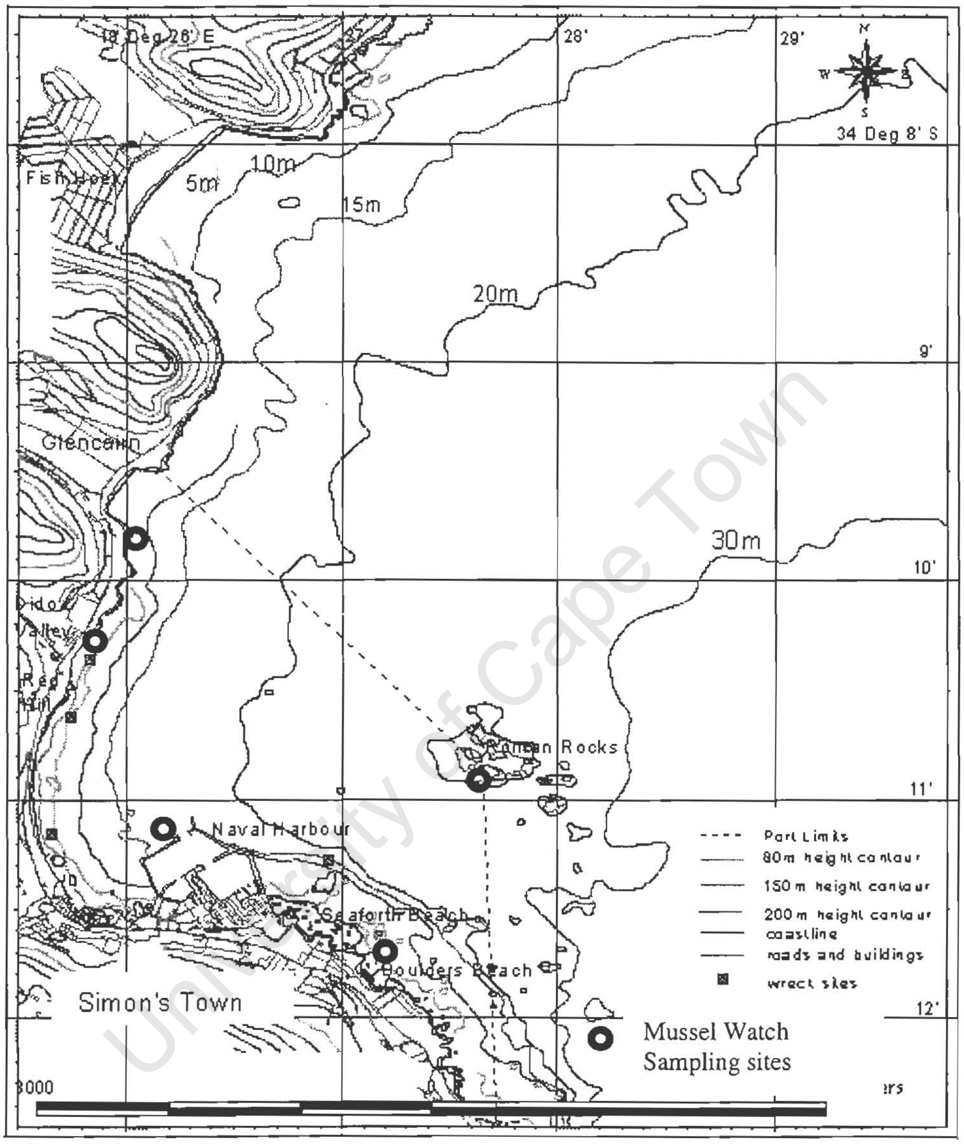


Figure 17 Map showing MCM mussel watch sampling sites

Urban Effluent

Urban wastewater is a significant contributor of plant nutrients to estuarine and coastal waters that may result in loadings of nitrogen and phosphorous above the "natural" amount referred to as eutrophication, typically originating from storm water runoff or sewage outfall. These conditions may lead to effects such as hypoxia (complete removal of dissolved oxygen) and anoxia (depletion of dissolved to concentration as low as 3 to 4.3 mg/l). If eutrophication is sufficiently severe, this condition can result in nuisance algal blooms, dieback of sea-grasses, and reduced populations of fish and shellfish.

Sewage and Industrial Effluent

Many urbanised coastal regions receive excessive nutrients and sewage effluent can often be a primary component of this. Cloete (1979) reported that sewage effluent was discharged into the surf zone in Simon's Bay at a rate of 0.4×10^{6} m^3 per annum, accounting for 1.26% of the total sewage discharge in False Bay. An upgrade has since taken place so that, at present, the pipeline at Simon's Town is the only one in False Bay that discharges in deeper water (approximately 2 m above the seafloor in 8-10 m depth) beyond the surf.

There have been a number of press reports of sewage spillages in Simon's Bay in the past few years. Often afflicted is the Admirals beach, implying that the South African Navy was responsible. The cause of these raw spills, were often blamed on pump breakdowns at the lowest point of the municipal sewage pipeline network in the area. The pump and manhole, owned by the local municipal authorities, is located below the Admiral's House in Naval property and serves the entire Simon's Town. The site is located alongside the mouth of the Baviaanskloof River, just above the high water mark and a malfunction results in an immediate spillage into Simon's Bay.

A law is in place for conventional sewage and industrial discharges. Section 21 of the National Water Act (No 36 of 1998) states that the discharge of waste or water containing waste through a sea outfall requires a licence. Some confusion exists under the act, however, about the classification of the sea as a water resource. The issue is made clearer by The Water Act of 1998. This act specified in section 41, that the issuing of a licence, may require an impact assessment which must comply with requirements in section 26 of the Environment Conservation Act (Act No. 73 of 1989) (Taljaard S, van Ballegooyen R.C and Morant P.D. 2000).

In terms of local legislation (i.e. by-laws and regulations), Simon's Town's bye-laws and regulations (passed by the old Simon's Town municipality) still apply, even after a number of local governments restructuring exercises. These older laws remain enforceable and exist alongside the new Metro Council by-laws for the control of sewage treatment works, networks and transporting of waste.
The South Peninsula Municipality (previously Simon's Town, Fish Hoek and Cape Town Municipality) that includes Simon's Town is one of five municipalities bordering False Bay. (Taljaard S, van Ballegooyen R.C and Morant P.D. 2000).

One such regulation which remains enforceable is the Simon's Town Municipality bye-law relating to industrial effluent (PN 771/1985, Province of the Cape of Good Hope Official Gazette 4399, 1 November 1985) for the harbour region. This region is defined as the areas adjacent to the sea in the vicinity of the town pier, owned or controlled by the Council (Taljaard S, van Ballegooyen R.C and Morant P.D. 2000).

The following as is an excerpt from Taljaard S, van Ballegooyen R.C and Morant P.D. 2000.
"......Water quality in the Sand River catchment in the Glencairn valley is monitored by the Scientific Services Department of the Cape Metropolitan Council (CMC). The river is also included in the monthly chemical monitoring programme of the Department of Water Affairs and Forestry (DWAF) at rivers and major storm water outlets into False Bay (W Kloppers, DWAF, pers. comm.). The CMC has a sampling point at Glencairn Beach, where the Elsies River discharges into False Bay, as part of their fortnightly bacteriological monitoring programme, but none in the river itself. Results from Glencairn Beach do not, however, indicate any health risk from this source."

The demand for advanced industrial Naval Harbour facilities in the post 2nd world war era in Simon's Town, to support the South African naval fleet led to the establishment of a number of specialist activities. These include a chemical cleaning bay, drydock and an electroplating and galvanising plant (Garrard 1991). Effluents from these sources contain heavy metals that are discharged into the sea as stormwater runoff. This happens during the rainy season.

Industrial effluent from Marine Oil Refiners of Africa Ltd. originally discharged into a stream that flowed down Dido valley (opposite the Naval Harbour entrance) and into the surf zone. Later (August 1979) pipes were installed so that effluents were instead discharged onto a nearby beach. Discharge rates of 0.05 x 10^{6} m^{3} per annum, 3000 and 5000 litres monthly were reported, although peak figures up to 10 000 litres were reached from time to time (Brown 1980). This effluent represented approximately 0.2% of the total industrial effluent discharge in False Bay (Brown 1980).

In a report by Brown (1980), he indicated that ".... *the effluent consisted largely of glycerol and fatty acids, together with emulsified oils and solid fats, and was virtually lacking in nitrogen. The only metal present in concentrations significantly higher than tap water was nickel, at about 0.55 mg/l. Chemical oxygen demand was in the region of 2500 mg/l , occasionally reaching much higher values. The pH varied from 8.6 to 9.4. The effluent was normally discharged at a temperature a few degrees above that of the stream, although on occasion it entered the stream and later the sea at 70 to 75°C, causing thermal pollution of the area.*" In addition he showed that phosphate and silicate levels were elevated at the out-fall vicinity, while oxygen and salinity levels were depressed to 2.5 mg/l and 31 psu, respectively in surface waters. Measurements taken at various distances from the out-fall indicate that all constituents and meiofaunal densities attained background levels within 200 m of the out-fall. Thermal effects were not addressed. Salinity levels of the beach sand were also found to be significantly depressed to a depth of 10 cm below the sand surface. It was suggested that effluent sinking into the sand formed a layer on top of the water table and acted as a barrier to the penetration of oxygen. From short-term tests conducted on certain fauna, no effects below 5-10 % concentration of effluent in seawater could be detected in any of the animals. Brown concluded however that reduced oxygen tensions were more damaging than actual toxicity.

Trace Metals

In the absence of a specialized knowledge of this field, discussions were held with Dr L Jackson (Dept. of Environment Affairs and Tourism), Dr J Baily (MCM), Dr J Largier (UCT Oceanography) and Dr P Montero (CSIR), Mr R Harding (MCM), giving an introduction to the subject.

Trace metals such as Cu, Zn, Pb, Ag, Hg, Cd, Ni, etc are potentially toxic in the water column, although do not generally remain in solution in seawater. In Simon's Bay they may originate from a number of sources such as stormwater runoff, sewage spills, chemical plants etc. The occurance of these trace metals in the marine environment is complexed by organic ligands from biological sources which dictates their bioavailability.

Accumulation in sediments

The increased industrialisation in Simon's Bay, particulary with respect to Naval and Small Craft Harbour activities, has resulted in the input of pollutants into the waters of Simon's Bay, usually contained in storm-water run-off. Heavy metals produced as waste products quickly move out of solution to form particles as they encounter slightly saline seawater. They are then either carried off as suspended solids or deposited on the seabed and accumulate onto the surfaces of mud and clay minerals. They are absorbed and may become persistent sources of contamination to the overlying water and surrounding organisms. Coarser grained sediments are generally less likely to be contaminated by heavy metals than finer grained or muddy seabeds (pers. Comm. Dr Jackson). In time, as the finer sediment became dominant, larger species, probably different from those that originally occupied the area established themselves and the benthic organisms were once again stabilised (Personal communication Dr J Bailey, Marine and Coastal Management). Scuba diving operations undertaken by the author in the region suggest that such a situation may exist in present day Simons Bay Harbour. Heavy metals entrapped in sediments below slow moving or stagnant sea water will remain in a stable particulate form and will continue to accumulate unless disturbed or flushed with fresh water. It is considered that typical disturbances would include severe episodic wind events, constructions, dredging, seabed trawling, ship's thrust from large ships, flooding, anchoring, scuba diving activities such as air-lifts and underwater explosions etc.

Although only trace metal concentrations and biota health are covered in this study, sediment distribution is also important to water quality studies since:

"………

- *it is possible to infer circulation patterns in the bay from the sediment distributions (e.g. low energy environments where sediments and pollutants accumulate)*
- *it is possible to infer where water column productivity is high in the bay (through a knowledge of the circulation and the deposition of biogenic sediments*
- *The sediments play a major role in determining specific benthic habitats within the bay.*
- *Sediment grain size is important in assessing the impact of a polluted effluent on sandy beaches, the coarser the grain size the less the impact (Chapman, 1981; CSIR, 1992).*
- *Trace metals and toxic compounds are mostly adsorbed onto very fine sediment particles (both lithogenic and biogenic) thus the movement and ultimate distribution of these fine sediments (< 60 μm) is a good proxy for the transport and fate of trace metals and toxic compounds should they be present in the environment*" (Taljaard S, van Ballegooyen R.C and Morant P.D. 2000)

A rigorous investigation of sediment distribution does not form part of this study, however, SA Navy trace metal data is presented where it is relevant to water quality issues in the area.

Sediment Biota Health

Biota sediment health data were obtained from the SA Navy and are relevant to the sediment samples referred to above.

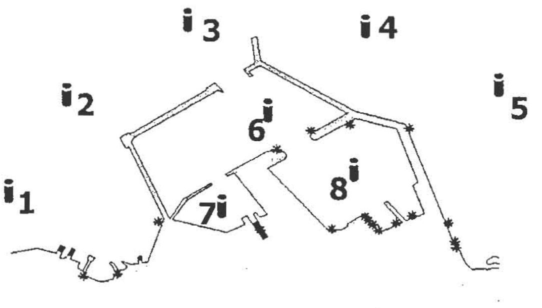
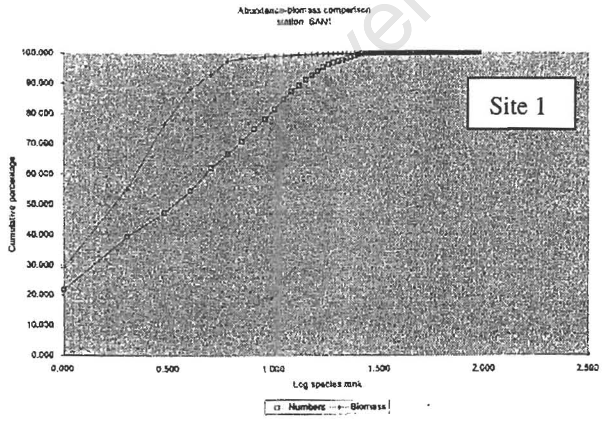
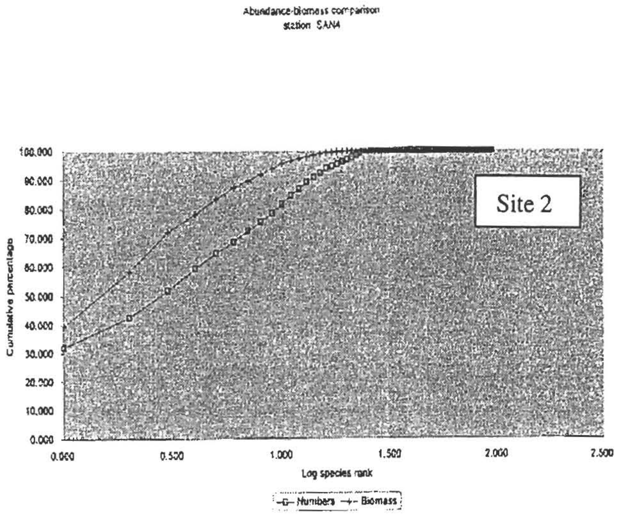


Figure 18 Sediment core samples collected during 1998 for K-Dominance plots

Co-incident with the collection of heavy metal sediments above, additional sediment cores were collected from 8 sites in the harbour and surrounding Simon's Bay (Figure 18) by SA Navy divers under the guidance of Mr Alistair Busby of Environmental Survey Laboratories CC during October 1996, 8 May 1997, 11 November 1997 and 23 February 1998. This was investigated by Lt K Dearlove, South African Navy environmental officer. K-dominance plots are given below. The November 1997 results could unfortunately not be reconciled with site locations and are therefore not presented here.





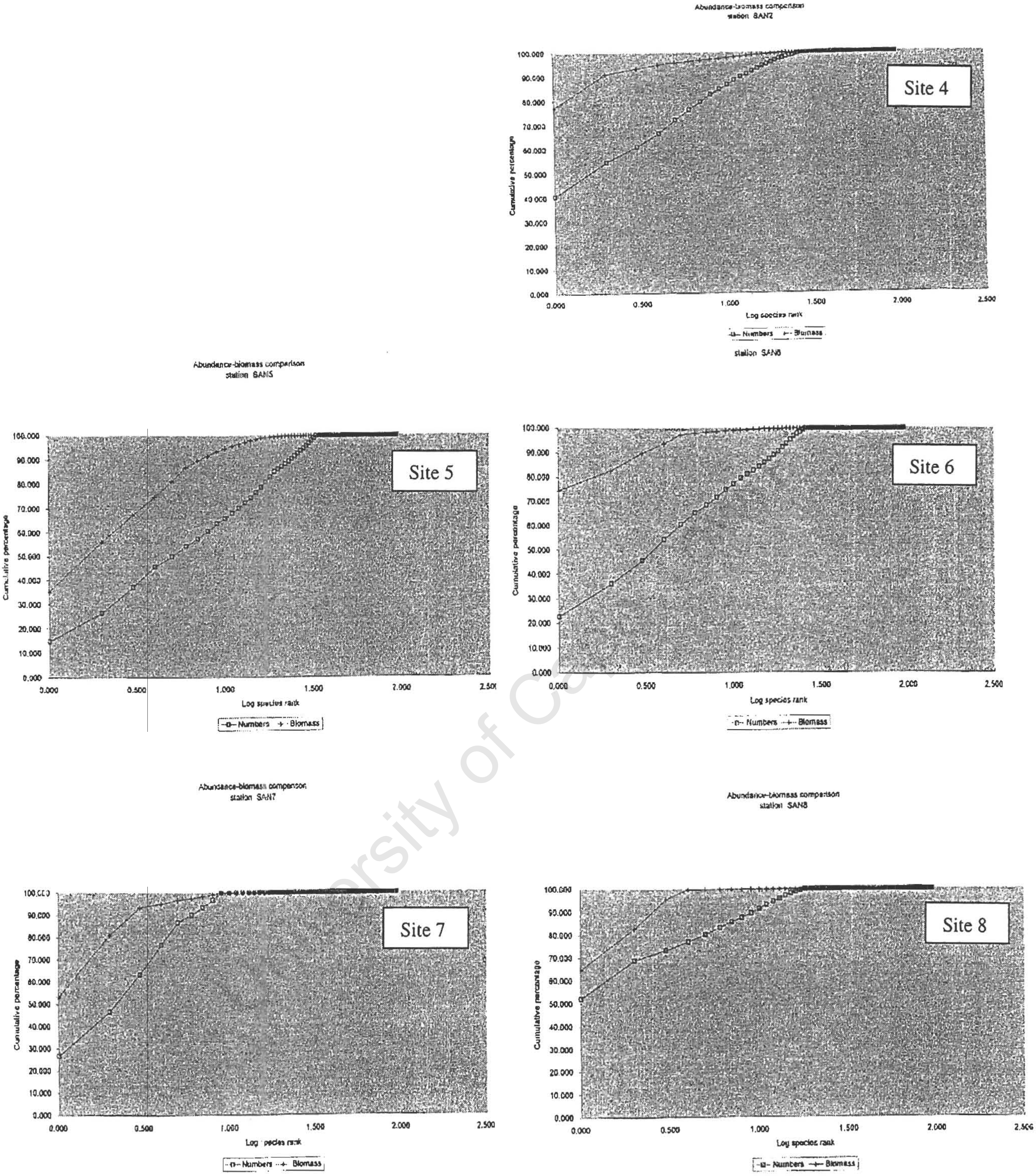


Figure 19 K-dominance plots of sediment biota measurements taken in Simon's Bay

The k-dominance plots (Figure 19) above are based on a method to assess the health of the benthic environment. Typically a healthy environment has a small numbers of large animals (such as prawns and clams etc) with a high overall biomass value. A polluted environment has a high number of tiny organisms with a low biomass. By plotting the biomass and numbers on the same graph of cumulative percentage vs species rank two curves are created (Figure 19). In a healthy environment, the biomass curve lies above the numbers curve, while in a polluted environment, the curves will cross and the numbers curve (Figure 19) will lie above the biomass curve (method described by Warwick R.M 1986) (Busby 1998). Although a biomass assessment was used to determine the health of the seafloor, this single method is not comprehensive and other methods eg. Fauna assessment, should not be overlooked.

Naturally Occurring Poisons

South African seas produce a number of natural poisons, eg. *Gonyaulax catanella,* now called *Alexandrium* (pers communication Dr T Probyn). This is one of many organisms responsible for 'Red-tide', which occurs independently of human activities and was first noted by Simon van der Stel in the 1680s (Brown 1987).

Algal blooms off the South African west and south coasts occur naturally throughout the year, but are most abundant during late summer and autumn (Lisbon '98). This type of poisoning occurs mostly on the west coast of South Africa although blooms of the algae Gonyaulax polygramma and Gymnodinium sp. have also been reported in False Bay. No record of Red Tide outbreaks exists for Simon's Bay, although a small number of outbreaks have occurred in False Bay. Such poisoning is categorised as :-

"...

- *paralytic shellfish poison (PSP) caused by the toxin known as saxitoxin in shellfish which has fed on toxic dinoflagellate plankton (red tide) of the genus Gonyaulax;*
- *diarrhetic shellfish poisoning (DSP)*
- *neurotoxic shellfish poisoning (NSP) (aerosol toxins), Ptychodiscus breve, which is the most widely studied organism causing NSP."* (Lisbon '98)

PSP is a result of consuming contaminated shellfish and no side effects are known to occur through normal recreational contact with 'red tide'. However with DSP and NSP can occur when coming into contact with the toxins released into the water by these specific species (Lisbon '98). Exposure to wind-blown cells are known to cause eye irritation (pers. comm. Dr H Waldron).

Beaches

Beaches within the port limits account for 21% (638 m) of the total Simon's Bay coastline (3040 m). Previous beach pollution work conducted in the area, by Brown (1971) looked at the organic content of sand. He concluded that on unpolluted Cape Peninsula beaches, however, the organic content was so low that it was not possible to make accurate measurements and Simon's Bay showed values ranging from 0.04% to 0.06% by weight. This can be interpreted as indicating that no toxic pollutant (trace metals) existed on those beaches, since no organic medium was available for deposition of toxins.

Summary

The diverse nature of the Simon's Bay coastline in the north western corner of False Bay has undergone numerous human induced changes during the last century and remains apparently healthy, while supporting diverse usage. Although the weather, water circulation and seawater properties are affected by local topography and artificial structures, they are largely dictated by changes and features that occur in the Cape Peninsula and False Bay.

Sewage and industrial effluent from Simon's Town and harbour activities have been discharged into Simon's Bay for approximately 100 years. Local legislation pertaining to sewage treatment, industrial effluent, conservation and waste discharge etc. has been improved, while various previous regulations remain in force.

Data has been collected in the Simon's Bay region for a number of years (in some cases), by the CMC (bacteriological), DWAF (rivers and storm water outlets), consultant such as Prof. Brown UCT for Marine Oil Refineries (industrial environmental impacts), MCM (Mussel Watch), SA Navy (seafloor sediments sediment biota and tides), IMT (currents, weather and sea water properties) and students such as de Chalain (bio-fouling studies).

These previous measurements together with those collected in this study are collated, examined and compared in context here to identify the physical forcing mechanisms and quality of the sea water constituents in Simon's Bay.

Chapter 2 Materials and Methods

The broad scope of this work dictated that data requirements were diverse. In order to understand both temporal and spatial variability of the region, both monitoring and repetitive 'snap shot' near synoptic measurements were required. Simon's Bay is relatively under-studied, such that little historic data exists. This is coupled with a general research shortfall for the greater False Bay. A database of water quality data was therefore a priority and the Simon's Bay Sea Watch 1 project rationale was based, inter alia, on this data shortfall. Part of this project was to establish baseline sea water quality values for the region. Simon's Bay Sea Watch 1 took place from 15-25 March 1999.

Climatic and oceanographic measurements were also required to understand the physical forcing mechanisms that are an important influencing factor on water quality. These can affect the input, dispersal, dilution, advection, concentration, and mixing of pollutants and secondarily affected waters eg. eutrophication from nutrient loading. No previous research relating to this part of the False Bay has been undertaken. Data such as local weather, ocean currents, physico-chemical properties, tides and sea level are important to the sea water quality readings.

Winds

Wind speed and direction were measured using a cup anemometer at a tower approximately 15 m above sea level on the eastern harbour wall and averages calculated every hour using a South African manufactured automatic recording weather station installed at the Harbour master's office. Data from the sensor travels approximately 120 m from the exposed 'highlight' tower (Figure 20) along a conducting cable, into a nearby connection room and underwater across the inner harbour entrance, along channeling to the harbour master's office (Figure 20). Wind speed and direction averages were logged each hour to an automatic recording data logger along with other standard meteorological variables. Wind direction 'cross-over' firmware supplied with the instrument allowed the 0/360 wind crossover so that winds were correctly vector averaged. Data were stored for the duration of the experiment and later downloaded to a personal computer at the Institute for Maritime

Technology (PTY) Ltd. This was accomplished using communications software and modem hardware supplied by the manufacturer. The data logger was a MCSX 8-channel analogue/digital data logger using 220V power supply with a rechargeable back-up battery.

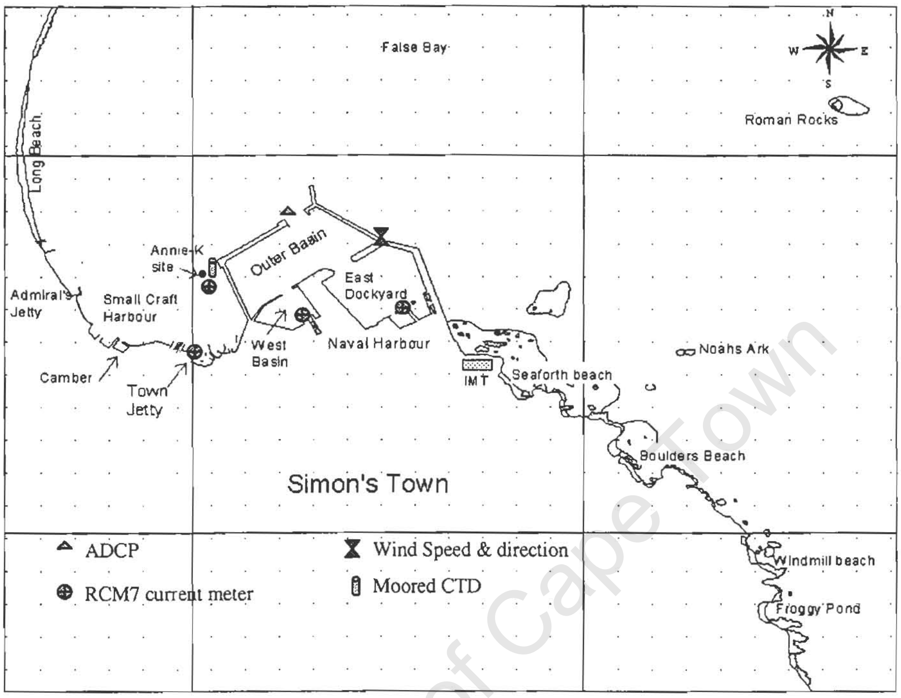


Figure 20 Map showing major localities, place names and time series measurement sites in Simon's Bay

Wind data for the duration of the "Simon's Bay Sea Watch 1" from 15 March 1999 to 23 March 1999 were used. Data obtained from the logger in engineering units were imported in Microsoft Excel spreadsheet format. Wind vectors were calculated for each record using the following trigonometric formula:-

$$\text{Wind Vector} = a * \text{COS}((b) * (\pi/180))$$

Where a = measured mean hourly wind speed,
b = measured mean hourly wind direction
$\pi/180$ = term used to convert value in radians to degrees

Wind vectors were then smoothed using a 5-point running mean to remove the high frequency signal for pictorial representation.

Currents

A RD Instruments upward-looking Acoustic Doppler Current Profiler (ADCP) Workhorse was used to measure current profiles at the harbour entrance (Figure 20). The current profiler had an operating frequency of 1200 kHz, utilising four upward looking beams, each with beam angles of 20 degrees with convex beam patterns and was set up to capture sixteen 1m depth bins. A blank after transmit of 1.76 m was used, with a distance of 2.82 m to the first data bin (the bin closest to the instrument). The instrument was set to ping every 5 seconds and accumulate 60 pings per ensemble, equivalent to a sampling interval of 5 minutes.

The current profiler was attached to a custom-made, 1m x 1m cross-shaped aluminium base plate for easy placement in the fine harbour sediment. Divers placed the ADCP on the seafloor of the harbour entrance, using two 50kg sand-bags as weighted supports on the plate. A 10m search line and weight was attached to one leg of the cross plate. The current meter was installed before a spring tide cycle at 1700 on 30/6/99 until 1000 on 1/7/99.

After recovery of the ACDP, data were downloaded to a PC using software provided by the manufacturer. Processed information was exported to a spreadsheet where the 16 bin fields of speed and direction were converted to vectors using the following function :

$$\text{Current Vector} = a * \text{COS}((b) * (\pi/180))$$

Where a = measured mean 10 minute current speed

b = measured mean 10 minute current direction

$\pi/180$ = term used to convert value in radian to degrees

The result from trigonometric functions such as the cosine used here, were in units of radians. They were converted to degrees by multiplying the result by $\pi/180$.

Means, maxima, minima and standard deviations were calculated for each bin over the sampling period.

Inner harbour current measurements

Currents were measured at the protected southeastern corners of the East Dockyard Basin and the Inner Basin of the Naval Harbour and under the Town Jetty in the Small Craft harbour (Figure 20) using Aanderaa RCM 7 current meters at 4 m, 6 m and 1.5m depths respectively. The raw data were extracted from the data storage unit of the instrument and calibration values were applied to produce data in engineering units. These text files were then imported into spreadsheets where vectors were calculated in the same way as described for the Acoustic Doppler Current Profiler. Current components were calculated using the north south axis as the primary axis. A 10- point running mean was used to filter the data to remove the high frequency instrument noise in the signal, weak currents were observed in Simon's Bay and a simple X-Y plot interpretation and reporting method was used to depict this (Figures 23-31).

