Technical Report

Adelaide Coastal Waters Study

Stage 2 *Research Program 2003 - 2005*

Technical Report No. 5 August 2005

Distribution of Suspended Matter in Adelaide Coastal Waters Using SeaWiFS Data

Final Technical Report

Government of South Australia

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Distribution of Suspended Matter in Adelaide Coastal Waters Using SeaWifs Data

Final Technical Report

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Adelaide Coastal Waters Study

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Executive Summary

Sea-viewing Wide Field-of-view Sensor (SeaWiFS) satellite data were used to examine spatial and temporal variability of suspended matter in the Adelaide Coastal Waters Study (ACWS) region in relation to seagrass degradation issues.

The objectives of Subtask3 PPM2 were to:

1. Analyse the temporal and spatial features of suspended matter in the Adelaide metropolitan waters between Pt Gawler and Sellicks Beach using SeaWiFS satellite observations for the period 1997-2003.
2. Examine low-cost, operational satellite remotely sensed data products to provide continuity for monitoring suspended matter levels in the Adelaide metropolitan waters after the de-commissioning of the SeaWiFS mission in December 2004.
3. Liaise with other ACWS study and external initiatives to address Stakeholder issues

SeaWiFS 1 km resolution data and the SEADAS v4.0 processing code which incorporated the Ocean Colour 4 (OC4) algorithm provided by NASA Goddard Space Flight was used to examine SeaWiFS observations from stations in the Adelaide metropolitan waters and in mid Gulf St Vincent. Suspended matter features in the broader ACWS study region (~ 2000 km^2.) were examined at a resolution of 9 km.

The following hypotheses were tested.

1. That discharges from major land based Wastewater treatment plants (WWTP's) and rivers were restricted to the nearshore region and
2. That locally generated waves have the potential for sea bed re-suspension.

Major Conclusions of the Study

The major conclusions of the study were:

1. That the impact of land based discharges was not detected at the SeaWiFS stations located a distance of about 2km offshore in the southern and central region and about 5km offshore in the northern region and

2. Locally generated winds were positively related to suspended matter variability at these distances offshore, which corresponded to a depth of about 10 metres.

These conclusions were based on the following findings:

Linear regression analysis indicated there was not a positive correlation between Wastewater Treatment Plants (WWTP's) and Torrens River discharge and observations of suspended matter at the SeaWiFS stations. This finding was consistent with previously reported water circulation patterns in the Adelaide metropolitan waters and results of ACWS field surveys conducted by the Flinders University of South Australia which indicated a dominant north-south tidal regime.

Linear regression analysis indicated there was a positive correlation between SeaWiFS observations of suspended matter in the central nearshore part of the study region and wind

data at Adelaide Airport. These results in conjunction with published wave data from the Seacliff region indicated that wind induced waves, under near fully-risen sea conditions, can disturb the sea bottom in waters 15 metres deep or less. These results suggested a possible causal relationship between wind induced waves and suspended matter variability and the need for further examination of the relationship between these parameters.

Features of suspended matter in the study region.

Water column features

SeaWiFS observations of suspended matter and water column measurements conducted by CSIRO Land and Water indicated that a phytoplankton dominated regime existed at the western boundary of the ACWS region and a suspended matter regime consisting of Coloured Dissolved Organic Matter (CDOM), tripton (non-algal particulate suspended matter) and phytoplankton in the Adelaide metropolitan nearshore waters.

Suspended matter variability for the period September 1997 - September 2003.

Levels of suspended matter at coastal SeaWiFS stations ranged from mean values between 5 mg m^{-3}-7 mg m^{-3} in the northern region, about 2 mg m^{-3} for stations in the central region and less than 1.5 mg m^{-3} in the southern region. The time of occurrence of maximum suspended matter levels at the coastal stations was in winter (June-August). At a deepwater reference station in mid Gulf St Vincent the mean value was 0.7 mg m^{-3} and maximum values occurred in the autumn (March-April)

Data coherency

Cluster analysis indicated that SeaWiFS observations of suspended matter were organised into 3 groups. Pt Gawler and Barker Inlet in the shallow northern section of the study region; Semaphore, Barcoo, Henley and Brighton in the central Adelaide metropolitan region; Pt Stanvac, Pt Noarlunga, Pt Willunga and Sellicks Beach in the southern region together with the reference station in mid Gulf St Vincent.

Periodicity in data.

Data from all SeaWiFS stations indicated the presence of annual and semi-annual components which were confirmed by spectral analysis. Linear regression analysis of SeaWiFS observations and Fourier series containing annual and semi-annual components produced a positive correlation which accounted for 49% - 60% of the total variation between the variables and was significant at the $p < .05$ level for all SeaWiFS stations except Pt Gawler.

Data trends

For the period between 1997 and 2003 SeaWiFS observations at some stations indicated a linear trend with time. At Pt Gawler the SeaWiFS observations indicated a linear trend associated with a decrease in suspended matter since about January 2000 which may be associated with implementation of nitrogen reduction strategies at the Bolivar WWTP. In the southern study region, suspended matter levels at Pt Willunga showed a linear trend associated with increased levels of suspended matter since about January 2000.

Euphotic depth consideration

The extent to which the remotely sensed radiance signal can be attributed to the water column and not the seabed substrate was examined by computation of the euphotic depth for *Posidonia sinuosa,* a dominant species in the study area. Euphotic depth was computed using extinction coefficient data supplied by the CSIRO Land and Water and the Australian Water Quality Centre and published data on minimum light requirements for seagrass. For *Posidonia sinuosa,* a reduction of irradiance to 12 % and 5% of the surface irradiance was examined. For these irradiance reductions, it was found that the depth of SeaWiFS stations was greater than the euphotic depth required for seagrass to maintain growth and respiration requirements. The contribution to the remotely sensed water leaving radiance from the water column by seagrass was therefore not likely to be an issue at the depth of the SeaWiFS stations.

Post SeaWiFS options.

Due to the termination of the SeaWiFS satellite program by NASA in December 2004, examination of the MODIS satellite characteristics was conducted to asses its suitability for monitoring water quality in the Adelaide metropolitan waters.

From a technical performance perspective the MODIS and SeaWiFS sensor spectral characteristics are similar with the former providing improved performance due to a narrower spectral bandwidth thus providing a better signal to noise ratio. Spatial resolution at 250 metre is available in addition to resolution of 500 metres and 1 kilometre. The MODIS sensor is designed to measure sea surface temperature which can be geo-referenced with spectral data for correlative investigations between physical and biological variables, if required.

Twice daily (morning and afternoon) MODIS satellite data can be accessed from a number of distribution centres in Australia within 24 hours. The MODIS products may be processed using a number of readily available software packages and, in conjunction with field studies, can be calibrated for parameters of interest, for example chlorophyll-a.

Analysis of SeaWiFS and MODIS suspended matter observations using a 2 year time series for several test regions in the Adelaide metropolitan waters which included a deepwater (30 metre) region in the middle of Gulf St Vincent and a region adjacent to the Adelaide metropolitan waters in about 11 metres of water was conducted. The SeaWiFS and MODIS observations of suspended matter indicated a strong positive relationship at the 30 metre deep region (r^2=0.95, p<.001) and the 11 metre deep region (r^2=0.81, p<.001).

As an example of the potential application in monitoring water quality, SeaWiFS observations of suspended matter offshore from the Bolivar WWTP and nitrogen as ammonia loads from the Bolivar WWTP for the period November 1998 - July 2003 were examined. Correlations of these data indicated a reasonable relationship (r^2=0.56, p < .001) between SeaWiFS observations of suspended matter, lagged by 1 month, and nitrogen as ammonia loads.

Conclusions and Stakeholder's issues

A number of major outcomes were achieved in this study that are significant on their own merit and link with other programs to address the Stakeholder issues. For example, in the Adelaide coastal waters, SeaWiFS observations of suspended matter indicated a limited offshore movement of major land based discharges. The practice of allowing land based discharges into the metropolitan waters would have initially confined the loss of seagrass mostly to the nearshore region due to the impact of treated sewage, stormwater and changes in land use. This hypothesis will be tested by outcomes of the physical model being developed for the ACWS which will illustrate the advection pathways of land-based and nearshore point sources under representative tidal and wind conditions.

The positive correlation between SeaWiFS observations of suspended matter and winds capable of generating waves which can feel the seabed indicated a possible causal relationship between these parameters. This result advances a hypothesis which can be tested by a wave model of the study region being developed by the physical modeling group. Wave model output geo-referenced to seabed sediment and seagrass distribution maps should indicate regions of the Adelaide waters where wave orbital velocities are capable of sediment re-suspension under various storm scenarios and may reveal a positive correlation with seagrass loss.

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1. SCOPE

1.1 Objectives of Subtask 3 – PPM 2

The objectives of this sub task were to:

1. Analyse the temporal and spatial features of suspended matter in the Adelaide metropolitan waters between Pt Gawler and Sellicks Beach using SeaWiFS satellite observations for the period 1997-2003.

2. Examine low-cost, operational satellite remotely sensed data products to provide continuity to monitor suspended matter levels in the Adelaide metropolitan waters after the de-commissioning of the SeaWiFS mission in December 2004.

3. Liaise with other study and external initiatives to address critical Stakeholder issues.

1.2 Application of SeaWiFS Remote Sensing in the Adelaide Coastal Waters Study.

The Adelaide Coastal Waters Study (ACWS) region is defined as the area between Sellicks Beach and Pt Gawler and approximately 25 km offshore (Refer Figure 1).

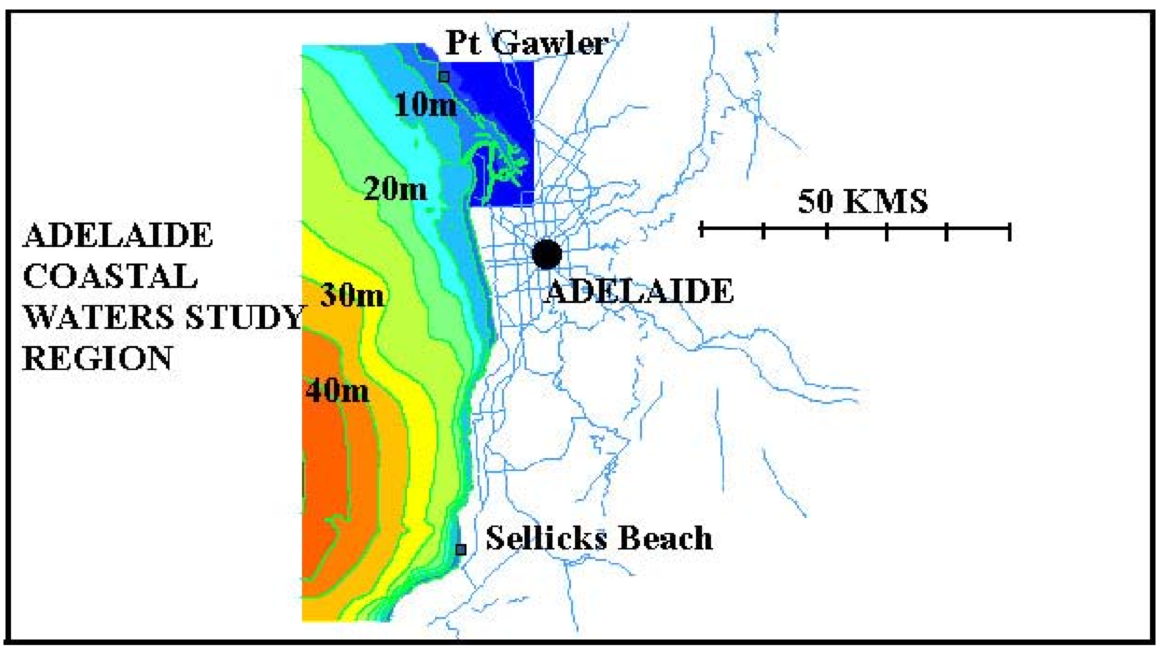

Figure 1. The Adelaide Coastal Waters Study region

The region was ideally suited to take advantage of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) data available from National Aeronautics Space Administration Goddard Space Flight Centre (NASA GSFC). The Centre provided operational (daily) ocean colour information in a number of spectral bands at a resolution of 1 km. The data and data processing code were available through the Authorised Research Users Scheme of which the author of this report is an active collaborator. The approach was considered to be a cost effective method to examine the variability of suspended matter over a large area (2000 km^2) in a non-intensive resource mode.

Following the classification used by the International Ocean-Colour Coordinating Group (IOCCG, 2000) the relatively shallow waters adjacent to the Adelaide metropolitan coastline are termed as Case 2 waters. Such waters contain phytoplankton; coloured dissolved organic material (CDOM) and dissolved inorganic particulate matter as well as other constituents. These waters differ from Case 1 waters which are represented by deeper Gulf or shelf oceanic types dominated by phytoplankton communities.

SeaWiFS satellite data together with field surveys have been successfully applied to examine broad scale coastal water quality issues in a number of locations. Recent examples are Engelsen et al (2002) in the Barents Sea; Kopelevich et al (2002) in the Black Sea; Gomes et al (2000) in the Bay of Bengal; Leonard et al (2001) in the north Pacific and Lluch-Cota (2002) in the eastern Pacific.

In a local context, the performance of the SeaWiFS data was examined by Petrusevics and Lennon (2002) and Petrusevics (2004) in analysis of suspended matter plumes in upper Gulf St Vincent, South Australia. SeaWiFS data indicated presence of a suspended matter plume which forms annually in the region during mid to late summer (January-February) and persists until late autumn (April-May). These findings were in agreement with suspended matter observations made during development of the Laser Airborne Depth Sounder (LADS) reported by Philips and Scholz (1982) thus giving support to the recent interpretation of the SeaWiFS observations.

Whilst the main emphasis of this study was concentrated on data from nearshore stations in the Adelaide coastal waters using the 1 km resolution SeaWiFS data, advantage was also taken of lower resolution (9 km) available from GSFC to briefly examine suspended matter variability in the whole of the Adelaide Coastal Waters Study region.

2. METHODOLOGY

2.1 The SeaWiFS Program

The NASA SeaWiFS project distributes data received from the SeaWiFS ocean colour sensor. Eight bands, covering the range 402- 885 nanometers (nm) are available as follows.

Table 1. Wavelength Parameters SeaWiFS Ocean Colour Sensor

Band	Centre Wavelength (nm)	Colour	Primary Use
1	402-422	violet	Dissolved organic matter
2	433-453	blue	Chlorophyll absorption
3	480-500	blue-green	Pigment absorption
4	500-520	blue-green	Chlorophyll absorption
5	545-565	green	Pigments, sediments
6	660-680	red	
7	745-785	near IR	
8	845-885	near IR	

2.2 Data Generation

Individual daily overpass files were downloaded from GSFC using file transfer protocol (FTP). Band 2 data (433 to 453 nm) were extracted and analysed using the SEADAS v4.0 processing code developed by NASA. The SeaWiFS Ocean Colour 4 (OC4) algorithm which is embedded in the SEADAS code was used in the analysis.

A description of the SeaWiFS OC4 is given by Liew et al (2001). The algorithm is a maximum band-ratio algorithm employing 4 spectral bands; Bands 2, 3, 4 and 5. Band 5 (555 nm) is taken as a reference wavelength band and three band ratios are computed for each measurement of the reflectance spectrum.

$R_{ij} = r_i / r_j$; i= 2, 3, 4; j=5,

where R_{ij} is the ratio of reflectance at band-i and band-j. The maximum of the three band ratios R_{max} = max {Rij: i= 2, 3, 4; j=5} is then taken as the parameter for calculating the chlorophyll concentration according to the equation given by O'Reilly et al (1998).

$Log_{10} (Chl\text{-}a_4) = a_0 + a_1 L + a_2 L^2 + a_3 L^3$; where $L = \log_{10} (R_{max})$

The coefficients a_i for the OC4 algorithm are:

$a_0 = 0.4708$, $a_1 = -3.8469$, $a_2 = 4.5338$, $a_3 = -2.4434$, $a_4 = -0.0414$

This algorithm was designed for computation of chlorophyll levels in the open sea, denoted as Case 1 waters (Morel 1988). For the SeaWiFS station established in the middle of Gulf St Vincent (depth >30 metres), the contribution from anthropogenic induced substances and sediments is small and the SeaWiFS signal represented the absorption at 443 nm by phytoplankton.

In the shallower waters adjacent to the Adelaide metropolitan coastline the SeaWiFS signal contains a contribution from other constituents in addition to phytoplankton.

During the course of the study, analysis of water samples taken in the Adelaide metropolitan waters by program RS 1 and reported by Dekker (2004) indicated that at 443 nm the absorption by CDOM and tripton (non-algal particulate suspended matter) was greater than absorption by phytoplankton.

Collectively, these constituents are referred to as suspended matter but it is recognized that the composition of suspended matter in the ACWS region varies from a phytoplankton dominated regime at the western boundary to a mixed regime of CDOM, tripton and phytoplankton in the Adelaide metropolitan nearshore waters.

The relative contribution of these components within the study region is discussed in detail in Section 5.1.

2.3 Data Processing

The data were processed to a common geographical and radiance format. Values of suspended matter (mg m^{-3}) from stations situated in the Adelaide metropolitan waters and offshore in Gulf St Vincent were derived from daily cloud free orbital data files. Mean monthly data sets were generated for each station. A total of 480 overpasses covering the period between September 1997 and September 2003 were processed. Typical image products, processed to a common geographical and radiance format, showing features of Gulf St Vincent in autumn and spring 2001 are shown in Figure 2 and Figure 3 respectively.

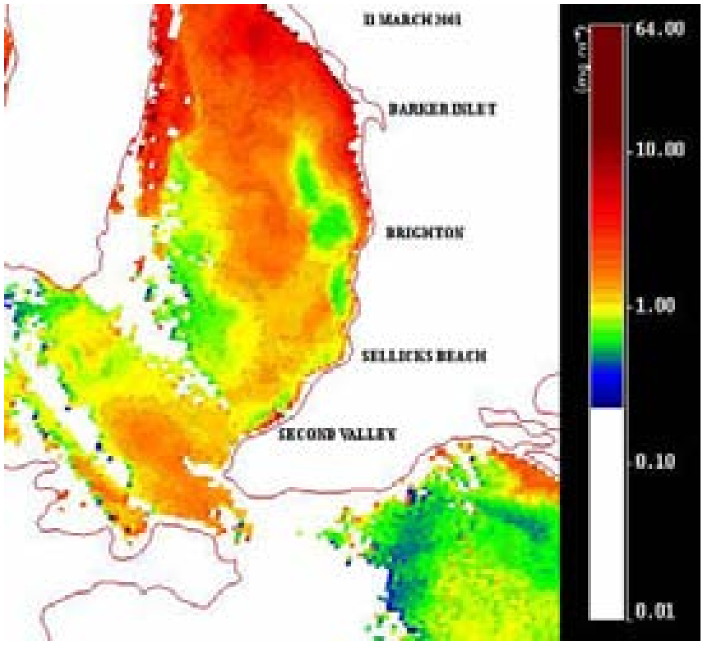

Figure 2. Suspended matter distribution in Gulf St Vincent, Autumn 2001.
Note plume of elevated suspended matter from head of GSV to Sellicks Beach indicating influence of gulf controlled processes on nearshore waters of southern metropolitan region.

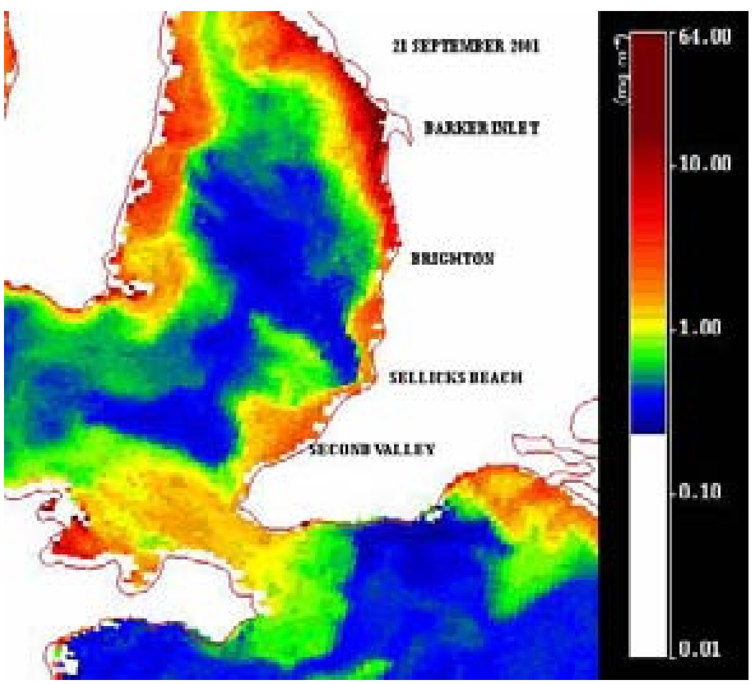

Figure 3. Suspended matter distribution in Gulf St Vincent, Spring 2001.
Note absence of mid gulf plume of elevated suspended matter.

2.4 Nearshore SeaWiFS Station Location Considerations

The locations of the SeaWiFS stations were chosen so that the influence of wastewater treatment plant (WWTP) effluent disposal and storm water discharge could be examined. This required consideration of a number of factors. To maximise the interception of land based discharges, SeaWiFS stations needed to be close to the point of discharge, however at the same time it was necessary to ensure that the stations were in adequate depth of water so that SeaWiFS signal was due to suspended matter in the water column and not influenced by a contribution from the sea bed. These requirements together with the following issues were considered in determining the location of the SeaWiFS stations.

2.4.1 Nearshore water movement.

Numerical modelling of water movement Bye (1976), Oceanique Perspectives (2000) in Gulf St Vincent and current measurements in the Adelaide metropolitan waters, Steedman (1985) indicated that alongshore currents dominate with offshore currents being relatively small. Under these conditions, land-based discharges are likely to be confined to a region a few kilometres offshore with dominant movement being alongshore. Typical patterns for residual (non-tidal) circulation under most frequently occurring wind conditions in the summer and winter for the northern portion of Gulf St Vincent are shown in Figure 4 and Figure 5 respectively.

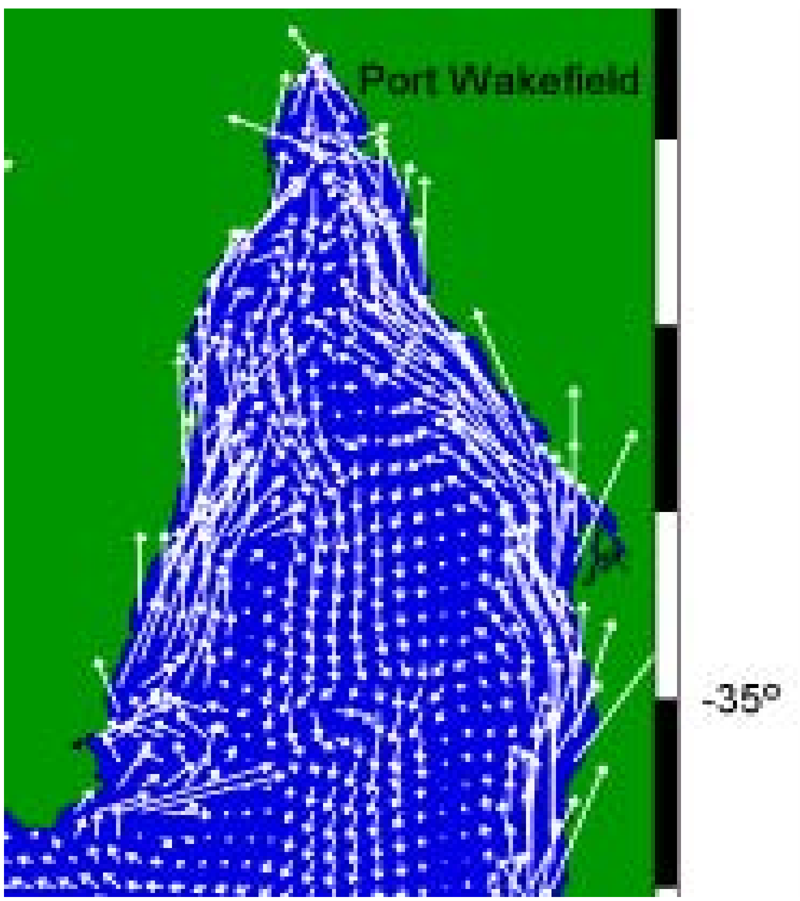

Figure 4. Residual water circulation Gulf St Vincent, Summer.
Under most frequently occurring winds[1] showing strong alongshore currents.
(Oceanique Perspectives, 2002)

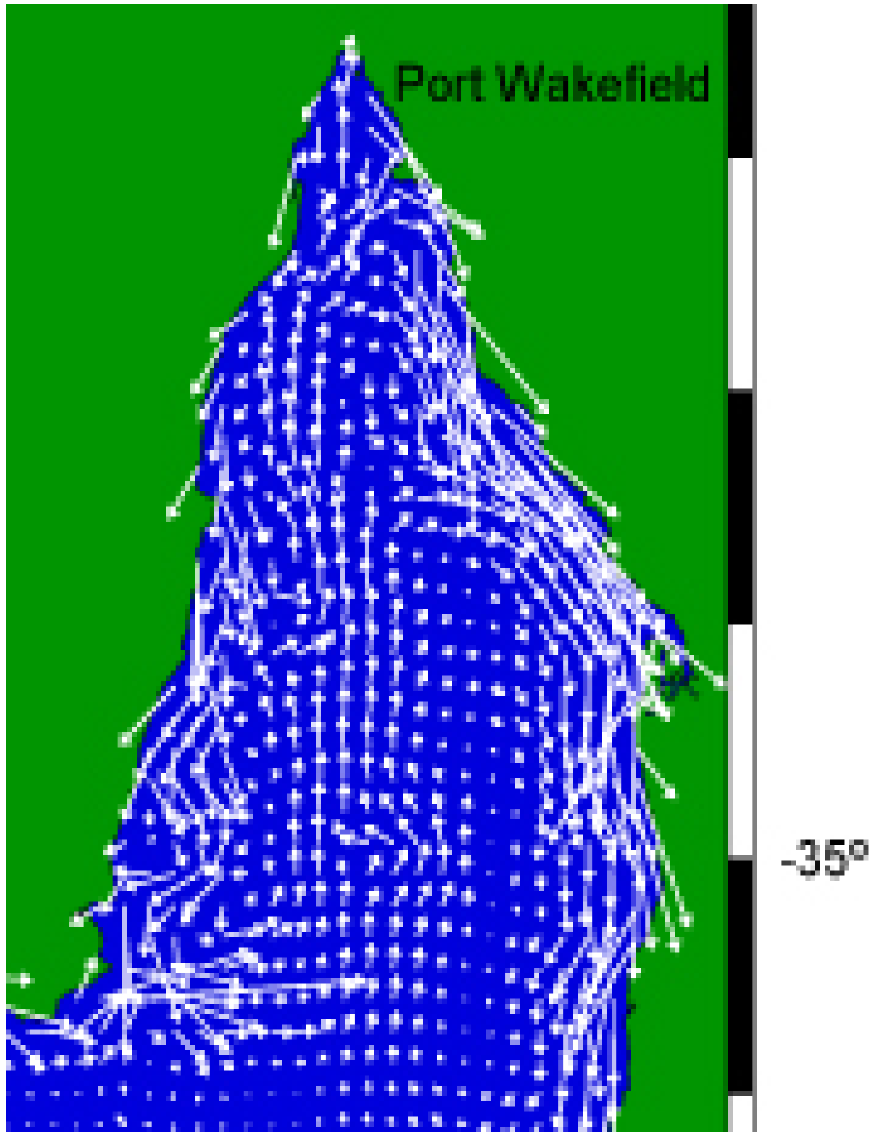

Figure 5. Residual water circulation Gulf St Vincent, Winter
Under most frequently occurring winds[1]
(Oceanique Perspectives, 2002)

Note [1]: Most frequently occurring winds refer to Bureau of Meteorology surface wind analysis detailing percentage occurrence of speed versus direction for any given time interval.