Tides and Sea level

Tides and sea level were measured using the 'SEABIRD' CTD, supplied by UCT Oceanography Department. The CTD was attached to the anchor of the Annie-K, 6 m below the surface (Figure 20). The instrument was supported by a pair of sub-surface buoys with a gross positive buoyancy of 42 kg. Tidal records were processed from the pressure measurements taken with the other parameters every hour from 17/3 to 25/3/99. This dataset was used to determine the mean instrument depth (6.5932 m), used to calculate the corrected depth. Predicted tide heights were obtained from the SA Tide Tables for the period 17/3 to 25/3/99 and similarly corrected by determining the mean sea level (1.017 m) related to chart datum for the same period. Sea level deviations from these means were then calculated for the Annie-K and predicted tides and plotted using Microsoft excel. Residuals were calculated by subtracting the hourly predicted sea level as calculated from the tidal constituents (SA Navy Hydrographic Office) from the hourly measured sea level. These residuals were smoothed using a 24 point moving average, for pictorial purposes only.

Harbour Flushing

Two methods of flushing were used.

Tidal Flushing

Tidal Prism = Basin Area x Tidal Range
Flushing Time = (Total basin Volume / Tidal Prism) x Tidal Period
(pers. communication J Sharples Southampton Oceanography Centre)

The tidal range for Mean High Water Springs (MHWS) used was1.80 m for Simon's Town (SA Tide Tables 1999) and a mean Tidal Period of 12.213 hrs was calculated (South African Tide Tables 1997 – January 10 to February 7). Basin areas were measured using a Geographic Information System (Arcview) at The Institute for Maritime Technology.

Wind Driven Flushing

Wind driven flushing was calculated as follows:

Cross sectional area of the harbour entrance x the current speed

These were calculated for the two predominant current layers, 0-6 m and 7-18 m.

Simon's Bay Sea Watch 1

Simon's Bay Sea Watch 1 was a monitoring program established in 1999 in collaboration with UCT Oceanography department, IMT and the South African Navy to obtain hydrographic measurements and samples in Simon's Bay.

The objective was to collect samples and measurements in support of IMT and naval requirements to establish a water quality knowledge base. To develop an understanding of the oceanic and forcing processes which effect water quality in the area and to provide student training.

Water quality measurements and samples were collected between 15 March 1999 and 24 March 1999 (Table 2, 3 and 4). Simon's Bay port limits were chosen to demarcate the study area and further divided into the Harbour, Oceanic and Small Craft regions (Figure 21) on the basis of known and/or perceived usage.

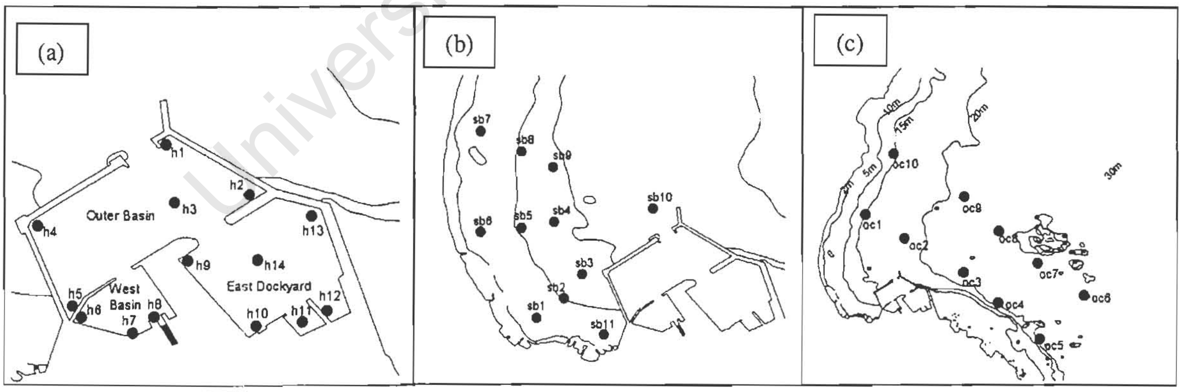


Figure 21 Map showing Simon's Bay Sea Watch 1, physico-chemical sampling sites and regions in Simon's Bay undertaken on three occasions each from 15 March 1999 to 23 March 1999 for regions (a) The Naval Harbour, (b) The Small Craft Harbour and (c) Oceanic. Lines offshore of the coastline denote depth contours.

A water analysis laboratory was set up at IMT and water samples were collected daily by various teams using a SA Naval craft (Namakura).

Region	Date	No. of Sites
Naval Harbour	15/3	14
Small Craft Harbour	16/3	10
Oceaic	17/3	4
Naval Harbour	18/3	14
Oceanic	19/3	10
Small Craft Harbour	20/3	11
No sampling	21/3	0
Oceanic	22/3	10
Naval Harbour	23/3	14
Small Craft Harbour	24/3	11

Table 2 Regions, dates and number of sites sampled during Simon's Bay Sea Watch 1

In addition, samples and measurements were taken every two hours from IMT's workboat (Annie-K) moored in the small craft mooring (Figure 20), which served as a moored sampling platform for the duration, during this period, dissolved oxygen, salinity and temperature were recorded at 1m intervals to the seabed using a Seabird CTDO (Conductivity, Temperature, Depth and Oxygen profiler). Water samples were obtained for nutrient and chlorophyll analyses every two hours from 9 am to 2 pm daily. Unfortunately, approximately 20 % of the samples collected from this source could not be analysed due to a sampling procedural error.

Two water samples were collected at each site, from the surface and seafloor. Time, equipment and personnel constraints only allowed for limited on-site analysis. The remaining samples were frozen and sent to the Phys/Chem laboratory of Marine and Coastal Management where they were analysed using a Technicon® auto-analyser.

Date	Time	Samples collected					
		Temperature, Salinity, Dissolved Oxygen Profile	PH	Secchi Depth	Floating Matter	Ammonium	Chlorophyll - a
			Top & Bottom	Column Max.	Regional	Top & Bottom	
15/3	12:06	✓	✓	✓	✓	✓	✓
	13:00	✓	✓	✓	✓	✓	✓
	14:00	✓	✓	✓	✓	✓	✓
16/3	10:20	✓	✓	✓	✓	✓	×
	11:15	✓	✓	✓	✓	✓	×
	12:15	✓	✓	✓	✓	✓	×
17/3	9:30	✓	✓	✓	✓	×	✓
	10:30	✓	✓	✓	✓	×	✓
	11:30	✓	✓	✓	✓	×	✓
	12:30	✓	✓	✓	✓	×	✓
	13:30	✓	✓	✓	✓	×	✓
18/3	10:40	✓	✓	✓	✓	✓	✓
	11:30	✓	✓	✓	✓	✓	✓
	12:30	✓	✓	✓	✓	✓	✓
	13:30	✓	✓	✓	✓	✓	✓
19/3	9:15	✓	✓	✓	✓	×	✓
	10:15	✓	✓	✓	✓	×	✓
	11:15	✓	✓	✓	✓	×	✓
	12:15	✓	✓	✓	✓	×	✓
	13:15	✓	✓	✓	✓	×	✓
20/3	9:00	✓	✓	✓	✓	✓	✓
	10:00	✓	✓	✓	✓	✓	✓
	11:00	✓	✓	✓	✓	✓	✓
	12:00	✓	✓	✓	✓	✓	✓
	13:00	✓	✓	✓	✓	✓	✓
21/3		×	×	×	×	×	×
22/3	10:15	✓	✓	✓	✓	✓	✓
	11:15	✓	✓	✓	✓	✓	✓
	12:05	✓	✓	✓	✓	✓	✓
	13:05	✓	✓	✓	✓	✓	✓
23/3	9:05	✓	✓	✓	✓	✓	✓
	10:00	✓	✓	✓	✓	✓	✓
	11:00	✓	✓	✓	✓	✓	✓
	12:00	✓	✓	✓	✓	✓	✓
	12:55	✓	✓	✓	✓	✓	✓

24/3	9:10	✓	✓	✓	✓	✓	✓
	10:10	✓	✓	✓	✓	✓	✓
	11:10	✓	✓	✓	✓	✓	✓
	12:10	✓	✓	✓	✓	✓	✓
	13:10	✓	✓	✓	✓	✓	✓

Table 3 Dates and times of constituents sampled showing Dates, times and samples collected / measurements taken on board the Annie-K from 15/3/99 to 24/3/99 during Simon's Bay Sea Watch 1. Tics represent samples collected and processed successfully while crosses represent samples not taken, or results discarded.

Water Quality Constituents

Samples collected during Simon's Bay Sea Watch 1 (Table 2, 3 and 4) were analysed and reported using units of μmoles/l or μg-atoms/l. These were compared with published values in the South African Water Quality Guidelines for Coastal Marine Waters (Department of Water Affairs and Forestry 1995). These values are quoted as μg/l in the guidelines and were converted to μmoles/l units by dividing guideline values by the respective atomic weight of the elements concerned eg. N in NH_4 as 14, P in PO_4 as 31 and Si in SiO_4 as 28.1. Values quoted by (de Chalain 1979) are in unit of μg-atoms/l.

Region	Date	No. of Stations	Constituents measured (top & bottom) and number of samples analysed							
			NH4	NO2	NO3	pH	Chl a	SiO4	PO4	Lab.
Naval Harbour	15/3	14		28	28			28	28	MCM
			28			28	28			IMT
Small Craft Harbour	16/3	10		20	20			20	20	MCM
			20			20	0			IMT
Oceanic	17/3	4		8	8			8	8	MCM
			8			8	8		8	IMT
Naval Harbour	18/3	14		28	28			28	28	MCM
			28			28	28		20	IMT
Oceanic	19/3	10		20	20			20	20	MCM
			20			20	19			IMT
Small Craft Harbour	20/3	11		22	22			22	22	MCM
			22			22	22			IMT
No sampling	21/3	0								
Oceanic	22/3	10		20	28			20	20	MCM
			-			20	20			IMT
Naval Harbour	23/3	14		28	20			28	28	MCM
			28			28	28			IMT
Small Craft Harbour	24/3	11		20	20			20	20	MCM
			22			21	22			IMT

Table 4 Dates, regions, number of stations sampled and number of samples processed for various seawater constituents. Lab column is the organisation where the laboratory processing was conducted. MCM=Marine & Coastal Management, IMT = Institute for Maritime Technology (PTY) Ltd.

Chlorophyll-a (Chl a)

Samples were analysed within a few hours of collection for Chlorophyll-a at IMT's laboratory by staff and students from UCT Department of Oceanography (Table 4). Eleven one litre samples were filtered through 25 mm, Whatman GFF filters. Chlorophyll was extracted from the Whatman GFF with 90% acetone. The absorption was then read with a spectrophotometer (UCT Oceanography) at 665 nm and 750 nm respectively (Parsons et al 1984).

pH

pH measurements were read directly from a Crison pH probe. Samples were all read at the IMT laboratory (Table 4).

Physico-chemical measurements

In addition to the collection of seawater samples during Simon's Bay Sea Watch 1 from 15-25 March 1999, at the stations shown in figure 21, a SEABIRD Conductivity Temperature Depth Oxygen and Turbidity Profiler (CTDO), was used to sample the physico-chemical properties. Raw data were converted to scientific units, filtered and averaged into 1m bins using standard manufacture's software provided with the instrument. Data were plotted as vertical profiles for each station. The surface 2 m layer (2 readings in each case) was extracted for all stations by region for the three respective sampling days, using a spreadsheet. Means, maxima, minima, standard deviations and ranges for these data were plotted and presented in table form (Table 7)

Eighty-four stations were sampled over a sequential period of 9 days (excluding 21/3/99) from three regions(Figure 21 and Table 4). The regions were chosen for their unique localities with respect to the surrounding coastline and usage. The Naval Harbour includes the West Basin, inner East Dockyard and the Outer Basin, which leads to the open waters of False Bay. The definition of "Naval Harbour" in this study excludes the oldest part of the SA Navy's water frontage, i.e., the parade ground, slipway, The Camber, the Admirals beach and the Admiral's jetty. These areas are instead geographically grouped with the Small Craft Harbour.

Sediments

Sediment sampling presented here did not comprise a formal part of the Simon's Bay Sea Watch 1, however, historic data sourced from the SA Navy is relevant in describing a potential pollution problem.

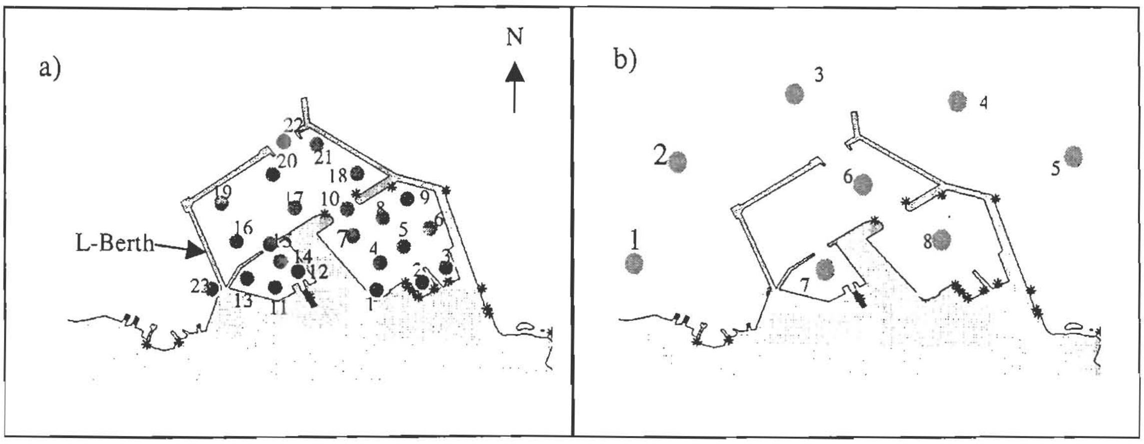


Figure 22 SA Navy sediment sampling sites undertaken in the vicinity of the Naval Harbour, a) 1991 and b) sampling date unknown. Asterics indicate stormwater outflow sites.

Twenty two sediment cores (site numbers 1- 22) were collected during 1991within the confines of the Naval Harbour by SA Navy divers (Figure 22a). A separate site (site number 23) was sampled outside the harbour at the southern extent of L-Berth (Figure 22a). Another eight sites were also sampled on two other occasions, 11 May 97 and 28 February 98 (Figure 22b). Samples were analysed for Iron, Copper, Lead and Zinc at the Materials Laboratory of the South African Navy (Garrard 1991).

It is uncertain what priority was used in the choice of heavy metals sampled. Equipment details of the cores used to collect the samples were not available. The choice of selected sites appears to have been based on determining a synoptic 'snap-shot' of the harbour while also sampling near potential pollution sources eg. the drydock. The date of collection could not be determined. Results were presented as an internal SA Navy report.
Sediment cores were again collected by SA Navy divers in the harbour and surrounding greater Simon's Bay by SA Navy divers under the guidance of Mr Alistair Busby of Environmental Survey Laboratories CC during October 1996, 8 May 1997, 11 November 1997 and 23 February 1998 on request by Lt K Dearlove, South African Navy Environmental Officer.

Mussel Watch

The results of mussel sampling presented here did not comprise a formal part of the data collection phase of Simon's Bay Sea Watch 1, however, historic data sourced from the Marine and Coastal Management are also relevant to this study in describing a potential pollution problem and establishing baseline conditions.

Amongst the sampling sites monitored bi-annually (October and May) mostly in the False Bay Region, four were within Simon's Bay (Figure 17). These were Glencairn, Marine Oil (Mackerel Bay), Simon's Town Naval Harbour entrance and Boulders (Figure 17). Data from Olifantsbos (Figure 60), outside False Bay were chosen as a control site. A minimum of 50 individual mussels of the same species and length (50 mm) are collected in close proximity at spring low tide.

Results presented here are spreadsheet plots and statistical summaries.

Heavy metal concentrations from the mussel watch programme were compared with those allowed by the South African Bureau of Standards (SABS) for human consumption of similar seafood. Levels quoted for wet mass were (units are PPM or μg/g):- Copper 50.0 (wet mass), 250.0 (dry mass), Mercury 1.0 (wet mass), 5.0(dry mass), Cadmium 3.0 (wet mass,15.0 (dry mass), Arsenic 3.0 (wet mass), 15.0 (dry mass), Lead 4.0(wet mass), 20.0 (dry mass), Zinc 300 (wet mass), 1500 (dry mass) and Tin 40 (wet mass), 200 (dry mass) (Foodstuffs, cosmetics and disinfectants Act, 1972, Government Notice R1518 of 1994). The mussels sampled in the Mussel Watch programme were analysed for **dry mass.** Therefore the SABS regulations are quoted as **wet mass** figures. Dry mass figures were increased by a factor of 5 for suitable comparison purposes between dry and wet mass. This factor provided for the fact that soft animal tissue consists of 80% water and is therefore concentrated during the drying pocess (pers. Comm. S Taljaard, CSIR referred to work by Brown 1996).

Chapter 3 Results

Currents

Although water constituents were measured in all harbour basins, suitable current meter mooring sites (that would not disrupt shipping) could only be found under protruding structures in the East Dockyard basin and the West Basin (Figure 20). The failure of the current meter compass in the East Dockyard current meter resulted in limited data. Limited discussions of the currents in the East Dockyard Basin and the Outer Basin are presented. It is suggested that the similar orientation, layout, water properties and water source in the three basins, implies that the currents exhibit similar features.

West Basin

The magnitude range and variability of the Aanderaa Recording Current Meter (RCM7) results are listed in Table 5. Current speeds measured for the duration of 16 March 99 to 3 May 99 revealed a current speed of 2.0 cm/sec for 551 of the 1149 hourly observations taken, equating to 48% of the observations. The normal distribution shows that no values were recorded in the lower 1.1 cm/sec. Calm current conditions were never observed (Figure 26).

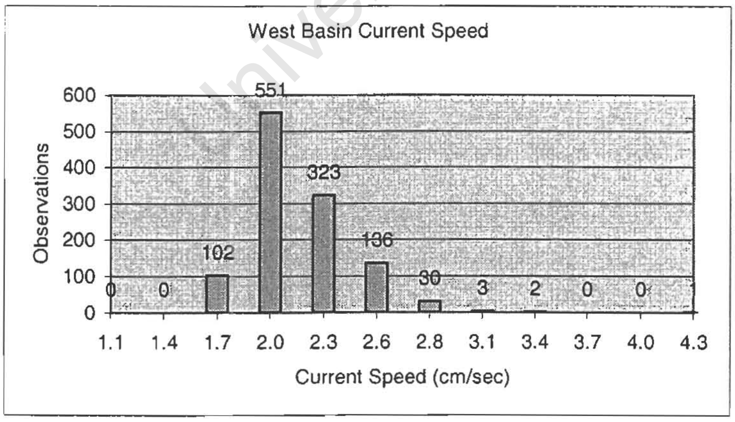


Figure 23 Histogram of current speed in the West Basin of the Naval Harbour

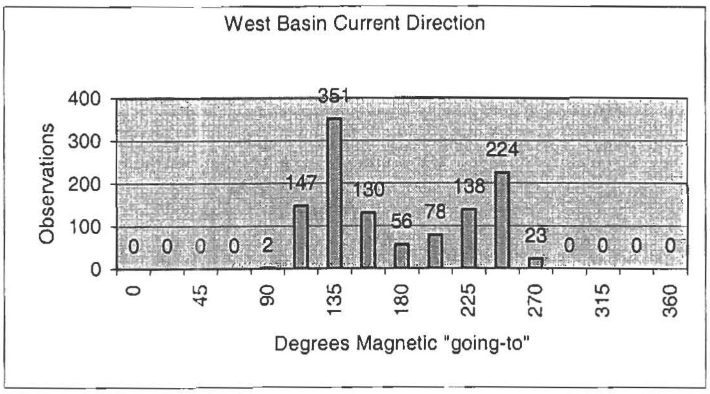


Figure 24 Current direction in the Inner Basin of the Naval Harbour

The plot (Figure 24) of current direction shows a bi-modal distribution with no observations in the northern sector.

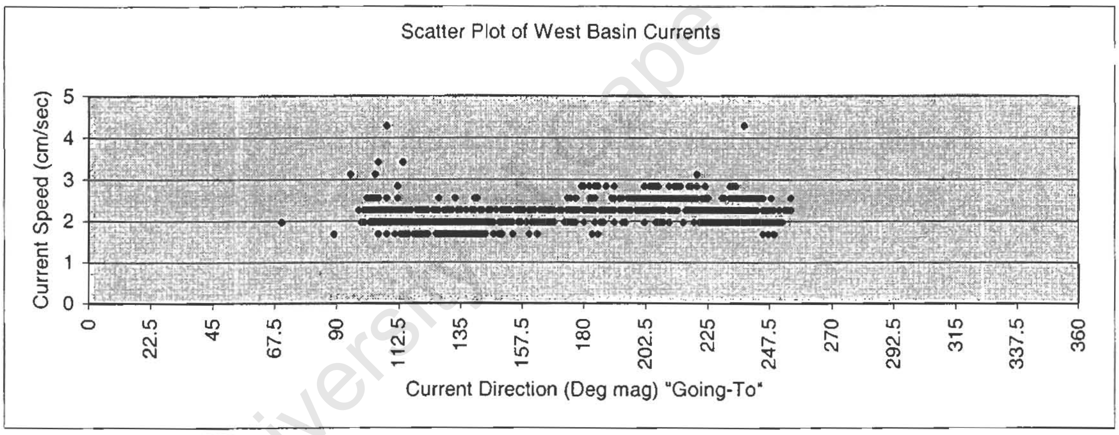


Figure 25 Scatter plot of current speed vs direction in the West Basin of the Naval Harbour

From the scatter plot of Current Speed VS Direction (Figure 25) for the full measurement period, points appear in a speed band of 1.7 to 4.3 cm/sec, with directions measured from 100 to about 250 degrees.

From the time series plot (Figure 30) of the north-south current components for the inner basin, “significant” current peaks occurred on 8 occasions. These peaks are defined here as component values that exhibit increases of more than 1.5 cm/sec over a 12-hour period.

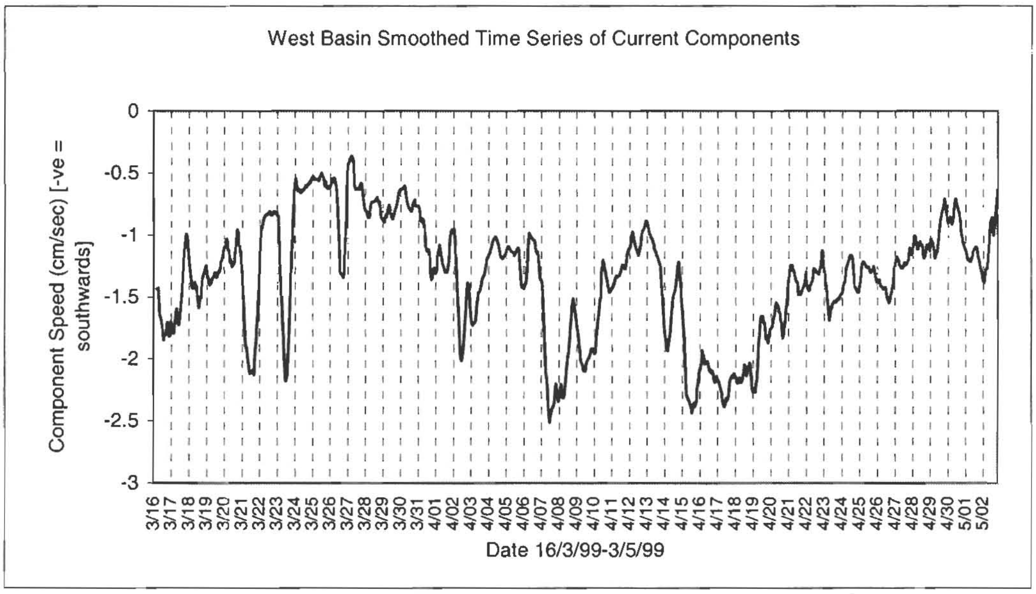


Figure 26 Smoothed time series current components for the West Basin of the Naval Harbour

East Dockyard

The compass in the Aanderaa Recording Current Meter (RCM7) used in the East Dockyard unfortunately failed and therefore no reliable directional information was available. The current speeds recorded were however reliable and a presented in Figure 27.

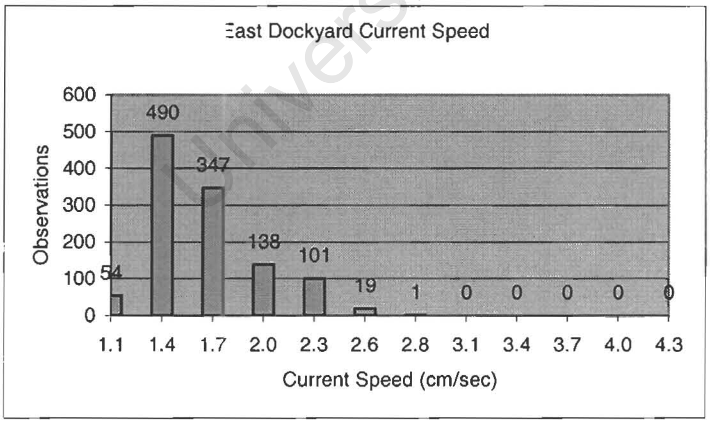


Figure 27 East Dockyard current speeds in the Naval Harbour

Current speeds measured for the duration of 16 March 99 to 3 May 99 revealed a median current speed of 1.4 cm/sec for 604 of the 1150 hourly observations taken, equating to 53% of the observations. The skewed normal distribution shows that 54 of the 1150 hourly samples taken recorded 1.1 cm/sec (relating to zero) or calm conditions for 5% of the measurement period.

Town Jetty

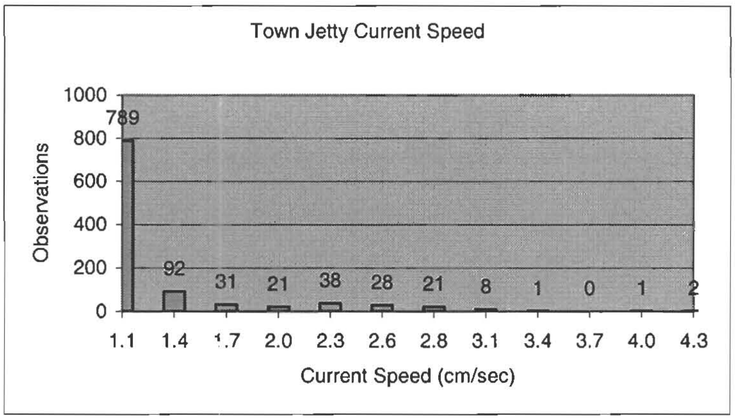


Figure 28 Histogram of current speed at the Town Jetty in the Small Craft Harbour

Current speeds measured for the duration of 16 March 99 to 3 May 99 revealed an anomaly high proportion (788 of 1032) of observations in the 1.1 cm/sec bin range (see Figure 30). This is below the threshold speed of the instrument and therefore appears to indicate predominantly calm conditions.

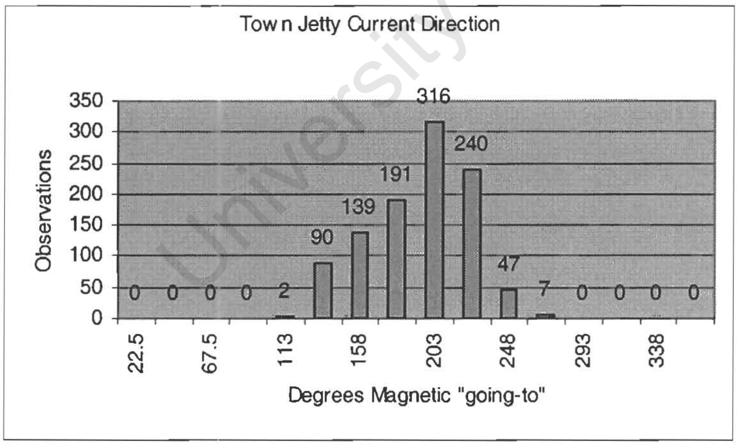


Figure 29 Histogram of current directions at the Town Jetty in the Small Craft Harbour.

The measurement site under the Town Jetty was prone to drifting seaweed and it is possible that the current meter rotor became fouled. This would have resulted in low or zero (recorded as 1.1 cm/sec i.e. threshold speed) current speed values. Such fouling was found to have occurred when the current meter was recovered at the end of the measurement period.

From the scatter-plot (Figure 30), 12 readings greater than 3 cm/sec occurred in the 180-270 degree sector, while current speeds in the other sectors were all below 3 cm/sec.

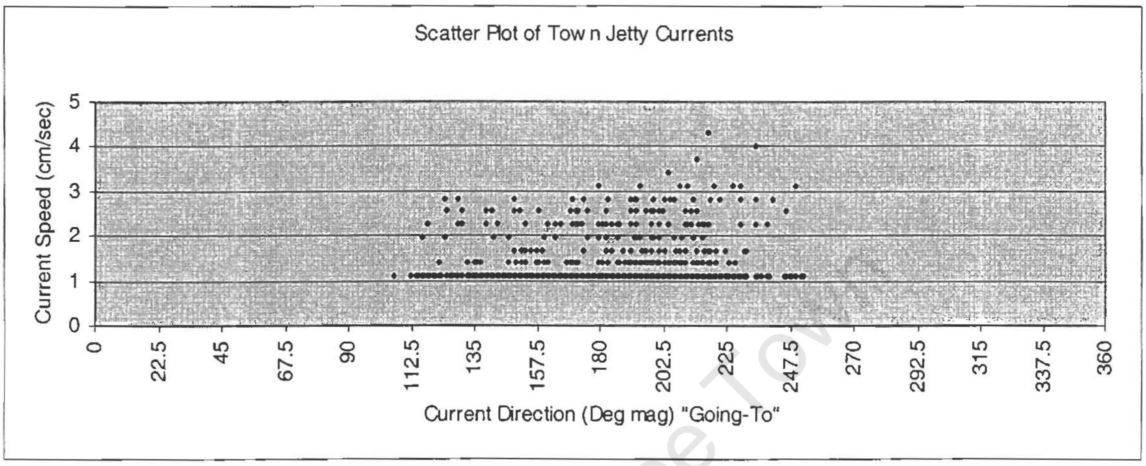


Figure 30 Scatter plot of current speed vs current direction at the Town Jetty

As with the West Basin (Figure 26), the current component time series for the Town Jetty meter (Figure 31) shows that the current exhibited negative values (towards the south) for the entire sampling interval with 8 "significant" peaks.

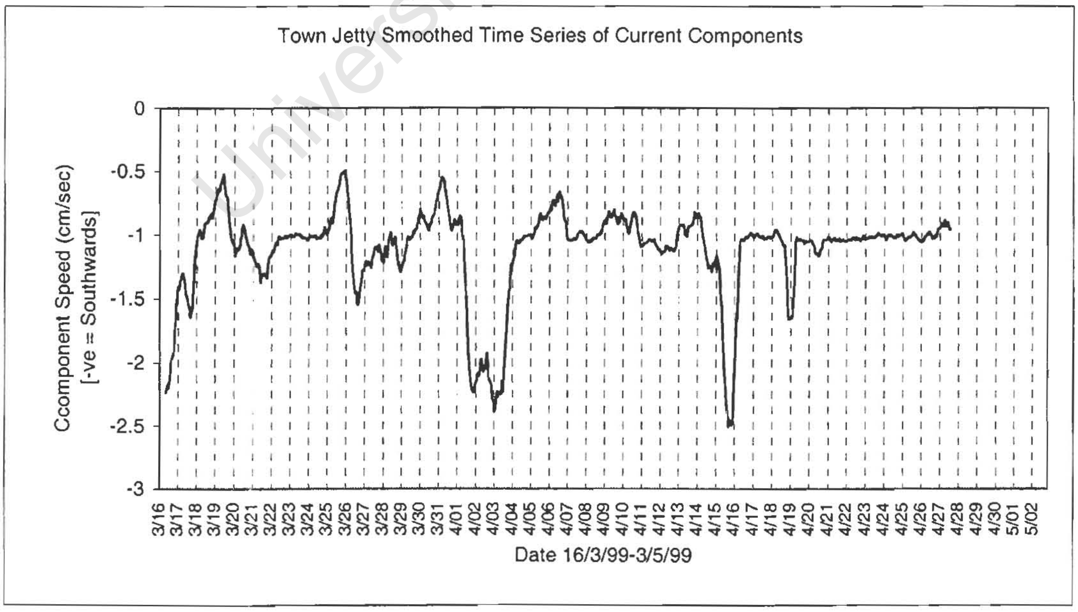


Figure 31 Smoothed time series current components at the Town Jetty

Wind and Current comparison

Tides can often be the most dominant flow forcing mechanism in enbayments and shallow coastal zones, resulting in an approximate 6 hourly predictable ebb and flood tidal stream, which are enhanced during neap and spring tides (Beer 1983). In the harbour confines of Simon's Bay, the tidal signal in the current speeds at the three sites measured are clearly evident and are especially evident during wind free conditions (Figure 32). This can usually be seen by the sinusoidal 6 hourly current reversals in a time series plot, however the plot representing un-smoothed current components from the 18-20 March in the Inner Basin and Annie-K record and from 20-21 March at Town Jetty (Figure 32), do not indicate the existence of tidal currents.

However tides are not the only forcing mechanism. Flow usually consists of an interaction of physical variables and this was found to be the case in Simon's Bay. A more significant force is responsible for prolonged (more than 6 hours) current reversals with higher velocities. The intermittent southerly component pulsing (lasting 1-2 days) of the south-easterly wind can be seen on two occasions in Figure 32b on the 21-22 March and 23-24 March. On both occasions, the West Basin currents reacted to these pulses and stronger SSW to SW (South South West to South West) currents were setup (Figure 32b). The resulting force of the wind on the surface, resulted in currents that were stronger than the tidal currents so that the tidal signal was not detected as a discrete flow in the Inner Basin during these pulses. The high frequency signal can be attributed to the instrument noise.

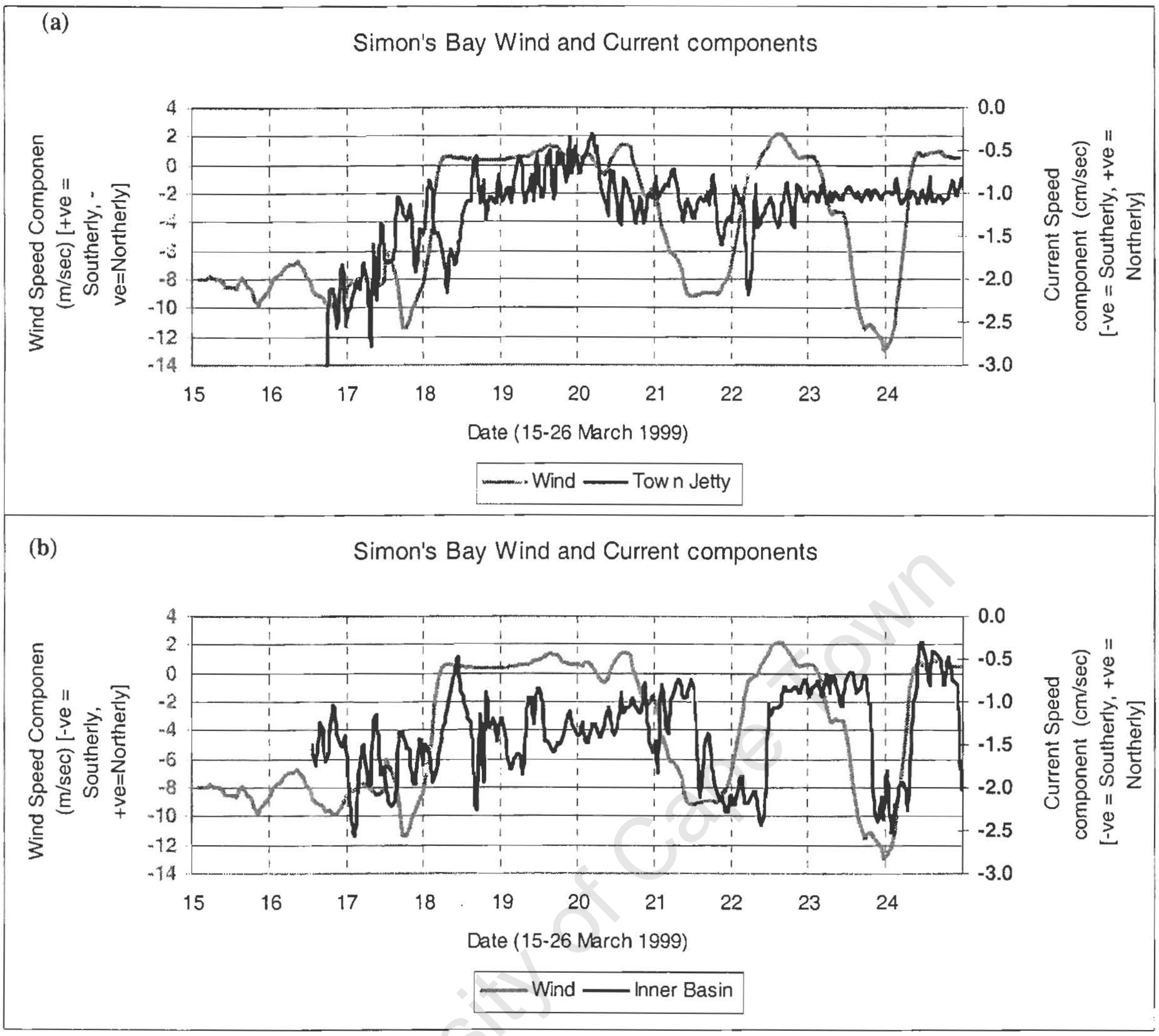


Figure 32 Comparison time series plot showing wind and current components measured in Simon's Bay for (a) The Town Jetty and (b) West Basin

At the Town Jetty however, the tidal current signal was superimposed on the wind event current pulse for the period 21-23 March (Figure 32a). A lag in the current reversal of 12 hours existed at the leading edge (at the start of the pulse) and 0-6 hours at the trailing edge. From this short record, a longer duration of the wind pulse (21-22 March) resulted in an increased wind driven setup current. The lag of the current reversal was longer (4-6 hours) during that event than the weaker second event on 23-24 March (Figure 32b). The same symptomatic reaction existed in the Town Jetty current, however the strength of the current event cannot be accurately determined due to the fouling of the rotor (Figure 32a).

Current reversals in both the Town Jetty and West Basin records (Figure 32) were noticed at the beginning of the record (15-18 March) during the first strong south-easterly wind event. The duration of this event was however longer (at least 4 days) than the later events, confirming that both duration and strength of the wind are required to affect these currents (Figure 32). The nature of this first event in the record could be indicative of the trailing edge of a lower frequency Coastal Trapped Wave. This would explain the early reversal of both the Town Jetty and Inner Basin before the wind reversal 17-18 March (Figure 32). The dynamics were instead driven by a basin-scale feature that acted in response to remote meteorological forcing.

The moderate flattening out of the signal in the Town Jetty plot from 23-25 March (Figure 32a) can probably be attributed to fouling of the current meter rotor by loose floating seaweed commonly found in the area. This factor may also have been responsible for reducing the speeds seen overall at that site and masking other events.

Harbour flushing

The entire Naval Harbour contains approximately $3400x10^3$ klitres, made up of the inner basin which holds approximately $300x10^3$ klitres, east dockyard $1000x10^3$ klitres and the Outer basin harbour $2100x10^3$ klitres. The cross sectional area of the harbour entrance was calculated to be 1560 m^2 by using depths referenced to chart datum, and taking the harbour mouth profile into account.

The Tidal prism method

These flushing times may be longer due to incomplete mixing of the harbour water. Water near the far end of the small basins does not reach the harbour entrance during the ebb. In addition, some of the water that leaves the harbour during an ebb tide, returns on the following flood. Results given here are means for the full tidal cycle, however since tidal flow typically peaks 3-6 hours before and after each tidal peak, flushing can occur at a variable rate. The mean period of 12.213 hrs (South African Tide Tables 1997 – January 10 to February 7) was calculated for Simon's Bay and the Mean High Water Springs (MHWS) was 1.8 m (South African Tide Tables 1997).

Basin	Area (m^3)	Total Basin Volume (m^3)	Tidal Prism (Area x MHWS)	Tidal Period (SA Tide Tables)	Flushing-Time (Tot Vol/Tidal Prism) x Tidal Period
Inner	37908	334515	68234	12.213	60 hrs
Outer	174502	2223968	31410		864 hrs
East Dockyard	135508	1139847	243914		57 hrs
East/Outer throughflow	4443	42870	7997		65 hrs
Harbour Total	**352361**	**3741200**	**634249**		**72 hrs**

Table 5 Basin and Total Harbour Volumes (m^3)

By using the tidal Prism method, a Flushing Time for the Naval Harbour of 72 hrs was calculated (Table 5).

Wind Driven flushing

From Table 6, harbour currents at the harbour entrance over the spring tide cycle on 30/6/99-1/7/99 indicated a current shear at 6 m below the surface. With a mean northerly current from 7 m to the seafloor of 4.3 cm/sec and a mean southerly current speed of 9 cm/sec in the surface layer above 6 m. This surface flow increased exponentially from 6 m to the surface. The current meter is unable to sample the 0-1m surface layer due its acoustic beam charateristics. This may be the fastest layer. Its exclusion would lead to an underestimate in flushing time.

Depth Bin (m below the surface)	Mean Current (cm/sec)
2	-193.3
3	-120.0
4	-12.4
5	-4.7
6	-2.9
7	-0.4
8	0.0
9	-0.1
10	0.2
11	1.7
12	2.5
13	3.8
14	5.9
15	8.6
16	9.6
17	6.3

Table 6 ADCP 5 minute averaged current meter vector component results in the harbour entrance recorded for the spring tide period 1700 on 30/6/99 to 1000 on 1/7/99 during a severe North Westerly storm. Negative values represent flooding southerly currents, positive values represent ebbing northerly currents.

When using the cross sectional area of the harbour entrance, the surface (1-6 m in this case) volume flow equated to 50 m^3/sec southerly flow and was in volumetric equilibrium with the lower (7-18 m in this case), northerly flow. By using volumetric figures for the lower layer at the entrance (Table 6) and applying the speed to the cross sectional area of that layer, the total harbour volume (3741200 m^3) flushed within 20.7 hours, considerably quicker than the tidal flushing.

Sea level

Sea level was measured at the Annie-K site (Figure 20) during the case study from 17/3-24/3/99.

New moon occurred on 17/3/99, while neap tide occurred at 0416 on 19/3 (SA Tide Tables). Neap tide occurred as predicted, with the same tidal ranges. This was preceded by non-tidal sea level perturbations on the 17/3 (see Figure 33 & 34), when at high tide, the measured sea level was 38 cm lower than the predicted tidal peak, followed by a higher (30 cm) than predicted low tide. The vertical tidal movement was depressed for that tidal cycle. It is unfortunate that measurements are not available for the preceding cycles. After the occurrence of the neap high tide, anomolous sea levels were recorded, as steadily increasing sea level above the predicted sea level for more than 48 hours (see 24 point moving average) in Figure 34. Later in the record, sea levels were once again surpressed, inititially starting at PM on the 21/3, with a brief respite at AM on 23/3, immediately followed by a continued sea level surpression of approximately 10 cm.

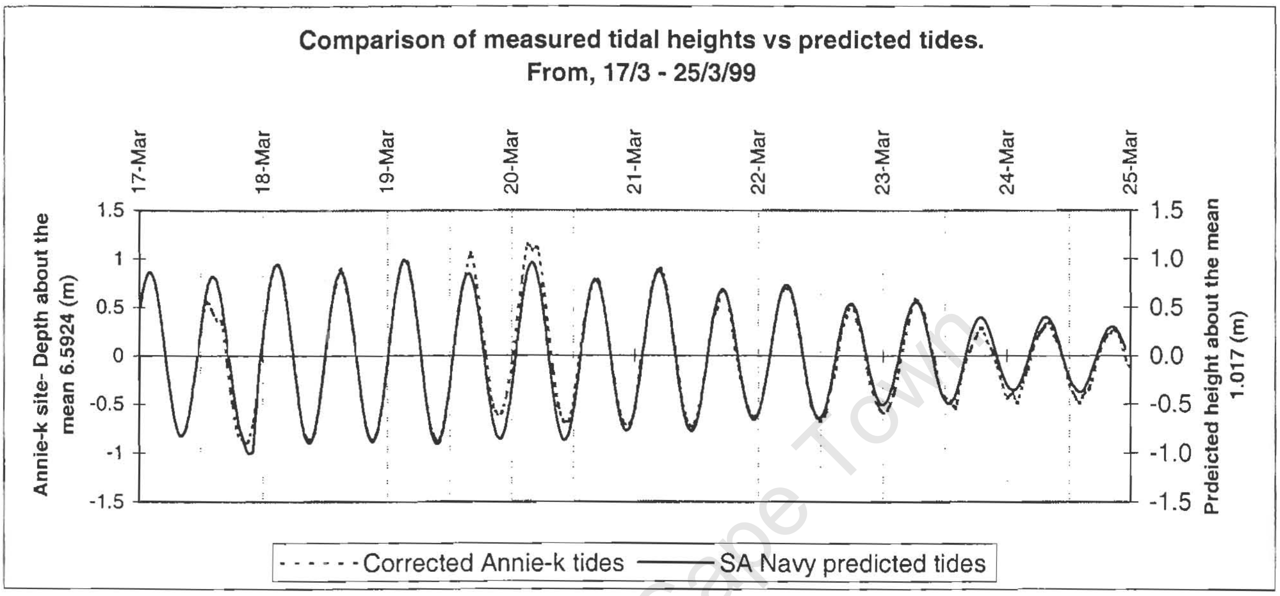


Figure 33 Sea level measured at the Annie-K site from 17/3 to 25/3/99.

On the 17/3, a tidal perturbation measuring 30 cm lower than the predicted high water and 38 cm higher than low water occurred, within a single tidal cycle (see figure 34). This can be seen as a single spike and trough in the beginning of the plot, with values that were about 3 times greater (0.60 m peak to trough) than similar high frequency changes measured throughout the remainder of the record, typically 0.1 to 0.2 m peak to trough. This 'event' occurred within a single tidal cycle, as a brief anomaly early in the data set.

Another, more persistent perturbation occurred on the 20/3, when the sea level was raised 0.05 m to 0.3 m above the measured mean of 6.5035 m for about 24 hours (Figure 33 and 34), peaking just after midnight on 20/3. This was followed by sea level lowering of 40 cm (from +30 to –10) over the following 3 days (Figure 34).

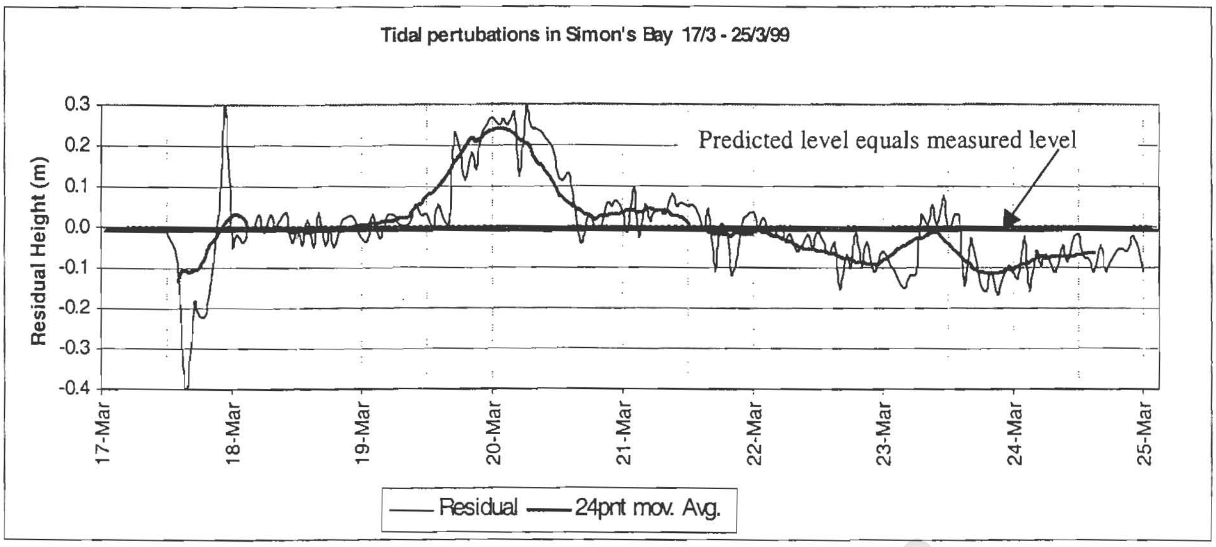


Figure 34 Tidal residuals in Simon's Bay 17/3 – 25/3/99. Residual represents the mean measured difference between the recorded sea level minus the predicted sea level, worked back to the absolute mean of the level recorded at the Annie-K. This mean "datum" was calculated to be 6.5924m.

Physico-chemical Properties

2m Surface Layer

	Naval Harbour	Small Craft Harbour	Oceanic
Temperature °C			
Mean	15.6	14.7	14.4
Maximum	18.3	16.3	15.7
Minimum	13.7	12.8	12.4
Standard Deviation	1.5	1.1	1.0
Range	4.6	3.5	3.3
Observations	84	64	48
Dissolved Oxygen mg/l			
Mean	7.0	6.9	8.2
Maximum	10.3	8.9	9.9
Minimum	5.4	4.7	6.5
Standard Deviation	1.1	1.2	1.1
Range	4.9	4.3	3.4
Observations	78	61	48
Oxygen Saturation %			
Mean	86	85	99
Maximum	120	110	122
Minimum	65	55	76
Standard Deviation	13	16	15
Range	55	55	47
Observations	78	61	48
Salinity (Practical Salinity Units)			
Mean	34.80	34.79	34.76
Maximum	35.06	34.96	34.92
Minimum	34.62	34.63	34.56
Standard Deviation	0.09	0.07	0.07
Range	0.45	0.32	0.37
Observations	84	64	48

Table 7 Surface 2m layer values (i.e.1 m and 2 m readings) from the CTD measurements taken in the Oceanic, Naval Harbour and Small Craft Harbour from 15 – 23 March 1999. Values are means for the physico-chemical properties in each region.

Temperature means, ranges, standard deviations, maxima and minima in the upper 2 m layer in the Naval Harbour were found to be higher than those in the Small Craft and Oceanic region (Table 7). The mean value recorded for the harbour was 15.6 °C, while values of 14.7 °C and 14.4 °C were measured for the Small Craft Harbour and Oceanic regions respectively (Table 7).

Mean dissolved oxygen and oxygen saturation values for the Naval Harbour and the Small Craft Harbour are similar, 7.0 mg/l (86 %) and 6.9 mg/l (85 %) respectively (Table 7). These were somewhat lower than the Oceanic region, where 8.2 mg/l (99%) was measured. Both minimum and maximum values were also highest in the Oceanic region, with the lowest range of values. The standard deviations for dissolved oxygen and saturation appeared similar for all regions (Table 7).

No significant salinity differences were found when comparing the regions. Mean values of 34.80, 34.79 and 34.60 were measured for the Naval Harbour, Small Craft Harbour and Oceanic regions respectively. This uniformity was noticed in the standard deviations, maximima and minima. No natural fresh water source occurs in the Naval Harbour (Table 7).

All basins and therefore the entire Naval Harbour experienced a lowering of temperatures between day one and day two, throughout the water column (Table 8). Temperature decreases were 2.7 °C for the Outer Harbour, 3.8 °C for the West Basin, 3.1 °C for the East Dockyard and 3.2 °C for the Naval Harbour (Table 8). Warming occurred between day two and day three for all basins, although less intense than the previous cooling. Temperature increases were 1.6 °C for the Outer Harbour, 1.1 °C for the West Basin, 1.0 °C for the East Dockyard and 1.2 °C for the Naval Harbour. Mean temperatures over the three measurement days were marginally higher in the West Basin (0.4 °C) than the other two basins. A mean of 15.2 °C was recorded for the three measurement days for the entire Naval Harbour. The Outer Basin and East Dockyard basin recorded identical temperature means (15.1 °C) while the West Basin mean temperature was 15.5 °C (Table 8).

Water Column

	Temperature ° C	Oxygen Saturation %	Dissolved Oxygen mg/l	Salinty PSU
Outer Basin				
Day1	16.4	82	6.5	34.85
Day2	13.7	79	6.6	34.75
Day3	15.2	77	6.2	34.78
Mean	15.1	79	6.4	34.79
West Basin				
Day1	17.6	82	6.3	34.88
Day2	13.9	75	6.2	34.76
Day3	15.0	71	5.7	34.76
Mean	15.5	76	6.1	34.80
East Dockyard Basin				
Day1	16.8	82	6.4	34.85
Day2	13.7	75	6.3	34.75
Day3	14.7	93	7.7	34.77
Mean	15.1	84	6.8	34.79
Entire Naval Harbour				
Day1	16.9	82	6.4	34.86
Day2	13.7	72	7.1	34.75
Day3	15.0	80	6.6	34.77
Mean	15.2	78	6.7	34.79

Table 8 Mean daily profiles of temperature, oxygen and salinty for the three basins within the Naval Harbour and the entire Naval Harbour. From 3 surveys conducted between 15-23 March 1999, sampled from identical sites on each occasion.

Mean dissolved oxygen was 6.4, 6.1, 6.8 and 6.7 mg/l for the Outer basin, West Basin, East Dockyard and entire Naval Harbour respectivly. The dissolved oxygen concentration of the water was highest in the East Dockyard and lowest in the West Basin (Table 8) and the percentage saturation was lowest in the West Basin (71 %) and highest in the East Dockyard (84 %). The West Basin mean saturation (76 %) was less than the than the Outer Basin (79 %), which was less than the East Dockyard (84 %). The mean for the Naval harbour was 78 % for the full sampling period (Table 8). Highest oxygen saturation for all basins for all occassions was recorded in the East Dockyard (93%) on day 3.

Salinity means for all basins and for the Naval Harbour were marginally different with a data range of 0.11 (Table 8). All basins followed a similar trend; a decrease in salinity from day 1 to day 2 followed, by an increase from day 2 to day 3. Salinity means for all three days were 34.79 for the Outer Basin, 34.80 for the West Basin, 34.79 for East Dockyard and 34.79 for the entire Naval Harbour (Table 8).

West Basin

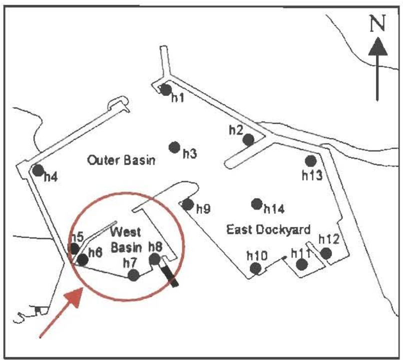
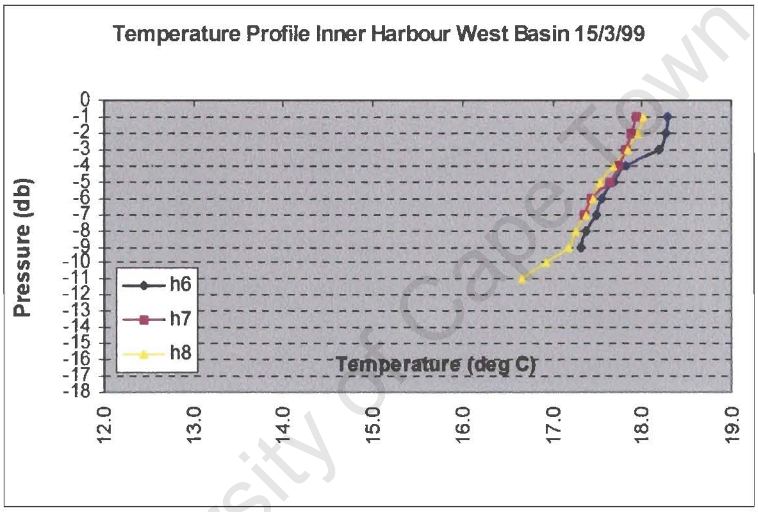
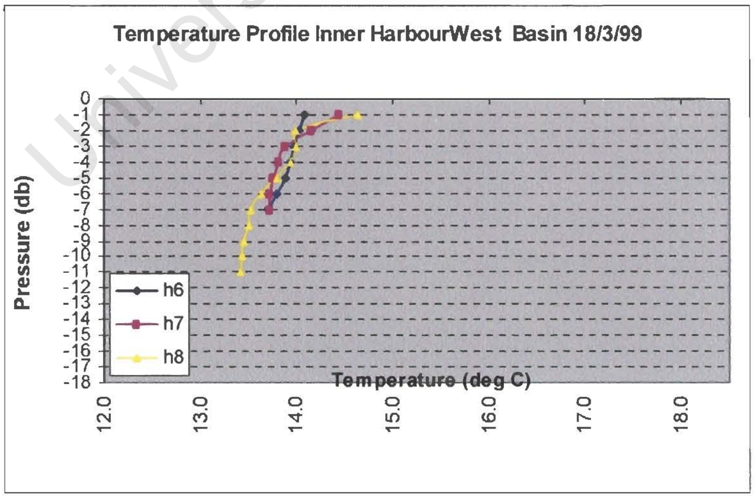


Figure 35 Map showing sampled stations in the Naval Harbour. West Basin stations are h6, h7 and h8 (encircled)





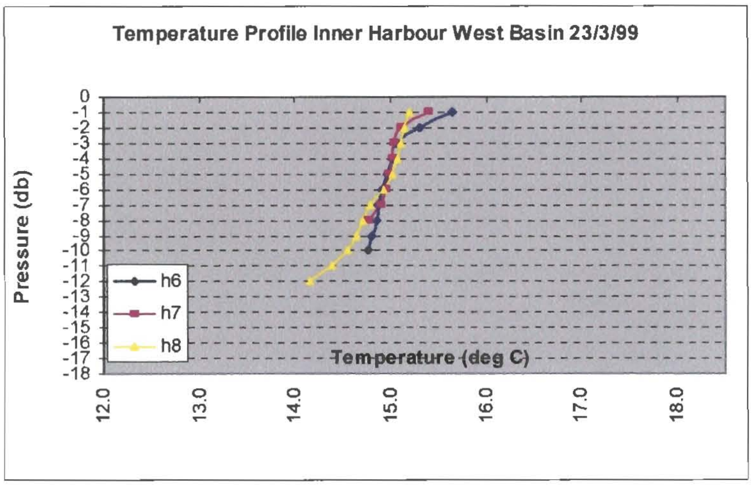


Figure 36 Temperature depth profiles for all West Basin stations during Simon's Bay Sea Watch

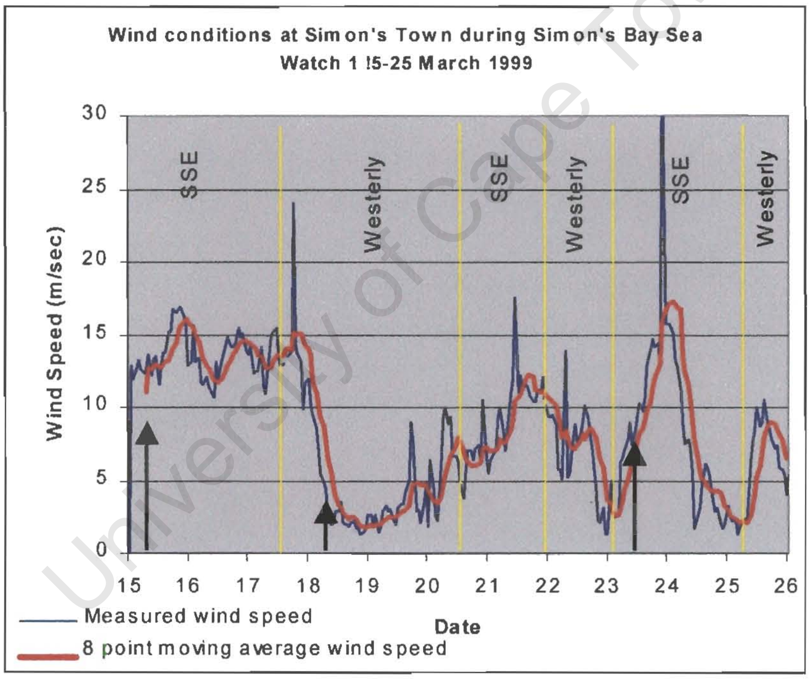


Figure 37 Wind measurements recorded at Simon's Town during Simon's Bay Sea Watch 1 (15-25 March 1999). Arrows indicate CTD station sampling times for the West Basin.