2.4.2 Offshore distribution of suspended matter

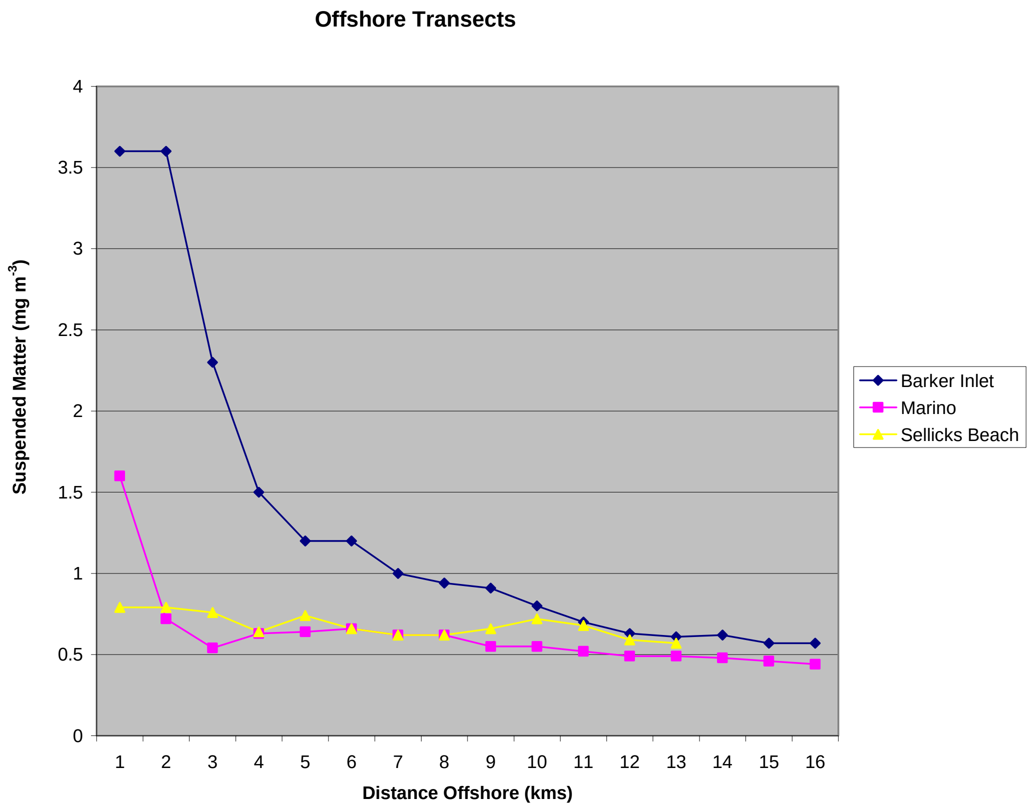

Figure 6. Distribution of suspended matter along offshore transects

The distribution of suspended matter along transects normal to the coast at Barker Inlet, Marino and Sellicks Beach was examined using SeaWiFS observations (Figure 6). At Barker Inlet, the level of suspended matter decreased from about 3-4 mg m^{-3} at the coast to 1 mg m^{-3}about 6 to 8 km offshore. At Sellicks Beach and Marino, concentrations of suspended matter less than 1 mg m^{-3} were observed within 1 to 2 kms of the coast. These results confirmed the expected rapid decrease of suspended matter concentrations normal to the coastline as a result of a hydrodynamic regime which favours mainly north-south currents adjacent to the Adelaide metropolitan coastline.

2.4.3 Proximity to land-based discharge.

Elevated nutrient levels may be expected in the vicinity of major land-based discharges. A combination of increased nutrient levels, local oceanographic regime feature such as the 'dodge' tide, calm winds and high solar radiation levels can often lead to the formation of algal blooms and hence increased levels of suspended matter. Within the constraints outlined above, SeaWiFS stations were located close to outlets of major WWTP's such as Bolivar, Glenelg and Christies Beach.

Similarly, to detect the influence of episodic discharges from major stormwater outlets and rivers such as the Torrens River, Barcoo Outlet and the Onkaparinga River, SeaWiFS stations were located close to these discharges. The location of the SeaWiFS stations varied between 2 to 5 km offshore and the depths ranged between about 6 metres in the northern region and about 15-20 metres in the southern part of the study area. Details of SeaWiFS stations are given in Table 2.

2.5 SeaWiFS station details

Table 2. SeaWiFS Station Details

SeaWiFS Station	**Latitude**	**Longitude**	**Depth m** (Referred to Chart datum) (2)	**Seabed Type.**
Pt Gawler	34º 39.6' S	138º 23.4' E	5-6	Medium-Dense Seagrass Cover (1)
Barker Inlet	34º 45.0' S	138º 27.0' E	5-7	Medium-Dense Seagrass Cover (1)
Semaphore	34º 49.2' S	138º 24.6' E	11-14	Medium-Dense Seagrass Cover (1)
Henley	34º 54.0' S	138º 26.4' E	9-10	Medium-Dense Seagrass Cover (1)
Barcoo	34º 58.2' S	138º 28.2' E	10-12	Medium Seagrass Cover (1)
Brighton	35º 01.2' S	138º 29.4' E	9-11	Medium Seagrass Cover (1)
Pt Stanvac	35º 05.4' S	138º 27.6' E	17-20	Sand and ascidians (3)
Pt Noarlunga	35º 09.0' S	138º 26.4' E	18-22	Sand with sparse seagrass (3)
Pt Willunga	35º 15.0' S	138º 27.0' E	11-23	Mostly sand (3)
Sellicks Beach	35º 19.8' S	138º 25.2' E	14-20	Mostly sand (3)
GSV Central	35º 00.0' S	138º 15.0' E	31	Mostly sand

Note 1*. Seagrass cover estimate based on seabed feature mapping using aerial photos with 8 classes of discrimination. (D. Blackburn, Program RS 1)*
Note 2. *A permanently established surface from which tide heights or chart soundings are reference to. Large variability in the depth at sites is due to the variation in the bottom profile over the 1 km SeaWiFS sensor "footprint".*
Note 3. *Based on information supplied by S. Bryars, Program EP 1.*

2.5.1 Euphotic depth derivation

In shallow waters, it is possible that a contribution to the remotely sensed water leaving radiance at 443 nm may be due to the presence of constituents located on the bottom such as seagrasses, macroalgae or micro phytobenthos (Peter Fairweather, pers. com). However, if the depth of water is greater than the depth at which light limitation occurs (the euphotic depth) for such constituents then the contribution of the bottom substrate to the water leaving radiance will be small.

In order to compute the euphotic depth, an estimate of the extinction coefficient for light at 443 nm was required. This was obtained from measurements of photosynthetically available radiation (PAR) and Trios RAMSES underwater spectrometer measurements.

2.5.2 PAR measurements of extinction coefficients

PAR measurements using a LICOR Quantum sensor were conducted in conjunction with the Australian Water Quality Centre on 24th February 2004 at SeaWiFS stations Semaphore, Henley, Barcoo and Pt Stanvac. The results are summarised in Table 3.

Table 3. Extinction coefficients from LICOR PAR measurements, 24th February 2004

Station	Latitude	Longitude	Station Depth (m) Chart datum	k, mean extinction coefficient (m^{-1}) (1)
Semaphore	34º 49.2' S	138º 24.6' E	14	0.34
Henley	34º 54.0' S	138º 26.4' E	9	0.36
Barcoo	34º 58.2' S	138º 28.2' E	10.5	0.41
Pt Stanvac	35º 05.4' S	138º 27.6' E	20	0.13

Note 1. *LICOR measurements were taken at 3 and 4 metres depth.*
LICOR measurements were in micromoles of photon per m^2 *per sec and averaged over 30 secs.*

The extinction coefficient, k, was calculated from the Beer-Lambert Law.

$k = -\ln(\beta_1/\beta_2) / \Delta z$
Where β_1 = mean PAR at depth 1
β_2= mean PAR at depth 2
Δz= depth difference of measurements

2.5.3 Trios RAMSES spectrometer measurements

Extinction coefficients were also computed from irradiance-depth measurements conducted by CSIRO Land and Water on 25th November 2003 using a Trios RAMSES underwater spectrometer. Measurements were conducted at the locations shown in Table 4.

Table 4. RAMSES station locations

RAMSES Station	Latitude	Longitude	Approx Location
AC_25_1	34º 38.64' S	138º 24.00' E	Offshore Pt Gawler
AC_25_5	34º 39.60' S	138º 22.86' E	Offshore Pt Gawler
AC_26_12	34º 44.10 'S	138º 27.00' E	West of Section Bank
AC_26_14	34º 47.52 'S	138º 27.24' E	Outer Harbour Approach Channel
AC_26_19	34º 48.78 'S	138º 28.86' E	Inshore Semaphore
AC_27_1	35º 02.70' S	138º 30.30 'E	Inshore Brighton South
AC_27_3	34º 59.04 'S	138º 30.36' E	Inshore Glenelg South

The location of the RAMSES stations in relation to the SeaWiFS and LICOR PAR stations is shown in Figure 7. The SeaWiFS stations and RAMSES stations were not co-located however the SeaWiFS and LICOR PAR stations were co-located.

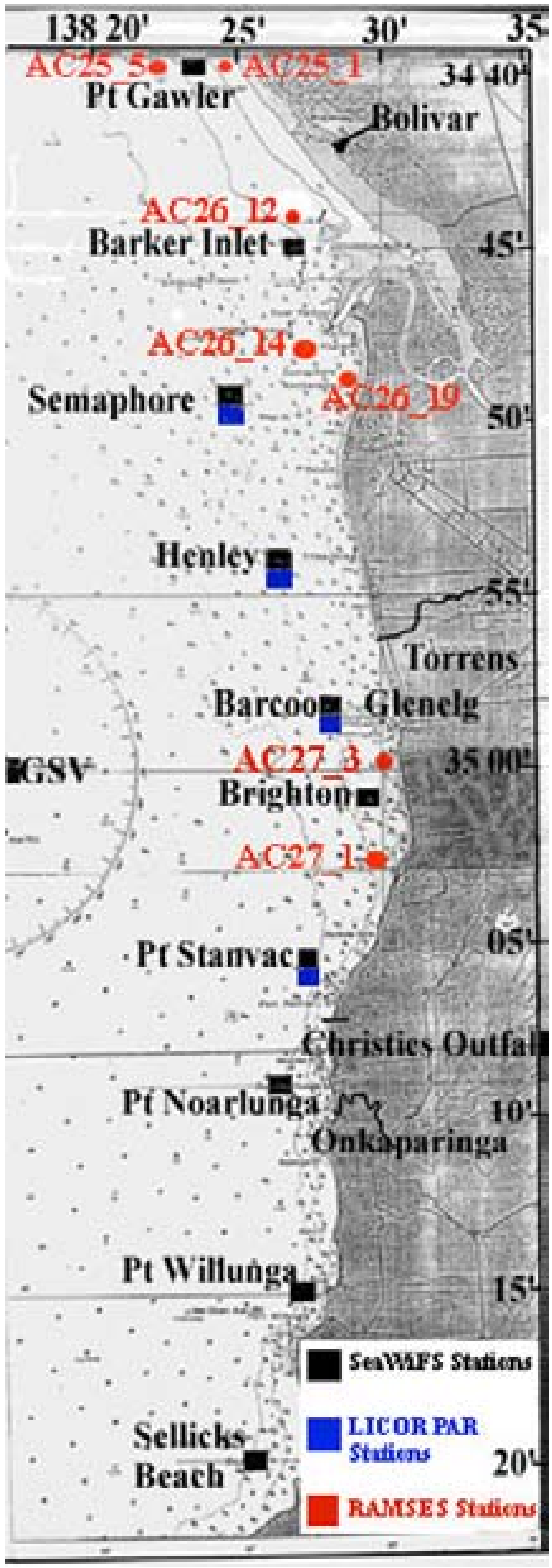

Figure 7. Location of SeaWiFS, LICOR PAR and RAMSES stations

2.5.4 Extinction coefficient derivations from the RAMSES data

The extinction coefficient at any wavelength is defined as the ratio of irradiance Ed (z) at depth z to irradiance Ed (0) just below the surface of the water body. Irradiance decreases in an exponential manner with depth and is represented by k, the vertical extinction (or attenuation) coefficient.

The relationship can be expressed in a form of the Beer-Lambert Law thus

$$Ed(z) = Ed(0) \exp(-k z)$$

Therefore $\ln Ed(z) = -k z + \ln Ed(0)$
Ed (z) = Irradiance at depth z
Ed (0) = Irradiance at just below the surface
k = extinction coefficient

The above equation is of the form y= mx + c and yields k (the extinction coefficient) from a plot of ln Ed (z) versus depth z. Results for RAMSES station (AC26_12), West of Section Bank, is shown Figure 8.

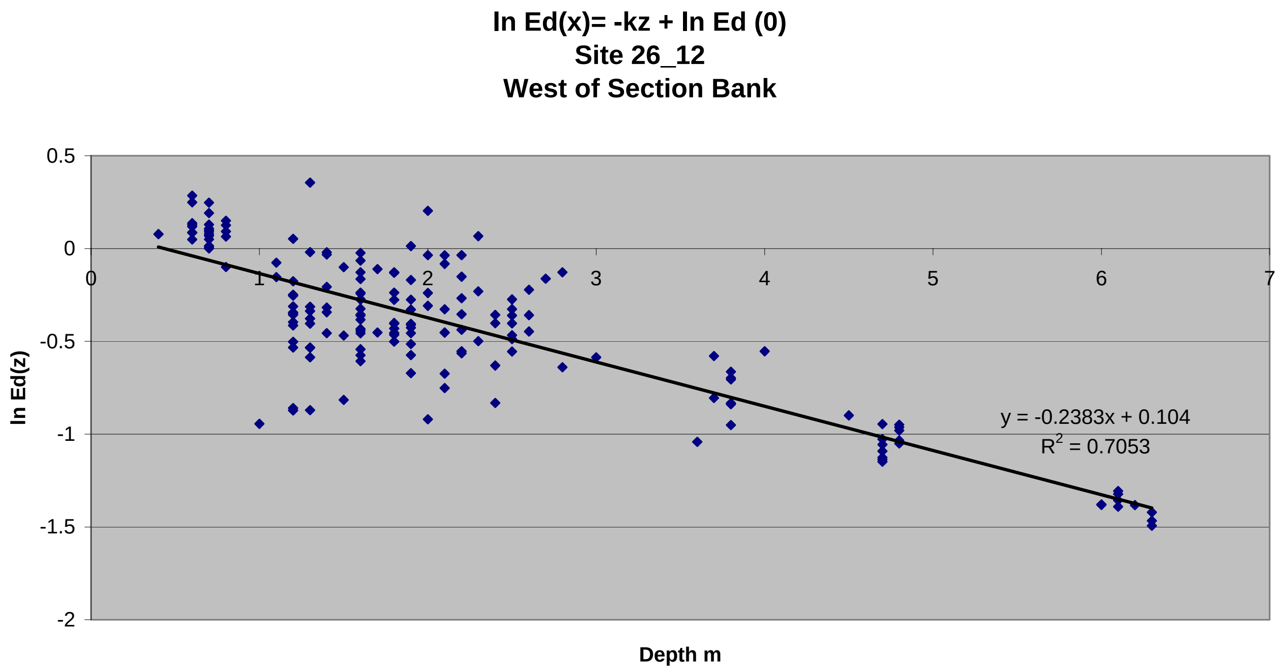

Figure 8. Irradiance versus depth for RAMSES station West of Section Bank

The extinction coefficients for the other RAMSES stations shown in Figure 7 were deduced in a similar manner and are given in Table 6.

2.5.5 Determination of the euphotic depth

In general terms, the euphotic zone extends from the atmosphere-sea interface downwards to a depth where the irradiance level falls to a given percentage of that at the surface. The thickness of the layer depends on the extent of light attenuation in the water column. The depth varies from several metres in turbid estuaries to several hundred meters in the open ocean.

Estimates of minimum light requirements of various genera of seagrass range between 5-30% of surface irradiance (Duarte, 1991). For *Posidonia sinuosa,* a dominant species in the study area, 12% of surface irradiance was reported by Gordon et al (1994) as the species' minimum light requirement.

The Beer-Lambert relationship was used to determine the euphotic depths using the extinction coefficients derived from the PAR and RAMSES surveys and using a reduction of irradiance to 12% of that of the irradiance level at the surface.

The results are given in Table 5 (applicable to SeaWiFS stations) and Table 6 (applicable to RAMSES stations) respectively. The calculated euphotic depth provides an estimate of the maximum depth at which seagrasses may receive sufficient light to produce carbohydrates through photosynthesis to meet growth and respiration requirements, Cheshire et al (2002). At depths greater than the euphotic depth, the contribution to the water leaving radiance due to seagrass will be small and most of the remotely sensed signal is due to constituents in the water column. The variation in euphotic depths across sites is further discussed in Section 5.

Table 5. Euphotic depths at SeaWiFS stations - derived from PAR measurements

Station	Latitude	Longitude	PAR Station depth chart datum (m)	k, mean extinction coefficient (m^{-1}) Note 1	Euphotic depth (m)
Semaphore	34º 49.2' S	138º 24.6' E	14	0.34	6.2
Henley	34º 54.0' S	138º 26.4' E	9	0.36	5.9
Barcoo	34º 58.2' S	138º 28.2' E	10.5	0.41	5.2
Pt Stanvac	35º 05.4' S	138º 27.6' E	20	0.13	16.3

Table 6. Euphotic depths at RAMSES stations

RAMSES Station	Approx. Location	Extinction Coefficient	Euphotic Depth (m)
AC_25_1	Offshore Pt Gawler	1.85	1.1
AC_25_5	Offshore Pt Gawler	.512	4.1
AC_26_12	West of Section Bank	.238	8.9
AC_26_14	Outer Harbour Approach Channel	.317	6.7
AC_26_19	Inshore Semaphore	.367	5.8
AC_27_1	Inshore Brighton South	.169	12.5

3. Analysis of SeaWiFS Observations

3.1 Whole of ACWS region

Features of suspended matter within the whole of the ACWS region were examined through application of the 9 km resolution SeaWiFS data set available from NASA/GSFC for the period 1997 to 2004.

The whole of the Adelaide Coastal Waters Study region between Pt Gawler and Sellicks Beach covers about 80 km x 25 km, an area of about 2000 km^2. The latitudinal and longitudinal boundaries of this region are 35º18.0'S-34º36S and 138º12'E-138º24'E respectively. The western limit of this region corresponded to a depth of about 36 meters. As indicated in Section 2.2 the suspended matter in this region varies from a phytoplankton dominated regime at the western boundary of the ACWS region to a mixed regime of CDOM, tripton and phytoplankton near the Adelaide coast.

3.1.1 Time series of the region for period 1997-2004

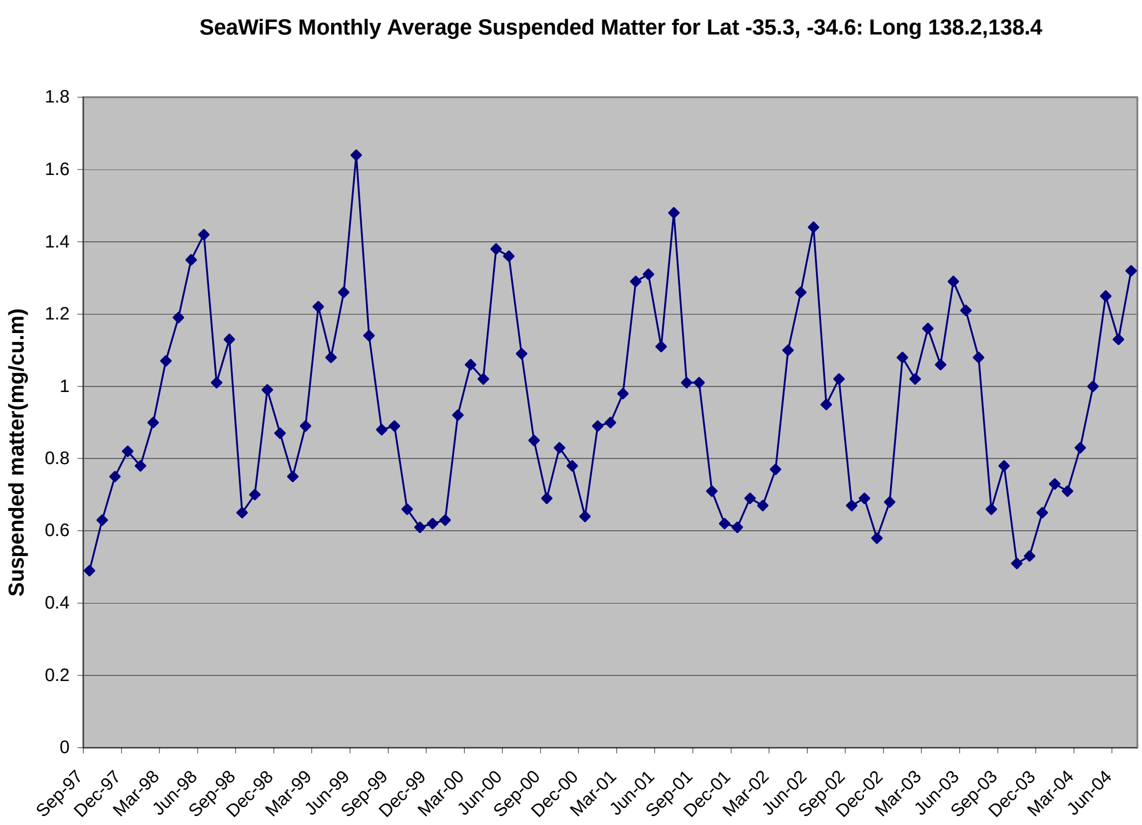

Figure 9. Time series of suspended matter levels for whole of ACWS region 1997 to 2004

The variability of suspended matter in the whole of the ACWS region was periodic with a strong annual component being evident. For the period 1997 to 2004, the mean value was 0.94 mg m^{-3} with a standard deviation of 0.26 mg m^{-3}. The maximum value was 1.64 mg m^{-3}. Maximum values of suspended matter occurred between May and July with the most frequently occurring period in June. Minimum values of suspended matter occurred during November and December with the most frequently occurring period in December.