Spatial variation in the thermal structure of the water column was evident and in this respect, it is important to compare the temperature profiles with the wind data (Figure 37). Even within this small basin, a west-east thermocline slope was setup during windy conditions. No spatial variation in the temperature profiles was noticed below the thermocline. However in the wind mixed layer above the thermocline, well mixed surface water was found on the windward shore, while distinctive thermoclines existed on the lea shore of the basin.

East Dockyard

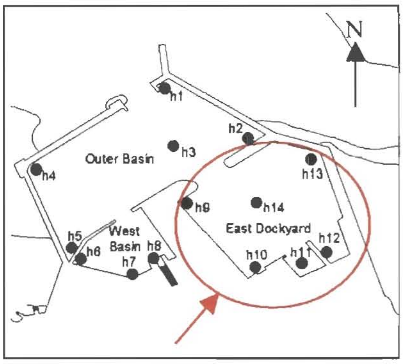
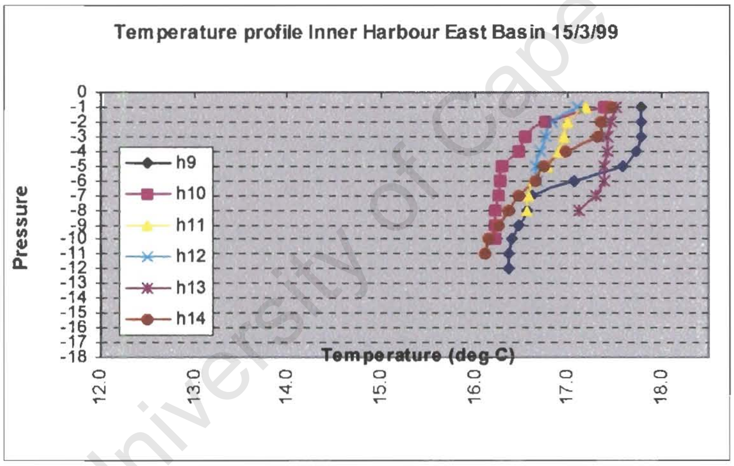
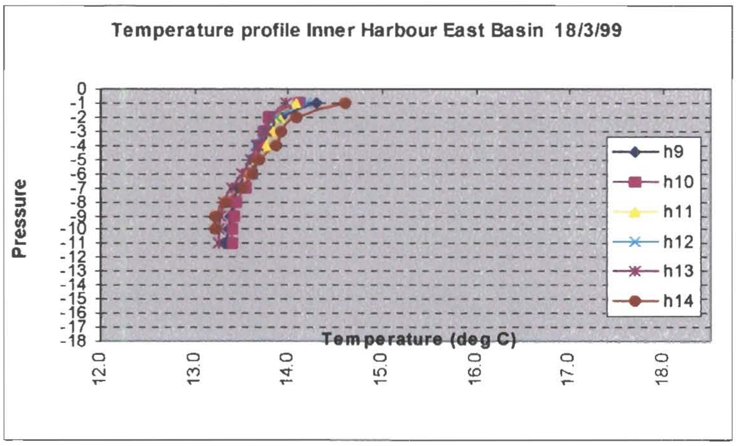


Figure 38 Map showing sampled stations in the Naval Harbour. East Basin (referred to as East Dockyard in the figure). Stations are numbered h9, h10, h11,h12, h13 and h14 (encircled).





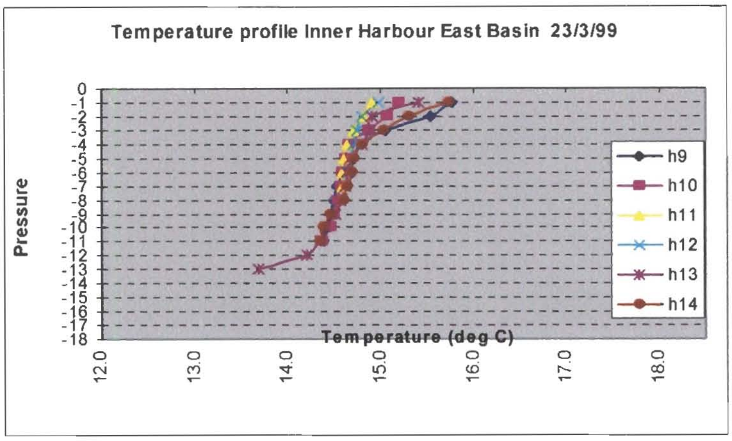


Figure 39 Temperature depth profiles for all East Dockyard stations during Simon's Bay Sea Watch 1

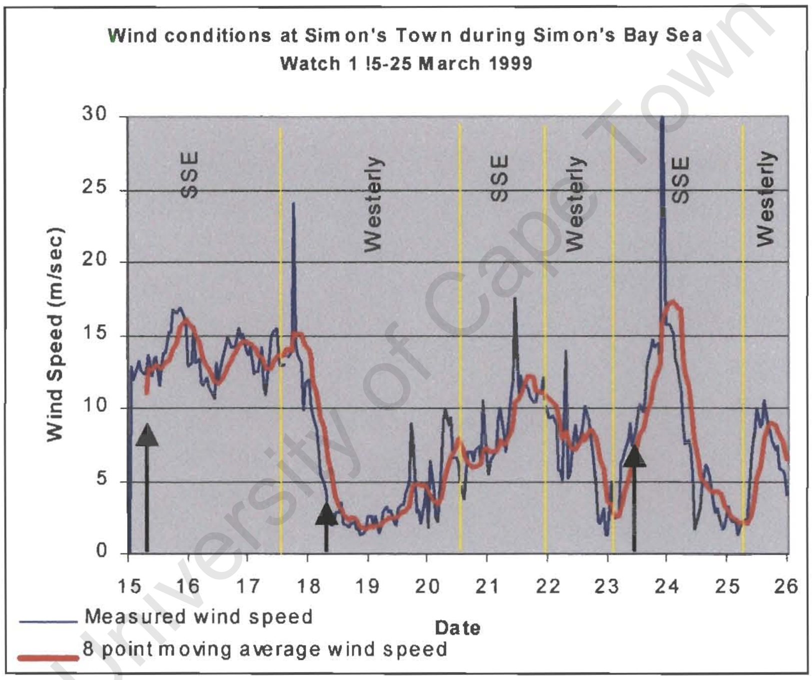


Figure 40 Wind measurements recorded at Simon's Town during Simon's Bay Sea Watch 1 (15-25 March 1999). Arrows indicate CTD station sampling times for the East Dockyard basin.

In a similar way that across-basin temperature structure was seen in the west Basin on the 15/3, a varying temperature structure was evident in the East Dockyard Basin on the same day. However in this basin the intra-basin differences were more striking. At the western end of the basin, during strong South South Easterly (SSE) winds the well- mixed warmer surface water became entrapped at station h9 (Figure 38 & 39, 15/3). A thermocline was noticed at 5-7 m below the surface. Below 7 m, the profiles were uniformly cooler and well mixed, indicating that the deeper parts of the basin exhibited similar water properties, with no noticeable entrapment, during all 3 surveys on the 15,18 and 23/3/99. The most striking feature in this basin was the approximate east-west thermocline gradient. At station h9, in the western windward shore of the basin, the thermocline depth was at 6 m, as warm surface water piled up and became mixed (Figure 39). However at station h12, a much weaker thermocline existed 1 m below the surface. This cross-basin thermocline structure appeared to be setup by local winds, creating a density differential, which would have resulted in increased cross-basin flow.

The wind speed was decreasing on the 18/3 (Figure 40), and spatially coherent temperature profiles were being re-established across the basin and the onset of the next cycle of surface heating had started. This can be seen as a weak, shallow thermocline throughout. Temperatures at all stations were lower from advection of colder water that occurred between 15-18/3 (Figure 38,39 and 56a).

Sampling on the 23/3 occurred just prior to the onset of another SSE. Even at that time, with prevailing winds of 5 m/sec, across-basin thermal surface structure had started to appear with inter-station variability below 4 m. A weaker thermal difference and structure was noticed compared with the samples collected on the 15/3 (Figure 39)

In summary, the East Dockyard Basin displayed noticeable cross-basin thermal variability during SSE winds. This variability was positively related to wind speed, and especially evident at winds greater than 10 m/sec.

Outer Basin

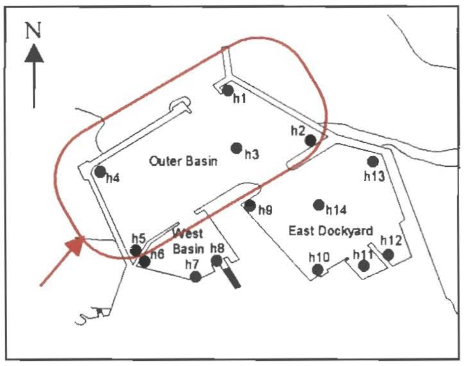
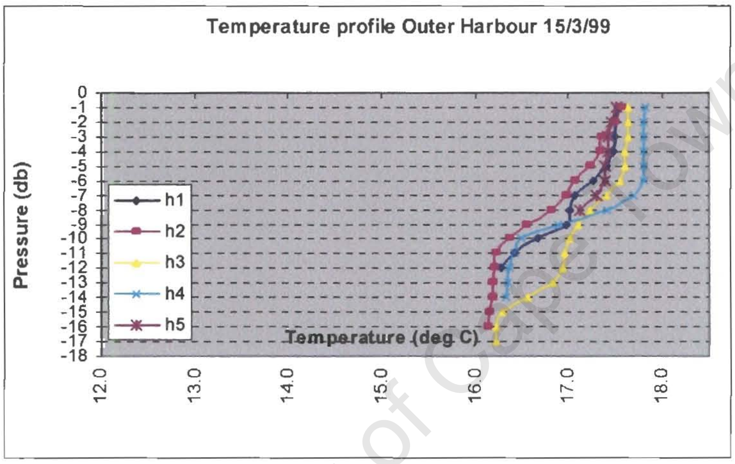
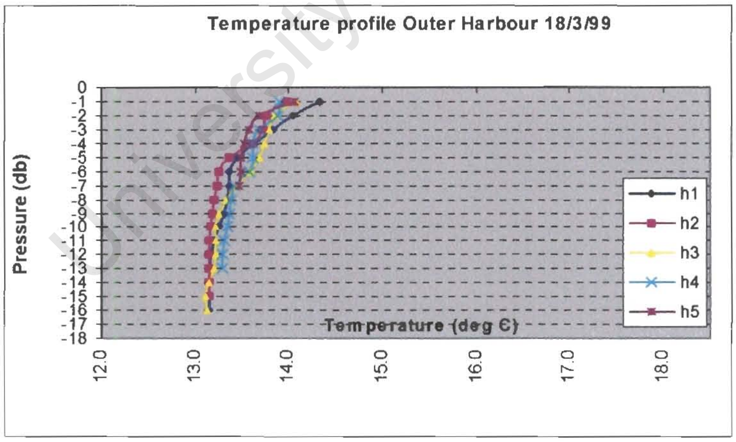


Figure 41 Map showing sampled stations in the Outer Basin Harbour. Stations are numbered h1, h2, h3, h4, and h5 (encircled).





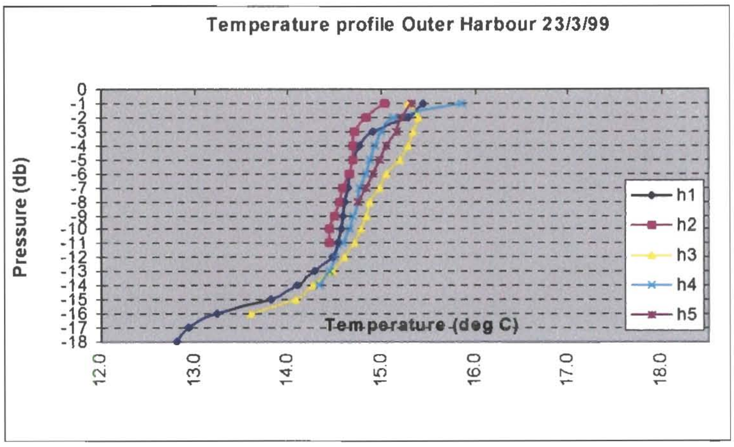


Figure 42 Temperature depth profiles for all Outer Basin stations during Simon's Bay Sea Watch

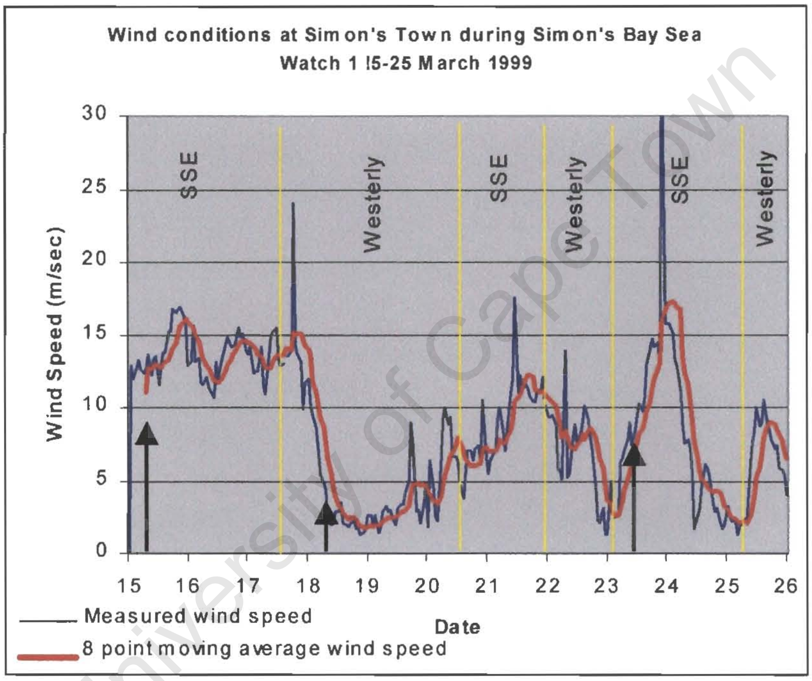


Figure 43 Wind measurements recorded at Simon's Town during Simon's Bay Sea Watch 1 (15-25 March 1999). Arrows indicate CTD station sampling times for the Outer Naval Harbour basin.

Measurements taken on the 15/3/99 (Figure 43) showed that warm water was present in the Outer Harbour, with a lower range of surface temperatures than in the East Dockyard (Table 8). The across-basin temperature structure seen in the other basins was also present here (Figure 42).

At the western end during strong SSE wind conditions, water was piled up, forcing warmer well-mixed surface water (0-6 m) to accumulate in the western corner at station h4. Station 4 had the most pronounced thermocline at a depth of 6 m – 11 m, with somewhat warmer (0.3° C) surface water than at the other sites (Figure 42, 15/3). The depth of this surface mixed layer, defined the thermocline depth and was 2-3 m deeper than at the other basins at the same time. A west-to-east shallowing (6 to 2 m) and weaking of the thermocline occurred across the basin (Figure 42, 15/3).

Station h3 is shown at the centre of the basin (Figure 41), the strong winds on that day resulted in drift of the boat towards the northern harbour wall. The surface profile therefore represented the central basin, while the deeper part of the profile was indicative of the temperatures at depth in the northern part of the harbour, near the harbour entrance. This may explain the warmer (0.5°C) water seen at station h3 at 10-14 m below the surface. It is thought that this originated from the oceanic area outside the harbour entrance as a localised tidal intrusion (Figure 42, 15/3).

Sampling on the 18/3 during a decreasing westerly wind speed (Figure 43), resulted in similar thermal water properties to those in the other basins, with minimal inter-profile differences. Water had cooled to 13° C - 14.3° C (Figure 42, 18/3). The close agreement of the profiles and the distinctive cooling throughout (Table 8 and Figure 55a) for all 3 basins indicated that flushing had occurred within the 3 days, since previous measurements (Figure 42 and 56).

On the 23/3, the SSE wind was increasing in speed and the cross-basin surface water temperature structure (as occurred on 15/3) was starting to develop again, with increased inter-station profile variability. The intrusion of colder (12.8-14° C) water was observed at the deeper stations (h3 and h1), not seen on the previous two sampling days (Figure 42, 23/3).

Oceanic

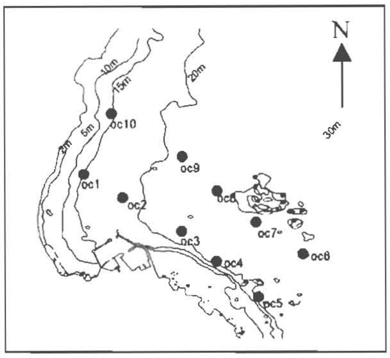
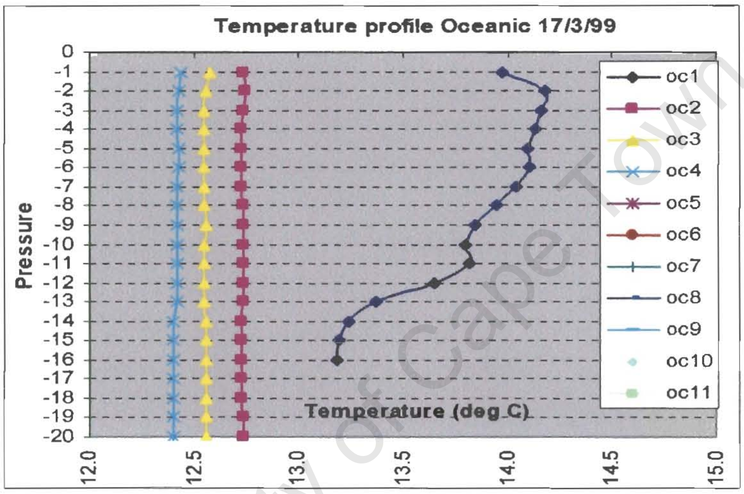
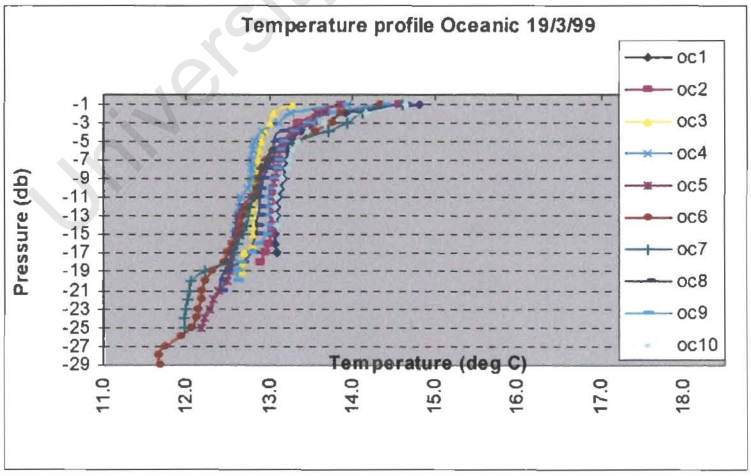


Figure 44 Map showing sampled stations in the Oceanic region. Stations are numbered oc1 to oc10.





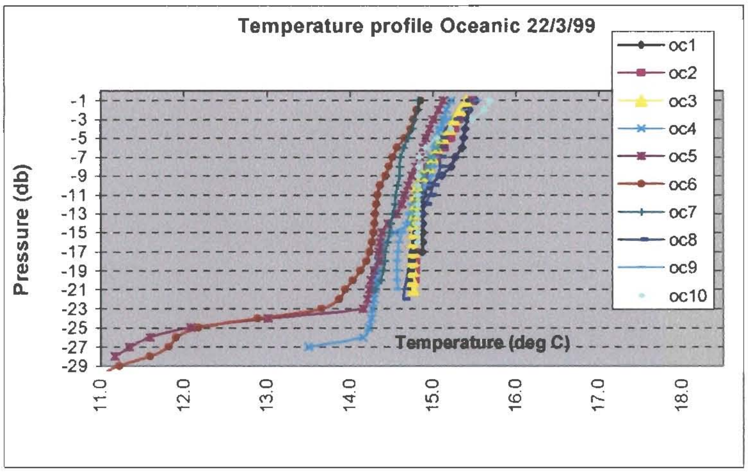


Figure 45 Temperature depth profiles for all Oceanic stations during Simon's Bay Sea Watch 1

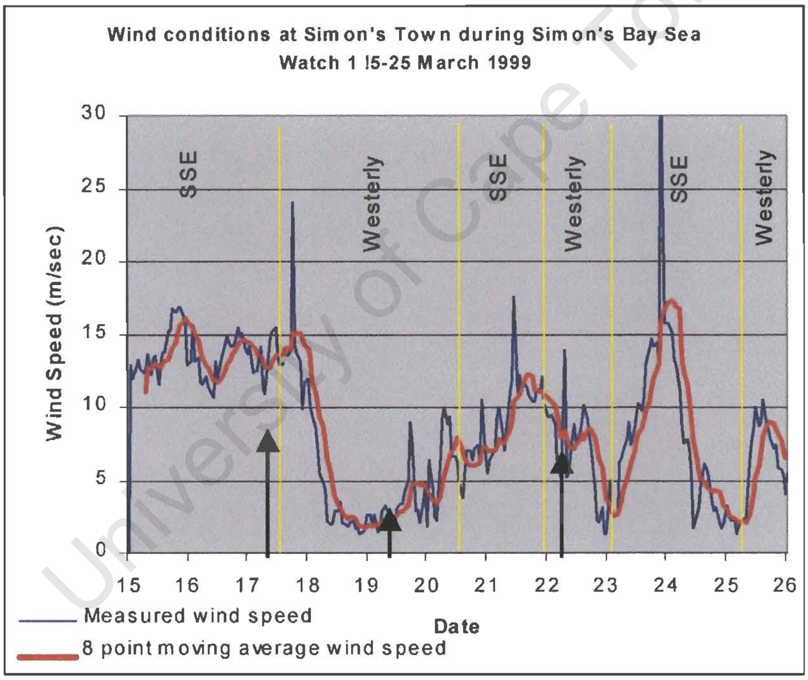


Figure 46 Wind measurements recorded at Simon's Town during Simon's Bay Sea Watch 1 (15-25 March 1999). Arrows indicate CTD station sampling times for the Oceanic region.

When examining the results for the Oceanic region, the significance of the sampling date should be considered, especially with respect to the prevailing wind conditions. The 1st occasion was 17/3/99, after a long spell of strong SSE (south south easterly) conditions (Figure 46). Only 4 stations were sampled on this day, due to rough sea conditions. The other scheduled sampling sites were abandoned (Figure 45, 17/3). The second sampling day was on 19/3/99, after a day of calm conditions, and the third sampling day was completed on 23/3/99, during increasing south-easterly conditions, after a brief respite lasting 1 day (Figure 46). On the first day (17/3/99), station oc1, nearest the coastline, exhibited a thermocline at 12m, with a wind mixed surface layer above. Stations oc2, oc3 and oc4 however, were well mixed from the surface to seafloor (20 m). Surface temperatures (1-4 m) were approximately 3° C warmer at site oc1 than at all three offshore sites (oc2, oc3 and oc4). This indicated the presence of a thermal front between oc1 and oc2 (Figure 45, 17/3). This will be examined later. It is postulated that this colder water originated as upwelled water from Cape Hangklip at the southeast corner entrance of False Bay 2-3 days earlier, forced by a persistently strong (>10m/sec) south-easterly wind (Figure 46).

On the second sampling day (19/3/99), a thermocline existed at 1-3 m at all stations, with temperatures less than 13.5° C below 5 m (Figure 45). Surface heating effects were evident in the upper 2 m made possible by the preceding 24 hours of low wind speeds (Figure 46). Weak thermoclines were observed below 19 m at the deeper sites (oc5, oc6 and oc7). Spatially, this deep cold layer originated as an intrusion at the deeper stations at the south-east corner of the sampling grid (stations oc4, oc5 and oc6) (Figure 45, 19/3). The forcing mechanism for this layer was either as part of the deep False Bay basin circulation or from the setup of a localised upwelling cell and intrusion, resulting from favourable offshore westerly/northwesterly winds (Figure 46).

The spatial separation of these stations was approximately 10 times that of the harbour measurements, and five times the Small Craft Harbour (see Figure 21). The inter-station variability however, on the latter two sampling days (19 and 22/3) was minimal, approximately 1° C below 3 m (Figure 45). This suggests that at such a scale, the area is dominated by the greater False Bay dynamics.

On the third sampling day (22/3/99), temperatures at all stations, throughout the water column had risen by 1 - 2° C since the previous sampling (19/3/99) and no significant surface thermal structure was evident (Table 8 and Figure 45) The shallow thermoclines that were present 3 days earlier, had been replaced by warmer wind mixed water to a depth of 21 m (Figure 45). The switching of the winds from weak westerly (Northwesterly over greater False Bay) to moderate SSE (Figure46) was the most likely cause of the intrusion of this warmer water. Below 23m however, at the deeper sites (oc4, oc5 and oc6) a strong thermocline was present, with the warmest bottom water at 25-26 m at the in-shore site oc4 (Figure 45, 22/3).

Small Craft Harbour

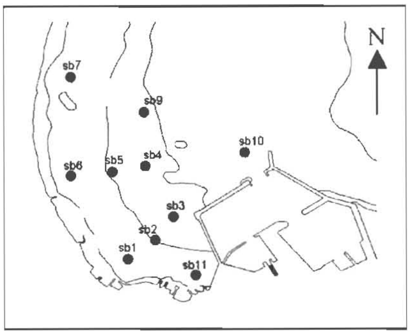
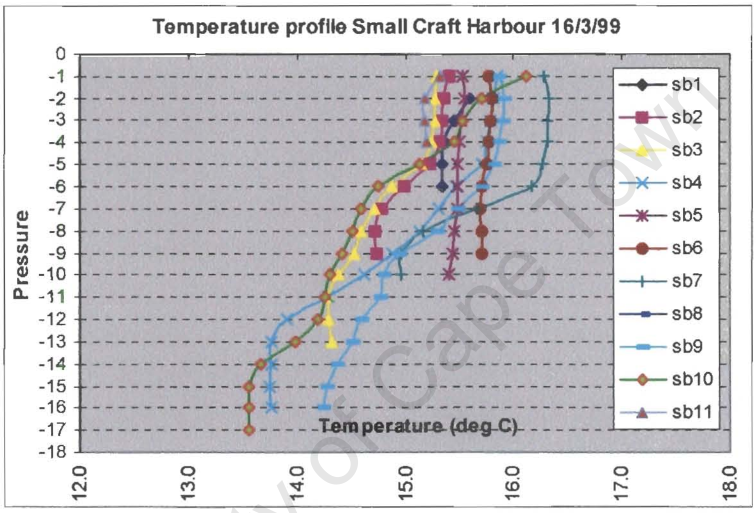
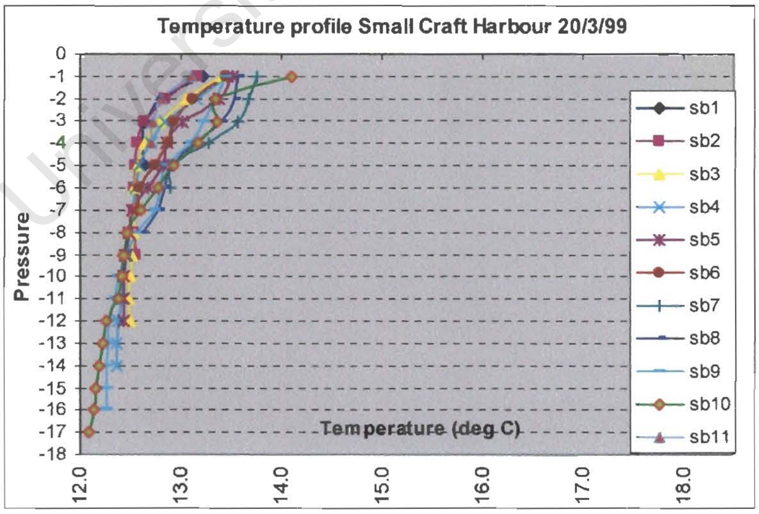


Figure 47 Stations sampled in the Small Craft Harbour.





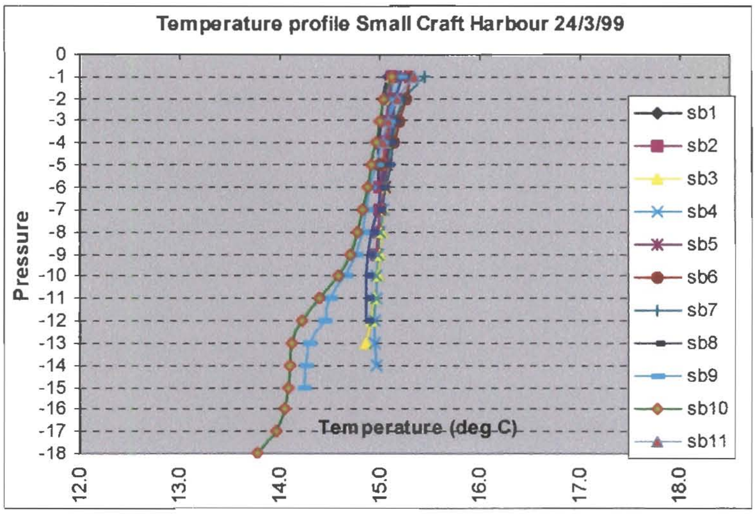


Figure 48 Temperature depth profiles for all Small Craft Harbour stations during Simon's Bay Sea Watch 1

The Small Craft Harbour was sampled on 16, 20 and 24/3/99 (Figure 47). On the 16/3/99, isothermal conditions were present at all shallow southernmost stations (sb1, sb2, sb5, sb6 and sb11). While the northernmost shallow station sb7 and all the deeper offshore stations (sb3, sb4, sb9 and sb10) had thermoclines, exhibiting a 2 layered system, with surface water approximately 0.5-1°C warmer than the southernmost stations (Figure 48, 16/3). These north/south sloping isotherms indicate the intrusion of warmer water from the north, as a wedge (site sb7 was the warmest, site sb11 the coolest) above the cooler coastal water. This is further illustrated in figure 49 - 52, showing vertical sections across three lines on this day.

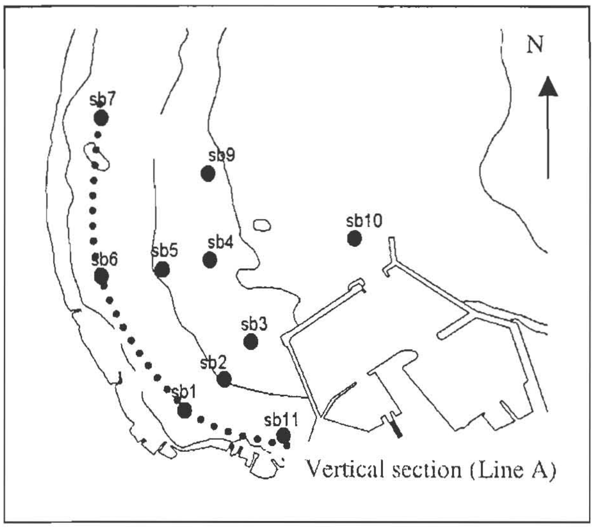


Figure 49 Map showing Line A in Simon's Bay

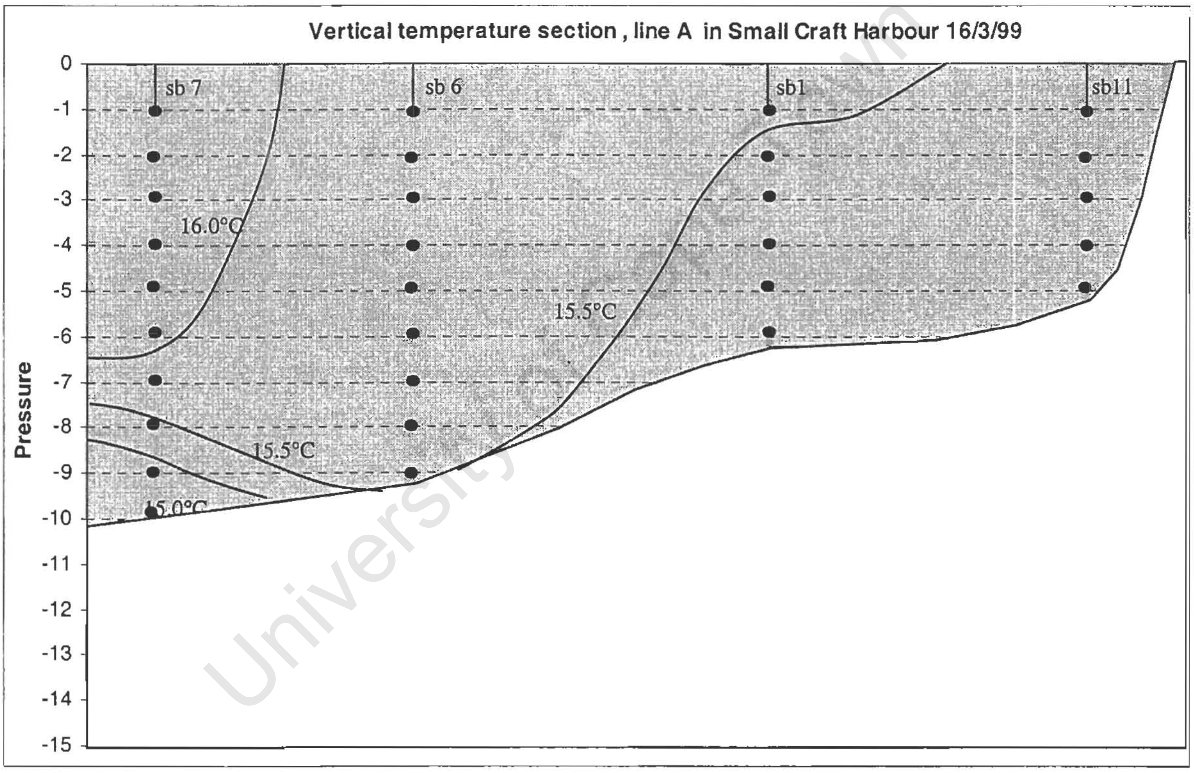


Figure 50 Vertical temperature section (Line A) of Simon's Bay on 16/3/99

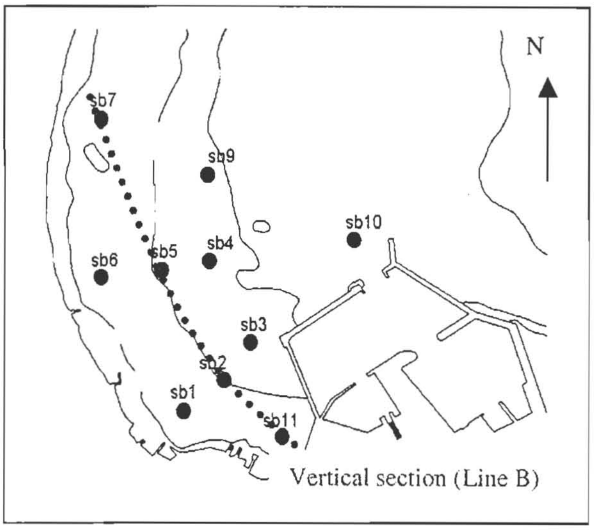


Figure 51 Map showing Line B in Simon's Bay

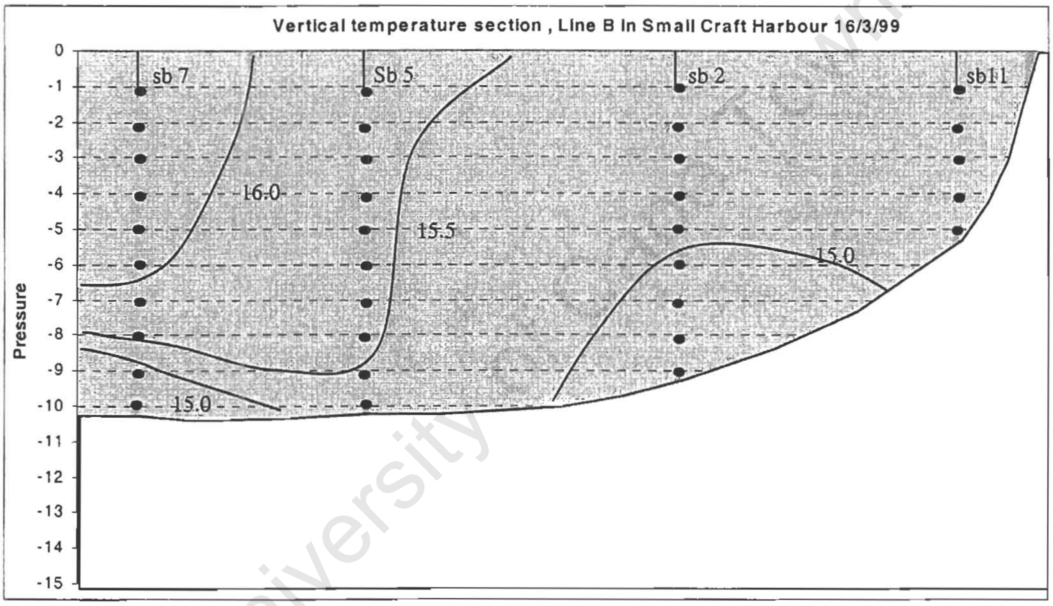


Figure 52 Vertical temperature section (Line B) of Simon's Bay on 16/3/99

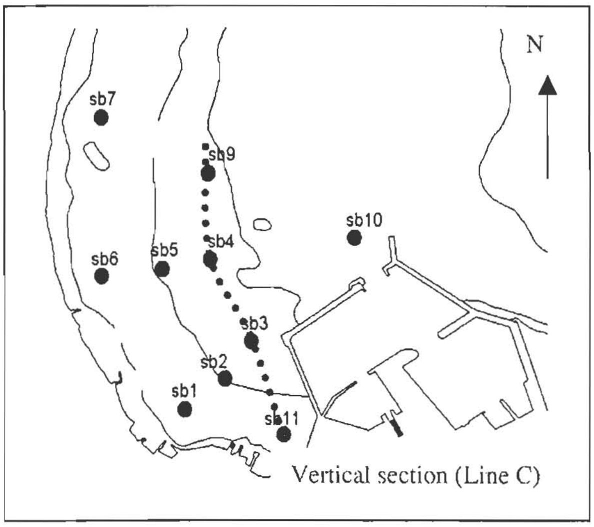


Figure 53 Map showing Line C in Simon's Bay

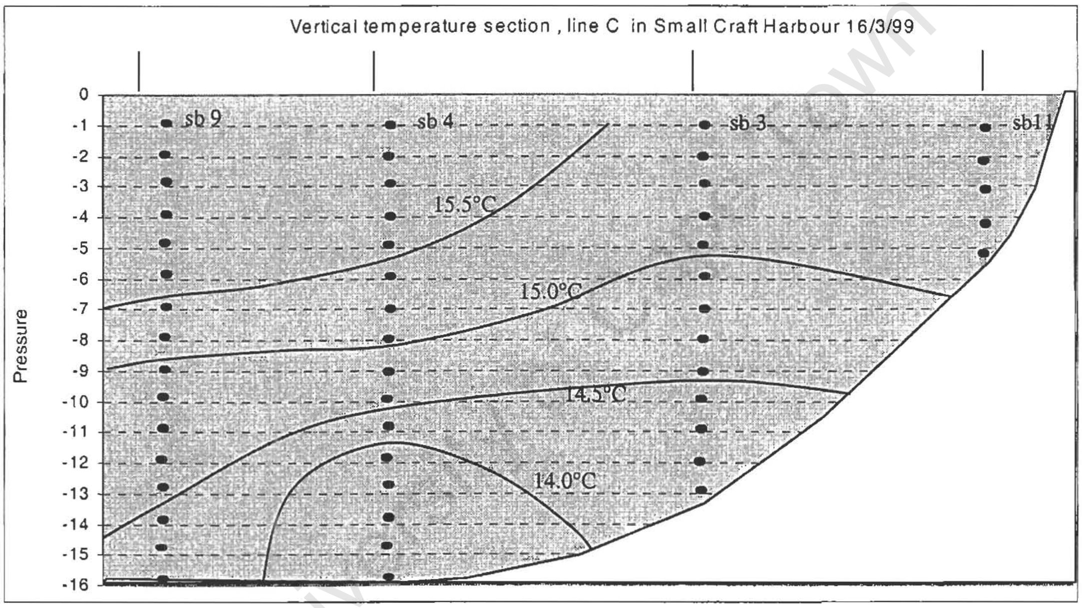


Figure 54 Vertical temperature section (Line C) of Simon's Bay on 16/3/99

On the 20/3/99 thermoclines had developed at all sites. Temperatures remained cooler overall in the more protected areas such as station sb11, sb1, sb2, and sb3, with warmest temperatures at the northern station sb7 and sb8. Temperature differences were about 0.5 ° C between the southern and northern stations (Figure 48). Shallow weak thermoclines at a depth of approximately 2 m were observed at stations sb1, sb2, sb3, and sb11. Deeper (> 4 m) thermoclines existed at stations sb7 and sb8, with a combination of the two types at the other stations (Figure 48, 20/3).

By the 24/3/99, warmer water had replaced the colder water that existed 4 days earlier. Stations sb1, 2, 3, 4, 5, 6, 7, 8 and 11 were all isothermal, with profiled temperatures being within 0.5 ° C. Deep thermoclines were seen at a depth of 11 m at offshore station sb9 and sb10 only, resulting in the bottom water 1 ° C cooler than at all the other stations (Figure 48, 24/3).

Dissolved water quality constituents

	Naval Harbour		Small Craft Harbour		Oceanic	
Nitrates NO_3-N (µg-atoms/l)	Surface	Bottom	Surface	Bottom	Surface	Bottom
Mean	4.36	5.76	5.39	6.28	5.43	8.15
Maximum	13.34	15.25	12.33	14.35	12.02	17.58
Minimum	0.00	0.74	0.11	0.20	0.00	0.02
Standard Deviation	5.38	5.39	4.47	4.74	4.76	6.02
Range	13.34	14.51	12.22	14.15	12.02	17.56
Observations	42	41	31	31	24	24

* West Coast average = 1.17, West Coast upwelled water = 20,
South Coast = 5.79

** (de Chalain 1979) site 3, harbour entrance = 4.37 at seafloor, January to October.

Nitrites NO_2-N (µg-atoms/l)						
Mean	0.09	0.08	0.13	0.13	0.11	0.10
Maximum	0.17	0.19	0.22	0.26	0.20	0.17
Minimum	0.00	0.00	0.04	0.04	0.00	0.00
Standard Deviation	0.06	0.06	0.06	0.06	0.06	0.05
Range	0.17	0.19	0.18	0.22	0.20	0.17
Observations	42	42	31	31	24	24

*Average for West coast = 0.3, South coast = 0.2

Phosphates PO_4-P (µg-atoms/l)						
Mean	0.98	1.17	0.98	1.14	1.08	1.38
Maximum	1.98	2.19	2.10	2.13	2.06	2.57
Minimum	0.26	0.38	0.18	0.25	0.43	0.45
Standard Deviation	0.59	0.57	0.58	0.61	0.53	0.62
Range	1.72	1.81	1.92	1.88	1.63	2.12
Observations	41	42	31	31	24	24

*Average for West coast = 1.71, South coast = 1.19

** (de Chalain 1979) site 3, harbour entrance = 1.06 at seafloor, January to October.

	Naval Harbour		Small Craft Harbour		Oceanic	
Silicates SiO_4	(µg-atoms/l)					
Mean	5.41	7.11	6.34	7.14	5.05	7.61
Maximum	13.34	14.17	14.23	14.31	8.94	15.95
Minimum	0.54	1.85	1.19	1.14	1.27	1.32
Standard Deviation	4.02	3.77	4.48	4.41	2.94	4.91
Range	12.80	12.32	13.04	13.17	7.67	14.63
Observations	42	42	31	31	24	23

*Average for West coast = 13.56, South coast = 5.20

** (de Chalain 1979) site 3, harbour entrance = 7.98 at seafloor, January to October.

Ammonium NH_4	(µg-atoms/l)					
Mean	1.41	2.60	5.50	5.15	1.66	2.38
Maximum	3.67	7.71	8.87	7.97	6.59	3.76
Minimum	0.06	0.83	3.57	2.17	0.59	0.83
Standard Deviation	0.90	1.59	1.73	1.78	1.57	0.87
Range	3.61	6.88	5.30	5.80	6.00	2.93
Observations	41	42	10	10	14	14

*In oxygenated unpolluted seawater ammonium rarely exceeds 5.

** (de Chalain 1979) site 3, harbour entrance = 2.57 at seafloor, January to October.

*Target values for SA Water Quality Guidelines, waters should not contain concentrations of dissolved nutrients that are capable of causing excessive or nuisance growth of algae or other aquatic plants or reducing dissolved oxygen concentrations below the target range.

Table 9 Nutrient concentrations in the Naval Hatbour, Small Craft Harbour and Oceanic regions for the surface and bottom layer (15-23 March 1999). Units are µg-atoms/l. * Comments with asterisks are from the Department of Water Affairs and Forestry. 1995. South African Water Quality Guidelines for Coastal Marine Watersare for marine and coastal waters, Volume 1. Natural Environment. ** Comments are results obtained from de Chalain (1979) from weekly samples in Simons Bay at 3 sites from Jan-Oct 1979, 1m above the seabed.

Nitrates – (refer to Table 9)

The mean nitrate value for all surface and bottom waters from all regions was 5.9 µg-atoms/l. This figure is 3 % higher than the mean south coast of 5.79 µg-atoms/l and considerably higher than the mean west coast value as reported in the SA Water Quality guidelines (excluding upwelled west coast water). It is considered that the values recorded here fell within an acceptable range for the West coast and South coast and therefore not considered to be a problem. The average west coast value as quoted in the SA Water Quality Guidelines is therefore probably underestimated. Nitrate mean and maximia were higher in the Bottom waters of the Oceanic region compared to the Naval and Small Craft Moorings, this is most likely due to deeper sampling in the Oceanic area. The highest recorded value was 17.58 µg-atoms/l from the bottom oceanic region and the minimum recorded was 0.00 µg-atoms/l from the surface waters of the Oceanic and Naval Harbour. The Oceanic region also accounted for the widest range of values recorded (17.56 µg-atoms/l) and the greatest standard deviation (6.02 µg-atoms/l). Bottom values were consistently higher than the surface values in all regions. Mean values for the surface Naval Harbour water were less than the natural south coast value, while oceanic bottom water values were slightly above. When comparing the mean values with the average natural West coast value however, all are higher by a factor of 3 to 7.

Nitrites – (refer to Table 9)

Natural levels of nitrite in seawater are usually very low, in open waters values range from 0.1-3.5 µg-atoms/l. With the conversion of nitrates to nitrites during plankton decomposition, raised levels would indicate excessive/increased levels of production. In Simon's Bay, the mean nitrite values for all surface and bottom waters for all regions sampled was 0.107 µg-atoms/l. This figure is 3 times lower than west coast mean (excluding west coast upwelled water) of 0.3 µg-atoms/l and about half the south coast average. Values were highest overall in the Small Craft Harbour, where the concentration more closely represented south coast rather west coast conditions. The nitrite mean, maxima and minima of the Small Craft Moorings exhibited values 20 % to 40 % higher than those of the Naval Harbour and Oceanic region. The maximums were 0.17 µg-atoms/l (top) and 0.19 µg-atoms/l (bottom) vs 0.22 µg-atoms/l and 0.26 µg-atoms/l when comparing the Naval Harbour with the Small Craft Harbour. When comparing the Oceanic region with the Small Craft Harbour similar figures were noticed, 0.20 µg-atoms/l (top) and 0.17 µg-atoms/l (bottom) vs 0.22 µg-atoms/l and 0.26 µg-atoms/l. A higher minimum value (0.04 vs 0 µg-atoms/l) was also measured in the Small Craft Harbour while the standard deviations were the same throughout. The data range was somewhat wider for the Small Craft Harbour. All values were either less than or marginally higher than the average west coast and south coast values.

Phosphates - (refer to Table 9)

Phosphate is an important nutrient and occurs naturally in seawater as phosphorous originating from land weathering. Permanently raised values are indicative of waste input. In Simon's Bay, bottom phosphate values were marginally higher than the surface values in all regions, typical of a natural environement, with related higher maxima, minima, standard deviation and range. Mean phosphate values were found to be 10 % lower in the Naval Harbour and Small Craft Harbour than those in the Oceanic region. Highest values were recorded throughout the bottom waters of the oceanic region. All means were lower than the natural west coast and south coast average of 1.71 µg-atoms/l and 1.19 µg-atoms/l, respectively. The only exception was the bottom water of the oceanic region (1.38 µg-atoms/l).

Silicates - (refer to Table 9)

Silicate is a nutrient used by certain single celled phytoplankton as their hard outer tests. A shortage of silicate in the water column therefore limits biological production. Highest recorded mean, maximum, standard deviation and range values occured in the bottom waters of the Oceanic region, similar to the other nutrients. Highest minimum values occurred in the bottom waters of the Naval Harbour (1.85 µg-atoms/l). The lowest mean value occurred in the surface waters of the Naval Harbour. Mean values were all higher than the south coast mean (5.20 µg-atoms/l) and less than the West coast mean (13.56 µg-atoms/l) and in general, more representative of south coast conditions. Bottom measurements were all within expected natural ranges, while the mean, maxima, standard deviation and data ranges in the surface waters of the Naval Harbour and Small Craft Harbour were all considerably higher than their oceanic counterparts (Table13). No pollution sources for silicate are provided in the SA Water Quality Guidelines.

Ammonium - (refer to Table 9)

Ammonium values were highest in the Small Craft Harbour for both surface and bottom water. For surface water the mean was 5.5 μg-atoms/l in the Small Craft Harbour, higher than the Naval Harbour (1.14 μg-atoms/l) and the Oceanic region (1.66 μg-atoms/l). Bottom waters of the Small Craft Harbour had a mean value which was similarly higher (5.15 μg-atoms/l) than the Naval Harbour (2.60 μg-atoms/l) and the Oceanic region(2.38 μg-atoms/l). These higher values in the Small Craft Harbour are reflected in the maximum, minimum and standard deviations for both surface and bottom waters. The raised values of the Small Craft Harbour exceeded the natural value of 5.0μg-atoms/l by 10 % to 11%. High values (> 5.0 μg-atoms/l) were also noticed in the bottom waters of the Naval Harbour. This was evident from the raised maximum (7.71 μg-atoms/l) for that region. Similarly, the widest range (6.88 μg-atoms/l) of values also occurred in the bottom waters of the Naval Harbour and the lowest range (0.87 μg-atoms/l) in the bottom waters of the Oceanic region.

Chlorophyll-a - (refer to Table 10 and 11)

Chlorophyll-a is not considered a water quality constituent in terms of the SA Water Quality Guidelines, however, it is a measure of total plant pigment produced by phytoplankton algae and higher plants. Chlorophyll-a levels are proportional to phytoplankton blooms and are therefore used as a method to detect and quantify blooms or the lack thereof. Typical values in seawater range from 0.02 mg/m^3 to more than 20 mg/m^3.

Chlorophyll-a	Naval Harbour (mg/m^3)	Small Craft Harbour (mg/m^3)	Oceanic (mg/m^3)
Mean	1.5	2.4	2.3
Maximum	4.7	4.6	4.4
Minimum	0.1	0.1	0.4
Standard Deviation	1.5	1.7	1.3
Range	4.6	4.5	4.0
Observations	42	21	22

Table 10 Chlorophyll-a results from surface waters during Simon's Bay Sea Watch 1 (15-25 March 1999).

Chlorophyll-a measurements were taken in Simon's Bay from 15-25 March 1999 at the same time as the above nutrient samples. Table 14 shows the spatial variability of cholorophyll-a at **2 m** depth in the Oceanic, Naval Harbour and Small Craft Harbour. Mean values were measured as 1.5 mg/m^3 for the Naval Harbour, 2.4 mg/m^3 for the Small Craft Harbour and 2.3 mg/m^3 for the surrounding Oceanic region (Table 11). Means for the Small Craft Harbour were slightly higher than the Oceanic region and than the Naval Harbour. The Small Craft Harbour had the lowest chlorophyll-a (minimum=0.1 mg/m^3). The maximum reading was recorded in the Naval Harbour (4.7 mg/ m^3), marginally higher than the Small Craft Harbour (4.6 mg/ m^3) and the Oceanic region (4.4 mg/ m^3). The greatest data range occurred in the Naval Harbour while the greatest standard deviation occurred in the Small Craft Harbour (Table 11).

Chlorophyll-a	Surface (mg/m^3)	Lower euphotic zone (mg/m^3)
Mean	1.9	1.7
Maximum	4.3	4.4
Minimum	0.2	0.1
Standard Deviation	1.5	1.5
Range	4.1	4.2
Observations	35	36

Table 11 Surface and lower euphotic zone chlorophyll-a results from a single Annie-K station in the Small Craft Harbour during Simons's Bay Sea Watch 1 from 15-25 March 1999.

During Simon's Bay Sea Watch 1 from 15-25 March 1999, a single monitoring station was maintained at the Annie-K mooring site in the Small Craft Harbour (Figure 21). Hourly water column profiles were sampled, together with water sampling. At this station, Mean surface waters contained 1.9 mg/ m^3 Chlorophyll, while the mean for lower euphotic zone waters was 1.7 mg/m^3 (Table 11). This difference equates to 10 % more chlorophyll-a in the surface waters than the lower euphotic zone. The minimum surface value was 0.2 mg/ m^3, while the mean lower euphotic zone value was 0.1 mg/ m^3. The lower euphotic zone range and standard deviation were both marginally higher than the surface values (Table 11).

Mechanism for water exchange

By comparing the water column temperature profiles as a time series (Figure 55), a number of water characteristics were observed. Intra profile variability on Day 1 and Day 2 was extensive as differing water column was measured in the same region, with significant cooling from Day 1 to Day 3, three °C in three days (Figure 55a). The Naval Harbour was sampled on the first day (15/3/99) of Simon's Bay Sea Watch 1. The area consisted of wind mixed 'surface' water (warm, turbid, high salinity, low nutrient, low density, high pH and low chlorophyll-a) with a distinct deep thermocline (Figures 35 - 42, and 55a).

On the second day (16/3), similar water properties as seen in the Naval Harbour, were evident in the Small Craft Harbour. The only exception was the raised ammonium values (Figure 55 & 56).

On the 17/3, the last day of strong, region-wide prolonged south easterly winds (Figure 46), samples collected in the Oceanic region showed that water in the region was in the process of being replaced by cooler well-mixed water with, lower pH, lower salinity, higher nutrient concentrations and lower dissolved oxygen (Figures 55, 56 & 46, 17/3), all typical of deeper water. On that day, collecting data was extremely difficult, so that only four oceanic stations could be completed. In hindsight, this turned out to be crucial in capturing the approaching advection, which was evident in the measurements taken between station1 and station 4 (Figure 46, 17/3). From the CTD and all chemical results an along-shore gradient was apparent, with different characteristics (chlorophyll-a, nutrients, dissolved oxygen and salinity) (Figure 56).