3.1.2 Time-longitude features

The suspended matter variability in the whole of the ACWS region is displayed on a time-longitude plot (Refer Figure 10). The western boundary corresponded to a depth of about 36 metres and the eastern boundary was adjacent to the Adelaide metropolitan coastline.

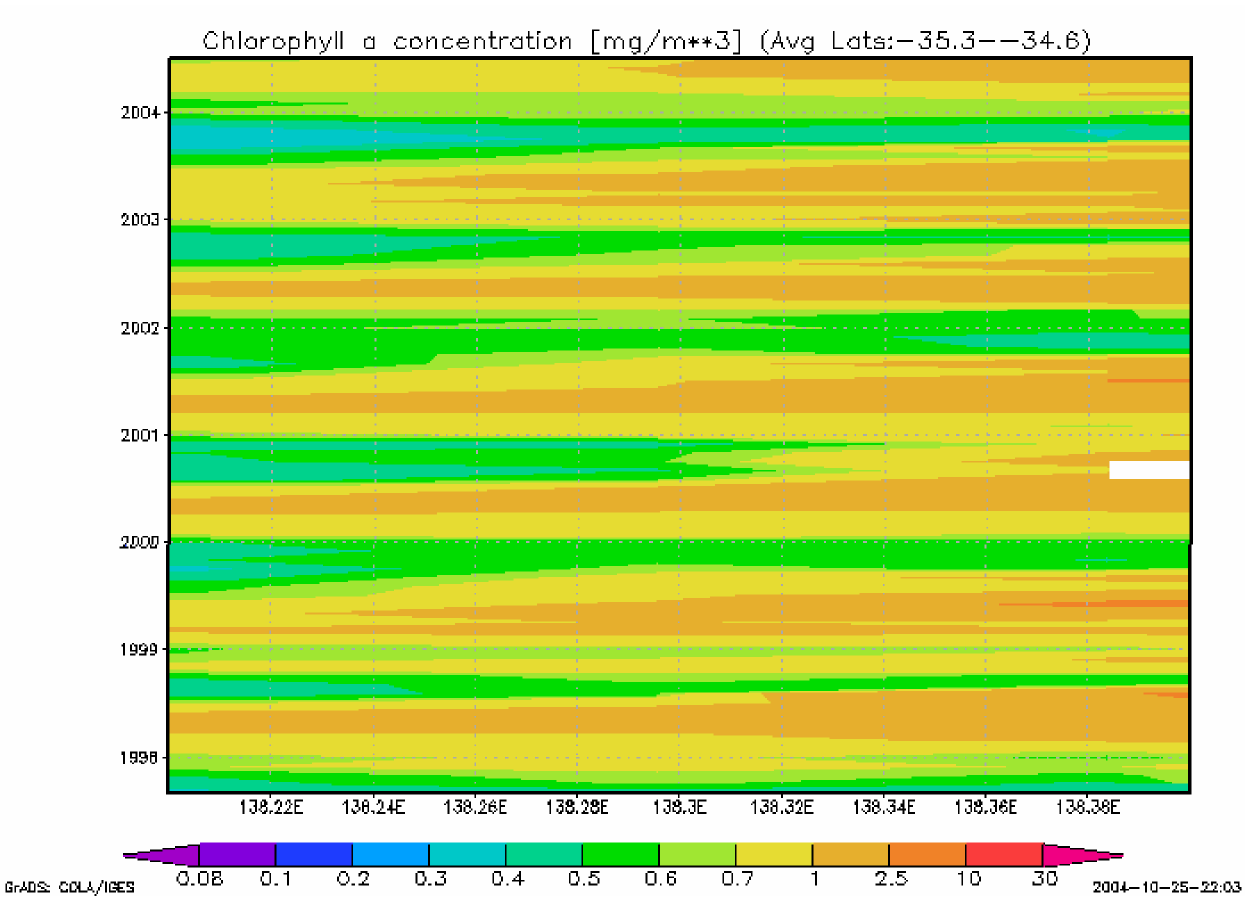

Figure 10. Time-Longitude suspended matter variation in the whole of ACWS region

For the period 1998 to 2004, periodic variation of suspended matter (expressed in this case as chlorophyll-a by NASA/GSFC) were clearly observed at the western boundary of the ACWS region and adjacent to the Adelaide metropolitan coastline. Low levels of suspended matter occurred in the latter portion of the year whereas higher levels occurred during the middle part of the year.

The duration of low and high levels of suspended matter was longitudinally dependent. For example, for the latter part of 2003 and within the discrimination level of the time-longitude plot the duration of low levels of suspended matter (for example, < 0.4-0.5 mg m^{-3}) was approximately 4-5 months at mid Gulf longitudes whereas at the Adelaide coastline the duration was 1-2 months. Similarly, during 2003, periods of relatively higher (for example, 1.0-2.5 mg m^{-3}) levels of suspended matter persisted at the Adelaide coastline for up to 5-6 months but for only significantly less time (~ 1 month) near the western boundary.

3.1.3 Time-latitude features

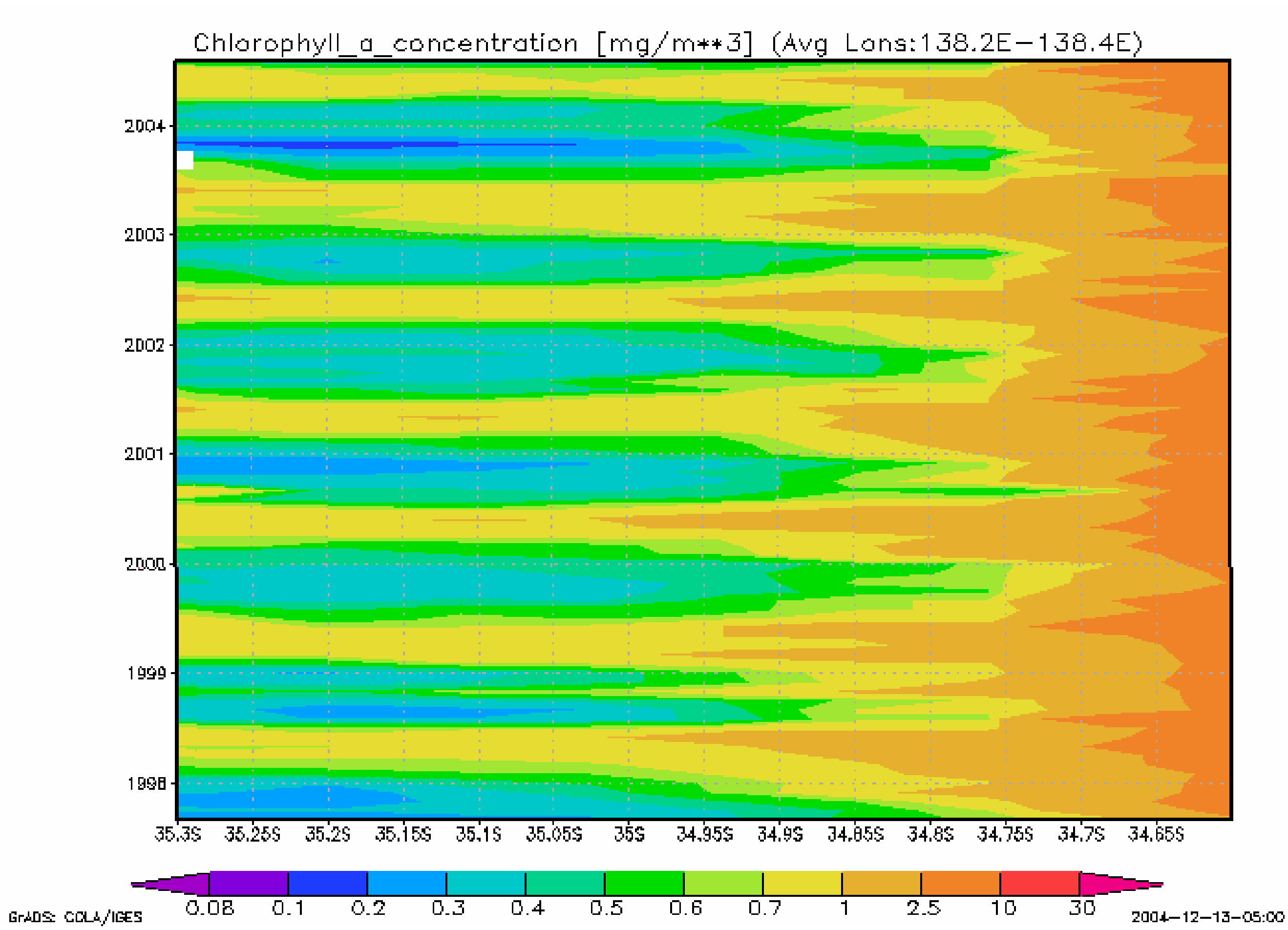

Figure 11. Time-Latitude suspended matter variation in the whole of ACWS region

The region covered in the time-latitude plot is between Pt Gawler and Sellicks Beach. A distinguishing feature of this plot is the periodicity in suspended matter which was apparent at annual and semi-annual intervals at all latitudes.

For any portion of the year, differences in suspended matter concentrations of an order of magnitude were noted between the northern and southern parts of the study region. Typical concentrations of suspended matter in the northern region ranged between 2.5-5 mg m^{-3} whereas in the southern region values were between 0.2-0.4 mg m^{-3}.

In the northern region, consistently high concentrations of suspended matter were noted throughout the year however in the southern region maximum concentrations of suspended matter occurred in autumn-winter whereas minimum concentrations occurred in spring-summer.

The use of the time-longitude and time-latitude plots provided an insight to the periodic nature of suspended matter variation in the study region which was further analysed by consideration of SeaWiFS observations from individual stations in the Adelaide nearshore waters.

3.2 Time series for SeaWiFS Coastal Stations

The location of SeaWiFS stations along the coastline stations are shown in Figure 7. The relevant summary statistics for data corresponding to each station for the period between September 1997 and September 2003 are given in Table 7.

Table 7. Summary statistics of suspended matter at SeaWiFS stations for period September 1997-September 2003

Station	Depth m (Referred to Chart datum)	Mean (mg m^{-3})	Standard Deviation (mg m^{-3})	Maximum (mg m^{-3})	Period of Maximum Value
Pt Gawler	5-6	5.5	2.9	16.4	July-August
Barker Inlet	5-7	7.1	4.2	23.0	July-August
Semaphore	11-14	2.2	0.8	6.0	June-July
Henley	9-10	2.5	1	5.0	June-July
Barcoo	10-12	2.1	1	6.3	June-July
Brighton	9-11	2.5	1.5	8.3	June-July
Pt Stanvac	17-20	1.4	.5	3.2	June-July
Pt Noarlunga	18-22	1.3	.5	3.4	June-July
Pt Willunga	11-23	1.3	.4	2.5	June-July
Sellicks Beach	14-20	1.4	.6	3.8	June-July
GSV Central	31	.7	.3	1.3	March-April

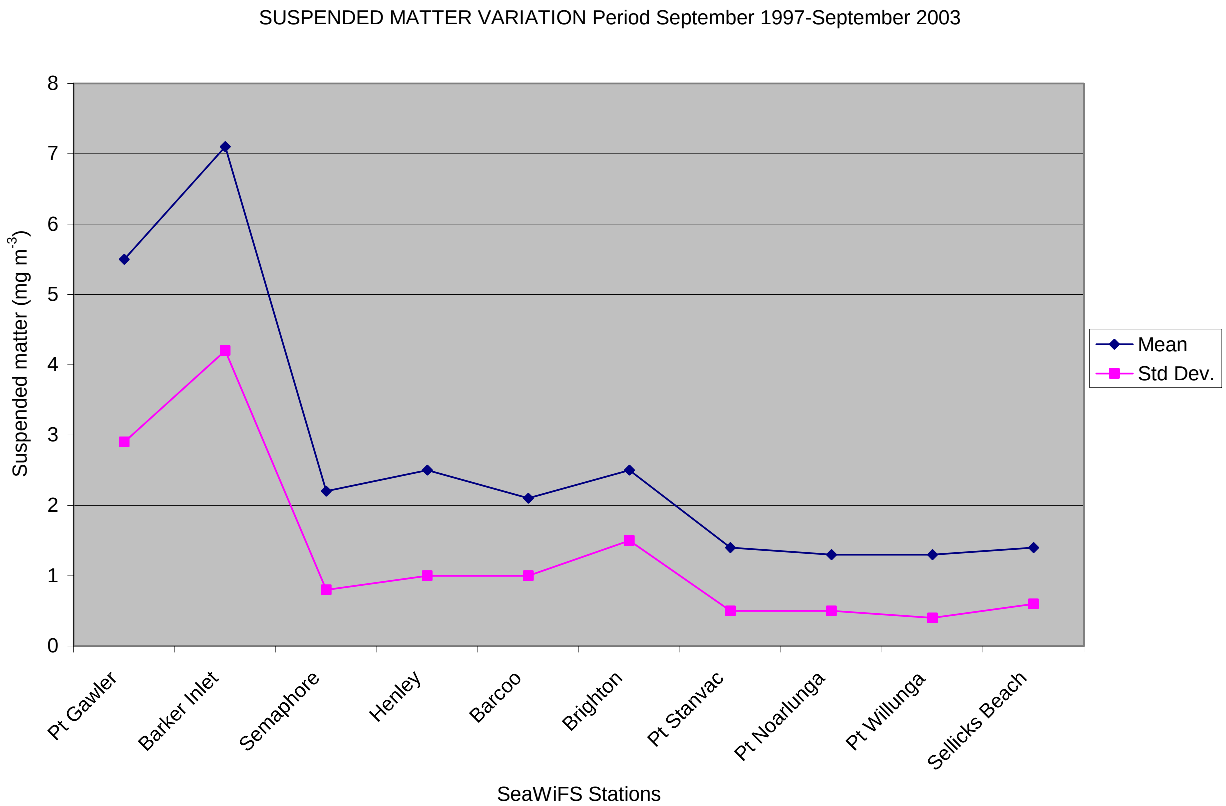

Figure 12. Mean and standard deviation suspended matter variation between Pt Gawler and Sellicks Beach, period 1997 to 2003

A north-south trend in the SeaWiFS observations is clearly visible in Figure 12. Mean values of suspended matter concentration varied from about 7 mg m^{-3} in the northern portion of the study region to 2-3 mg m^{-3} in the central portion and between 1-2 mg m^{-3} in the southern portion.

The time series of suspended matter for the period September 1997 – September 2003 for SeaWiFS stations in the northern, central, southern portion of the study region and in Gulf St Vincent are shown in Figure 13 to Figure 22.

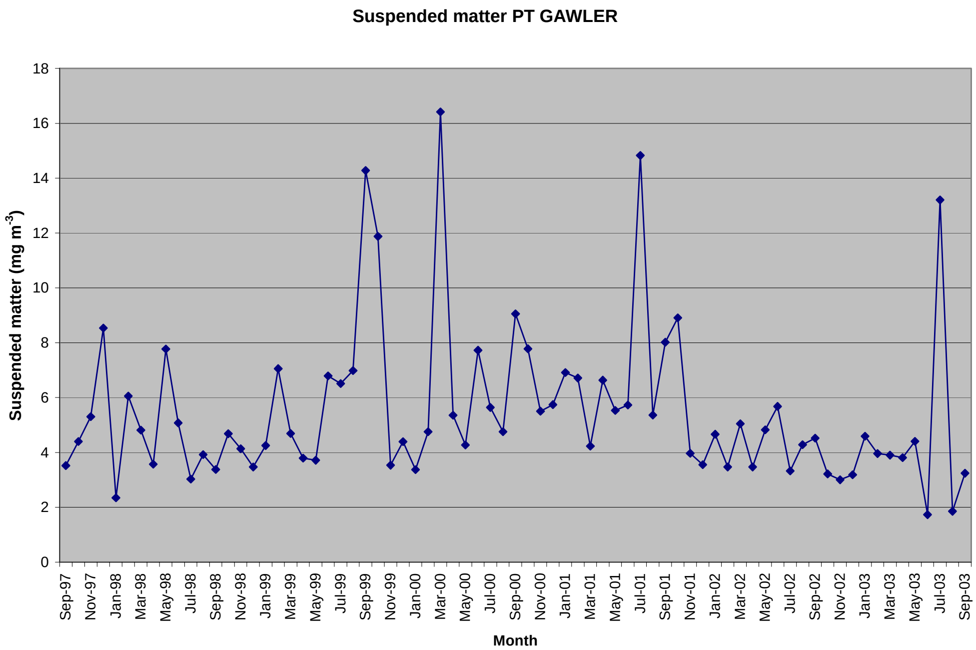

Figure 13. Suspended matter variation - Pt Gawler

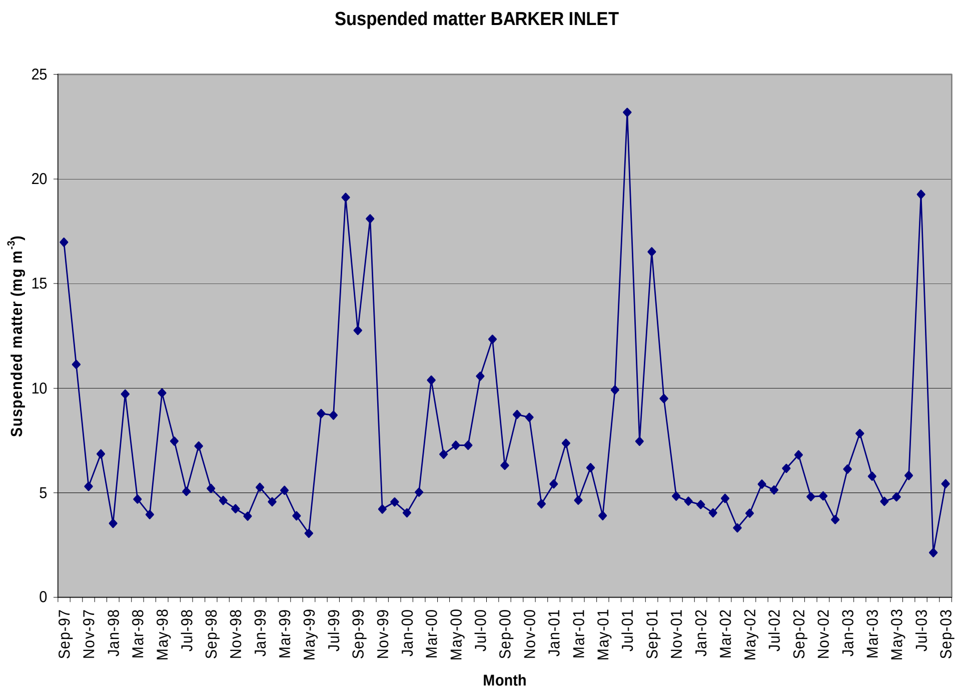

Figure 14. Suspended matter variation- Barker Inlet

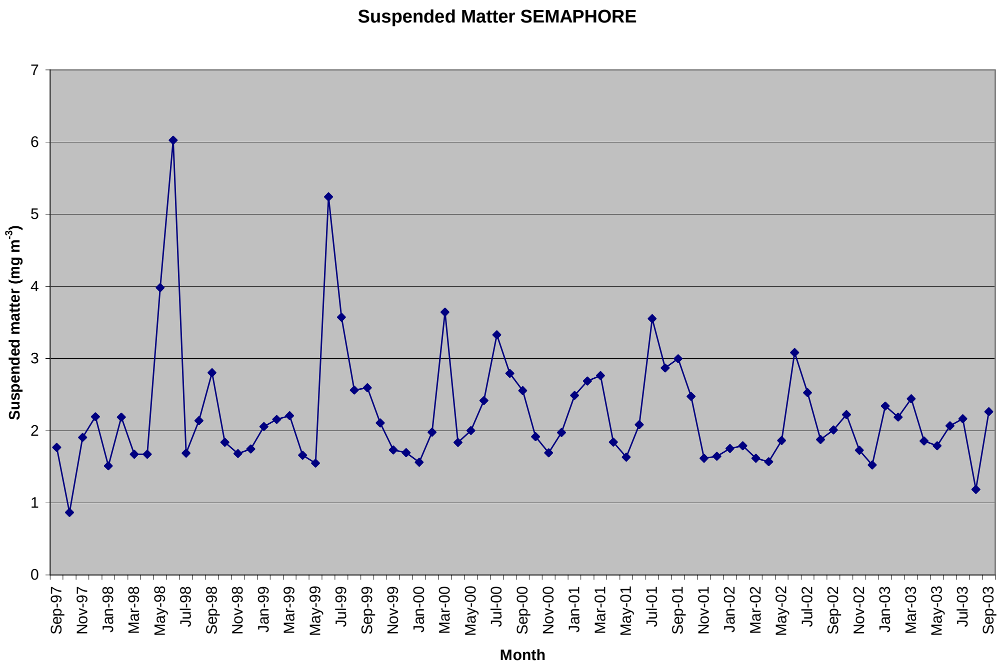

Figure 15. Suspended matter variation - Semaphore

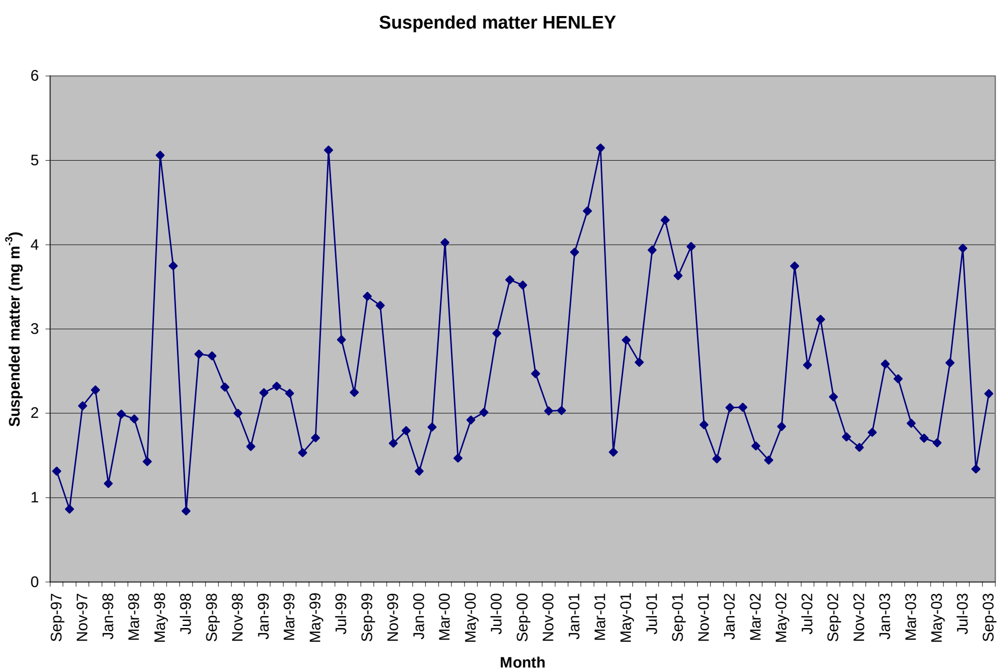

Figure 16. Suspended matter variation - Henley

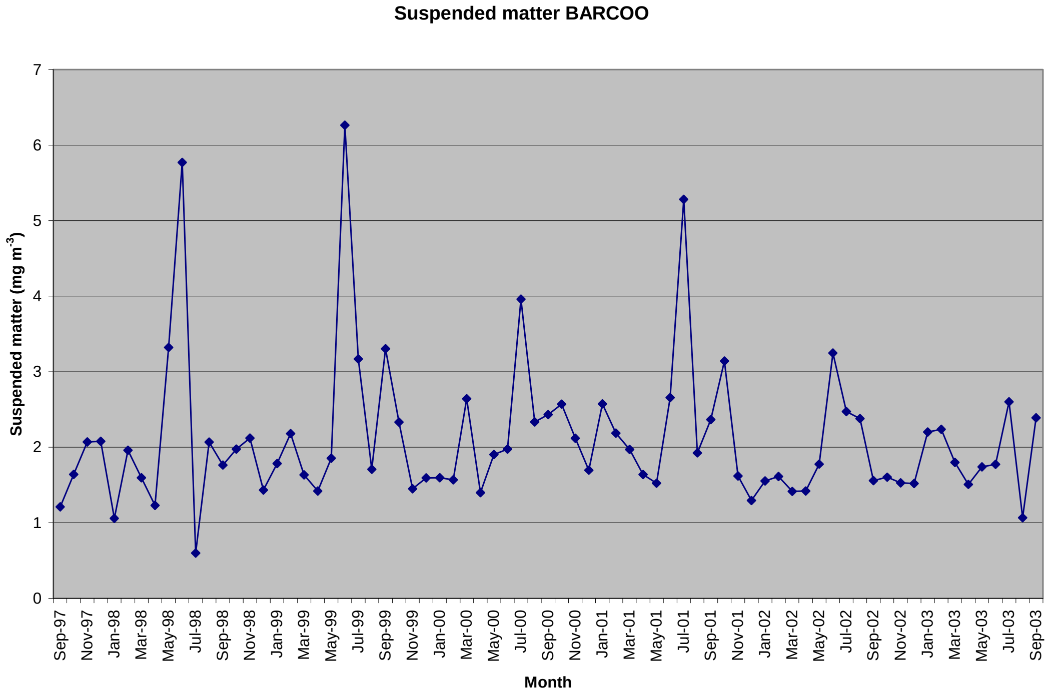

Figure 17. Suspended matter variation - Barcoo

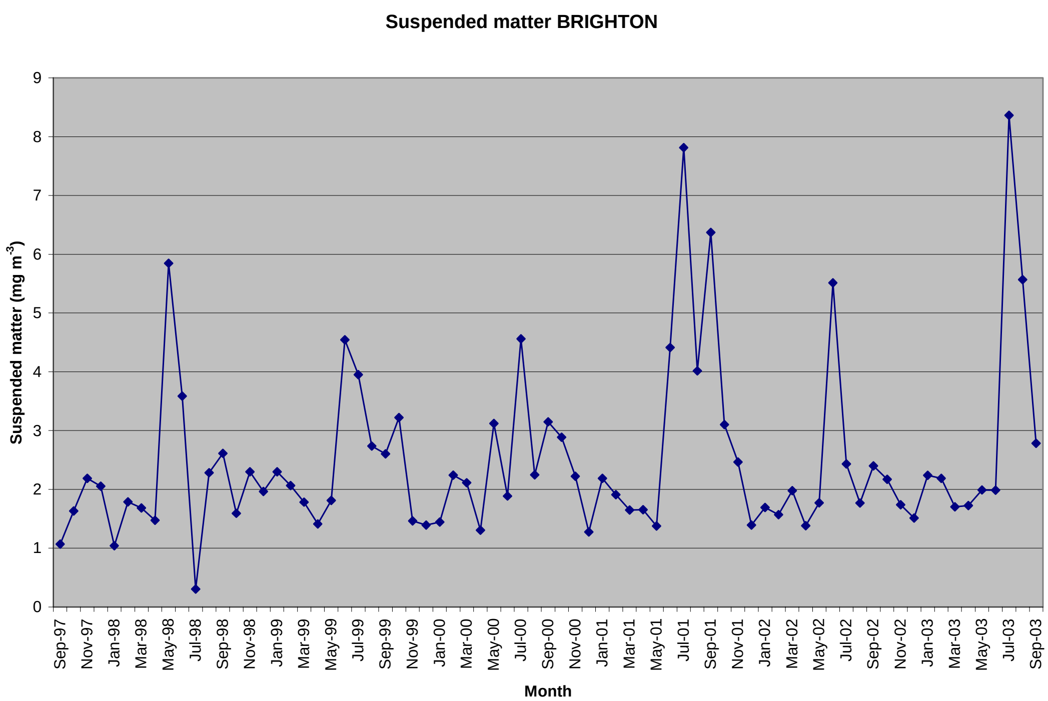

Figure 18. Suspended matter variation – Brighton

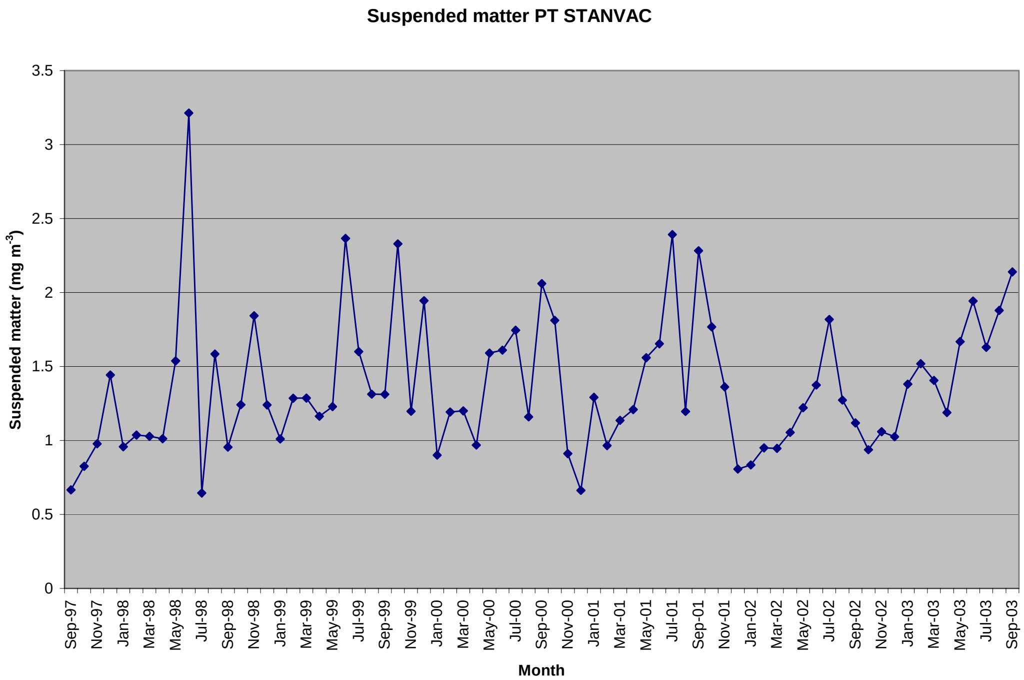

Figure 19. Suspended matter variation - Pt Stanvac

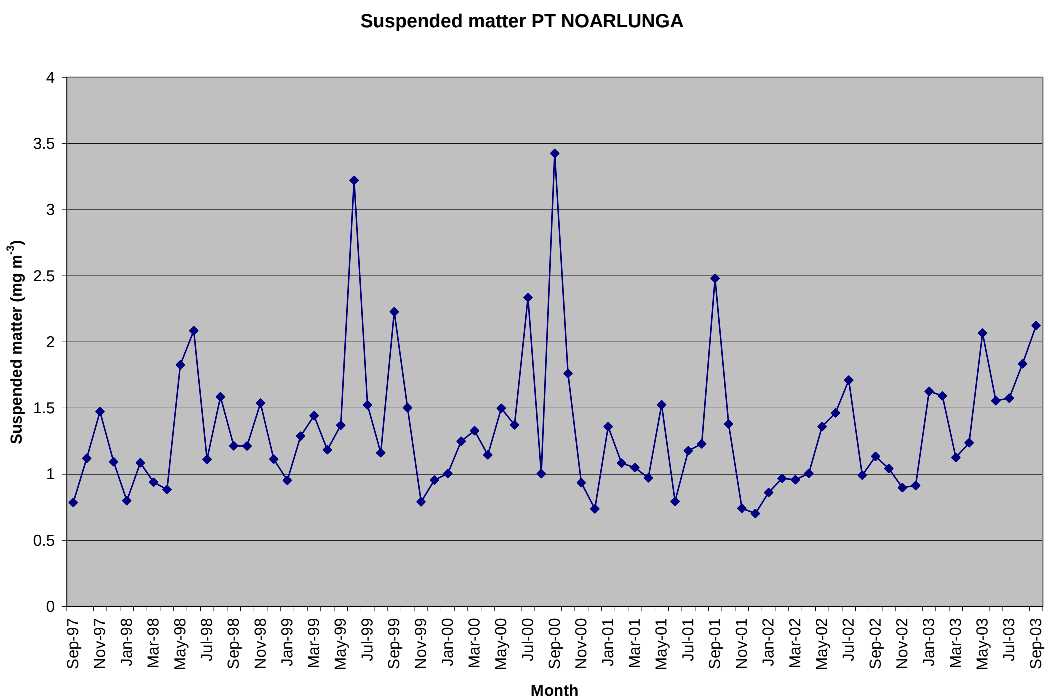

Figure 20. Suspended matter variation - Pt Noarlunga

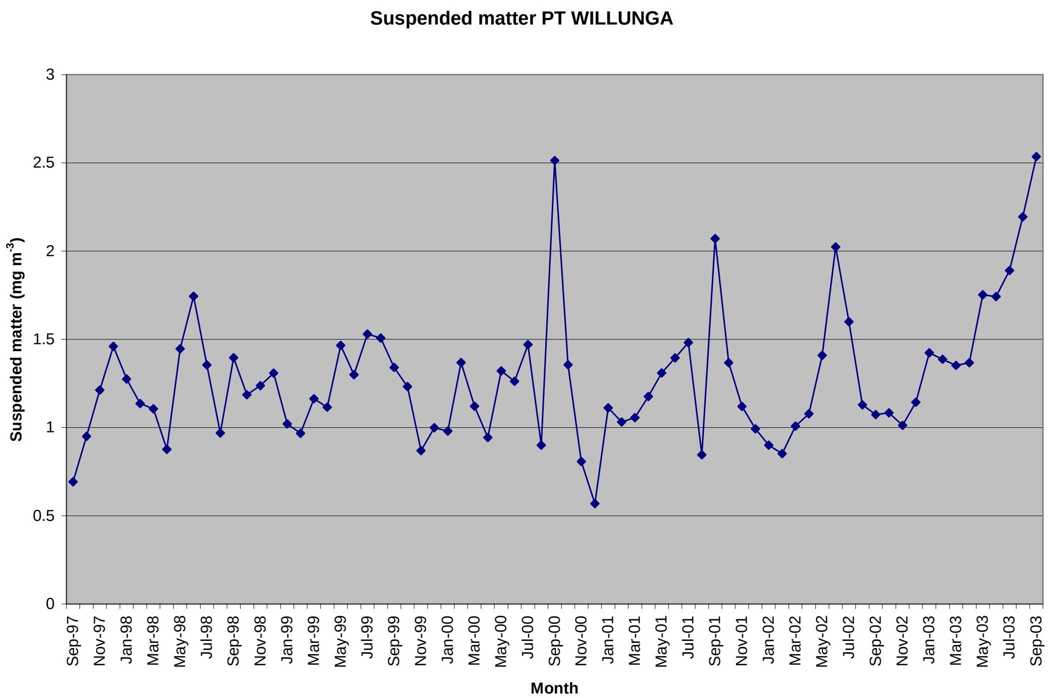

Figure 21. Suspended matter variation- Pt Willunga

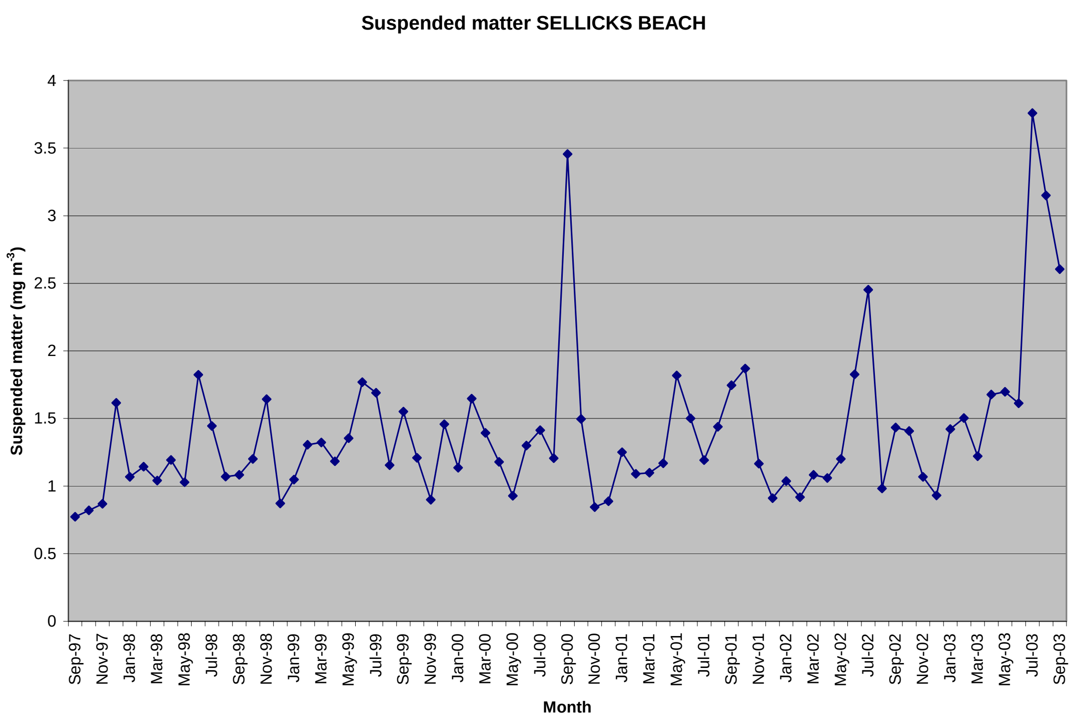

Figure 22. Suspended matter variation- Sellicks Beach

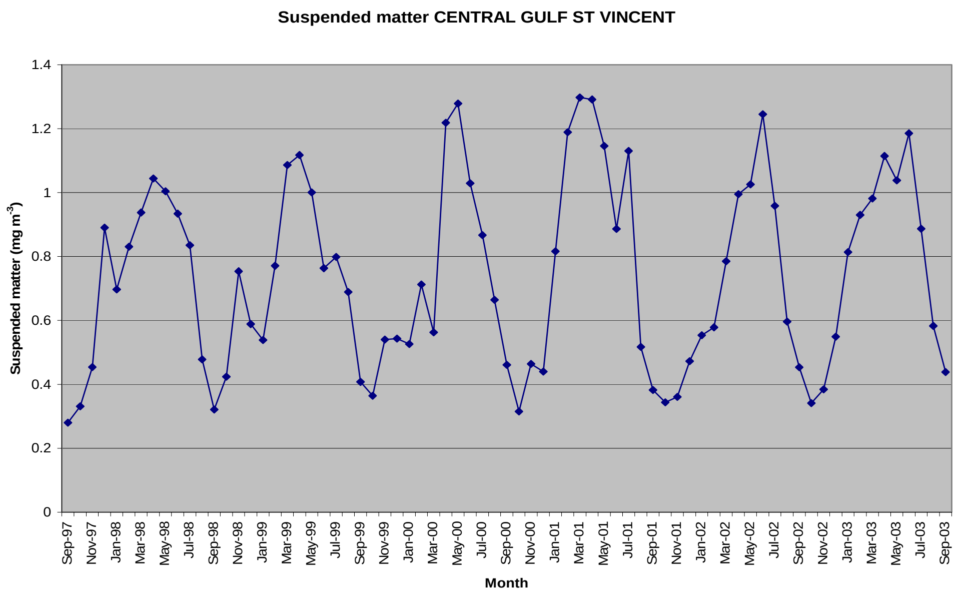

Figure 23. Suspended matter variation – Central Gulf St Vincent

3.3 Spectral analysis of SeaWiFS observations

Observations of suspended matter from all SeaWiFS stations indicated periodicity in suspended matter levels and suggested the presence of annual and semi-annual components. The data were subjected to spectral analysis using the StatSoft statistical package STATISTICA (1995) which confirmed initial observations of periodicity. The time series for all SeaWiFS observations were subjected to mean subtraction and de-trending prior to spectral analysis.

An example of spectral analysis results of SeaWiFS observations for the Semaphore station is shown in Figure 24. This indicated presence of annual and semi-annual components with the annual component being dominant. These results are in contrast with spectral analysis of SeaWiFS observations from the central GSV station which show only an annual component (Refer Figure 25).

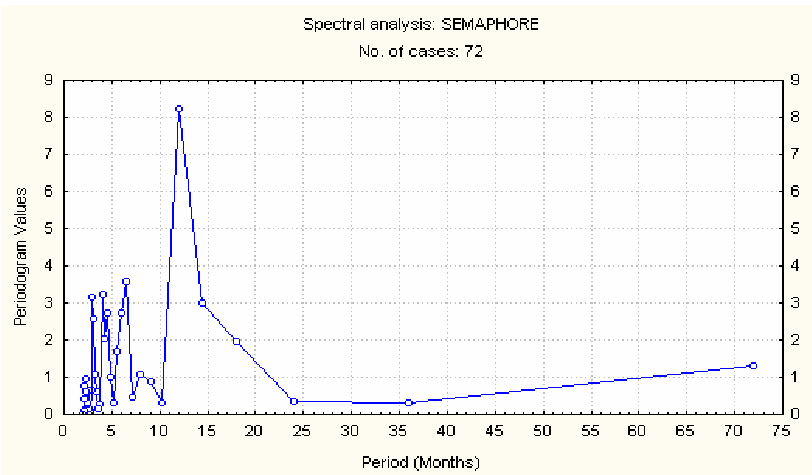

Figure 24. Spectral components for SeaWiFS data – Semaphore station

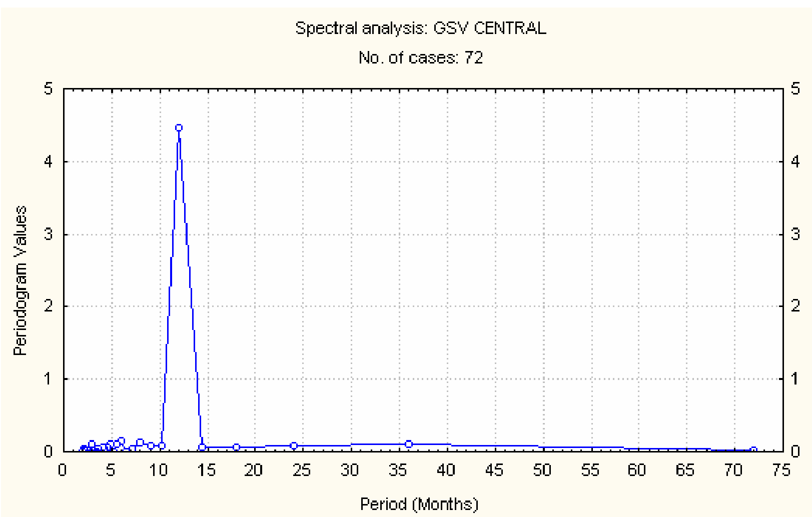

Figure 25. Spectral components for SeaWiFS data from central GSV station

The statistical significance of the spectral analysis results, that is, the extent to which the SeaWiFS observations at each station were different from random observations was tested by application of the Bartlett Kolmogorov–Smirnov (B K-S) d-test (STATISTICA, 1995). If the distribution of observations was random, that is, followed a normal distribution, this would produce a periodogram whose values followed an exponential distribution. Thus by testing the distribution of the periodogram produced by the SeaWiFS observations against the exponential distribution it was possible to test whether the SeaWiFS observations are different from a random (or white noise) distribution.

The B K-S test was also applied to a time series representing a sine wave and a random number function in order to rank the results of the SeaWiFS observations with respect to periodic and random variation.

Results as a function of position of the SeaWiFS stations along the coastline with respect to Pt Gawler are shown in Figure 26. For comparison, the results should be compared to a B K-S value of 0.88 for a sine wave and 0.11 for a random number series. The result of the B K-S test indicated that the SeaWiFS observations for all stations, except for Pt Gawler and to a lesser extent for Henley, showed a greater tendency to be periodic rather than being random in nature.

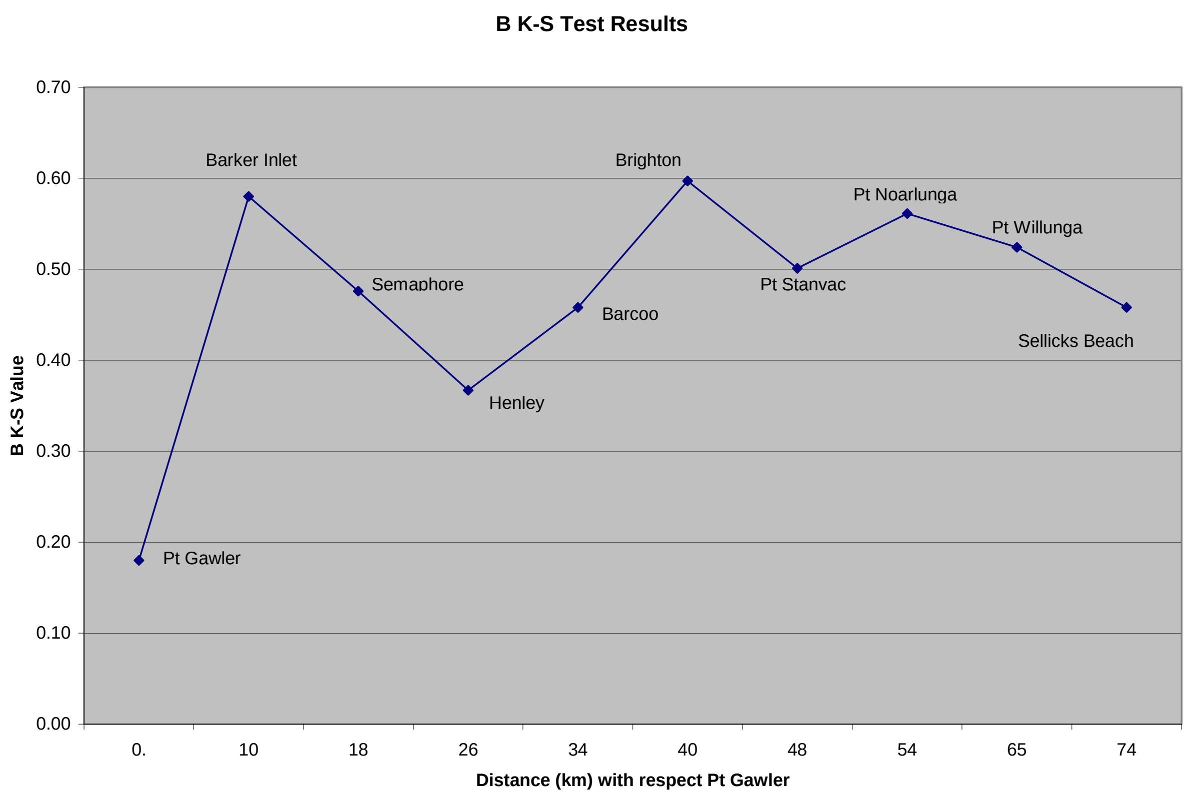

Figure 26. Results of B K-S test for SeaWiFS stations.

3.4 Fourier Analysis

An alternative method to test for seasonality involved use of a Fourier series which included annual and semi-annual components. The sine and cosine terms corresponding to a periodicity of 12, 6, 4 and 3 months were regressed against the SeaWiFS observations. The model and hypothesis employed in this technique is described by Correll and Barnes (2003). The results of the analysis are given in Table 8.

TABLE 8. Results of statistical tests of annual and semi-annual component

Station	No. Observations	r^2 value	p-value	Component (month)
Pt Gawler	72	.11	.49	12,6,3,4
		.07	.55	12,6,3
		.04	.58	12,6
		.02	.40	12
Barker Inlet	72	.30	<0.05	12,6,3,4
		.27	<0.05	12,6,3
		.26	<0.05	12,6
		.21	<0.05	12
Semaphore	72	.34	<0.05	12,6,3,4
		.28	<0.05	12,6,3
		.21	<0.05	12,6
		.16	<0.05	12
Henley	72	.21	<0.05	12,6,3,4
		.16	<0.05	12,6,3
		.13	<0.05	12,6
		.09	<0.05	12
Barcoo	72	.36	<0.05	12,6,3,4
		.24	<0.05	12,6,3
		.21	<0.05	12,6
		.15	<0.05	12
Brighton	72	.34	<0.05	12,6,3,4
		.31	<0.05	12,6,3
		.31	<0.05	12,6
		.26	<0.05	12
Pt Stanvac	72	.32	<0.05	12,6,3,4
		.26	<0.05	12,6,3
		.23	<0.05	12,6
		.20	<0.05	12
Pt Noarlunga	72	.32	<0.05	12,6,3,4
		.23	<0.05	12,6,3
		.20	<0.05	12,6
		.20	<0.05	12
Pt Willunga	72	.30	<0.05	12,6,3,4
		.26	<0.05	12,6,3
		.22	<0.05	12,6
		.22	<0.05	12
Sellicks Beach	72	.23	<0.05	12,6,3,4
		.22	<0.05	12,6,3
		.20	<0.05	12,6
		.17	<0.05	12

Inclusion of the annual and semi-annual components produced a positive correlation which accounted for 49% - 60% of the total variation between the variables and was significant at the $p < .05$ level for all SeaWiFS stations except Pt Gawler.

3.5 Data Trends

It was noted that the SeaWiFS observations at some stations indicated a linear trend which was found to be statistically significant. For example, at Pt Gawler the SeaWiFS observations indicated a decrease in the mean monthly suspended matter between about January 2000 and September 2003. The proximity of this station to the Bolivar WWTP and an oceanographic regime (Oceanique Perspectives, 2000) which favours transport between Barker Inlet and the Pt Gawler region may reflect the reduction in suspended matter due to the Environmental Improvement Program for the Bolivar WWTP. The observations and trendline for the Pt Gawler station are shown in Figure 27.