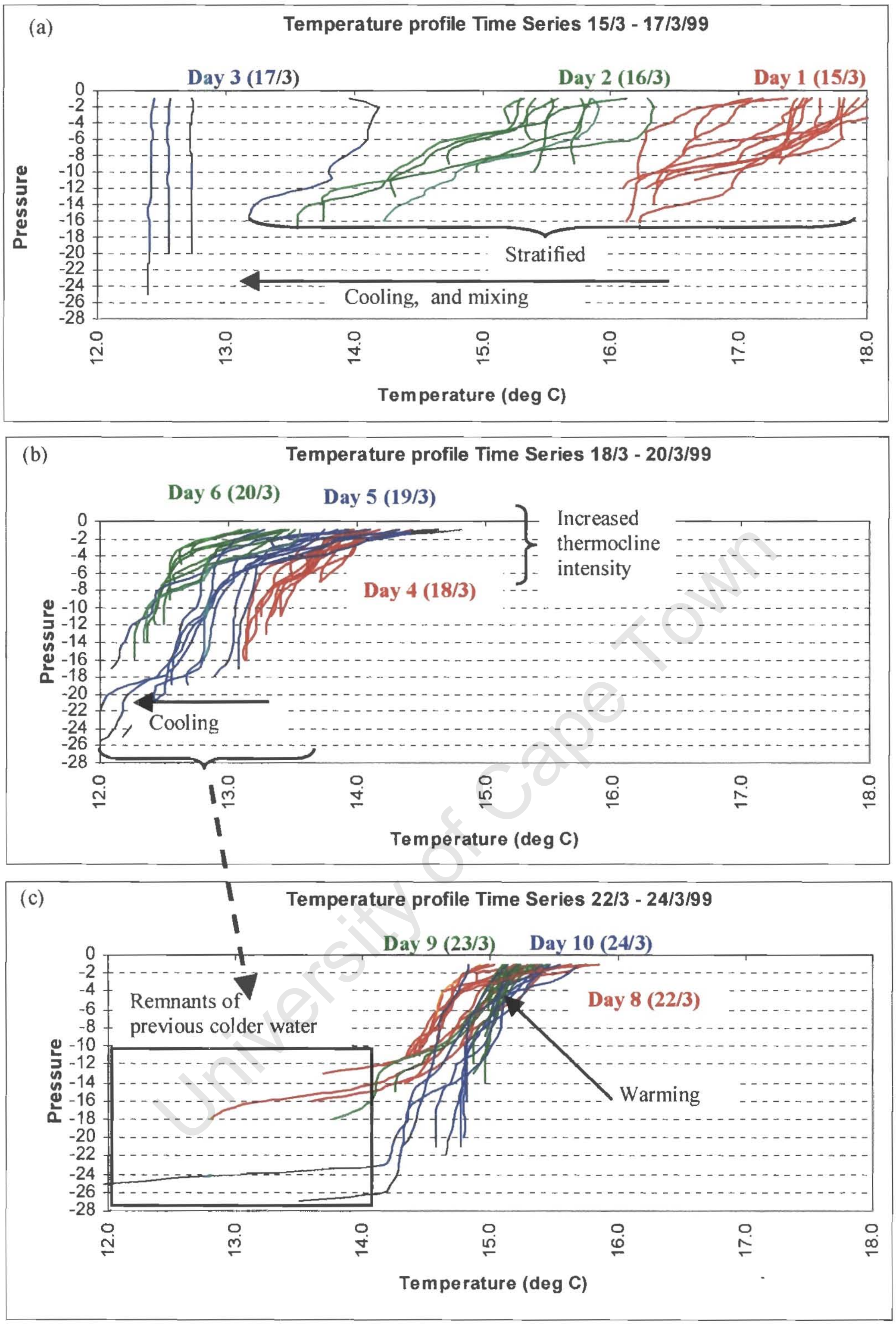


Figure 55 Water column temperature time series showing profiles in Simon's Bay from 15/3-24/3/99.

A distinct temperature front/interface between station 1 and the other 3 stations was apparent (Figure 45 and 55). The chemical interface however was subtle, with increasing chlorophyll-a values occurring between station 1 and the other stations (Figure 56). The onset of this water was accompanied by a single sudden anomalous sea level depression and elevation at the corresponding flood and ebb tide of that day (Figure 33 and 34). This fall and rise in the residual sea level preceding the upwelling, coupled with an increase in nitrate concentrations, agrees with the findings of Waldron, Probyn and Brundrit (1997).

This sequence of events was associated with raised Chlorophyll-a values, symptomatic of a localised phytoplankton bloom. Such cooler well-mixed water is normally indicative of False Bay water between July and September (Atkins1970b referred to by Gründlingh 1991). It is suggested that the source of this recently upwelled bottom water was from central False Bay, advected into Simon's Bay primarily by currents induced by local winds as a Coastal Trapped Wave (CTW).

The next day (18/3), this cooler well mixed advected water moved into the Naval Harbour and Small Craft Harbour, heating slightly (Figure 55, 56, 36, 39, 42 and Table 8). This coincided with a two fold increase in backscatterance in the Naval Harbour with a concurrent secchi depth decrease (Figure 56).

By the following day (19/3), evidence of this water was still seen in the Oceanic region as well as those on the Annie-K, but not occurring at the Town Jetty yet (Figure 56), indicating that the spatial extent of this cooler advected water (first noticed in this region on the 17/3) included Simon's Bay and probably extended further into False Bay. Surface nitrate and silicate values had decreased somewhat while nitrites, bottom silicates and phosphates increased slightly (Figure 56). No phytoplankton bloom had occurred yet as is evidenced from the low chlorophyll-a values, coupled with secchi depths of 6-7 m (Figure 56). By this time, the wind had abated (Figure 46) and the effects of two days of sun warming could be seen by the developing shallow thermocline at all sites in the Oceanic region (Figure 45, 19/3 and Figure 55), the Town Jetty (Figure 56).

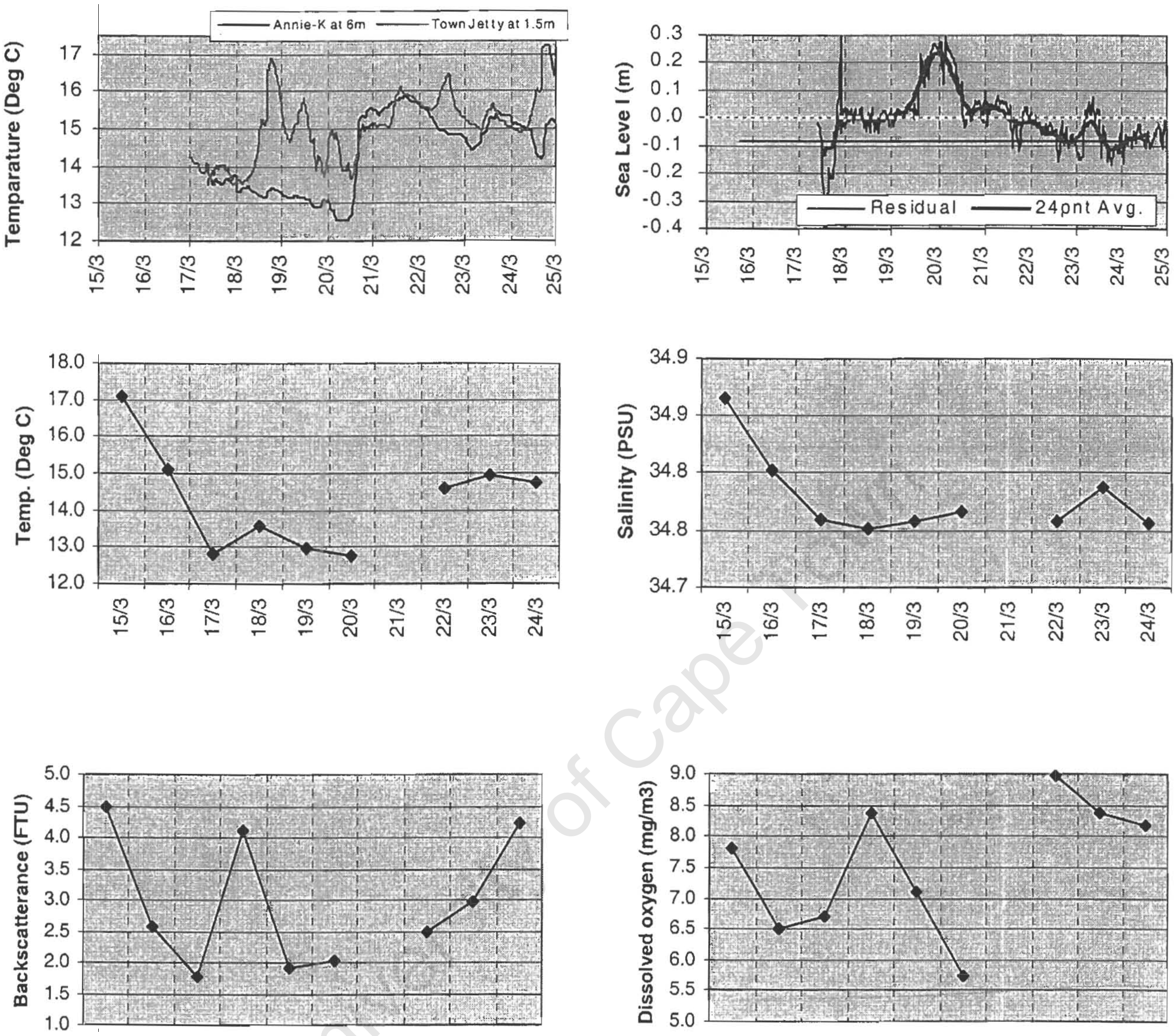


Figure 56 Time series plot of mean constituents measured during Simon's Bay Sea Watch 1. (15-25 March 1999)

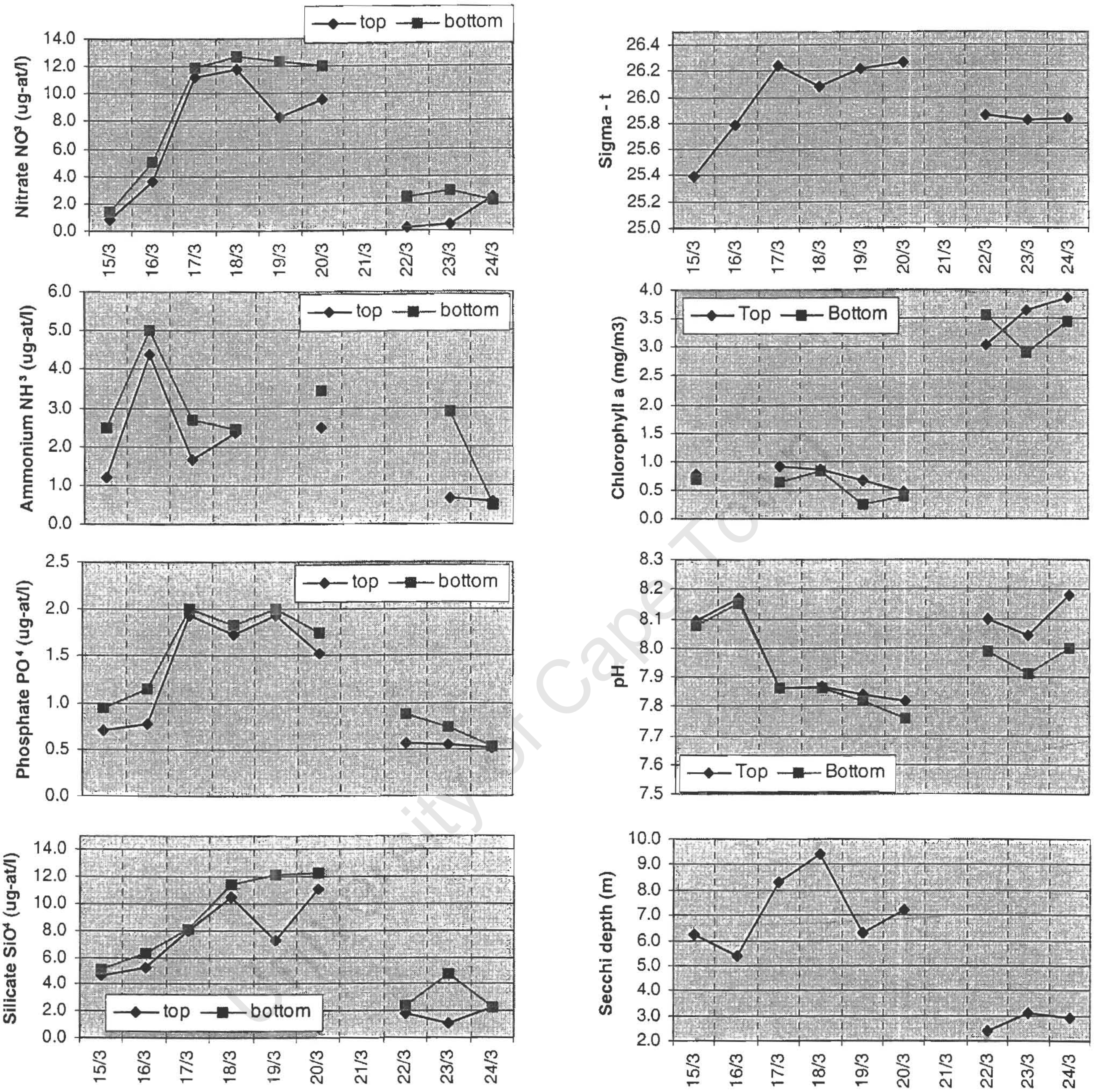


Figure 57 Time series plot of mean constituents measured during Simon's Bay Sea Watch 1. (15-25 March 1999)

On the 20/3 water from the Small Craft Harbour exhibited similar characteristics to the water observed in the bottom waters of the Oceanic region the previous day, indicating that the entire Small Craft Harbour had become inundated with nutrient rich, cooler water (Figures 55 and 56). This was evident in the CTD profiles (Figure

48), where cooler water was clearly seen at the southern stations and warmer water at the northern stations of the Small Craft Harbour, as the cold water moved in. Water at a depth of 3 m was found to be 1 degree warmer in the south than in the north of the Small Craft Harbour, resulting in a north-south longshore surface temperature gradient in a depth range of 1-2 m (Figures 50, 52 and 53). Sea level time series data, collected at the Annie-K for the same period gave the greatest tidal height on the morning of 20/3, 24 hours after the predicted neap tide. A significant tidal residual was also seen at this time, whereby the sea level was raised by 30 to 40 cm (Figure 33 and 34). There had been a respite in the southeasterly wind and resultant weak currents for two days prior to the sea level event (Figure 32). The advection of the cooler water was also seen in the temperature time series for the Annie-K and at the Town Jetty from p.m. on the 18/3 to a.m. on 20/3 (Figure 56). This advection at the Town Jetty for the same period correlated with the tidal cycle, as cooling was noted with each ebbing tide and lesser heating with each flooding tide resulting in overall cooling. This temperature related tidal effect did not occur to the same extent in the temperature record at 6 m below the Annie-K, relatively cool water was still seen in that record (Figure 56). Chlorophyll-a readings remained low for the entire period.

Although no water sampling took place the following day (21/3/99), the moored CTD, current meter and weather station time series records were available. The records showed that on the afternoon of the 20/3, after two days of calm/light winds and sun warming, the southeasterly wind started blowing again (Figure 32). This moderate-strong wind blew for 1.5 days, coinciding with anti-clockwise flow in the Harbour Basins and Small Craft Harbour (Figure 32). Increased vertical mixing with the surrounding warmer water was observed and the sea level was raised by 30 cm above the predicted value (Figure 33 and 34).

The previous few days of nutrient rich advection, followed by sun warming, wind mixing and increased dissolved oxygen potential, provided suitable conditions for plankton growth. Chlorophyll-a readings steadily increased at the Annie-K site throughout the morning resulting in a plankton bloom in the Small Craft Harbour on the 22/3/99 (Figures 56 and 57), in slightly warmer well-oxygenated water. This was accompanied by decreased nitrates, phosphates, silicates, sigma-t, secchi depths (Figure 56 and 57) and increased pH, backscatterance and dissolved oxygen. The bloom was still evident in the Small Craft Harbour on the 24/3 (Figure 57), when the study ended, whereby the plankton probably started to decay due to the already depleted nutrient supply. Typical water properties and features during the bloom was 14-15 Deg C well-mixed water with high values of dissolved oxygen (90%-110% or 8-9.5 mg/l). By the 24/3, the ammonium levels at the Annie-K and all other nutrients in Simon's Bay had reduced considerably (Figure 57).

Sediments

Sediment sampling presented here did not form part of the Simon's Bay Sea Watch 1 sampling. The SA Navy collected 22 small sediment cores (site numbers 1- 22) during 1991 within the confines of the Naval Harbour and a separate site (site number 23), outside the harbour at the southern extent of L-Berth (Figure 22a). Samples were analysed for Iron, Copper, Lead and Zinc at the Materials Laboratory of the South African Navy (Garrard 1991).

No official South African guidelines exist for heavy metal concentrations in marine sediments. A draft guideline is being developed by Dr L.F Jackson, Marine Pollution Division, Department of Environment Affairs and Tourism. Chief Directorate: Environmental Quality and Protection for the London Convention 1995.

The context of the guidelines was based on dredging and spoil of sediments and does not refer to natural undisturbed conditions such as Simon's Bay.
It has been established that currents are weak, especially in the harbour confines, it is considered unlikely that significant sediment accretion will occur and therefore unlikely that dredging the harbour has been necessary. Although the guidelines are based on a dredging scenario, it is still applicable to this study in the context of contingencies.

The guidelines refer to cautionary and prohibition levels. Metal concentrations included are for Copper, Zinc, Chromium, Nickel, Arsenic and Lead. They were quoted under Table 2, Annex I and Annex II Substances.

Annex I	Action level (PPM)	Prohibition level (PPM)
Cadmium	1.5 – 10.0	> 10

Mercury	0.5 – 5.0	> 5

Annex II	Special care (PPM)	Prohibition level (PPM)
Arsenic	30 -150	> 150
Chromium	50 -500	> 500
Copper	50 -500	> 500
Lead	100-500	> 500
Nickel	50 -500	> 500
Zinc	150-750	> 750

Table 12 Precautionary and prohibitive heavy metal concentration guidelines for seabed sediment (London convention 1999, in draft)

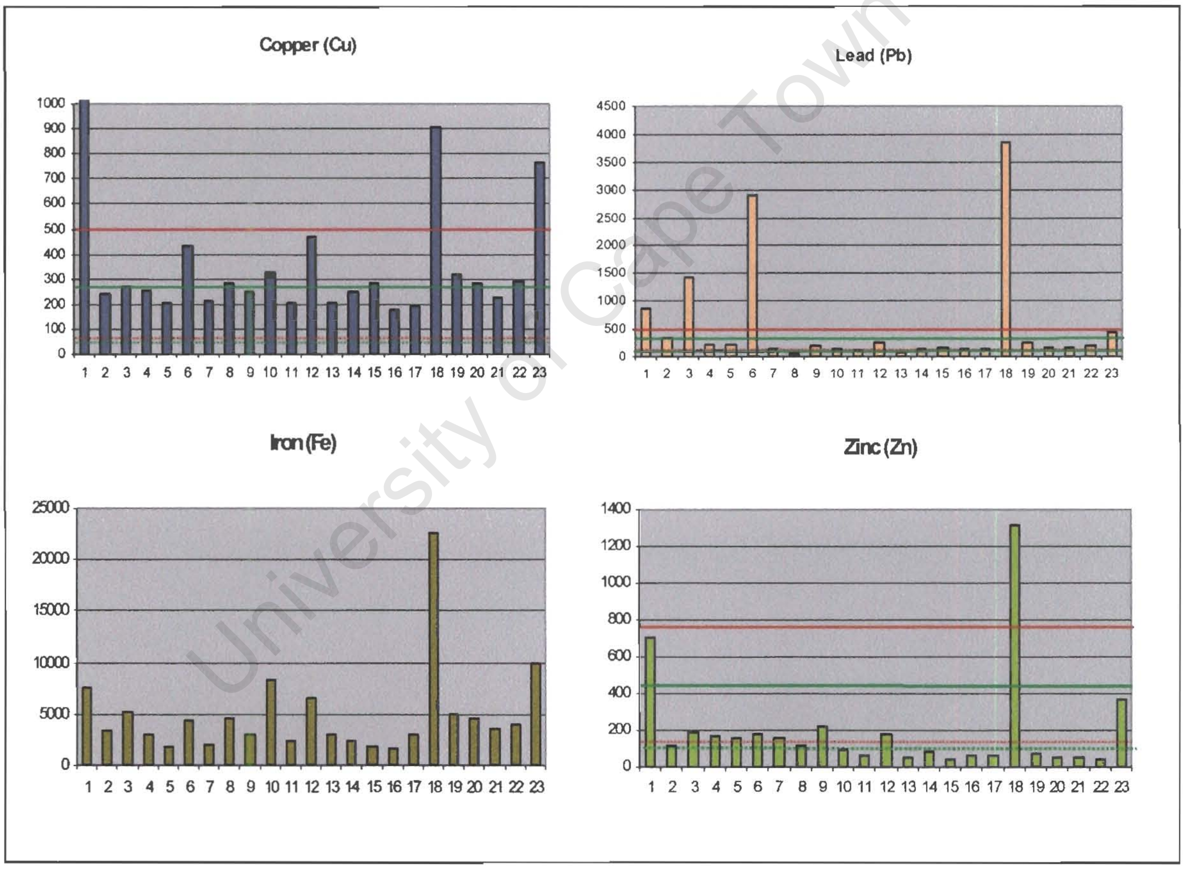


Figure 58 Sediment concentration plots at sites within the confines of the Naval Harbour sampled and analysed for Iron, Copper, Lead and Zinc during 1991 (Figure 25a) by the South African Navy (Garrard 1991). The y-axis represents the metal concentration in parts per million (PPM) while the x-axis represents the site number. Cautionary or action levels are represented as a broken red represent high risk values line while prohibition level are represented as a solid red line according to the London Convention (in draft). In plots where lines are missing, no guideline values were available. Green lines denote NOAA 1995 guideline values for Estuarine and coastal sediments for field concentration that pose an ecological risk. Broken green lines are low risk, while solid green lines

Internationally, the National Oceanic and Atmospheric Administration (NOAA) published guidelines in 1995 relating to sediment health, in which biological effects were used as indicators concerning levels of pollutants in sediments. Using results from the Great Lakes region in the USA, pollutants in sediments were classified according to whether biological effects were observed and were thereby considered to represent an ecological risk. Risks were further subdivided into low, medium and high risk values in units of parts per million or µg/g dry weight. Cadmium 0.6 – 9.6 (i.e. low to high risk), Zinc 410-150, Copper 34-270, Lead 46.7-280, Asenic 8.2-70, amongst others (pers. Comm. Dr T Probyn, Marine and Coastal Management).

The sediment results for 1991 are shown in figure 58, and those of 11 May 1997 and 28 February 1998 are shown in figure 59.

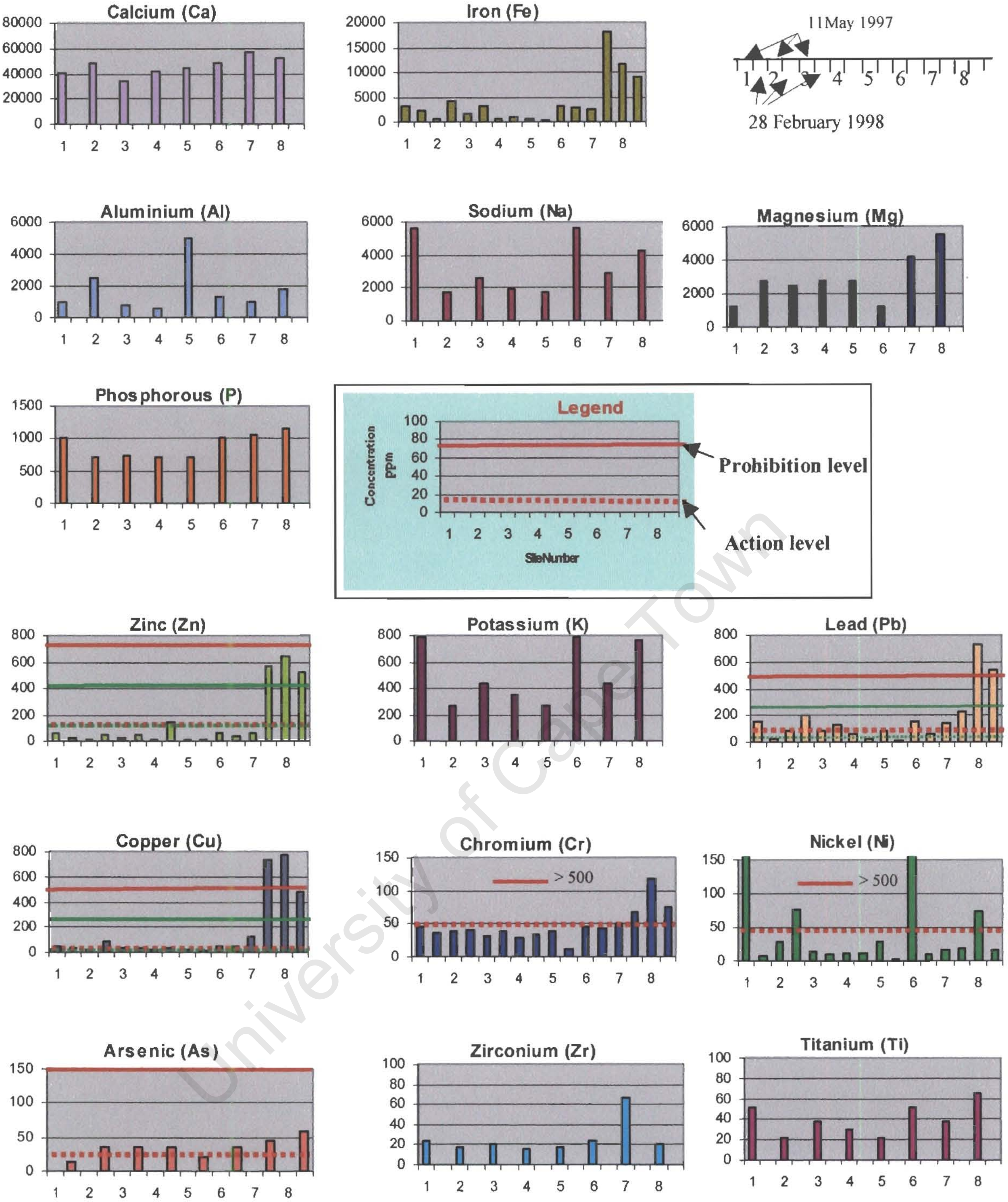


Figure 59 Heavy metal sediment concentrations at 8 sites in the Simon's Town Naval Dockyard and surrounds on two occasions (11 May 1997 and 28 February 1998). The first reading represents the results from 11 May 1997 while the second reading represents the 28 February 1998 results. The y-axis represents the metal concentration in parts per million (PPM) while the x-axis represents the site number. Cautionary or action levels are represented as a broken red line while prohibition level are represented as a solid red line according to the London Convention (in draft). Green lines denote NOAA 1995 guideline values for Estuarine and coastal sediments for field concentration that pose an ecological risk. Broken green lines are low risk, while solid green lines represent high risk values

Mussel Watch Programme

Mussel sampling presented here did not comprise a formal part of the Simon's Bay Sea Watch 1. However historic data (1985-1997) in Simon's Bay and surrounds, obtained from the Marine and Coastal Management are helpful in describing a potential pollution problem and is therefore relevant for completeness of this study (Figure 17 & 61).

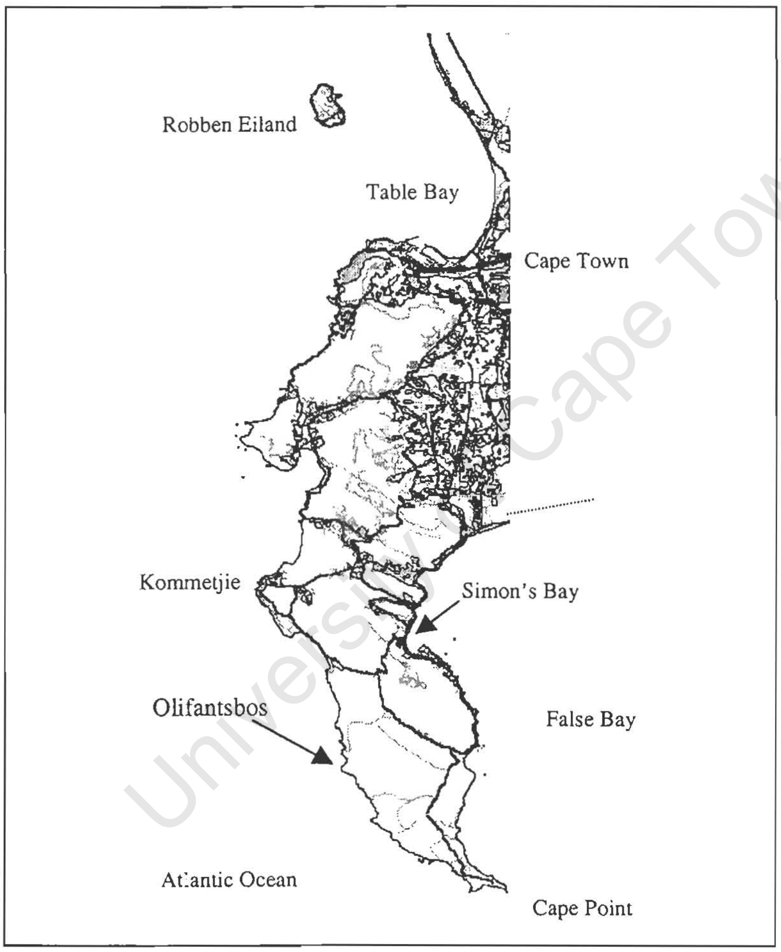


Figure 60 Map showing the Cape Peninsula, Simon's Bay and the Olifantsbos Mussel Watch control site

Metal concentrations

Cadmium (Cd) concentrations

Cadmium levels in *Perna Perna* from collection sites at the Harbour entrance and Glencairn have been below the levels recorded at the other sites since October 1987 (Figure 61). This includes the control site at Olifantsbos, which was marginally lower than the Harbour on one occasion (October 1993). Since May 1987, Cadmium levels at Olifansbos have been two to three times the values measured at the entrance to the Naval Harbour. Cadmium levels at Marine Oil were 50 % higher than Glencairn until May 1994 (excluding March 1993). Results from Boulders showed that the site had higher levels than at Marine Oil, Glencairn and the Harbour since May 1987, with the exception of a single peak in the Glencairn reading during May 1995. Values at Olifantsbos were higher than at all other sites for 11 of the 23 measurements taken (i.e. 48 % frequency occurrence). Boulders was highest for 9 of the occasions (i.e. 39% frequency occurrence), the Harbour on 2 occassions (i.e. 9 % frequency occurrence) and Glencairn on one occasion (i.e. 4 % frequency occurrence). These figures include the data shortfall periods for the Harbour and Marine Oil from October 1995. Cadmium levels were lowest at the Harbour for 10 of the 23 occasions (i.e. 43% frequency occurrence). Maximum levels of Cadmium were measured at all sites between May 1994 and October 1995.