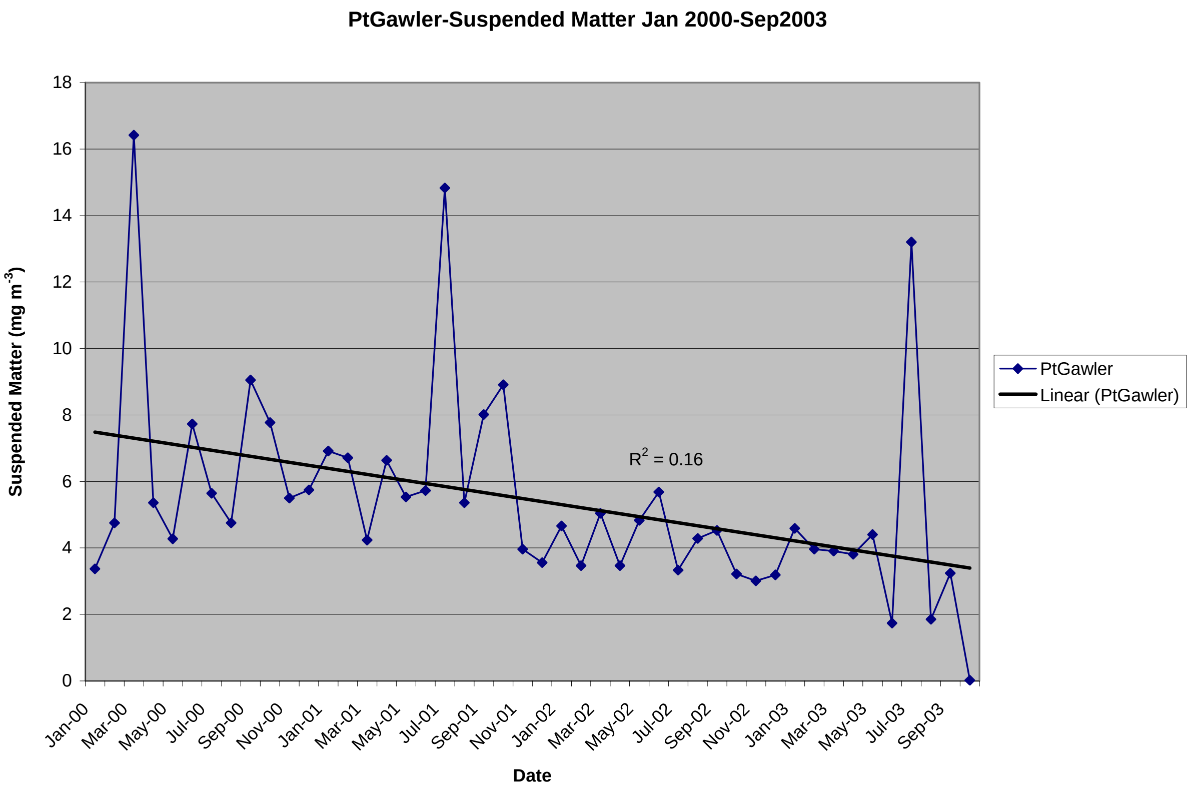

Figure 27. Time series and trendline SeaWiFS observations at Pt Gawler.

In the southern region, SeaWiFS observations for Pt Willunga indicated that suspended matter levels had increased since about January 2000. The observations and trendline for the Pt Willunga station are shown in Figure 28.

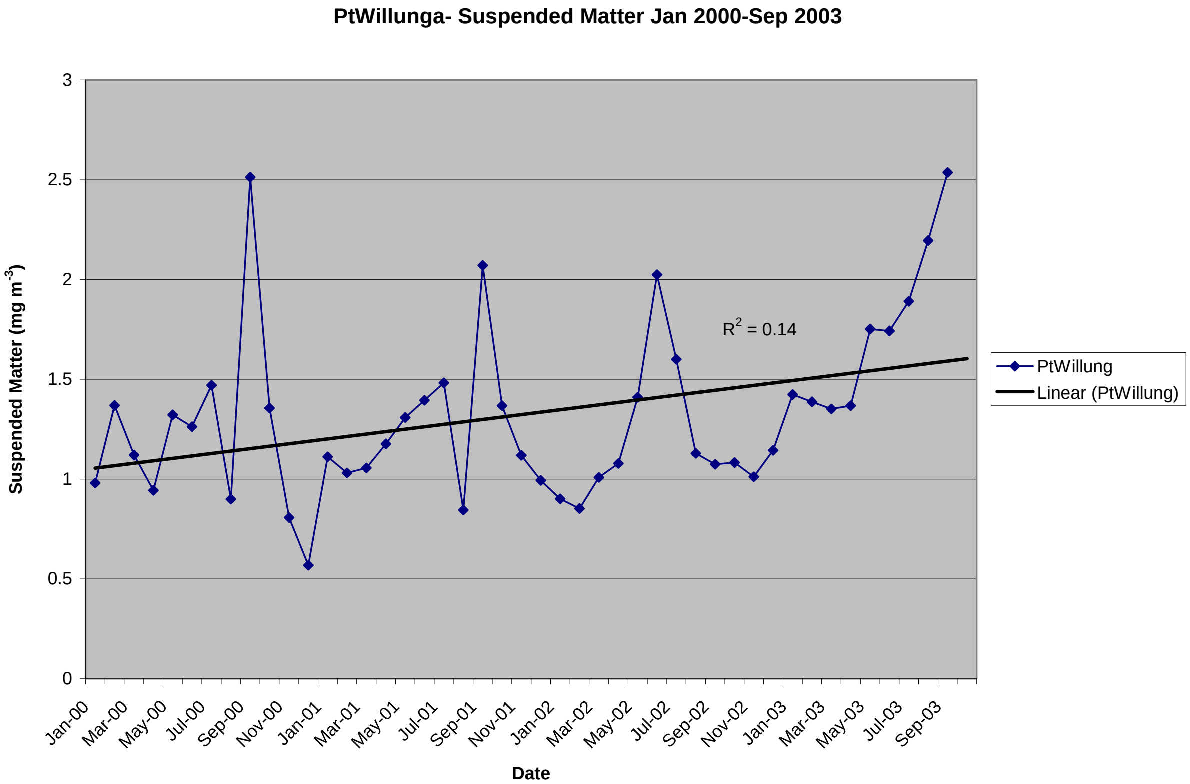

Figure 28. Time series and trendline – SeaWiFS observations at Pt Willunga

3.6 Cluster analysis

The extent to which the time series of observations from SeaWiFS stations exhibited similar temporal patterns for the period September 1997-September 2003 was examined using cluster analysis technique (STATISTICA,1995). This technique grouped SeaWiFS stations which have similar temporal attributes together through creation of a 2-dimensional "map" which showed dissimilarities as distances (Refer Figure 29).

The linkage distance shown in Figure 29 is defined as the geometric distance in multi-dimensional space and is computed as follows:

Linkage distance (x, y) = $(\Sigma_i (x_i - y_i)^2)^{0.5}$ where x, y are the co-ordinates of two variables in multi-dimensional space.

A vertical line across the plot at "linkage" distance =12" identified the northern stations Barker Inlet and Pt Gawler as one group. Central stations included Semaphore, Barcoo, Henley and Brighton as another group, and the southern stations Pt Stanvac, Pt Noarlunga, Pt Willunga, Sellicks Beach and GSV Central as another group.

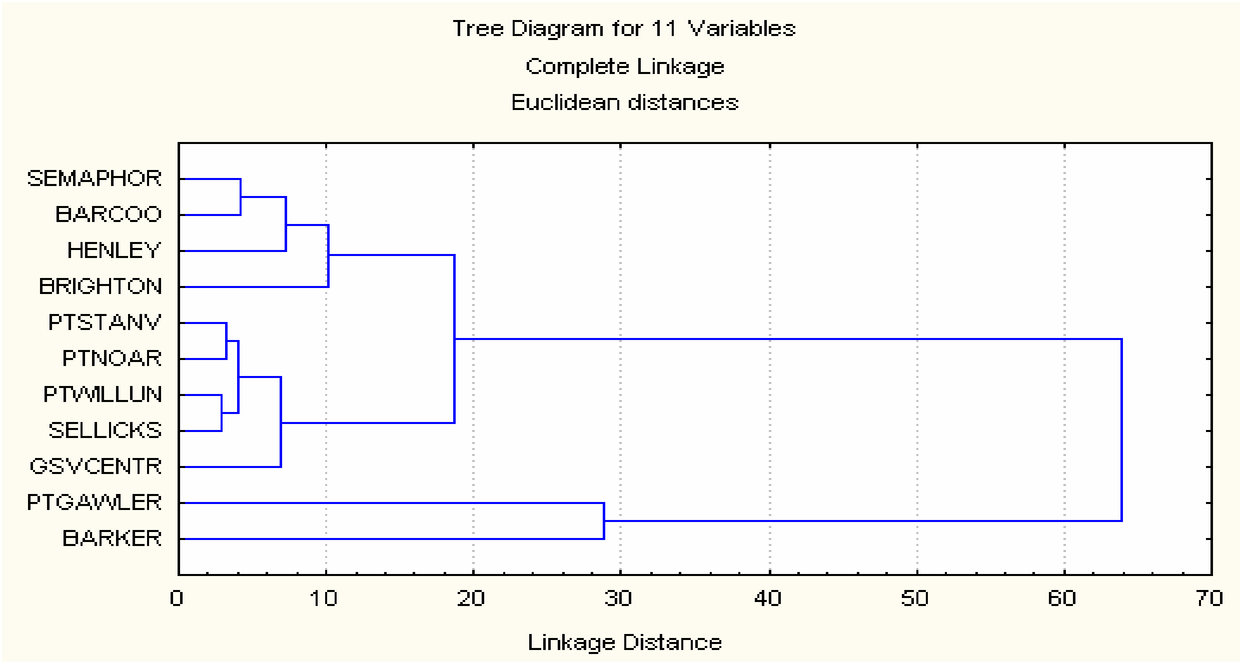

Figure 29. SeaWiFS station grouping

The grouping of the stations appears consistent with the case that SeaWiFS observations in the southern region may be influenced more by gulf-governed processes (See Figure 3) whereas the stations in the Adelaide metropolitan central and northern waters are influenced more by land based discharges.

4. SeaWiFS Oservations – Regional Factor Analysis

In this section, the relationship between SeaWiFS observations of suspended matter and factors important to seagrass condition in the Adelaide metropolitan waters are examined.

4.1 SeaWiFS observations-Land based discharges relationship

The hypothesis that the dominance of an alongshore current regime in the Adelaide metropolitan waters restricts offshore transport of WWTP and major river discharge was tested by examining the relationship between land based discharges and suspended matter observations at SeaWiFS stations. The relationship was tested using a linear regression model and applied to the major land based discharges below. The results of the linear regression analysis are shown in Table 9.

4.1.1 Bolivar WWTP

The relationship between Nitrogen as NH_3 load from the Bolivar WWTP and suspended matter observations at SeaWiFS station at Pt Gawler (about 9km NW of Bolivar) and Barker Inlet (about 6 km SW of Bolivar) (Refer Figure 7) for the period June 1998 to August 2003 was examined.

4.1.2 Torrens River

Monthly flowrate from the Torrens River and suspended matter observations from SeaWiFS stations at Henley (about 6.5 km NW of River Torrens outlet) and Barcoo (about 5.5 km SW of River Torrens outlet) (Refer Figure 7) for the period September 1997 to September 2003 was examined.

4.1.3 Glenelg WWTP

The relationship between Nitrogen as NH_3 load from the Glenelg WWTP and suspended matter observations at SeaWiFS station at Barcoo (about 5 km W of the Glenelg WWTP discharge) (Refer Figure 7) for the period July1998-December 2002 was examined.

4.1.4 Christies Beach WWTP

The relationship between Nitrogen as NH_3 load from the Christies Beach WWTP and suspended matter observations at SeaWiFS station Pt Stanvac (about 4.5 km NNW of the Christies Beach WWTP discharge) and Pt Noarlunga (about 5 km SW of the Christies Beach outfall) (Refer Figure 7) for the period September 1998-June 2003 was examined.

Table 9. Results of linear regression analysis of SeaWiFS observations and land based discharge data

SeaWiFS Station	Land –based discharge	r^2
Pt Gawler	Bolivar WWTP	.015
Barker Inlet	Bolivar WWTP	.03
Henley	Torrens River	.08
Barcoo	Torrens River	.05
Barcoo	Glenelg WWTP	.04
Pt Stanvac	Christies Beach WWTP	.002
Pt Noarlunga	Christies Beach WWTP	.01

In all cases considered, the results indicated there was no significant positive correlation between the WWTP and Torrens River discharge and the observations of suspended matter at the SeaWiFS stations which were located approximately 2 to 5 km directly offshore.

This supported the hypothesis that offshore transport of discharge from WWTP's and Torrens River is confined to the nearshore region. These results also supported earlier SeaWiFS observations of suspended matter distribution shown in Figure 6 that indicated that, along the metropolitan coastline and except for the Barker Inlet region, levels of suspended matter decreased rapidly to <1 mg m^{-3} within 2 to 3 km offshore.

The linear regression results were in agreement with outcomes of previous investigations of water movement conducted in the Adelaide metropolitan waters by Bye (1976), Oceanique Perspectives (2000), field studies using drogued buoys (FIAMS, 1979; Petrusevics, 1986) which indicated strong alongshore movement. The lack of strong offshore movement was demonstrated from analysis of tidal constituents by Steedman (1985) using current meter stations offshore from Barker Inlet and Grange (Refer Table 10).

Table 10. Major tidal current constituents in northern portion of the ACWS region

Constituents	OFFSHORE BARKER INLET N-S (cm/sec)	OFFSHORE BARKER INLET E-W (cm/sec)	OFFSHORE GRANGE N-S (cm/sec)	OFFSHORE GRANGE E-W (cm/sec)
M_2	9.6	2.5	14.6	.8
S_2	10.6	1.5	15.8	.7
O_1	1.1	1.4	2.2	.5
K_1	2.6	1.8	4.2	.9

The outcome of the above studies and anecdotal reports of stormwater plumes being confined close to the coast (<1 km) substantially support the assertion that movement of land based discharges further offshore than say 1 to 2 km is highly unlikely.

This suggests that reported loss of seagrass in the offshore region is unlikely to be directly due to the influence of land based discharges.

4.2 SeaWiFS observations - Wind induced wave relationship

4.2.1 Background

The contribution of wave induced bottom stirring to suspended matter levels in the Adelaide metropolitan waters and hence impact on seagrass may be more significant than generally considered.

Disturbance of the seabed by wind induced waves is dependent on the nature of the seabed substrate, wave orbital velocity and the critical velocity threshold for re-suspension for a given sediment grain size. These aspects are not the subject of this sub-task. However the hypothesis that regional wind induced waves may reach the seabed of the Adelaide metropolitan waters and hence provide a mechanism for sea bottom disturbance with the potential to impact on seagrass health was considered.

4.2.2 Available Data

Data from a wave recorder operated by the former SA Department of Marine and Harbors (1986) during early 1980's at Seacliff in the southern part of the Adelaide metropolitan waters were available for analysis. The data consisted of mean monthly significant wave periods for the year 1981 and a record of short term significant wave period observations from winter 1985.

For a fully developed sea, a spectrum of waves with different periods is generated. However, the significant wave period (T_s) is related to the wavelength (λ) by $\lambda = 1.56\ T_s^2$ (Gourlay and Apelt, 1978). Theoretically, wave action extends to a depth of about half the wavelength (Philips, 1969).

The depth of feel of waves was computed for the mean monthly significant wave period recorded at the Seacliff wave beacon. The beacon was located approximately 2 km offshore in a depth of water of about 10 metres (Refer Table 11).

Table11. Wave data Seacliff 1981

Period	**Significant Wave Period (1) T_s (sec)**	**Theoretical depth of feel by wave $=1.56T_s^2/2$ metres**
JAN 81	3.17	8
FEB 81	5.75	25
MAR 81	6.23	30
APR 81	8.38	55
MAY 81	4.32	14
JUN 81	4.25	14
JUL 81	4.12	13
AUG 81	4.49	16
SEP 81	4.83	18
OCT 81	4.53	16
NOV 81	3.41	9
DEC 81	3.78	11

Note 1. Significant wave period is defined as the average period of the highest 33.3 % of the waves in a record.

Based on these computations, it is apparent that the seabed of the southern Adelaide metropolitan waters can be affected by waves out to a depth of 10 to 15 metres for a significant portion of the year. The short term higher frequency nature of the local wave regime is illustrated in Figure 30 which shows observations from the Seacliff wave recorder at 4 hour intervals over a period of about 1 week during August 1985.

This portion of the record included an event with a significant wave period of between 8 to 11 secs. which lasted for about 12 hours. Such events are more than adequate to generate waves that can feel the seabed to a significant depth. This record, albeit of short duration demonstrated that the southern portion of the Adelaide metropolitan waters can be subjected to wave conditions conducive to seabed disturbance.

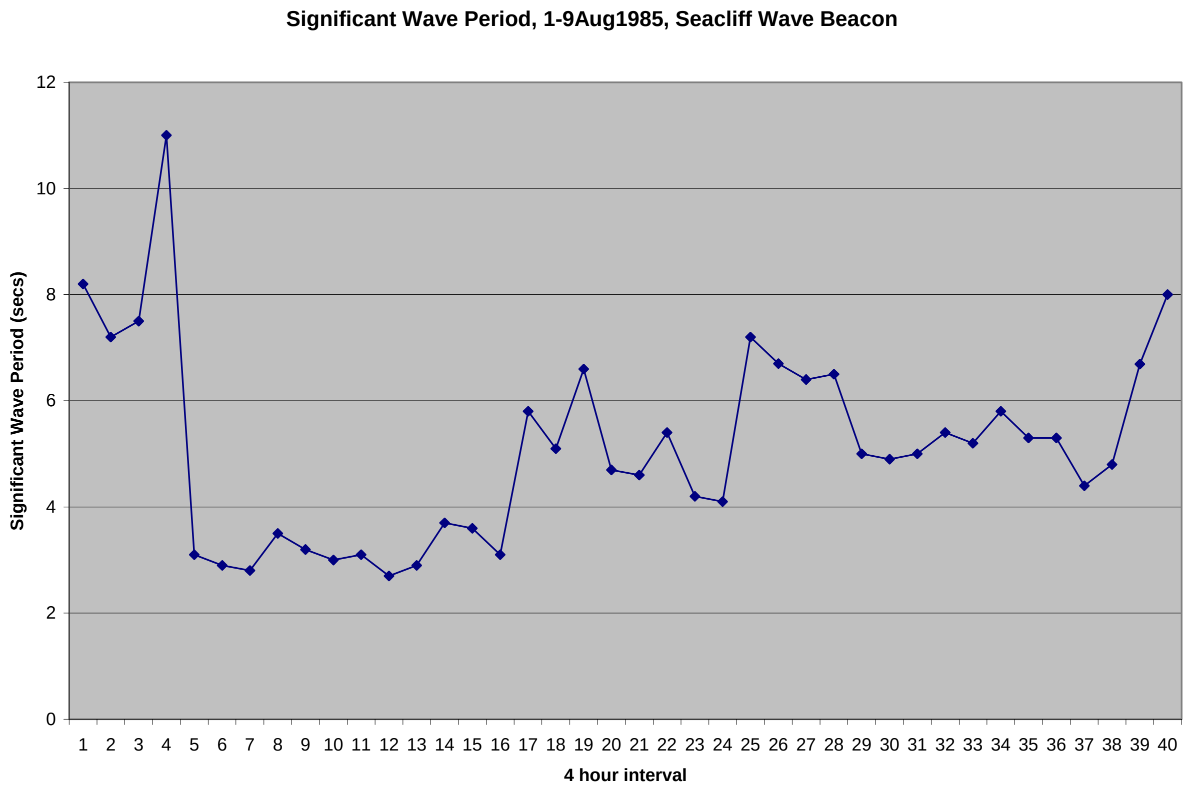

Figure 30. Four hourly significant wave period data. 1 to 9 August 1985 Seacliff wave recorder

4.2.3 Data analysis

Regression analysis between SeaWiFS observations and wind data from the Bureau of Meteorology for Adelaide Airport was used to test the hypothesis that SeaWiFS suspended matter observations are linked to winds which are capable of "feeling the seabed".

Examination of wind records at Adelaide Airport indicated that 9am wind observations were representative of the winter wind regime where storms are likely to provide a greater potential for adverse impact on seagrass by wave action. 3pm wind observations at Adelaide Airport were more representative of the summer wind regime. Although these observations also included the sea-breeze, they were not as energetic as winter winds.

In the absence of marine-platform based wind observations, the data from Adelaide Airport provided the most representative data set for the central portion of the ACWS region.

Wind direction for 9am observations were filtered to include only those data that would satisfy the *fetch lengths* necessary to produce a fully risen sea condition (that is, winds from the SSW-WNW sector). Mean monthly 9am wind observations from the SSW-WNW sector at Adelaide Airport for the period September 1997 to July 2003 are shown in Figure 31.

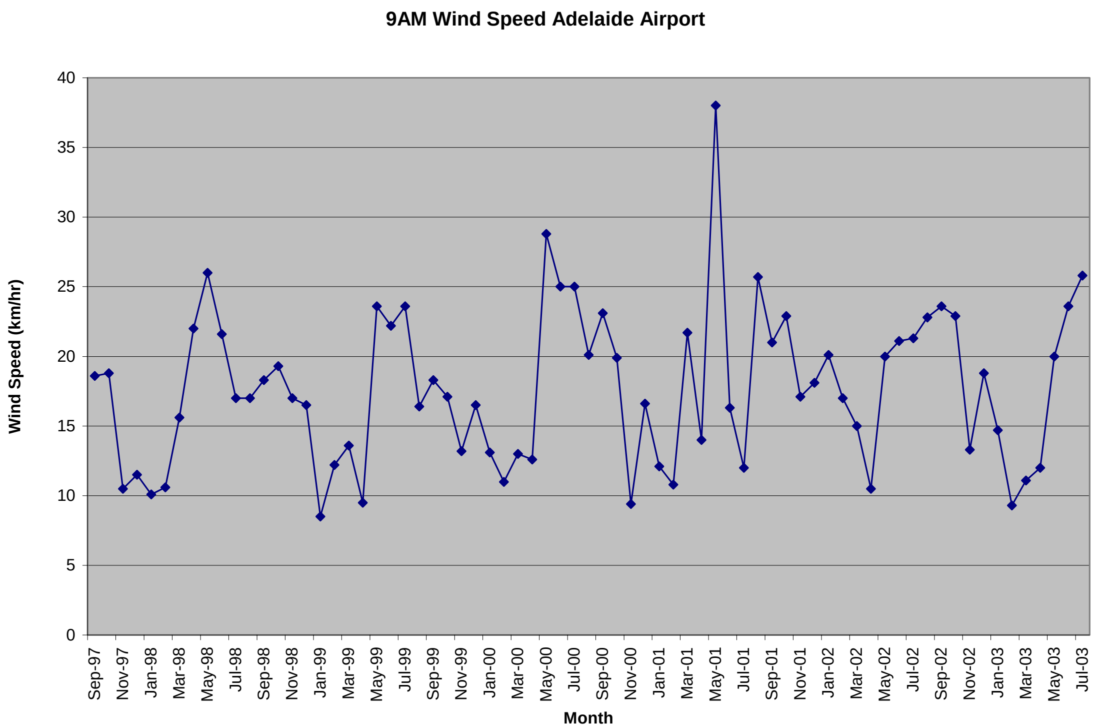

Figure 31. 9am wind observations at Adelaide Airport 1997 to 2003

The transfer of energy from the atmosphere to the water surface is via wind stress and is related to the wind strength in a non-linear manner. A comparison of linear and non-linear relationship was examined with best fit applied to a scatter plot of suspended matter observations against wind data. The results of the scatter plot analysis are shown in Table 12

Table 12. Scatter plot analysis for suspended matter and 9am wind data Adelaide Airport.

Station	r^2, Linear fit	r^2, Exponential fit
Barker Inlet	.17	.19
Semaphore	.15	.14
Henley	.12	.14
Barcoo	.26	.25
Brighton	.27	.34
Pt Stanvac	.23	.21
Pt Noarlunga	.12	.10
Sellicks Beach	.12	.12

The spatial variability of the agreement between wind and suspended matter observations for the linear and exponential fit is shown in Figure 32.

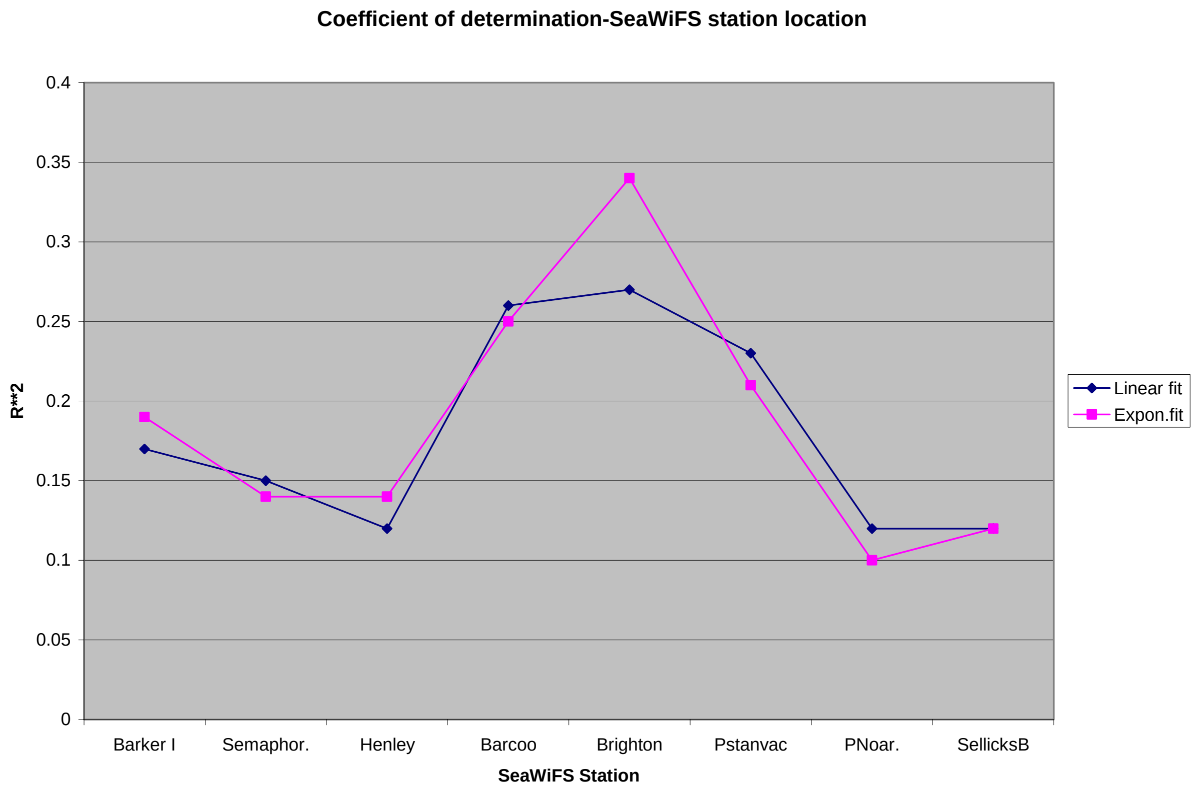

Figure 32. Scatter plot analysis of SeaWiFS suspended matter with 9am wind observations at Adelaide Airport

For Barker Inlet, Henley and Brighton SeaWiFS stations, a marginal improvement in the correlation was noted through application of an exponential relationship.

The results infer a possible proximity effect of SeaWiFS stations at Barcoo, Brighton and Pt Stanvac to the source of the wind observations, Adelaide Airport, however the SSW-NNW sector over which the winds were considered suggest a synoptic wind field which would produce near constant conditions over the Adelaide metropolitan waters.

The scatter plot analysis suggested that wind conditions and suspended matter observations were positively correlated. Linear regression analysis conducted on wind data and SeaWiFS suspended matter observations indicated that the relationship was significant at the 0.05 level. These results provided evidence of a possible causal relationship between wind induced waves and suspended matter and a need for further examination of wave induced impact on seagrass health.

In a study in lagoon waters in Florida, a positive relationship between average wind speeds and average tripton levels was reported by Christian and Sheng (2000) which suggested that increased wind speed led to increased tripton concentration probably as a result of sediment re-suspension and turbulent mixing.

5. Discussion

5.1 Interpretation of the remotely sensed signal.

This section considers in greater detail:

- whether the sea bed substrate, particularly seagrass, contributed to the water leaving radiance levels and
- examination of water quality data to determine the relative composition of the constituents in the water column.

The first issue involved application of water column light measurements obtained from field surveys to determine euphotic depth based on published light limiting conditions for seagrass. The second issue involved examination of water column absorption properties at a wavelength of 443 nm at several locations in the study region to determine the relative composition of constituents measured by the SeaWiFS sensor.

5.1.1 LICOR Measurements - February 2004

LICOR optical measurements conducted in conjunction with the Australian Water Quality Centre (AWQC) and as published data on minimum light requirements for seagrass species, were used to determine the euphotic depth. Minimum light requirements for various genera of seagrass range between 5 to 30% of surface irradiance (Duarte, 1991). For *Posidonia sinuosa* 12% of surface irradiance was reported by Gordon et al (1994) as the species' minimum light requirement. Figure 33 shows the computed euphotic depths based on a PAR irradiance reduction to 5% and 12% of surface irradiance and the water depth at a number of SeaWiFS stations.

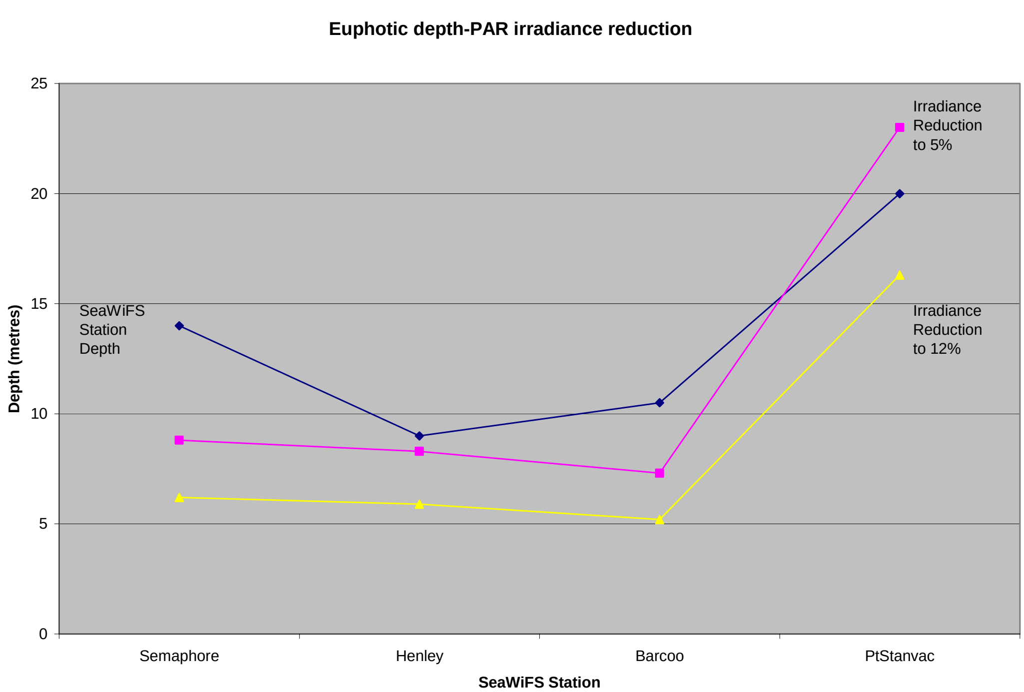

Figure 33. Euphotic depth-PAR irradiance levels for SeaWiFS stations

SeaWiFS station depths were appreciably greater than the euphotic depths corresponding to a reduction of light level to 12% of surface irradiance. Apart from the SeaWiFS station at Pt Stanvac, station depths were greater than euphotic depths corresponding to a reduction of light to 5% of surface irradiance. Based on the above, the contribution to the water leaving radiance from seagrass at these stations was not expected to be significant. Under the circumstances, the SeaWiFS observations at these stations were considered to be representative of the water column and not due to the sea-bed.

5.1.2 Trios RAMSES measurements - CSIRO Land and Water, November 2003

Trios RAMSES spectrometer measurements (Refer Section 2.5.3) were conducted several months prior to the LICOR PAR measurements and at different locations to the LICOR PAR stations (Refer Figure 7). Whilst a direct comparison with the LICOR PAR measurements cannot be made, the Trios RAMSES data provided independent estimates of extinction coefficients from which euphotic depths for the northern and southern parts of the study region could be made.

Table 13 shows the extinction coefficients calculated from the Trios RAMSES data (Column 2) at the sites tabled. The euphotic depths (Column 3) were calculated using the extinction coefficient derived from RAMSES data and the light threshold criterion for seagrass (*Posidonia sinuosa*) of 12% SI (surface irradiance) reported by Gordon et al (1994). Column 5 and Column 6 show extinction coefficients and corresponding euphotic depths based on the LICOR PAR measurements.

Despite the widely different measurement conditions for the LICOR PAR and Trios RAMSES surveys, general regional similarities may be observed. For example, for the Trios RAMSES stations in the northern region (between Pt Gawler and Semaphore) the average euphotic depth, (for a SI = 12% factor) was about 5.3 metres. The average euphotic depth for Semaphore and Henley SeaWiFS stations determined by the LICOR PAR measurement for the same light reduction level of SI =12%, was about 6.1 metres.

The depth of the SeaWiFS stations in the northern region were greater than 6 metres (Table 13) thus any contribution to the water leaving radiance from the seabed substrate was not likely to be significant at these stations. These stations are in the shallowest section of the ACWS region.

The above outcomes were supported by results reported by Dekker (2004) which inferred that the Trios RAMSES spectrometer measurement levels from the seabed substrate (nominally between 450-600 nm) decreased for water depths greater than 6 metres thus making it more difficult for species/genus identification. However, the water column composition estimation of chlorophyll-a, CDOM and tripton became quite reliable as most of the signal is derived from the water column.

Table 13. Comparison of euphotic depths derived from RAMSES and LICOR measurements

	2	3	4	5	6	7
RAMSES Station	Extinction coefficient calculated from RAMSES data (m^{-1}). Note 1	Euphotic Depth (m) based on RAMSES data	SeaWiFS Station	Extinction Coefficient based on LICOR measurement @ SeaWiFS Station. Note 2	Euphotic Depth based on LICOR measurement	SeaWiFS Station Depth (m) chart datum
Offshore Pt Gawler	1.85	1.1	Pt Gawler			5-6
Offshore Pt Gawler	.512	4.1	Barker Inlet			5-7
West of Section Bank	.238	8.9	Semaphore	0.34	6.2	11-14
Outer Harbour Approach Channel	.317	6.7	Henley	0.36	5.9	9-10
Inshore Semaphore	.367	5.8	Barcoo	0.41	5.2	10-12
Inshore Brighton South	.169	12.5	Brighton			9-11
			Pt Stanvac	0.13	16.3	17-20
			Pt Noarlunga			18-22
			Pt Willunga			11-23
			Sellicks Beach			14-20

Note 1-Measurements conducted 25 November 2003
Note 2-Measurements conducted 24 February 2004

Trios RAMSES measurements were not conducted south of Brighton, however LICOR PAR extinction coefficient measurements were conducted at Pt Stanvac which indicated that the euphotic depth, for SI=12%, was about 16 metres compared to a mean depth of about 18.5 metres for the SeaWiFS station at Pt Stanvac. Again, this suggested that a contribution to the water leaving radiance from the seabed substrate at this station was unlikely and that the signal measured by the SeaWiFS sensor was due to the water column.

5.1.3 Water column properties - CSIRO Land and Water, November 2003

The RAMSES/CASI survey of November 2003 indicated that the major constituents of the water column were phytoplankton, tripton and CDOM, Dekker (2004). The absorption characteristics of these constituents at 443 nm are given in Table 14 and the relative contribution to light attenuation in the water column in Table 15.

Table 14. Absorption coefficients of major water column constituents at 443 nm.

RAMSES STN	LOCATION	Phytoplankton Absorption (m^{-1})	Tripton Absorption (m^{-1})	CDOM Absorption (m^{-1})
AC25_5	Pt Gawler	.027	.041	.133
AC26_12	Barker Inlet	.038	.026	.076
AC26_14	Largs	.059	.03	.073
AC27_1	Brighton	.014	.010	.059

Table 15. Percentage of light absorbed by major water column constituents at 443 nm.

RAMSES STN	LOCATION	Phytoplankton (%)	Tripton (%)	CDOM (%)
AC25_5	Pt Gawler	13.4	20.4	66.1
AC26_12	Barker Inlet	27.1	18.5	54.3
AC26_14	Largs	36.4	18.5	45.1
AC27_1	Brighton	16.6	12.5	71.0

The results indicated that during the period of the Trios RAMSES survey (November 2003) a significant percentage of the absorption in the water column was attributed to the presence of CDOM with the largest values being found in the northern part of the study region around Bolivar and Pt Gawler and in the vicinity of Brighton.

These findings indicated that the nearshore waters of the ACWS region consist of a mixed regime of CDOM, tripton and phytoplankton with the biggest contribution due to CDOM. The SeaWiFS signal consisted of a contribution from all three components.

Locally, the source of CDOM (attributed to fulvic acid due to breakdown of seaweed and humic acid due to breakdown of terrestrial plant material) is not well documented although it is suspected that the Barker Inlet/Port Adelaide system including the Bolivar WWTP may be a contributing factor in the northern part of the study region. In a study to characterize the temporal and spatial variability of CDOM absorption over an annual cycle in Narragansett Bay, Rhode Island, Keith et al (2002) suggested that the magnitude of CDOM absorption is related to seasonal variability of freshwater input. Continuous freshwater input from the Bolivar WWTP and episodic stormwater input along the Adelaide metropolitan coastline may be related to CDOM levels in the nearshore waters.

5.1.4 OC4 chlorophyll algorithm derived data - field data comparison.

The absorption characteristics of constituents of the water column, such as CDOM, may be used to provide an indication of the expected performance of the SeaWiFS OC4 chlorophyll algorithm in coastal waters. For example, in coastal waters around Singapore, Liew et al (2001) reported that for low CDOM concentrations ($G = 0.1\ m^{-1}$, where G is the absorption coefficient) the agreement between OC4 algorithm derived values of chlorophyll and field measurements was generally good. However at higher CDOM concentrations ($G= 0.5\ m^{-1}$) the OC4 algorithm overestimated chlorophyll concentrations due to inclusion of the CDOM component.

The results of the CSIRO RAMSES survey in November 2003 indicated that absorption due to CDOM was consistently high at all RAMSES stations (Refer Table 14) and thus it was expected that the SeaWiFS observations (which consisted of CDOM, tripton and phytoplankton) and field measurements of chlorophyll are likely to be different. Chlorophyll measurements conducted by SA Environment Protection Authority from the Brighton and Semaphore jetties were compared with suspended matter obtained from satellite measurements on the same day from the nearest SeaWiFS stations to the Brighton and Semaphore jetties. The mean difference between SeaWiFS observations and jetty measurements was 1.1 mg m^{-3}, with a standard deviation of 0.77 mg m^{-3} (N=44).

In addition to the effect of CDOM, variability of chlorophyll levels must be expected due to horizontal phytoplankton "patchiness" and produce a further compounding factor in comparison of the OC4 algorithm derived data (measured over 1 km^2) and field data (point source). Spatial patchiness of chlorophyll, primarily due to rapid response of phytoplankton to nutrients, has been reported at the mesoscale (Mahadevan and Campbell, 2002) and in a local context by Waters and Mitchell (2002) who reported spatial variability of chlorophyll at centimetre scale in the Port Adelaide River.

5.2 Spatial variability of suspended matter

The distribution of suspended matter in the study region for the period September 1997 to September 2003 is shown in Figure 34.

Levels were greatest in the northern section of the study region at Pt Gawler and Barker Inlet. The mean levels for Pt Gawler and Barker Inlet were 5.5 mg m^{-3} and 7.1 mg m^{-3} respectively. Maximum values during the winter at these stations exceeded 15 mg m^{-3} and 20 mg m^{-3}.

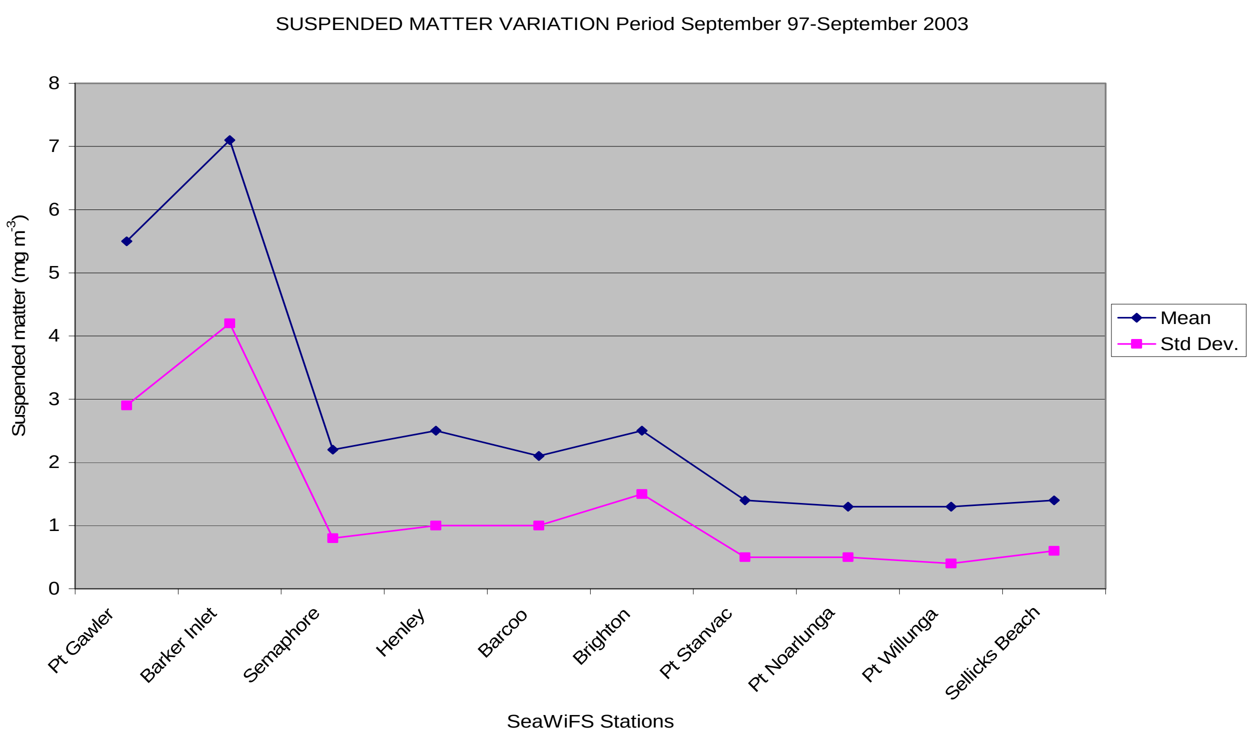

Figure 34. Variation of suspended matter along Adelaide metropolitan coastline.

The elevated levels for the Barker Inlet and Pt Gawler station are attributed to the water quality of the region which is impacted by the various point source discharges entering the Barker Inlet/Port Adelaide River Estuary.

These point source discharges include treated wastewater from the Bolivar wastewater treatment plant (WWTP), industrial discharges from Penrice Soda and Penrice bittens and industrial cooling water from power generation plant on Torrens Island. In addition, a number of stormwater drains enter the region. Major nutrient sources to the area are the Bolivar WWTP and the Penrice Soda plant in the Port Adelaide River.

Additional salt is added to the region from the Penrice bittens discharge. Stormwater flows contribute small but measurable loads of nutrients as well as being a major contributor of other pollutants such as heavy metals. The overall water quality of the area is considered to be mildly mesotrophic with the region around the discharge from the Bolivar WWTP showing highest level of water column nutrients and chlorophyll-a (Lord et al, 1996).

The above suggests that the water quality of the relatively shallower region offshore from Barker Inlet is strongly influenced by land based discharges within and from the Barker Inlet/Port Adelaide River Estuary.

Water column absorption data (Dekker, 2004) indicated that the highest levels of CDOM, non-algal-particulate matter and chlorophyll levels were recorded in the Barker Inlet region during field observations of the study region in November 2003. The water exchange between the Barker Inlet and Gulf St Vincent is characterised by a strong east-west tidal regime (MFP Australia, 1996) which favours transport of suspended matter towards SeaWiFS stations of Pt Gawler, Barker Inlet and possibly Semaphore thus accounting for the relatively high levels of suspended matter at these stations.

South of the Barker Inlet/Pt Adelaide River Estuary, the dominant tidal regime is north-south. As indicated in Section 4.1.5, there was no significant correlation between major land based discharges such as the Torrens River and Glenelg WWTP and suspended matter observations at SeaWiFS stations located 2 to 3 km offshore. Lack of offshore transport was reported for the discharge of the Patawalonga Creek which was confined within 500 to 600 metres of the shore (Lord, 1996).

In the region between Glenelg and Pt Stanvac, minor stormwater drains are located at Broadway, Glenelg; Harrow Rd, Wattle Ave, Edwards St and Young St at Brighton. In this region, stormwater discharges onto the beach and diffuses into the nearshore region where the dominantly north-south current system transports suspended matter along shore. Such observations are consistent with studies reported by Petrusevics (1982) involving dyed beach sand releases on the beach and in the littoral zone at Brighton and Seacliff where offshore movement of dyed sand was limited to 50-100 metres.

The levels of suspended matter showed a marked decrease at Semaphore and Henley. At these stations, mean levels were 2.2 mg m^{-3} and 2.5 mg m^{-3} and maximum levels being 6 mg m^{-3} and 5 mg m^{-3} respectively. The mean levels of suspended matter at Barcoo and Brighton were 2.1 mg m^{-3} and 2.5 mg m^{-3} with maximum values of about 6 mg m^{-3} and 8 mg m^{-3}.

Several small rivers such as Marion Creek, Waterfall Creek and Field River are found south of Brighton. Most of the time these rivers are dry, however on occasions rivers such as the Field River can discharge large volumes of turbid water. Exceptionally large offshore movement, up to 4 km, of turbid water has been associated with discharge of the Field River after a particularly heavy period of rain such as on 3 March 1983 (Petrusevics, 1984). However such events are rare and most stormwater is confined to a narrow inshore band adjacent to the coast which can be clearly identified (Refer Figure 35). Figure 35 highlights a dominant and consistent pattern of stormwater discharge into the Adelaide metropolitan waters where the extent of offshore movement of stormwater discharges rarely exceeds 200 to 300 metres.

Suspended matter levels at SeaWiFS stations south of Brighton were small with mean concentration of 1.4 mg m^{-3} and a maximum value of about 3.2 mg m^{-3} at Pt Stanvac.

In the vicinity of Pt Noarlunga, a number of land-based discharges are found which include the Christies Beach WWTP discharge, the Christies Creek, Onkaparinga River and a number of stormwater drains. These contribute seasonal and highly variable quantities of urban stormwater and run-off from semi-rural catchments. However, the impact of these land based discharges is confined to the nearshore region as indicated by the absence of a positive correlation between discharge of the Christies WWTP and suspended matter observations at the nearby offshore SeaWiFS stations. The mean levels of suspended matter at Pt Noarlunga were 1.3 mg m^{-3} with a maximum value of about 3.4 mg m^{-3}.

Figure 35. Sediment plumes after rainfall event 3 March 1983. Dept Lands SA Survey 2954. (Scale of the photo is given by the length of the Brighton jetty (200 metres long)

5.3 The temporal variation of suspended matter

SeaWiFS suspended matter observations within the Adelaide metropolitan waters showed significant seasonal variation. Typical temporal distribution of suspended matter observed at SeaWiFS stations for the period September 1997 to September 2003 is shown in Figure 14 which represents the variation of suspended matter at the Semaphore SeaWiFS station. Maximum values of suspended matter were noted to occur at this station and all other coastal SeaWiFS stations in the winter (June to August) (Refer Table 7).

The seasonal nature of suspended matter variability, particularly the occurrence of maximum values of suspended matter in the winter, was examined in relation to seagrass productivity reported by other investigators.

Ainslie et al (1994) reported that the productivity (leaf blade) of *Posidonia sinuosa* in upper Spencer Gulf showed a pronounced seasonal cycle with maximum levels occurring between October and April and minimum values during winter (June and July). Neverauskas (1988) examined the effects of shading on *Posidonia sinuosa* in the Adelaide metropolitan waters and found that in the winter the standing biomass levels were similar to that reported by Ainslie et al (1994). Walker and McComb (1988) reported that seagrass species in temperature waters tended to show a pronounced seasonal variation with distinct growing season in the summer.

Observations of 9am monthly mean wind speeds at Adelaide Airport indicated that maximum wind speeds occurred in the winter (Refer Figure 36). The winds represented conditions from the SSW to WNW sector with speeds up to 20-25 km/h. As indicated in Section 4.2 above, winds of that magnitude and within the specified directions were capable of generating a fully risen sea and producing waves capable of reaching the seabed in depths up to and including 10 to 15 metres. In addition to sediment re-suspension possible as a result of sea bed disturbance, stress on seagrass blades due to wave action, together with reduced water temperature and photoperiod (Refer Figure 36) may contribute to conditions where seagrass may not be able to meet growth and respiration needs at times when seagrasses require building reserves prior to reproduction in the summer (Cheshire et al, 2002). A reduction in light level to below photosynthetic compensation level for seagrass due to increased suspended matter levels was considered an important factor in seagrass decline (ACWS, 2004).

The possibility of greater stress on seagrass in the relatively shallower northern region cannot be discounted. In addition to a greater potential for re-suspension, greater light attenuation was reported by Dekker (2004) in the northern region of the study area. Results of the CASI survey in November 2003 indicated that the extinction coefficient for incident light varied between 0.238 m^{-1} and 0.367 m^{-1} for the Outer Harbour region to about 0.169 m^{-1} at Brighton. Similarly, suspended sediment concentrations were about 2.2 to 2.6 mg/l at Largs Bay compared to about 1.9 mg/l for Glenelg. These conditions may produce increased seagrass stress in the northern region.