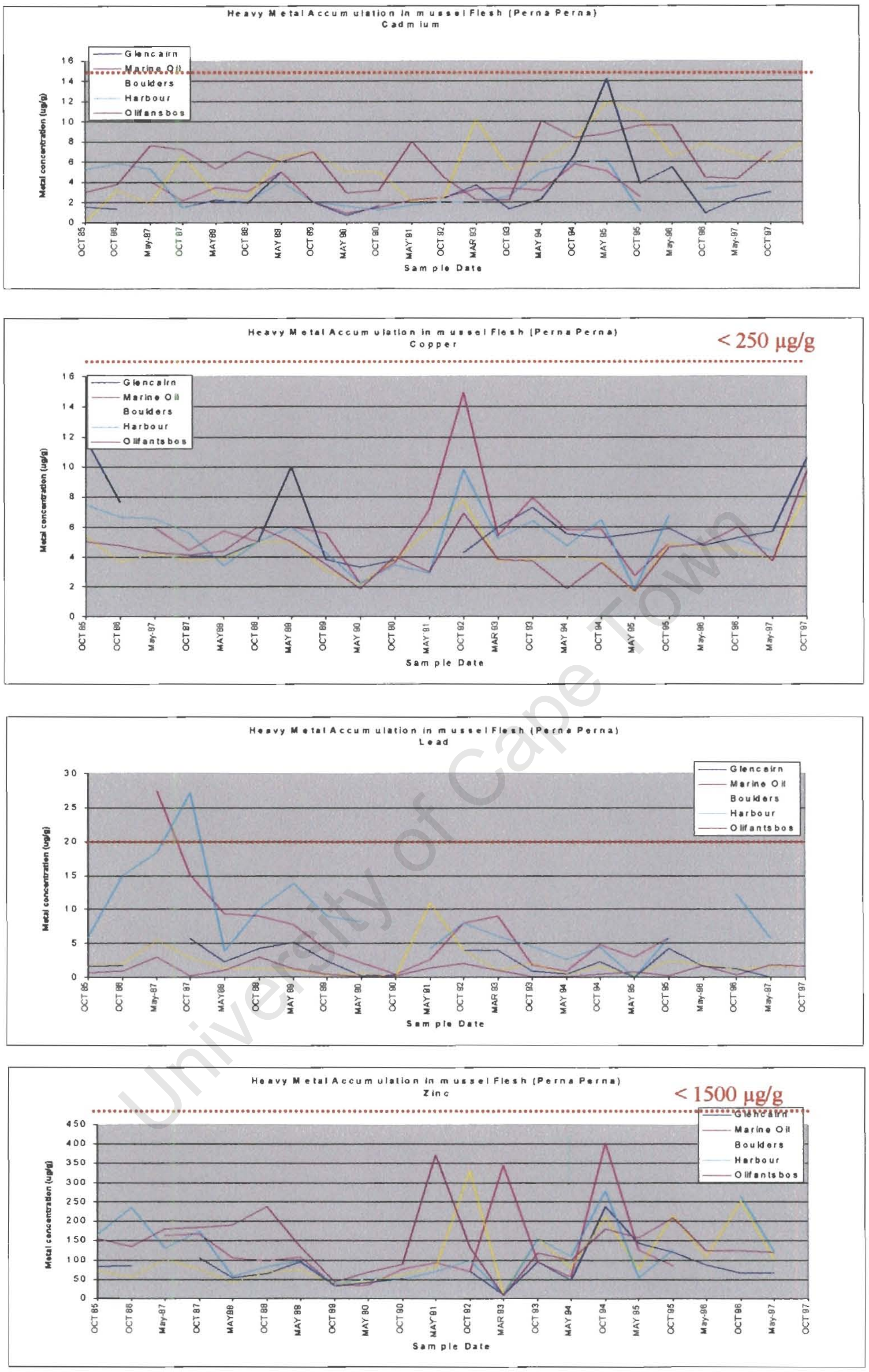


Figure 61 Time series plots of heavy metal accumulation of cadmium, copper, lead and zinc in the mussel tissue of *Perna Perna* from October 1985 to October 1997. Units are µg/g or Parts per Million. The broken red line represents levels safe for human consumption as defined in the

Copper (Cu) concentrations

Copper concentrations for Olifantsbos and Boulders were within 25 % of each other for 19 of the 22 sampling occasions (i.e. 86 % frequency occurrence) (Figure 61). All sites recorded minimum values during May 1990. Greatest copper concentration was recorded at the Marine Oil site during October 1992. On that occasion, all sites recorded a 13 year peak, exhibiting higher values than the preceding 7 years, since the start of the mussel watch program and greater than the following 5 years. The Glencairn site however was the exception, instead exhibiting higher values at the start with a maximum peak during May 89 for the same 13 year period, although data is missing for a part of the time series. A marked concentration increase occurred at all sites at the end of the data set during October 1997.

Lead (Pb) concentrations

Marine Oil and the Harbour sites exhibited higher concentrations of lead on 15 of the 17 occasions in which a comparison could be made (Figure 61). These two sites also showed similar trends throughout the 12-year recording period. The most notable signal for these two sites is the high values recorded at the start of the series from October 1985 to May 1989, with a distinctly declining trend. During this period, both sites recorded levels of lead from 5 μg/g to greater than 25 μg/g. Boulders exhibited a single significant peak during May 1991. This was followed about a 1½ years later (Oct 92 to Mar 93) by a peak in the other sites, especially Marine Oil and the Harbour. A visual interpretation of the graph suggests that the while all sites appeared to correlate somewhat, Boulders exhibited no apparent correlation with other sites. The Harbour site had the greatest short-term variation, with a concentration in excess of 25 μg/g to less than 5 μg/g in six months from October 1987 to May 1988. Olifansbos had the least concentration of lead for 16 of the 22 records (73 % frequency occurrence). Concentrations at Olifantsbos exceeded other sites for 2 of 22 records (9 % frequency occurrence).

Zinc (Pb) concentrations

Olifantsbos, Boulders and Marine Oil sites exhibited increases in zinc concentrations by a factor 3 to 4 over 6 months (Figure 61). This occurred twice during the sampling period at the Marine Oil site. These peaks occurred at differing times for each site from October 1990 to October 1994. The October 1994 peak however was notable by its consistent increasing signal observed at all sites by a factor of 7.5 and 13. Glencairn results were consistently low compared to the other sites, for the entire sampling period. Lowest readings were recorded for 10 of the 19 comparable samples (i.e. 53 % frequency occurrence). Olifansbos concentrations were consistently higher than at all other sites for 9 records between May 1987 and May 1991.This site also exhibited higher readings than at other sites on the most number of occasions. The Harbour site concentrations were higher than all other sites on 4 occasions and conversely lower than all other sites on 3 occasions. There appeared to be an increasing trend for all sites from March 1993 to May 1997.

Site specific measurements

	Cd	Cu	Pb	Zn	Hg	Fe	Mn
Glencairn							
Mean	3.09	5.79	2.39	81.59	0.11	78.60	7.18
Max	14.25	11.89	5.72	237.80	0.30	81.70	8.02
Min	0.70	3.31	0.00	11.10	0.00	75.50	6.34
std dev	4.05	2.18	1.98	62.26	0.10	2.97	0.80
Range	13.55	8.58	5.72	226.70	0.30	6.20	1.68
Observations	17	17	16	17	14	2	2
Marine Oil							
Mean	2.93	6.38	6.46	123.62	0.15	76.16	7.20
Max	5.75	15.08	27.44	403.30	0.37	n/a	n/a
Min	0.90	2.22	0.48	34.00	0.00	n/a	n/a
std dev	1.43	3.34	7.84	114.25	0.13	n/a	n/a
Range	4.85	12.86	26.96	369.30	0.37	n/a	n/a
Observations	17	17	17	17	16	1	1
Boulders							
Mean	5.84	4.18	2.11	107.35	0.08	135.25	3.28
Max	11.94	7.80	10.90	330.00	0.32	198.10	4.67
Min	1.88	1.61	0.14	11.70	0.00	72.40	1.89
std dev	2.96	1.51	3.13	94.52	0.10	60.17	1.33
Range	10.06	6.19	10.76	318.30	0.32	125.70	2.78
Observations	19	19	19	19	16	2	2
Naval Harbour Entrance							
Mean	3.22	5.21	8.68	118.47	0.13	153.15	3.61
Max	6.19	9.80	27.20	279.60	0.32	219.90	5.01
Min	1.04	1.83	0.00	9.90	0.00	86.40	2.21
std dev	1.73	2.10	7.53	78.79	0.11	63.91	1.34
Range	5.15	7.97	27.20	269.70	0.32	133.50	2.80
Observations	19	19	18	19	16	2	2
Olifantsbos							
Mean	6.01	4.39	1.02	145.55	0.07	157.60	2.48
Max	10.06	9.72	3.00	371.50	0.35	476.80	5.08
Min	2.20	1.71	0.10	7.80	0.00	63.55	0.74
std dev	15.51	4.26	4.30	97.49	3.82	112.31	1.23
Range	7.86	8.01	2.90	363.70	0.35	413.25	4.34
Observations	21	21	21	20	18	18	19
SABS Foodstuffs Requirements	15.0	250	20	1500	5	-	-

Table 13 Summarised statistics of heavy metal accumulation in mussel tissue of *Perna Perna*. Units are µg/g. SABS figures quoted are maximum levels for consumption of mussels as described in the South African Bureau of Standards Foodstuff Consumption and Disinfections act and regulations, Government Notice R1518 of 1994.

Glencairn – Refer to Table 13

Although the mean cadmium concentration (3.09 µg/g) was similar to the other sites, the maximum cadmium concentration (14.25 µg/g) was measured at Glencairn (Table 13). Conversely the minimum (0.70 µg/g) measured at all sites was also at Glencairn. This resulted in the largest (13.55 µg/g) data range for cadmium compared to all other sites.

Cadmium levels never exceeded the maximum allowable for human consumption at Glencairn.

Copper mean, maximum, minimum, std dev, and range values at Glencairn were all within the same data range as the other sites. Mean copper concentrations were higher at Glencairn than at Boulders and the Naval Harbour but lower than the Marine Oil site. The minimum copper concentration at Glencairn was higher than at any other site. Like all other sites, copper concentrations measured were always considerably below the maximum allowed for human consumption.

Mean lead concentrations at Glencairn (2.39 µg/g) were below Marine Oil and the Naval Harbour but marginally higher than at Boulders. Lead concentrations never exceeded the maximum allowed for human consumption, although data gaps did exist.

Zinc concentrations at Glencairn (81.59 µg/g) were significantly lower than at all the other sites and the maximum concentration detected was also lowest at Glencairn, with the lowest standard deviation (62.26 µg/g). On no occasion during the sampling period (19 observations) at Glencairn was the concentration of lead above the maximum allowed for human consumption.

Although the range of mercury (Hg) concentrations was lowest at Glencairn, the means and other statistical values were similar to those found at the other sites. Like all other sites, mercury concentrations measured were always below the maximum allowed for human consumption.

Mean iron (Fe) and Manganese (Mn) concentrations at Glencairn were marginally higher than at Marine Oil, while both were considerably lower than at the other sites.

The small dataset for Fe and Mn should be taken into account in any findings.

Marine Oil – Refer to Table 13

Samples taken from the Marine Oil site exhibited the lowest mean Cadmium reading (2.93 µg/g) than all other sites (Table 13). The site never exhibited concentrations of cadmium exceeding the maximum allowed for human consumption.

Mean copper concentrations (6.38 µg/g) were higher at Marine Oil that at all the other sites. Like all other sites, copper concentrations measured were always below the maximum allowed for human consumption.

Mean zinc concentrations (123.62 µg/g) were higher at Marine Oil that at all the other sites, however concentrations measured were always below the maximum allowed for human consumption during the sampling period.

There appeared to be an overall decline in lead concentrations for the sampling period. On a single occasion, during May 1987, the lead concentration at Marine Oil exceeded those allowed for human consumption.

The mean mercury concentration (0.15 µg/g) was however highest at Marine Oil than at all other sites. The same applied to the maximum, minimum and range values measured for copper and zinc. Like all other sites, mercury concentrations measured were always below the maximum allowed for human consumption.

Iron and Manganese samples were too few to be used in any of these findings.

Boulders – Refer to Table 13

The mean concentration of cadmium (5.84 µg/g) at Boulders was highest than at all other sites (Table 13). Boulders never exhibited concentrations of cadmium exceeding the maximum allowed for human consumption. The mean concentration of cadmium (5.84 µg/g) was highest at Boulders than at all the other sites.

The mean copper concentration (4.18 µg/g) at Boulders was lower than at all the other sites. Like all other sites, copper concentrations measured were always below the maximum allowed for human consumption.

The mean lead concentration at boulders was 2.11 µg/g. Although the Boulders site exhibited lowest lead concentrations in the bay, these values were higher than those measured at the control site at Olifanstsbos.

The mean zinc concentration at Boulders was 107.35 µg/g. Levels exceeding the consumption maximum never occurred.

The mean mercury concentration (0.08 µg/g) was lowest at Boulders than at the other sites, never exceeding the maximum allowed for consumption during the measurement period.

Iron and Manganese samples were too few to be used in any of these findings.

Naval Harbour entrance – Refer to Table 13

The mean lead and zinc concentrations (8.68 µg/g and 118.47 µg/g respectively) were highest at the Naval Harbour than all other sites. The range of data recorded for lead at this site was also higher than at the other sites. There appeared to be an overall decline in lead concentrations for the sampling period. On a single occasion, during October 1987, the lead concentration at the Naval Harbour entrance exceeded those allowed for human consumption.
All other heavy metal concentrations were within the ranges of those at the other sites.

Iron and Manganese samples were too few to be used in any of these findings.

Chapter 4 – Discussion

Currents

Figures 62 – 66 are qualitative representations of the flow in the West Basin. They are intended as graphical tools to depict general flow characteristics related to dynamic forcing mechanisms such as winds and tides.

Harbour Currents - West Basin

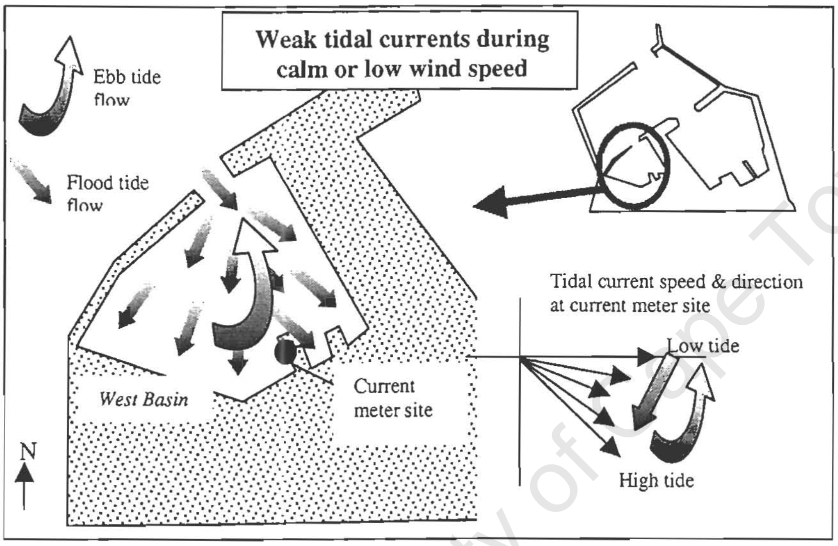


Figure 62 Pictorial representation of weak tidal currents in the West Basin during calm or low wind speed conditions.

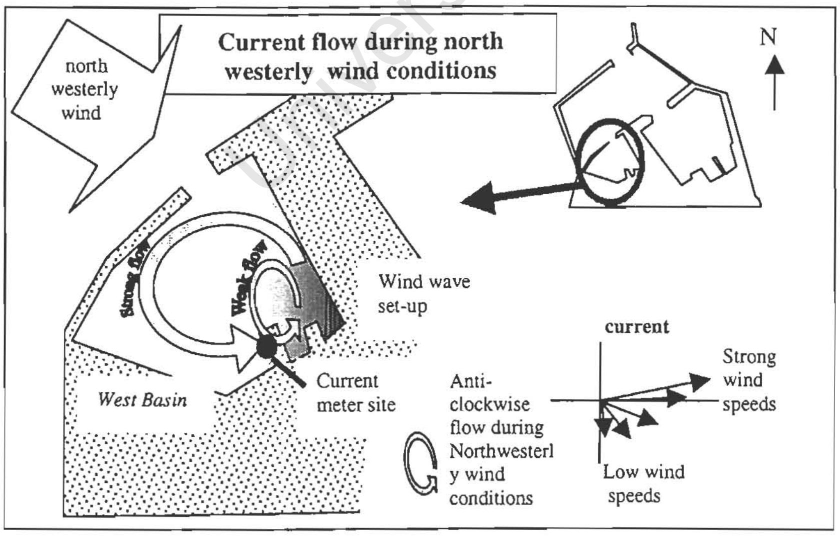


Figure 63 Pictorial representation of currents in the West Basin during north westerly wind conditions

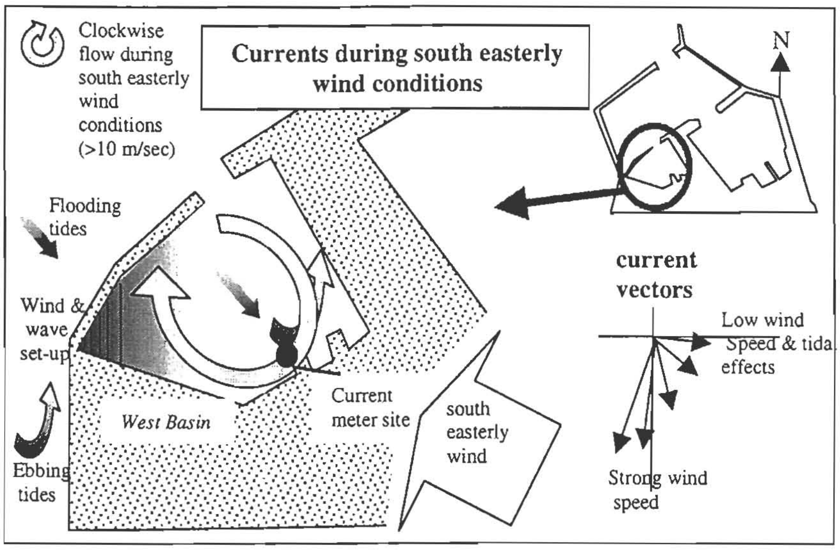


Figure 64 Pictorial representation of currents in the West Basin during south easterly wind conditions

Currents measured in the Harbour basin were weak. No flow occurred in the arc from northwest to northeast, indicating that flow always followed the shape of the basin. The current speeds were evenly distributed across the direction ranges and SSW currents were generally strongest while easterly currents were weakest. Tidal flow was not clearly evident above the instrument noise. Weak clockwise wind-driven south to southwesterly flow dominated, resulting from strong persistent southerly easterly winds, interspersed by weaker anti clockwise southeast flow from northwesterly winds (Figure 62 - 64).

The Oceanic Region and Small Craft Harbour

Vector components revealed positive values throughout the Small Craft Harbour series, indicating that clockwise flow predominated (Figure 65). Tidal Flow was weak, insignificant and easily masked by wind driven current flow. These wind driven currents accounted for the major flow fluctuations and easily dominated during persistent southerly component wind events exceeding 10 m/sec.

The mean flow in the Oceanic region was not measured during this study for the entire water column. In another project conducted by IMT (Wainman 1996) for the South African Navy, current meter data were collected from a site about 5 km NE of Roman Rocks, from 23 December 1992 to 8 March 1993 and from 26 August 1993 to 13 October 1993 at 17 m and 19 m depth respectively, in a water depth of 34 m.

Flow was predominantly southerly and northerly without calms. Current speeds greater than 10 cm/sec occurred for 5 % of the time spread evenly between northern and southern sectors, while the predominant speeds were 4 - 6 cm/sec occurring in all sectors.

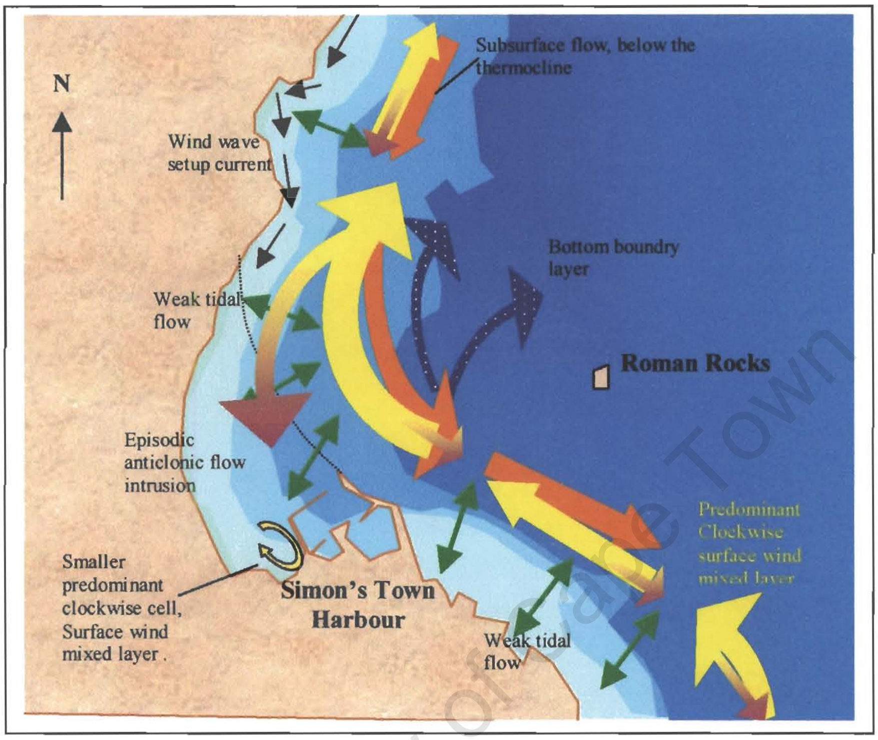


Figure 65 Pictorial representation of the major currents in the Oceanic region surrounding Simons Bay Although the data has not been presented as part of this study, the results are discussed briefly below.

Although tidal currents were noticed at times in the oceanic region, they did not appear to be the primary flow, instead current changes from the stronger flow occurred every 2, 4 and 7 days. The overall displacement at this site after 48 days was 5.25 km towards the NNE sector, inclusive of 13.75 km towards the north and 11.25 km towards the South.

The displacements mentioned above are however critically linked to the instrument depth (18 m in this case) and appeared NNE and polarized most likely due to the fluctuation of the intensity of the surface wind mixed layer. It can therefore be assumed that the record displayed both surface and bottom water characteristics at varying times. Surface oceanic water therefore flows past Simon's Bay mostly following the depth contours and in a clockwise direction. In this mode, excluding tides and upwelling, minimal mixing occurred within the harbour regions in Simon's Bay, and the oceanic dynamics did not appear to contribute to flushing of the protected harbour waters in any way. The proportion of clockwise flow regime vs the anti-clockwise flow has yet to be established.

Summary

Since weak currents were measured in Simon's Bay, tidal water exchange with the greater False Bay was minimal. Tidal currents were easily masked by stronger wind driven currents. Currents (more explicitly bay water exchange) by themselves, were not observed as the dominant process for sustaining an acceptable level of water quality in Simon's Bay, and, water exchange occurred sporadically, forced by the dynamics of False Bay. Since currents have not primarily been responsible for significant water exchange in Simon's Bay, two factors are likely to have benefited the quality of water in the region.

- Weak flow has probably resulted in minimal "external" inflow to Simon's Bay, thereby reducing the likelihood of potential pollution from surrounding water e.g. from the more densely populated northern False Bay coastline.
- The predominant clockwise flow of the surface wind mixed layer from the greater False Bay, which passes Simon's Bay from south to north has supplied South Atlantic oceanic water to the region via the predominantly "natural" (low human impact) coastline from Cape Point. Simon's Bay has therefore received mostly unpolluted water into the region, contributing to the natural biological health of the system.

These descriptions of the flow however are limited to surface layers, usually above the thermocline. The measurement depths were 6 m for the Annie-K site and 1 m for the Town Jetty. From other ADCP measurements taken at the harbour and north of the Annie-K site, it was evident that two opposing flow regimes existed, usually with a shear at 6 m. This appeared to apply to the surrounding oceanic region as well.

Harbour Flushing

From the ADCP results, the Naval Harbour flow was conveniently categorised as (a) surface layer between 0-2 m, (b) intermediate surface layer at 3 m, (c) shear layer at 4-5 m, (d) core layer 6-16 m and (e) bottom boundary layer 16 – 19 m. Flow properties at these layers varied in both duration and strength. At the surface, moderate strength currents occurred during southerly flow (i.e. entering the harbour) for 91 % of the measurement period. The strength of the flow was stronger during southerly than during northerly flow events. Speeds were also considerably stronger at this surface layer than at depth (Table 6). The greatest current shear occurred at 2 m - 4 m below the surface at all times. The 'core' subsurface layer, defined as having similar flow characteristics from the time series plot, occurred between 6 m and 16 m. This layer represented a large entrance volume, proportionally, and therefore exhibited rather weak currents in order to compensate for the stronger flowing 'thin' surface layers. This core subsurface layer alternated between northerly and southerly flow with a periodicity of 10 minutes to 4 hours. A distinct pattern of strong consistent currents and weak variable currents was evident. Northerly flowing water leaving the harbour and not reaching the full length of the harbour wall appeared to either be flushed back into the harbour or partly forced into the Small Craft Moorings towards Long Beach by weak tidal currents.

During episodic anti-clockwise flow in the oceanic region, water originating from the Naval Harbour can be expected to mix with the surrounding oceanic water while spreading offshore and south-eastwards past the northern extent of the harbour wall.

The strong northwesterly storm event that occurred during this study, produced a strong wind driven current that entered the harbour in the upper 6 m layer at a mean speed of 193 cm/sec for the upper 2 m sampling layer, decreasing quickly to 2.9 cm/sec at 6 m water depth. This intense wind mixed layer resulted in considerably quicker flushing of the harbour. During these conditions the harbour was flushed within 20 hrs, compared with 73 hours as calculated for tidal flushing. Wind driven circulation is therefore an important water flushing mechanisms for the harbour, increasing horizontal and vertical mixing and dispersion. This factor has probably significantly contributed to the sustained natural (background) dissolved constituent levels found in Simon's Bay.

Tides and Sea Level

In many other coastal habitats, the exchange of seawater is dominated by tidal stream ebbing and flooding currents, particulary those areas that have large tidal ranges. Simon's Bay has a low tidal range. The maximum excursion between Mean Low Water Springs (MLWS) and Highest Astronomical Tide (HAT) is (2.09 - 0.24) m. The bay bathymetry and topography dictates that the vertical tidal range is not manifested as a large horizontal excursion and Simon's Bay has a small tidal range. The coastal tidal extent or tidal prism (the volume of water displaced during a change of tide) is greatest in the Small Craft Harbour due to the moderate sloping nature of the seafloor. This region therefore experiences the some tidal flow, as seen in the current meter records, but current speeds are generally weak. Water is **not** flooded and ebbed across a wide shallow bay or estuary as is sometimes the case in other coastal habitats. In contrast, the tidal range of the harbour basins is minimal, as result of their steep vertical walls.

Tidal flow was insignificant and water exchange was dominated by wind driven flow. However, weak tidal currents probably exist in the intertidal zone, close to the shore, and assist with the onshore/offshore transportation of surface waters, dilution and mixing. Low tidal ranges in Simon's Bay, means that the area does not depend on tidal flow for water exchange.

The sea level perturbations observed in this study (residuals of up to 30 cm) in association with a prior pulse of cold nutrient rich water correlated with significant influence on the physico-chemical results. These residuals are indicative of external forcing mechanisms from False Bay that appear to have originated from recently upwelled bottom water was from central False Bay, advected into Simon's Bay primarily by currents induced by local winds as a Coastal Trapped Wave (CTW). This was detected as a fall and rise in the residual as noticed on the 17/3/99, accompanied by significant water property changes that lasted three days (Figure 56 and 57). It is thought that the regular flushing of Simon's Bay through such a process has significantly contributed to the sustained natural dissolved constituent levels and water properties of the region. Its indirect effect on the water constituents is important in assisting or characterising natural phytoplankton blooms.

Physico-chemical Properties

The physico-chemical measurements taken in the surface wind mixed layer, to a depth of 2 m, serve as a useful tool in terms of a spatial comparison. When used with the nutrients results, the physical processes and resulting water quality criteria can be interpreted. The S A Water Quality Guidelines differentiate between physico-chemical properties, nutrients and inorganic constituents. The former two were focal to this part of the study. The physico-chemical properties measurements made in the sun warmed mixed layer and nutrient determinations made in different regions/areas/zones mean that physical processes and water quality criteria can be interpreted in context.

Mean sea temperatures of the upper mixed layer (2 m) in both the Naval Harbour and the Small Craft Harbour were warmer than the surrounding Oceanic region, while temperatures in the Naval Harbour were warmer than in the adjacent Small Craft Harbour. Solar heating and shallow depth is the main cause of warmer water in the harbour. The only possible anthropogenic source of heating is engine coolant water of the ships used in the harbour, although due to the 'low' key shipping activities, these are not thought to contribute significantly to the heating in the area. Increased temperatures reduce the dissolved oxygen capacity of the water. This can be seen in the lower levels of dissolved oxygen and saturation seen in these areas when compared to the surrounding Oceanic region. This implies that temperature and dissolved oxygen values have been somewhat modified by the overall altered bay layout. Values of both temperature and dissolved oxygen are still however within the target values as described in the SA Water Quality Guidelines.