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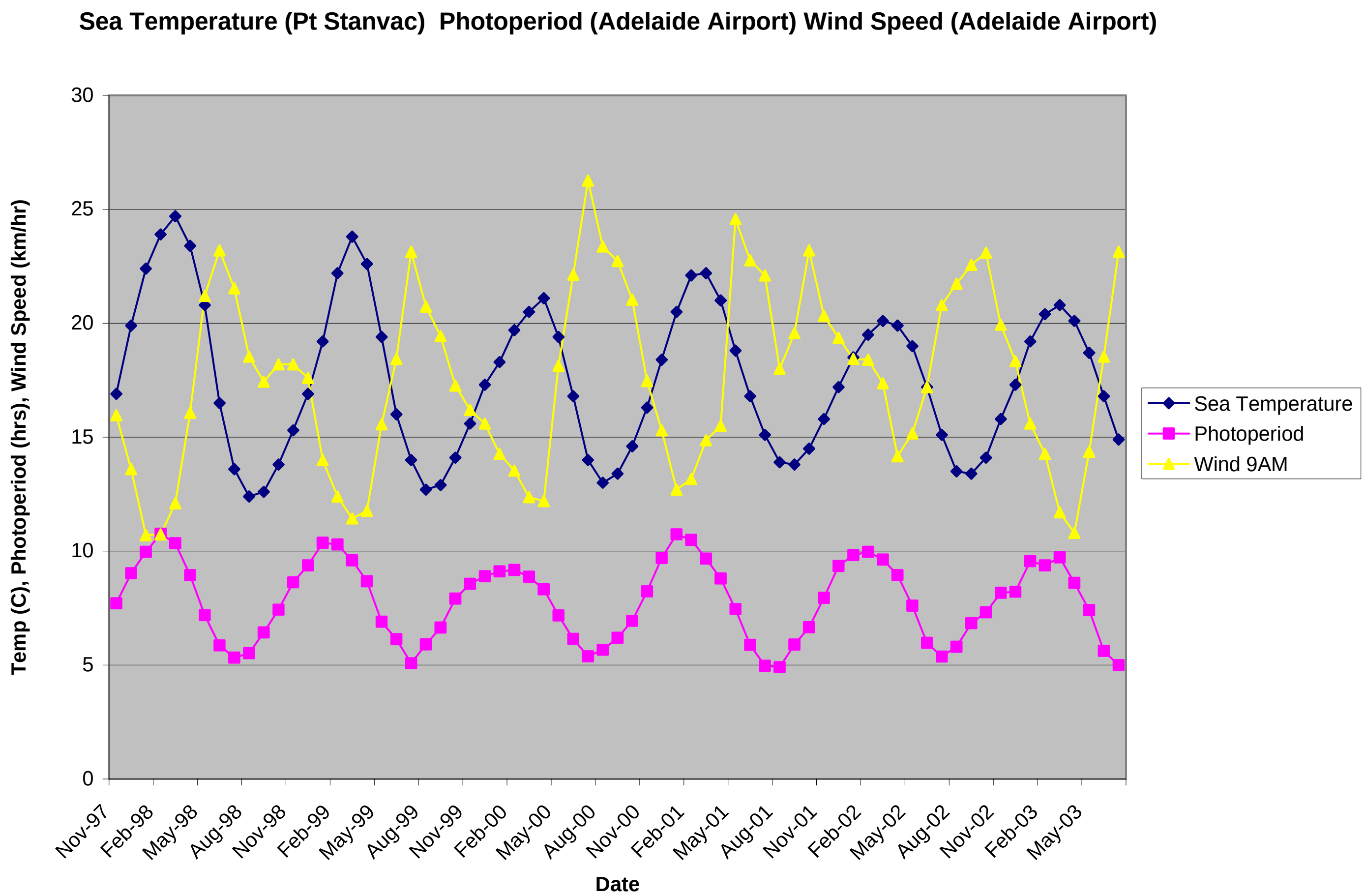

Figure 36. Variation in sea temperature, photoperiod and wind strength – Adelaide metropolitan waters, 1997 to 2003

5.4 Post SeaWiFS monitoring considerations

A component of this sub task required examination of suitable remote sensing techniques to monitor water quality in the Adelaide metropolitan waters following expected termination of the SeaWiFS mission at the end of 2004. This required consideration of a different remote sensing platform, but at the same time recognising that the SeaWiFS data record between 1997 and 2004 provided an important baseline of information which should be continuous with data from an alternative remote sensing platform.

Factors that were considered included:

- Continuity of data
- Spectral coverage
- Sea surface temperature option
- Spatial resolution
- Near real time data acquisition
- Applicability of alternative platform to water quality monitoring

5.4.1 Continuity of data.

The existing database of SeaWiFS observations for the period 1997 to 2004 offers the flexibility that the observations can be re-generated for any other required locations in South Australian waters. MODIS data, available since about 2002 provides a valuable two-year over lap period with SeaWiFS data to allow inter-sensor comparison. Coupled with an expected system operational lifetime of about 10 years, the MODIS Aqua and *Terra* platforms offer long term monitoring of water quality trends into the next decade.

Time series of SeaWiFS and MODIS *Aqua* suspended matter data for the period 2002 to 2004 provided by NASA GSFC for 9km x 9km test areas in Gulf St Vincent were examined for case Studies 1 and 2 below.

In Case Study 1, the test area was approximately 10 km offshore from Glenelg in 30m depth of water. The agreement was excellent with the worst case relative error being 20% to 25% between the two time-series. No lag between the series was evident (Refer Figure 37). A scatter plot of the data sets is presented in Figure 38. Linear regression analysis indicated that the data sets were highly correlated (r^2=0.95, p<.001).

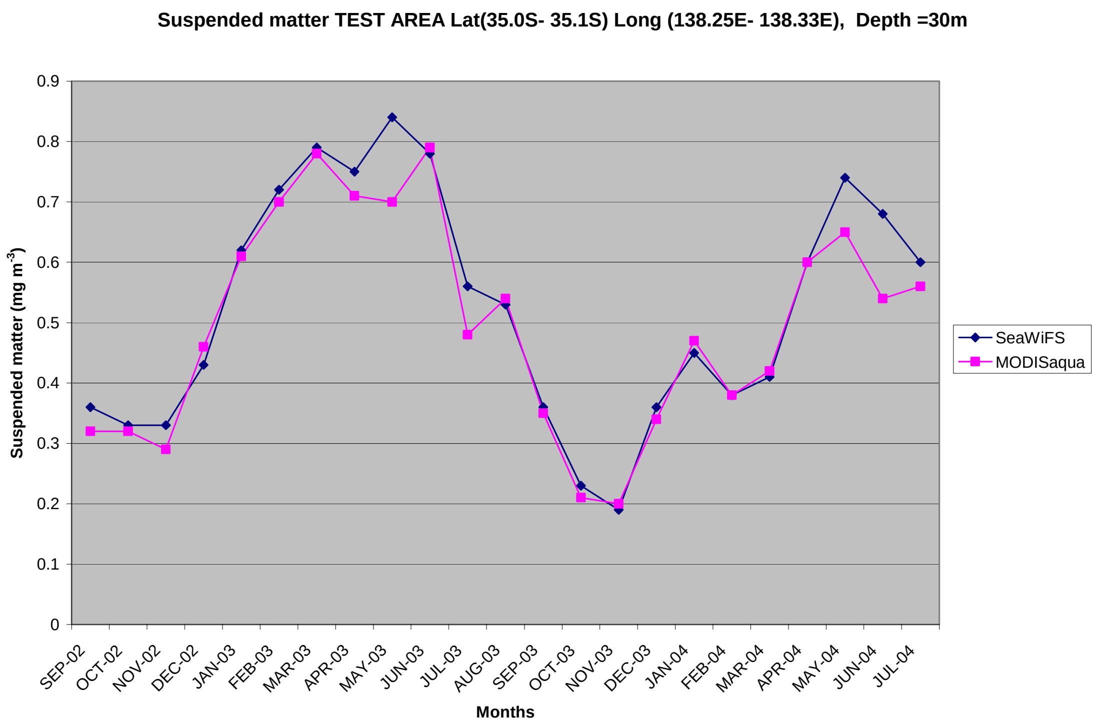

Figure 37. Comparison of SeaWiFS and MODIS *Aqua* suspended matter data for offshore test area depth 30 metres.

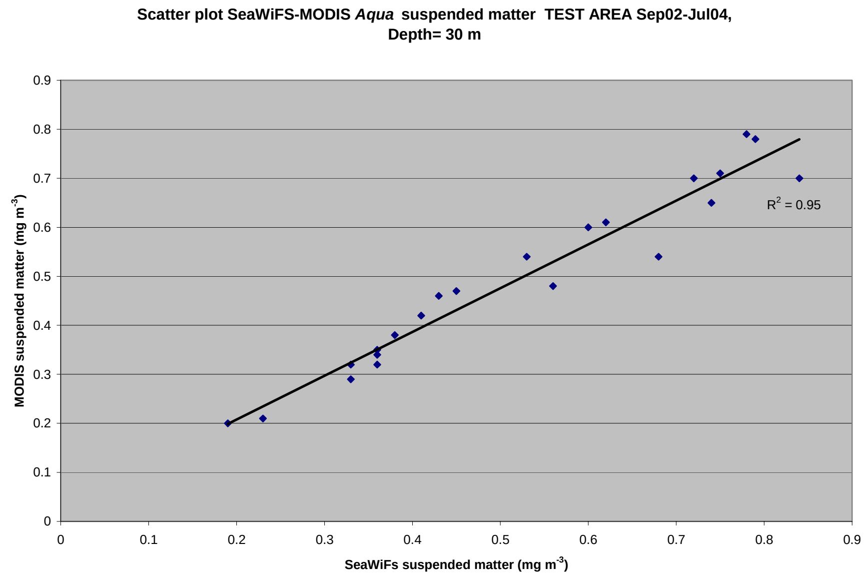

Figure 38. Scatter plot SeaWiFS and MODIS *Aqua* suspended matter for offshore test area depth 30 metres.

In Case Study 2, the test area was located approximately 5 km offshore from Glenelg in about 11 metres of water. The agreement was good with the worst case relative error being about 45% between the two data series. No lag between the series was evident (Refer Figure 39). A scatter plot of the data sets is presented in Figure 40. Regression analysis carried out to test for positive correlation indicated that the data sets were highly correlated (r^2=0.81, p<.001).

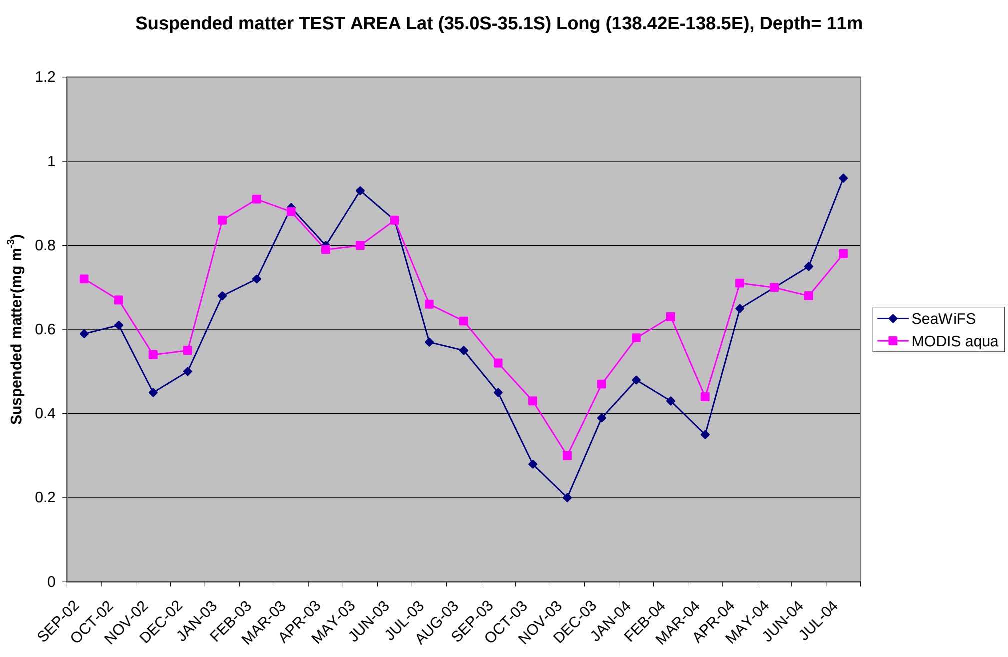

Figure 39. Comparison of SeaWiFS and MODIS *Aqua* suspended matter data for offshore test area depth 11 metres.

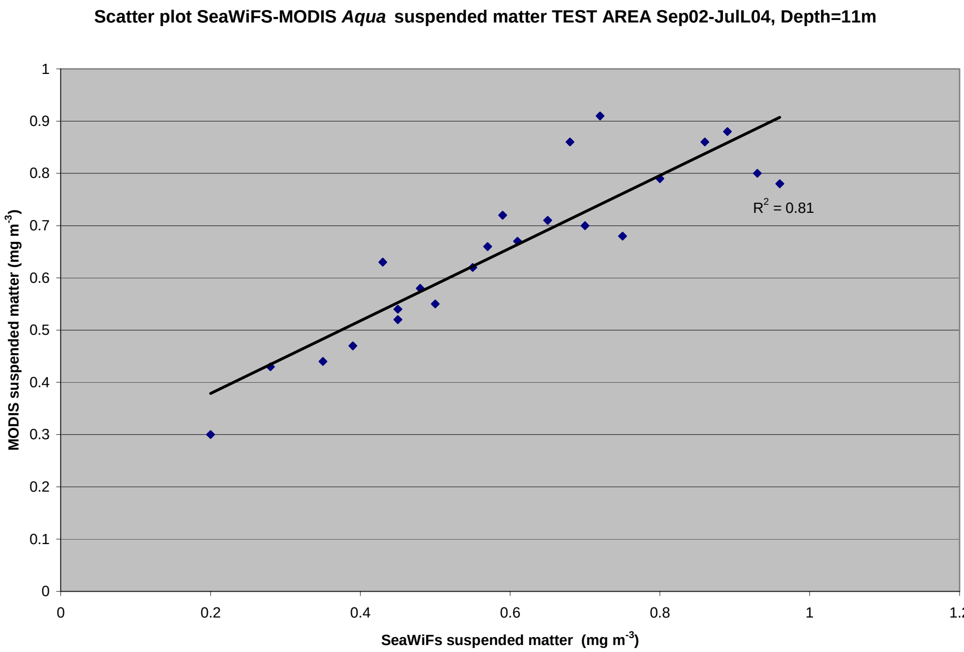

Figure 40. Scatter plot of SeaWiFS and MODIS Aqua suspended matter data for offshore test area depth11 metres.

The good agreement between SeaWiFS and MODIS *Aqua* data for the 30metre test area is due to the fact that the major constituent in water at this depth is chlorophyll which the SeaWiFS and MODIS sensors at 443 nm were designed to measure. As previously indicated, the major constituents of the water column near the coast are CDOM, tripton and chlorophyll. The response of the SeaWiFS and MODIS sensors to the spectral signature of these constituents is marginally different (Refer Table 15).

5.4.2 Spectral coverage

The spectral colour bands on MODIS are similar to the SeaWiFS band (Refer Table 15) thus ensuring continuity of measurement of variables such as CDOM, tripton and chlorophyll in the nearshore Adelaide waters.

Table 16. SeaWiFS and MODIS sensor characteristics.

SeaWiFS Spectral bands (nm)	SeaWiFS spatial resolution Unrelated to band	MODIS Spectral bands (nm)	MODIS spatial resolution Unrelated to band
412	1000	412	1000
443		443	500
490		488	250
510		531	
555		551	
		11.77-12.27 (µm) Sea Surface Temperature	

A major advantage of the MODIS bands is the narrower bandwidth, 10 nm compared to 20 nm for SeaWiFS bands (NASA, 2000). This narrower band width enhances atmospheric correction by avoiding absorption of radiation by adjacent wavelengths, such as the absorption due to atmospheric oxygen.

5.4.3 Sea surface temperature option

In addition to measurements in the visible portion of the spectrum the MODIS sensor is designed to measure sea surface temperature. Sea surface temperature is influenced by environmental factors such as wind, air temperature and cloud coverage which also have an influence on biological aspects of the sea. Having a satellite system able to provide data on variables which may have physical-biological links is an advantage and presents an opportunity to conduct correlative studies between physical and biological variables if required.

5.4.4 Spatial resolution

The spatial resolution offered by the MODIS platforms includes a 1 km resolution option thus providing continuity to the SeaWiFS data of the same resolution. Due to the spatial patchiness of suspended matter, uniformity of spatial resolution is an important factor to consider in extending the data base provided by the SeaWiFS sensor. The MODIS sensor however can also provide spatial data at 500 metre and 250 metre resolution. The increased spatial resolution would allow mapping of more detailed surface features of suspended matter.

5.4.5 Near- real time data acquisition

MODIS *Terra* and MODIS *Aqua* satellites work in tandem providing local am and pm coverage to allow observations of short term (half-day) fluctuations in sea water optical properties. The data is downloaded in real time by receiving stations located in Hobart and Alice Springs. Under normal circumstances, the overpass data is available from Geoscience Australia the next day. Typical file size is about 100 MB. The MODIS product may be processed with a number of readily available software packages.

5.4.6 Applicability of MODIS data to water quality monitoring

MODIS data supplied by Geoscience Australia are expressed in terms of spectral radiance (W/m^2-µm-sr) which may be related to parameters of interest such as chlorophyll-a through ground truthing with the latter carried out at the time of satellite overpass.

Oceanique Perspectives, in conjunction with the School of Chemistry, Physics and Earth Sciences at the Flinders University of South Australia has commenced a joint study involving regular water sampling of the Adelaide metropolitan waters in order to inform determinations of chlorophyll-a values and MODIS radiance field chlorophyll-a relationship studies. Time series of cloud free MODIS *Aqua* and *Terra* images acquired since about 2002 are being used in field measurement related analysis. Development of a statistically robust relationship between chlorophyll-a field data and MODIS data over a sufficiently long period to include seasonal variability will provide the basis for a simple, non-labour intensive technique for monitoring of chlorophyll-a levels in South Australian waters.

5.5 Example of application of SeaWiFS data for monitoring WWTP discharge.

The potential of SeaWiFS observations to be used to monitor water quality trends in receiving waters adjacent to major WWTP discharges was examined. In this instance the discharge from the Bolivar WWTP was considered. This entailed taking into consideration the Bolivar WWTP discharge characteristics, the local oceanographic regime and the strategic location of a SeaWiFS station to optimise interception of the discharge from the Bolivar WWTP.

Aerial photographs taken over a period of 13 years indicated that the Bolivar WWTP discharge was confined largely to an inter-tidal channel which drained into Barker Inlet (Refer Figure 41). The near constant NE-SW alignment of the drainage channel permitted a SeaWiFS station to be positioned adjacent to the WWTP discharge such that interception of the discharge plume by the SeaWiFS sensor “footprint” was optimised (Refer Figure 42).

A SeaWiFS station was positioned offshore from the WWTP discharge such that the depth of water over the SeaWiFS “footprint” varied between 0.5 to 2.0 metres chart datum. The SeaWiFS signal integrated water leaving radiance over an area of 1 km^2 that included the discharge plume and surrounding shallow sub-tidal flats.

Despite high levels of chlorophyll-a measured within the discharge plume (800-1000 µg/l) (Kinhill Engineers, 1995), a higher contribution from CDOM and tripton in the region of the SeaWiFS “footprint” was expected. Refer Dekker 2004 and Table 15. The SeaWiFS station shown in Figure 42 was labelled “Bolivar East”.

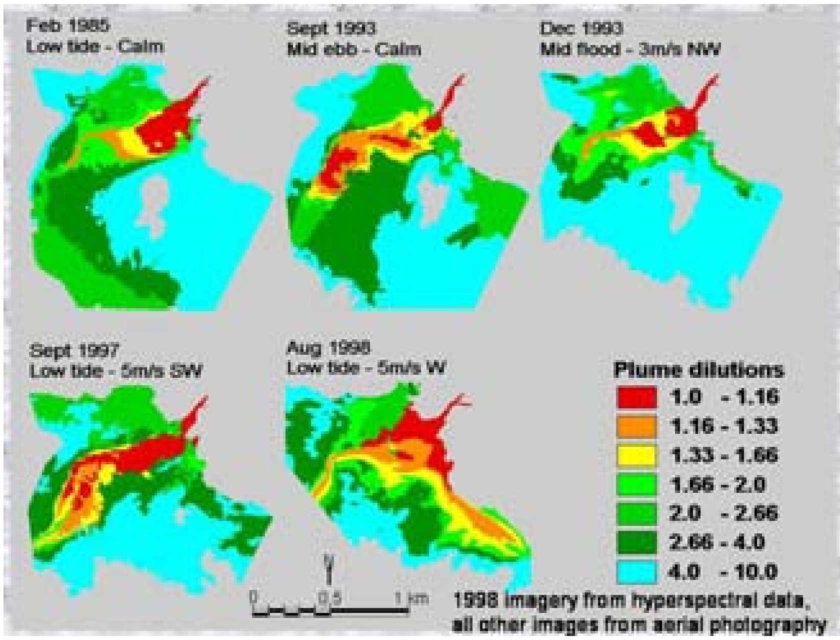

Figure 41. Bolivar WWTP discharge plume characteristics for period 1985 to 1998. (Photo by D. Blackburn)

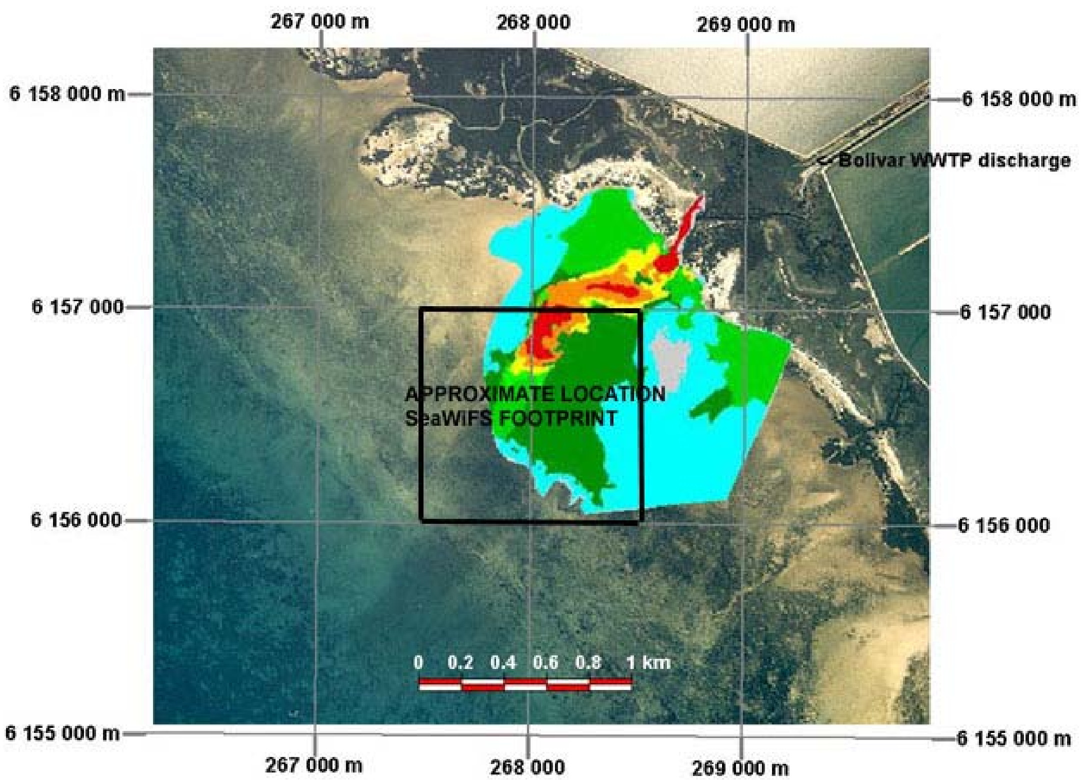

Figure 42. Location of the Bolivar East SeaWiFS station in relation to discharge plume from Bolivar WWTP, September 1993. (Photo by D. Blackburn)

5.5.1 Bolivar WWTP load characteristics

The discharge load from the Bolivar WWTP for the period November 1998 to July 2003 was deduced from flow-rate and Nitrogen as NH_3 concentration data provided by the Environment Protection Authority (Refer Figure 43).