No significant variability in salinity concentrations were detected and all stations were within the limits recommended in the SA Water Quality Guidelines.

All physio-chemical properties of the seawater in Simon's Bay were close to the background natural level, during the study period, indicating that the areas is biologically healthy.

Water Quality Constituents

Nitrates

Nitrate means and maxima were found to be 20 % to 30 % higher in the Bottom waters of the Oceanic region compared to the Naval and Small Craft Harbour (Table 9). Mean values for all regions were higher in the bottom waters than the surface. The Oceanic region bottom water also accounted for most of the variability in the data with the Naval Harbour exhibiting the least variability. Anthropogenic sources of nitrate usually originate from sewage discharges, agricultural runoff and septic tank seepage. All nitrate values measured during this study period, are similar to the ambient values indicated in the SA Water Quality Guidelines.

Nitrites

Mean nitrite values were found to be generally low (Table 9). Anthropogenic sources of nitrite usually originate from sewage discharges, agricultural runoff and septic tank seepage. All nitrite values measured during this study period, are similar to the natural background values indicated in the SA Water Quality Guidelines.

Ammonium

Ammonium concentrations from bottom samples in the Naval Harbour were consistent with those measured by (de Chalain 1979) at the harbour entrance. The Naval Harbour surface water exhibited the lowest surface values, 4 times less than the Small Craft Harbour. The Small Craft Harbour was the only region where the surface ammonium values were higher than those at the bottom (Table 9).

Ammonium values in the Small Craft Harbour were 10% to 11% higher than the recommended natural excedence value (SA Water Quality Guidelines). A mean of 5.5 µg/l occurred in the Small Harbour (Table 9). The South African Water Quality Guidelines for Coastal Marine Waters (Department of Water Affairs and Forestry 1995) state that "*In oxygenated unpolluted seawater ammonium rarely exceeds 5 µg-*

at/l". Higher readings for the Small Craft Harbour are reflected in the mean, maximum and standard deviation. The sample size was however small, compared to the Naval Harbour (Table 9). The result therefore also represents a single snap shot of the area. The raised values are of a cause for concern, unless a longer sampling programme can demonstrate that ammonium values are lower. Anthropogenic sources of ammonium usually originate from sewage discharges, agricultural runoff and septic tank seepage. Sewage is the single highest source of liquid pollution in the area, originating from the municipal out-fall (in the northern part of Simon's Bay), yachts and sewage pump failures or pipeline breakages. Microbiological results of sampling conducted by the Cape Metropolitan Council in the area over many years show that Simon's Bay water quality is very similar to most other sites sampled in False Bay for recreational purposes (suitable for recreation for a large proportion of samples collected). It is not known however, to what extent nutrient loading may be occurring in the Small Craft Harbour, aided by weak currents, anthropogenic input (yachting activities, runoff etc.), wind shear and reduced vertical mixing. This topic merits further research.

Phosphates

All phosphate means were lower than the natural West Coast average of 1.71µg-at/l (Table 9). Anthropogenic sources of phosphate usually originate from sewage discharges (including detergents), certain manufacturing and plating waste products, agricultural runoff and dairy farm runoff. No evidence of anthropogenic input of phosphates was found in any of the three areas. Since all regions have values less than the natural background West Coast and South Coast values (SA Water Quality Guidelines) it can be assumed that no significant phosphate enriched pollution exists in Simon's Bay.

Silicates

Silicate values measured in Simon's Bay are more indicative of South Coast water properties and in most cases about half the concentration of silicates found on the West coast (Table 9). Although the mean values were all within those given for the South and West coasts, raised maxima, standard deviation and range was noticed in the surface waters of the Naval Harbour and Small Craft Harbour when compared to the surrounding Oceanic region. These increased levels may require further monitoring in future. No indication of anthropogenic silicate sources are given in SA Water Quality guidelines.

Dissolved Oxygen

Dissolved oxygen is considered a non-conservative variable of surface water. Its natural levels (% saturation) are largely governed by temperature/salinity and further modified by organic content (SA Water Quality Guidelines). It can be used as a valuable tracer for biological and chemical processes occurring in the sea (Grasshoff et al. 1983). It serves to characterise and index the biological history of water such as circulation and mixing processes (Drew 1999). Gaseous exchange (including oxygen) by molecular diffusion occurs at the sea/air interface and is enhanced by wave action. "*The concentration and dispersion of oxygen in the sea is controlled by the solubility of oxygen gas in the water and by interplay between biological processes*" (Drew 1999). Dissolved oxygen is supplemented through photosynthesis of plant material, while oxygen uptake occurs during respiration. Sediment uptake of oxygen is thought to consist of:- Biological oxygen demand (BOD), chemical oxygen demand (COD) and absorbed oxygen (AO) (Drew (1999), SA Water Quality Guidelines).

Results from this study show that reduced dissolved oxygen concentrations existed in the Naval Harbour and Small Craft Harbour. While the absolute values are difficult to judge due to complex biological interplay and physical processes that existed at that time, the results were less than those published in the SA Water quality Guidelines for natural water. Whereas mean dissolved oxygen values of 6.97 and 6.92 mg/l (for the 2m surface layer) were measured in this study in the Naval and small Craft Harbours respectively (Table 7) these figures are less than 8.135-7.976 mg/l quoted in the SA Water Quality Guidelines for the equivalent salinity and temperature values measured in the both harbours (Table 7). Values recorded in the Oceanic region (8.18 mg/l) compared with those from the Guidelines. Reduced wind shear and hence reduced vertical mixing, associated with the harbour regions of Simons's Bay is thought to be the main cause of such reduced dissolved oxygen values and merits further research.

Reduced dissolved oxygen concentrations in the 'enclosed' harbour regions of Simon's Bay do not appear to have impacted negatively on the water quality of region. Although these areas of reduced vertical mixing occur, they are frequently flushed by the local forcing mechanisms of False Bay such as Coastal Trapped Waves, advection and episodic wind driven currents, and do not at present appear to pose a risk to the Fauna or Flora of Simon's Bay.

Salinity

Low salinities are usually associated with cold upwelled water. The surface water of the Oceanic region was found to be 0.03 PSU fresher than the Naval Harbour and 0.04 PSU fresher than the Small Craft Harbour (Table 7). This is further evidence of the restricted basin flows experienced. The seasonal small river that flows into the Small Craft Harbour did not flow during this study and therfore it's effect on the hydrodrography of the Small Craft Harbour is not yet clear, although this is not expected to be significant for most of the year.

Chlorophyll-a

There was no evidence of eutrophication in any of the three regions.
Mean chlorophyll values were relatively low and there was little spatial variability in chlorophyll-a readings. There was slightly wider range of values, with a higher maximum and a lower minimum in the Naval Harbour than the other surrounding regions. The results show that patches of slightly higher chlorophyll water occur in the Naval Harbour (Table 10 and 11).

Sediments

Although sediment samples were not actually collected during this investigation, the importance of sourcing and relating two previous unpublished works to this rather general study of water quality in Simon's Bay is pertinent. Especially in the light of the rarity of the data and the SA Defence force ownership of such results. Although work is underway to categorise sediments according to their heavy metal concentrations (personal communication Dr L Jackson), this has been only for purposes of sediment removal and spoil (London Convention 1999 in draft). The

NOAA guidelines may be more applicable and should therefore be investigated further.

From the detailed sampling undertaken in the Naval Harbour during 1991, concentrations of copper exceeded the cautionary and prohibition levels at all sites. Results were similar for lead and sediment pollution for the other heavy metals was less than copper and lead. No clear picture emerged when comparing concentrations in the harbour with the surrounding sites. Except for copper, lead, zinc and iron, that exhibited distinctly higher concentrations in the harbour.

Cautionary and prohibition levels for copper, lead, zinc, chromium, nickel an arsenic relating to sediment removal and replacement were exceeded in some areas. These are indicative of the industrial nature of the Naval harbour and most cases, high concentrations appear to have been 'contained' by the harbour. Although the sediment biota measurements through abundance biomass comparisons indicate a healthy biomass in the harbour and surrounds, this is only one way of measuring such health and other methods should also be investigated.

In summary, pollution loading of heavy metals has occurred in the sediments in some regions of the Naval harbour, but has been confined to those regions and does not appear to have severely affected the biota of the harbour and immediate surrounds.

Mussel Watch Programme

Safe concentrations of metals in mussels from these methods have not been clearly established as environmental indicators. Further complicated by local conditions, mussel physiology, reproductive state, species differences, depth, temperature, salinity, temporal trends and age and size of the mussel (Kramer 1994).
From extensive sampling conducted in the USA, trends in concentrations are usually not detected and those that are detected are a decrease. As the number of samples collected over time increases, it is expected that trends will be detected (Kramer 1994). The same can be said for the results presented for Simon's Bay. The only exception being the reduction in levels of lead detected at the Harbour and Marine Oil sites.

One method of determining safe concentrations is to compare the heavy metal concentrations from the mussel watch programme with levels allowed by the South African Bureau of Standards (SABS) for human consumption of similar seafood. Levels quoted for wet mass are (units are PPM or µg/g):- Copper 50.0 (wet mass), 250.0 (dry mass), Mercury 1.0 (wet mass), 5.0 (dry mass), Cadmium 3.0 (wet mass,15.0 (dry mass), Arsenic 3.0 (wet mass), 15.0 (dry mass), Lead 4.0 (wet mass), 20.0 (dry mass), Zinc 300 (wet mass), 1500 (dry mass) and Tin 40 (wet mass), 200 (dry mass). (Foodstuffs, cosmetics and disinfectants Act, 1972, Government Notice R1518 of 1994.) However the mussels sampled in the Mussel Watch programme are analysed for **dry mass** and therefore the SABS regulations require a factor of 5 increase for comparison purposes. This factor takes into account the fact that soft animal tissue consists of 80% water (personal communication, S Taljaard, CSIR referred to work by Brown 1996).

When comparing the levels measured against those permitted for human consumption, Lead exceeded the allowed level at two sites (Naval Harbour Entrance and Marine Oil on both occasions during 1987).

Naturally occurring poisons

With increased globalisation of shipping, and the resulting possibility of phytoplankton spores being transported from infected waters in ships' ballast tanks, toxic bloom outbreaks may increase in Simon's Bay. This is further fueled by the possibility of eutrophication from erosion, accidental sewage spillages and seepage resulting from increased population growth in the area. .

Chapter 5 – Conclusions

The confined sea and coastline of Simon's Bay has maintained its good water quality, and, the array of diverse impacts did not pose an environmental threat to the region. Wind, water circulation and remote forcing effects are important physical processes in Simon's Bay which have resulted in sufficient mixing with the greater False Bay to maintain a biologically healthy system The area is influenced by the dynamics of False Bay, while Simon's Bay does not appear to have contributed towards any significant pollution in the bay. Water in the confined harbour regions flushed adequately with the surrounding False Bay so that natural background values were maintained. Human impacts on water quality were minimal as evidenced from the water quality and Mussel Watch results. Although high concentrations of certain heavy metals were noticed in the sediments within the harbour, these appear to have accumulated in the sediment with no impact on the biota. Negative impacts were not detected in the water column above these sediments. However the weak circulation of the region implies that the area is more sensitive to pollutant loading than other more exposed bays of South Africa.

The coastline was modified by the construction of the harbour, which appears to have restricted the exchange of water from Simon's Bay to False Bay and created areas of reduced wind shear, resulting in reduced vertical mixing. These negative impacts are likely to have caused the area to be more vulnerable to human induced pollution. However, anthropogenic input to date appears to have been sustainable. Wind mixing, wind induced currents and other external forcing mechanisms have been critical in maintaining this balance. The wind protected regions such as the Small Craft harbour, however, exhibited lower dissolved oxygen concentrations and increased ammonium concentrations when compared to the surrounding False Bay, indicating that a degree of sensitivity exists, which should be monitored.

These water quality variables and procedures can be used as baselines for other similar harbours.

Dynamics

The Naval Harbour

The lack of a tidal signal in the current meter records well inside the Naval Harbour at 5 m depth is an indication that flow in those regions is governed by the larger scale local forcing mechanisms. This helps to simplify a potential complex interaction of continental shelf waves, local wind forcing and the surrounding bay circulation, each with it's own variability and complexity. Small scale eddies, not resolved as part of this study, probably exist within the harbour, especially during prolonged wind events and an ebbing or flooding tide. Although the currents were generally weak, wind driven currents during storm conditions at the harbour entrance were significant and have likely been an important flushing mechanism for sustained water quality. The absence of calm conditions for the measurement period, was significant in aiding dispersion and mixing within each basin. Flow directions in the West Basin were distinctly nodal about the 135 and 247 degree axis. These flow directions were parallel to the nearby harbour wall and since no large underwater obstructions exist in this basin, the assumption is made that flow was generally clockwise as a result of wind driven currents.

It is noteworthy that the current meter temperature record showed warming co-incided with the onset of clockwise flow and developing southeasterly wind conditions. Cooling occurred with the cessation of south easterly or developing north-westerly winds.

Small Craft Harbour

From the current meter records at the Annie-K site and Town Jetty, the Small Craft Harbour was also minimally affected by tidal fluctuations. As with the Naval Harbour, low frequency current changes were noted, not necessarily co-inciding with the local wind patterns. These significant current fluctuations can only be attributed to large scale forcing mechanisms such as Coastal Trapped Waves. The wide opening of the Small Craft Harbour, from the harbour wall to Lower North Battery, results in a less inhibited flow of water than in the Naval Harbour, where the dynamics behaved more like a closed system, being more susceptible to the local wind effect and flushed often. This has both water quality benefits and drawbacks. The larger opening to False Bay means that diffusion and mixing is improved in the Small Craft Harbour by this unhindered water access (the downside is that pollutants are more difficult to contain), although the observed lower dissolved oxygen values negate this proposition. The large opening of the Small Craft Harbour has contributed to sustained water quality.

Lowered dissolved oxygen values in the Small Craft Harbour were not associated with increased residence times, decreased temperatures or decreased salinity as may be expected, other circumstances (stormwater run-off, sewage discharges or certain industrial waste) or reduced vertical wind mixing are thought to be responsible.

All current measurements were recorded at 6 m-9 m and shallower, no seafloor current record therefore exists for this initial study period. From recent ADCP measurements collected at the entrance to the Naval Harbour, and in the Small Craft Harbour (van der Riet Duckitt 1999), evidence exists of a current shear at about 4 to 6 m below the surface. This resulted in a two-layer system with distinctly differing flow characteristics, which has likely benefited the region through increased mixing and water exchange. A thorough understanding of the characteristics and dynamics of these layers is required in the context of understanding the fate of pollutants and the underlying water quality issues.

Tides played a lesser role in the greater circulation of the water in Simon's Bay, due to the limited tidal excursion in Simon's Bay, in the littoral zone however, tidal currents create small scale eddies which results in turbulent diffusion and mixing. This effect was evident as a weak tidal signal at the Town Jetty.

During calm wind conditions, tidal fluctuations provided a weak, driving force, however, sea level fluctuations, after subtracting the tidal effect occurred, without a clear indication of their cause. This primary study made use of synoptic weather charts to assess the impact of weather (changes in atmospheric pressure) on sea level and the meteorological effect over this period was considered insignificant. It is intended to use detailed local atmospheric data in a planned future study. It is thought that these perturbations are important in understanding the dynamics of the area in relation to the wider False Bay and greater maritime region. Evidence from this study, such as nutrient, density, pH, temperature and dissolved oxygen changes suggested that these sea level perturbations were closely related to mixing, advection and hence primary production. This single factor merits further research.

From the ADCP results, a better understanding of the water column in Simon's Bay was achieved. It was first thought that the system was 2-layered, separated by a thermocline. It was found however, that at depth (>15 m), the system was sometimes separated into 3 layers. The major layers were the surface wind mixed layer, which either existed due to the preceding wind event according to fetch, strength and duration or was entirely absent due to an extremely shallow thermocline. This layer was sometimes extensive, extending briefly to the seafloor at 20 m. The interface at the next deeper layer coinsided with the thermocline, below which the water was usually cooler, slightly less saline and hence more dense. A distinctive difference between the layers was the often opposing or varying current directions as was shown from the ADCP results. The deepest layer was the bottom boundary layer, which was a thin bottom layer usually between 0.5 m and 3 m above the seabed. Current meter work conducted on the seafloor at the harbour entrance at 20 m water depth has confirmed the existence of this layer (Wainman & Gildenhuys 1998). The flow was found to be considerably weaker than the surface layer, but with a similar direction. Currents flowing north and northeastwards, along the surrounding bathymetry at 1-4 cm/sec typically occurred. Strongest currents were measured during spring (October to December). The spatial extent and significance of this boundary layer in Simon's Bay has not yet been thoroughly investigated. The bottom boundry layer dynamics are important when considering sediment transport and dispersal mechanisms. This is especially relevant to harbour dredging, dumping, and point source pollution sources on the seabed, such as sewage outfall.

The sewage outfall near the northern shores is close to the Lower North battery and has been in operation for many years. Although this was not investigated in detail, preliminary findings indicate that that this treated effluent is carried away towards the north on most occasions. The main reason for this is that the outfall site is sufficiently far northwards in Simon's Bay, within the greater False Bay clockwise /anticlockwise flow pattern. No evidence of eutrophication (excessive levels of nitrate, phosphate and ammonium (NH^4)) was noticed from the sites sampled near the outfall.

Oceanic Region

The spatial extent of the Oceanic region sampled during this study, represented an area about 12 times the size of the Naval Harbour and 4 times that of the Small Craft Harbour. Oceanic results represented the mesoscale portray the characteristics of the water of the north-western False Bay. Oceanic surface water at 1-2 m depth was 1.2 °C cooler than the Naval Harbour and 0.3 °C cooler than the Small Craft Harbour, implying that areas of pronounced entrapment such as the Naval Harbour has resulted in some local heating, whereas the Small Craft Harbour is less affected. This is supported in the dissolved oxygen results where minimal temperature and salinity differences (factors which affect the % concentration in seawater) were seen between the Oceanic and Small Craft harbour and yet dissolved oxygen differences were significant for surface water (1-2 m), implying that water exchange took place between the Oceanic and Small Craft Harbour, but that other circumstances altered the dissolved oxygen concentrations in that basin.

Oceanic water in the north-western corner of False Bay flowed along the axis of the depth contours, more frequently towards the north than the south. Flow often switched 180° and resulted in water that was returned close to its origin. This resulted in a pulsed clockwise and anticlockwise flow, with minimal displacement of water from each reciprocal flow change. Water therefore appeared to remain resident in the north western corner of False Bay for extensive periods of time, with a resultant displacement of about 4 km /day. This low displacement is not typical of False Bay. Progressive vectors at 6 other sites throughout False Bay showed significantly more vector displacement (Wainman 1996). No one has thus far resolved the circulation of False Bay. Results from this study suggested that: The water in the northwestern corner of False Bay originates mainly from the western entrance of False Bay via a through-flow between Whittle Rock and Miller's Point. Upon arriving, the water may remain resident for 2-3 days, to within 4 km of Simon's Bay. Thereafter it is destined for Seal Island at slow reciprocal north south pulsing rates.
Then flushed south-eastwards towards the eastern side of the mouth of False Bay. Mechanisms already identified by Jury (1991) assist in describing this eastern False Bay circulation, such as reduced surface wind stress offered by the downslope jet,

wind wake, the opening of the expansion fan and additional forcing from the localised western pressure ridge.

Water Quality Constituents

Water quality constituents were measured in Simon's Bay viz. nitrates, nitrites, phosphates, pH, dissolved oxygen, temperature, chlorophyll-a and ammonium. The Oceanic, Naval Harbour and Small Craft Harbour results were compared after extensive sampling of each region 3 times over a 10-day period.

Water in the Naval Harbour was found to be very healthy by industrial standards, completely acceptable for recreational purposes and in most cases within the target required for natural waters. This result is encouraging, however, complacency within a entrapped ecosystem is short sighted and the area should be monitored. A baseline now exists for future comparisons.

No previous published benchmark/baseline water quality values exist for Simon's Bay, however, of note is the work conducted by de Chalain (1979). As part of his biofouling investigations, nutrient sampling was conducted in the region for a 10-month period and is useful here in comparing these results. From de Chalain's (1979) work, all constituents measured 1m above the seabed, at 3 sites, exhibited lower variability between July and November. Extensive variability in the signal was noticed for nitrate, ammonia and silicate between January and July. It is now thought that the latter period is likely to be concomitant with the passages of Coastal Trapped Waves. No samples were collected during November and December. This recent study supercedes de Chalian's (1979) monitoring and can be considered the being the latest water quality status for Simon's Bay

When comparing the results with the targeted values as described in the SA Water Quality Guidelines, ammonium values in the Small Craft Harbour were found to be above the target value for the natural environment. The Small Craft Harbour was the only area where the mean surface values exceeded the bottom values. The same inversion was observed when comparing the surface and bottom chlorophyll-a values, however note that bottom samples were collected within the euphotic zone as secchi depths extended to the seafloor. This seemingly anonmolous situation should be further invetsigated. Daily surface and bottom values at the Annie-K site for the sampling period were identical and within the target ammonium value recommended by the SA Water Quality Guidelines. For the rest of the Small Craft region, both surface and bottom values were within the recommended target value as described in the South African Water Quality Guidelines for Coastal Marine Waters (Department of Water Affairs and Forestry 1995) for natural waters.

The source of the higher ammonium in the Small Craft Harbour has not been established in this report. However, it may be due to the regions' reduced circulation and compounded by anthropogenic inputs.

Oxygen consumption is the net result of biological oxygen demand (BOD), chemical oxygen demand (COD) and absorbed oxygen (AO) (Drew 1999). Although the oxygen values measured in the Small Craft Harbour, were within the SA Water Quality Guidelines for natural waters, the 1.26 mg/l difference between the Oceanic and Small Craft Harbour surface waters (1-2 m) was significant. The dissolved oxygen of water is a non-conservative property and its solubility is largely dependent on salinity and temperature (SA Water Quality Guidelines), which were similar in all regions. Since, lowered dissolved oxygen values in the Small Craft Harbour do not appear to be associated with increased residence times, decreased temperatures or decreased salinity as may be expected, other circumstances (stormwater run-off, sewage discharges or certain industrial waste) are thought to be responsible.

With the exception of one patch in the small craft harbour, all water quality constituents measured in the water column during this study, appear to be naturally induced. No evidence of significant or excessive anthropogenic input or nutrient loading was detected. This result is encouraging in the light of the location of the local sewage outlet and the extent of the industrial activity in the region (i.e. Naval activities, Oil refinery activities and Jewelry manufacturing). The fact that a group of subsistence fisherman still successfully make a living from Dido Valley Beach (Mackerel Bay) is testimony to this healthy state.

A small seasonal river (Baviaanskloof) originating from a waterfall in the mountains above Simon's Town flows into Simon's Bay alongside the Admiral's Jetty. The effect of this river on the Bay and the resultant water quality and surrounding beach pollution, merits further research.

Water in False Bay and therefore Simon's Bay has been classified in the past as 'West Coast' water, since the area is adjacent to the greater western coast of South Africa. Although this argument may hold true from the morphological (characterised according to coastal geography) perspective, water constituent results presented here, as compared with the values given in the South African Water Quality Guidelines for Coastal Marine Waters (Department of Water Affairs and Forestry 1995) shows otherwise. False Bay should instead be re-categorised as a transition between south and west coast water, and thereby deserves a unique classification.

Sediments

It is postulated that during the building of the harbour, the seabed sediments were modified, and benthic populations inhabiting the seabed at the time became unstable during this transition period, typically replacing the natural environment consisting of few animals and large biomass with many smaller, low biomass, individuals.

Fine surface sediments have accumulated in the Naval Harbour due to 90 years of reduced flow. Fine low-density particulate matter (clays), carrying heavy metal contaminants from harbour activities, has not been transported away from the site, and accumulation of heavy metals has occurred. Planktonic organisms are known to pelletise these clays into larger faecal particles that are in turn re-eaten by other animals.

Heavy metals entrapped in sediments, such as those in the Naval Harbour and immediate vicinity, underlying slow moving sea water will remain in a stable particulate form and continue to accumulate unless disturbed or flushed. Typical disturbances would include severe episodic wind events, dredging, seabed trawling, ship's thrust from large ships, flooding, anchoring, scuba diving activities such as air-lifts, construction and underwater explosions etc. With these factors in mind, the most important criterion for managing the seabed environment in Simon's Bay is that minimal disturbance should occur, especially in areas where prohibitively high concentrations were found. The entrance to the Sturrock Dry Dock (western corner of the East Dockyard Basin) facility is noted here as particularly vulnerable to such disturbance. Other cautionary areas include the centre of the East Dockyard basin, the southeastern corner of the Outer basin and at the stormwater runoff site at seaward southern side where L Berth starts (near the Simon's Town Yacht Club). In cases where dredging or disturbance cannot be avoided, applicable monitoring and remedial procedures should be in place. Although many metals have been presented here, Cadmium, Arsenic and Mercury are regarded as the most dangerous (Personal communication Dr L.F Jackson). Samples collected here are rather dated and spatial coverage in some areas could be improved. It is recommended that further monitoring and research be conducted.

Evidence from these sediment results indicates that an incremental accumulation of heavy metals has occurred. The water column above accumulated heavy metal sediments has remained 'healthy' and unaffected so long as the sediments remain undisturbed. Disturbance of the seabed will result in heavy metals going into solution, possibly resulting in prohibitively higher concentrations in the water column.

Mussel Watch

It is important that such a dataset exists for Simon's Bay with good temporal and spatial coverage. This information is useful as a long term monitoring tool for the area. No serious localised long-term pollution problem appears to exist and mussels in this quasi-industrial/metropole coastal region have been safe for human consumption at all sites (except the Naval Harbour Entrance and Marine Oil on one occasion each during 1987). Given the Industrial nature of these sites, these results are encouraging. It is imperative that this important programme continues into the future so that continuity of this dataset is maintained and longer-term trends established. This single source of historic and future data should be used a bio-monitoring guideline for the region. An additional control site at Roman Rocks is being evaluated at present with assistance from The Institute for Maritime Technology (PTY) Ltd. on behalf of the SA Navy.

Chapter 6 – Summary

Simon's Bay tucked away in the Northwestern corner of False Bay, offers protection from winter storms whilst also being the home port of the South African Navy. A wide diversity of users gain benefit from this small 3 km strip of coastline and semi-enclosed bay that is intrinsically linked to the quality seaside lifestyle it provides. Historically 3 ships are known to have wrecked in the area, their remains having been stabilised by the environment. Development has been accompanied by a major Naval Harbour, a yacht club, tourist water frontage, and infrastructure, all effecting the dynamics and resulting water quality of Simon's Bay to greater or lesser extent.

Some previous work has been published regarding False Bay but an understanding of the forcing mechanisms, spatial and temporal variability and water quality remain largely unknown. There was a need for background measurements, guidelines and management of the region. This is the first published work relating to the dynamics, forcing and response and water quality issues in Simon's Bay.

Currents in Simon's Bay and the Naval Harbour were found to be generally weak and layered. Two or three layers existed most of the time, while wind mixed water extended throughout the water column on occasions. Flow was driven mainly by a combination of prevailing wind and remotely forced coastal-trapped waves, which has sustained a high level of water quality in the region. This highlighted the importance of sea level measurements. Tides and waves played a lesser role in the circulation of the bay. Seasonal southeasterly winds with increased fetch created setup conditions, vertical current shear and increased vertical mixing have resulted in regular water exchange with the surrounding False Bay. Weak, localised circulation cells appear to be present in the Naval Harbour basins and the Small Craft Harbour, which have consequences for water quality issues. During calm warm conditions, surface sun heating resulted in the establishment of a thermocline often detected to a depth of 6 m.

Weak currents have ensured that the heavy metals in the sediments have remained in the confines of the area, without being flushed out to the surrounding areas, thereby remaining entrapped and prevented from returning to a solution state. During calm conditions, water in the harbour was flushed every 72 hrs, however, during storm conditions, flushing was reduced to 21 hrs.

Observations in this study showed that nutrient advection occurred episodically, after prolonged, strong, southerly component wind conditions, resulting in phytoplankton blooms.The Small Craft Harbour region should be considered environmentally sensitive. This is in view of the increased levels of ammonium and reduced dissolved oxygen concentrations, reduced wind stress, reduced circulation accompanied by reduced vertical mixing and increasing anthropogenic input, especially sewage. The sensitivity is exacerbated by a localised wind shear between the outer harbour wall and the Admiral's Jetty, resulting in increased air warming and surface heating during all wind conditions (Maritz 1999). However, there was no evidence of adverse eutrophication found in this study.

The high levels of trace metals measured in the Sediment of the Naval Harbour are significant in comparison with the low levels found surrounding the harbour. Sediment in the harbour should not be disturbed, so that the raised trace metal concentrations remain trapped in the mud layers. Remedial precautions are required with respect to waste removal from ship works in the Dry-dock. Sediment levels in the Small Craft Harbour have not been measured and in view of its increased sensitivity to re-solution state, should be treated with caution, especially with respect to dredging or any sediment disturbance.

The Mussel Watch results are generally encouraging, indicating that the region continues to be healthy, with no significant run-off or out-falls severely impacting the region.

Although naturally occurring poisons from red tides do not appear to be common in the area, the possibility exists that this will occur again and may be aggravated by the sensitive nature of the Small Craft Harbour. With increased international naval and commercial shipping, the threat of seeding of 'alien' phytoplankton exists.

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