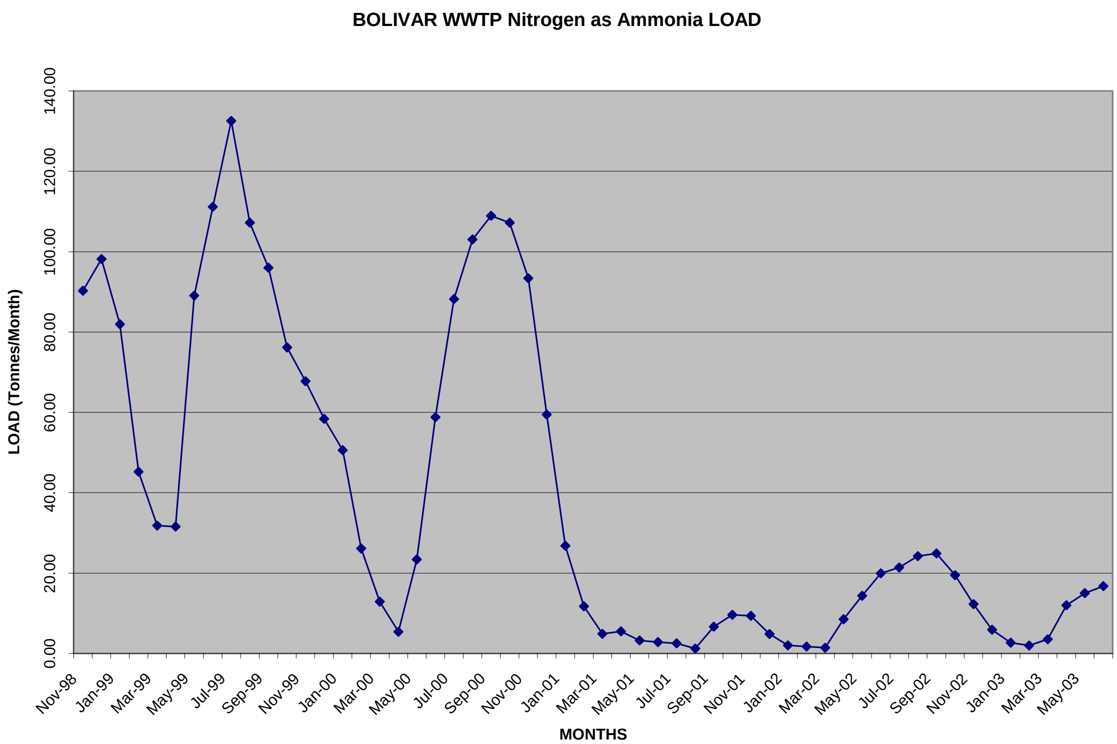

Figure 43. Bolivar WWTP Nitrogen as NH_3 load

For the period November 1998 to July 2003 the Nitrogen as NH_3 load into Barker Inlet exhibited periodic behaviour which was strongly linked to seasonal rainfall patterns and utilisation of the treated WWTP effluent by the horticulture industry in the Virginia region north of the Bolivar WWTP. Linear regression between rainfall at Adelaide Airport and lagged (1month) flow-rate from the Bolivar WWTP showed a positive correlation (r^2=0.66, $p<0.001$).

In the winter (July and August), the flow-rate from the Bolivar WWTP to Barker Inlet is higher due to ingress of storm water to the WWTP and a decrease in demand by the horticulture industry in the Virginia district. In late autumn, lower rainfall and increased demand for treated effluent water by the horticulture industry resulted in a decrease in the load discharged to Barker Inlet that was clearly evident around March to May for most years (Refer Figure 43).

Furthermore, as a result of the introduction of nutrient reduction strategies under the Environmental Improvement Programs initiated by SA Water at the Bolivar WWTP (ACWS Newsletter, 2004), a significant reduction in nutrient load occurred at the beginning of 2001. At this time or shortly afterwards, the Nitrogen as NH_3 load from the Bolivar WWTP was reduced from about 110 tonnes/month in September - November 2000 to about 10 - 25 tonnes/month within two years.

5.5.2 SeaWiFS observations - Bolivar East Station.

The time series of observations of suspended matter from SeaWiFS station “Bolivar East” also showed periodicity (Refer Figure 44).

Linear regression of the Bolivar WWTP Nitrogen as NH_3 load and the SeaWiFS observations, (lagged by 1 month), showed a positive correlation (r^2=0.56, p< 0.001) (Refer Figure 45). A lag of 1 month between the variables was used to allow for flow delay through the WWTP due to effluent stabilisation in the storage lagoons before the treated effluent is discharged into the sea via a surface canal into the northern end of Barker Inlet.

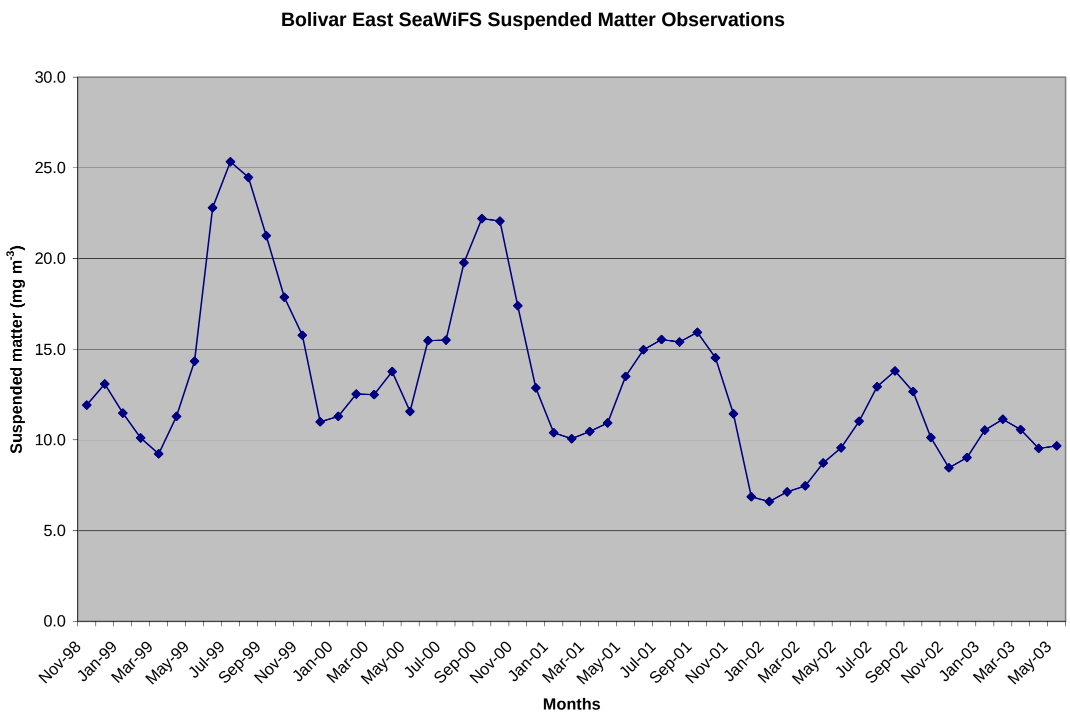

Figure 44. Time series SeaWiFS station Bolivar East

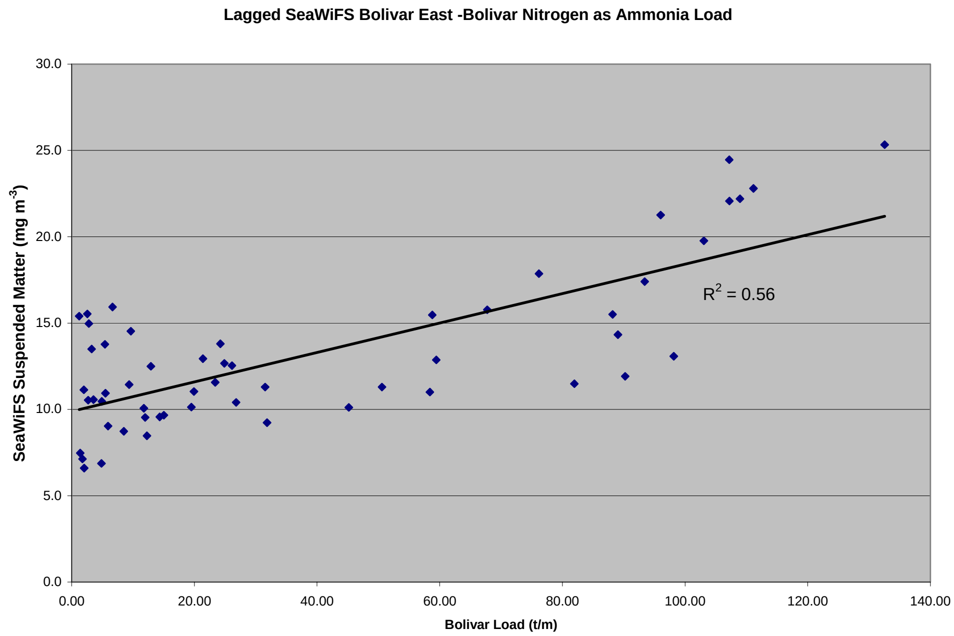

Figure 45. Lagged SeaWiFS Bolivar East – Bolivar WWTP Nitrogen as NH_3 load

5.5.3 Outcome

Monitoring of suspended matter, from a land-based point source discharge such as the Bolivar WWTP was possible due to the discharge plume being a strong spatially delineated feature with a high suspended matter contrast to the adjoining background. These factors ensured a high signal to background ratio at the wavelength of measurement (443 nm). Under the circumstances, it was possible to optimise the location of the SeaWiFS "footprint". This outcome emphasised the requirement for detailed knowledge of water movement patterns with respect to land based discharges which in this case was readily available from previous studies in the region (Lord, 1996).

The successful result suggested that satellite sensors with compatible spatial and spectral characteristics to SeaWiFS, such as MODIS *Aqua* or *Terra*, appear to be highly promising tools which should be examined further to establish their potential for monitoring water quality in the Adelaide metropolitan waters.

5.6 Summary of stakeholder issues achieved

A number of issues were posed by the Stakeholders of the ACWS and documented in the Stakeholders Requirements Report, July 2001. The issues raised embraced a number of disciplines which were to be addressed at task and Study level. The outcomes provided in Table 17 are based on the results obtained throughout the course of the PPM 2 Sub-task 3 investigations. The outcomes presented are relevant on their own, however in combination with results from other components of Program PPM 2 and other programs significantly more value added outcomes will be generated which will broaden the scope of understanding in relation to seagrass decline in the Adelaide metropolitan waters. The outcomes listed below are a Subtask 3 contribution to the overall ACWS consideration of the issues.

Table 17. Stakeholder issue outcomes

Issue ID #	Task	Sub-task 3 PPM2 related outcome
3.2.1.1	What is fate of nutrients……… ?	Physical pathways can be specified. Based on results of suspended matter variability, land based discharges experience limited offshore transport. Correlation between SeaWiFS observations 2-3 km offshore and land based discharges is not significant.
3.2.1.4	Effect of target N reduction……?	Noticeable reduction observed in 2001 in SeaWiFS suspended matter levels for well defined discharges such as Bolivar WWTP.
3.2.4.2	What is impact of high turbidity discharges ?	High levels of suspended matter noted in SeaWiFS observations in winter. Extended prolonged periods of elevated suspended matter levels may attenuate light levels to below photosynthetic compensation levels for seagrass.
3.2.5.1	Why have we lost/continue to lose nearshore seagrasses	Impact due to seabed agitation caused by wind waves is possible. Nearshore seabed region to depth of 10-15 metres and shallower can be affected by waves generated by winter wind conditions.
3.2.5.4	Is recent trend to discharge freshwater to sea causing significant disturbances?	Nearshore coastal system originally affected by land based discharges. Present freshwater discharge is limited to degraded nearshore regions of seagrass.
3.2.5.7	Is seagrass loss progressive or episodic?	Periodic variability in light reduction due to possible re-suspension caused by periodic wave agitation suggests episodic loss of seagrass.
3.2.6.5	In addition to nutrient enrichment, what other factors contribute to algal bloom formation.	Elevated levels of suspended matter only weakly dependent on water temperature. Low tidal and wind mixing plus higher summer insolation levels more likely to be important.
3.2.7.4	What are relative impacts of different outfalls along coast?	Presently little effect in offshore (>2-3 km) region due to limited offshore advection of land based discharges. Initial impact may have occurred in nearshore region.
3.2.7.7	How significant are turbid water discharge plumes on coastal biota?	Increased suspended matter levels may cause decrease in light level to seagrass.

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Appendices

Appendix A - SeaWiFS data

Station	PtGawler	Barker Inlet	Semaphore	Henley	Barcoo	Brighton
Latitude	34°39.6' S	34°45.0'S	34°49.2'S	34°54.0'S	34°58.2'S	35°01.2'S
Longitude	138°23.4'E	138°27.0'E	138°24.6'E	138°26.4'E	138°28.2'E	138°29.4'E
Month	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}	mg m^{-3}
Sep-97	3.52	16.98	1.77	1.31	1.21	1.07
Oct-97	4.40	11.14	0.87	0.86	1.64	1.63
Nov-97	5.30	5.30	1.91	2.09	2.07	2.19
Dec-97	8.54	6.86	2.19	2.28	2.08	2.05
Jan-98	2.35	3.54	1.51	1.17	1.06	1.04
Feb-98	6.06	9.72	2.19	1.99	1.96	1.79
Mar-98	4.81	4.69	1.67	1.93	1.60	1.68
Apr-98	3.57	3.96	1.67	1.43	1.23	1.47
May-98	7.77	9.77	3.98	5.06	3.32	5.85
Jun-98	5.08	7.47	6.03	3.75	5.77	3.59
Jul-98	3.03	5.06	1.69	0.84	0.60	0.30
Aug-98	3.92	7.23	2.14	2.70	2.07	2.29
Sep-98	3.38	5.21	2.80	2.68	1.76	2.61
Oct-98	4.68	4.63	1.84	2.31	1.98	1.59
Nov-98	4.13	4.24	1.68	2.00	2.12	2.30
Dec-98	3.47	3.87	1.75	1.61	1.43	1.96
Jan-99	4.25	5.26	2.06	2.24	1.79	2.30
Feb-99	7.06	4.57	2.16	2.32	2.18	2.07
Mar-99	4.69	5.12	2.21	2.24	1.63	1.78
Apr-99	3.79	3.89	1.66	1.53	1.42	1.41
May-99	3.72	3.06	1.55	1.71	1.85	1.81
Jun-99	6.8	8.78	5.24	5.12	6.26	4.54
Jul-99	6.5	8.70	3.57	2.87	3.17	3.95
Aug-99	7.0	19.12	2.56	2.25	1.71	2.74
Sep-99	14.3	12.76	2.60	3.39	3.31	2.60
Oct-99	11.9	18.10	2.11	3.28	2.33	3.22
Nov-99	3.5	4.21	1.73	1.65	1.45	1.46
Dec-99	4.4	4.56	1.70	1.79	1.59	1.39
Jan-00	3.4	4.04	1.56	1.31	1.60	1.44
Feb-00	4.8	5.03	1.98	1.84	1.57	2.24
Mar-00	16.4	10.38	3.64	4.02	2.64	2.11
Apr-00	5.4	6.83	1.84	1.47	1.40	1.30
May-00	4.3	7.27	2.00	1.92	1.90	3.12
Jun-00	7.7	7.27	2.42	2.01	1.97	1.89
Jul-00	5.6	10.57	3.33	2.95	3.96	4.56
Aug-00	4.8	12.34	2.79	3.58	2.33	2.25
Sep-00	9.1	6.31	2.56	3.52	2.43	3.15
Oct-00	7.8	8.74	1.92	2.47	2.57	2.89
Nov-00	5.5	8.61	1.69	2.03	2.12	2.22

Dec-00	5.7	4.47	1.97	2.03	1.70	1.28
Jan-01	6.9	5.42	2.49	3.91	2.57	2.19
Feb-01	6.7	7.37	2.69	4.40	2.19	1.91
Mar-01	4.2	4.64	2.76	5.15	1.97	1.65
Apr-01	6.6	6.20	1.84	1.54	1.64	1.65
May-01	5.5	3.90	1.63	2.87	1.52	1.38
Jun-01	5.7	9.92	2.08	2.61	2.66	4.41
Jul-01	14.8	23.19	3.55	3.94	5.28	7.81
Aug-01	5.4	7.46	2.87	4.29	1.92	4.02
Sep-01	8.0	16.52	3.00	3.63	2.37	6.37
Oct-01	8.9	9.51	2.48	3.98	3.14	3.10
Nov-01	4.0	4.83	1.62	1.87	1.62	2.47
Dec-01	3.6	4.60	1.65	1.46	1.29	1.39
Jan-02	4.7	4.43	1.75	2.07	1.55	1.69
Feb-02	3.5	4.04	1.79	2.07	1.61	1.57
Mar-02	5.0	4.73	1.62	1.61	1.42	1.98
Apr-02	3.5	3.32	1.57	1.45	1.42	1.38
May-02	4.8	4.02	1.87	1.84	1.78	1.77
Jun-02	5.7	5.41	3.08	3.75	3.25	5.51
Jul-02	3.3	5.14	2.53	2.57	2.47	2.43
Aug-02	4.3	6.17	1.88	3.12	2.38	1.77
Sep-02	4.5	6.81	2.01	2.20	1.56	2.40
Oct-02	3.2	4.81	2.22	1.72	1.60	2.17
Nov-02	3.0	4.85	1.73	1.60	1.53	1.74
Dec-02	3.2	3.71	1.53	1.78	1.52	1.51
Jan-03	4.6	6.13	2.34	2.59	2.20	2.24
Feb-03	4.0	7.83	2.19	2.41	2.24	2.19
Mar-03	3.9	5.79	2.44	1.88	1.80	1.70
Apr-03	3.8	4.59	1.86	1.71	1.51	1.73
May-03	4.4	4.80	1.79	1.65	1.74	1.99
Jun-03	1.7	5.83	2.07	2.60	1.77	1.99
Jul-03	13.2	19.27	2.17	3.96	2.60	8.36
Aug-03	1.9	2.13	1.19	1.34	1.07	5.57
Sep-03	3.2	5.43	2.26	2.23	2.39	2.78

Station	**PtStanvac**	**PtNoarlunga**	**Pt Wilunga**	**Sellicks B**	**GSVcentral**
Latitude	**35°05.4'S**	**35°09.0'S**	**35°15.0'S**	**35°19.8'S**	**35°00.0'S**
Longitude	**138°27.6'E**	**138°26.4'E**	**138°27.0'E**	**138°25.2'E**	**138°15.0'E**
Month	**mg m^{-3}**	**mg m^{-3}**	**mg m^{-3}**	**mg m^{-3}**	**mg m^{-3}**
Sep-97	0.67	0.78	0.69	0.77	0.28
Oct-97	0.83	1.12	0.95	0.82	0.33
Nov-97	0.98	1.47	1.21	0.87	0.45
Dec-97	1.44	1.09	1.46	1.62	0.89
Jan-98	0.96	0.80	1.28	1.07	0.70
Feb-98	1.04	1.09	1.14	1.14	0.83
Mar-98	1.03	0.94	1.11	1.04	0.94
Apr-98	1.01	0.88	0.88	1.19	1.04
May-98	1.54	1.83	1.45	1.03	1.00

Jun-98	3.21	2.08	1.74	1.82	0.93
Jul-98	0.65	1.11	1.36	1.45	0.84
Aug-98	1.58	1.59	0.97	1.07	0.48
Sep-98	0.95	1.21	1.40	1.08	0.32
Oct-98	1.24	1.21	1.19	1.20	0.42
Nov-98	1.84	1.54	1.24	1.64	0.75
Dec-98	1.24	1.11	1.31	0.87	0.59
Jan-99	1.01	0.95	1.02	1.05	0.54
Feb-99	1.29	1.29	0.97	1.31	0.77
Mar-99	1.29	1.44	1.16	1.32	1.09
Apr-99	1.16	1.18	1.12	1.18	1.12
May-99	1.23	1.37	1.47	1.35	1.00
Jun-99	2.37	3.22	1.30	1.77	0.76
Jul-99	1.60	1.52	1.53	1.69	0.80
Aug-99	1.31	1.16	1.51	1.15	0.69
Sep-99	1.31	2.23	1.34	1.55	0.41
Oct-99	2.33	1.50	1.23	1.21	0.36
Nov-99	1.20	0.79	0.87	0.90	0.54
Dec-99	1.95	0.95	1.00	1.46	0.54
Jan-00	0.90	1.01	0.98	1.14	0.53
Feb-00	1.19	1.25	1.37	1.65	0.71
Mar-00	1.20	1.33	1.12	1.39	0.56
Apr-00	0.97	1.15	0.94	1.18	1.22
May-00	1.59	1.50	1.32	0.93	1.28
Jun-00	1.61	1.37	1.26	1.30	1.03
Jul-00	1.74	2.34	1.47	1.41	0.87
Aug-00	1.16	1.00	0.90	1.21	0.66
Sep-00	2.06	3.43	2.51	3.46	0.46
Oct-00	1.81	1.76	1.36	1.50	0.32
Nov-00	0.91	0.94	0.81	0.84	0.46
Dec-00	0.66	0.74	0.57	0.89	0.44
Jan-01	1.29	1.36	1.11	1.25	0.82
Feb-01	0.96	1.08	1.03	1.09	1.19
Mar-01	1.14	1.05	1.06	1.10	1.30
Apr-01	1.21	0.97	1.18	1.17	1.29
May-01	1.56	1.52	1.31	1.82	1.15
Jun-01	1.65	0.79	1.40	1.50	0.89
Jul-01	2.39	1.18	1.48	1.19	1.13
Aug-01	1.20	1.23	0.85	1.44	0.52
Sep-01	2.28	2.48	2.07	1.75	0.38
Oct-01	1.77	1.38	1.37	1.87	0.34
Nov-01	1.36	0.74	1.12	1.17	0.36
Dec-01	0.81	0.70	0.99	0.91	0.47
Jan-02	0.83	0.86	0.90	1.04	0.55
Feb-02	0.95	0.97	0.85	0.92	0.58
Mar-02	0.95	0.96	1.01	1.08	0.78
Apr-02	1.05	1.01	1.08	1.06	1.00
May-02	1.22	1.36	1.41	1.20	1.03
Jun-02	1.37	1.46	2.02	1.83	1.25
Jul-02	1.82	1.71	1.60	2.45	0.96
Aug-02	1.27	0.99	1.13	0.98	0.60

Sep-02	1.12	1.13	1.07	1.43	0.45
Oct-02	0.94	1.04	1.08	1.41	0.34
Nov-02	1.06	0.90	1.01	1.07	0.38
Dec-02	1.03	0.91	1.14	0.93	0.55
Jan-03	1.38	1.63	1.42	1.42	0.81
Feb-03	1.52	1.59	1.39	1.50	0.93
Mar-03	1.41	1.13	1.35	1.22	0.98
Apr-03	1.19	1.24	1.37	1.68	1.11
May-03	1.67	2.07	1.75	1.70	1.04
Jun-03	1.94	1.55	1.74	1.61	1.19
Jul-03	1.63	1.58	1.89	3.76	0.89
Aug-03	1.88	1.84	2.20	3.15	0.58
Sep-03	2.14	2.12	2.54	2.60	0.44

Appendix B Water Temperature - Pt Stanvac
Rainfall - Adelaide Airport
Photoperiod - Adelaide Airport
Wind speed - Adelaide Airport

Date	Mean WaterTemp (°C) PtStanvac	Mean Rainfall(mm) Adelaide Air	Mean Photoperiod (hr) Adelaide Air	Mean Wind (km/hr) Adelaide Air
Nov-97	16.9	62.1	7.7	16.0
Dec-97	19.9	44.0	9.0	13.6
Jan-98	22.4	23.2	10.0	10.7
Feb-98	23.9	15.2	10.8	10.7
Mar-98	24.7	12.1	10.3	12.1
Apr-98	23.4	41.5	8.9	16.1
May-98	20.8	43.4	7.2	21.2
Jun-98	16.5	65.3	5.9	23.2
Jul-98	13.6	48.5	5.3	21.5
Aug-98	12.4	54.6	5.5	18.5
Sep-98	12.6	46.3	6.4	17.4
Oct-98	13.8	45.9	7.4	18.2
Nov-98	15.3	39.2	8.6	18.2
Dec-98	16.9	26.6	9.4	17.6
Jan-99	19.2	17.7	10.4	14.0
Feb-99	22.2	10.3	10.3	12.4
Mar-99	23.8	24.3	9.6	11.4
Apr-99	22.6	21.3	8.7	11.8
May-99	19.4	41.0	6.9	15.6
Jun-99	16	46.5	6.1	18.4
Jul-99	14	60.7	5.1	23.1
Aug-99	12.7	47.2	5.9	20.7
Sep-99	12.9	43.0	6.6	19.4
Oct-99	14.1	44.9	7.9	17.3
Nov-99	15.6	49.9	8.6	16.2
Dec-99	17.3	41.7	8.9	15.6
Jan-00	18.3	23.7	9.1	14.3
Feb-00	19.7	30.9	9.2	13.5
Mar-00	20.5	28.9	8.9	12.4
Apr-00	21.1	45.3	8.3	12.2
May-00	19.4	44.6	7.2	18.1
Jun-00	16.8	60.7	6.1	22.1
Jul-00	14	58.5	5.4	26.3
Aug-00	13	57.1	5.7	23.4
Sep-00	13.4	51.8	6.2	22.7
Oct-00	14.6	58.7	6.9	21.0
Nov-00	16.3	45.7	8.2	17.5
Dec-00	18.4	30.0	9.7	15.3
Jan-01	20.5	8.5	10.7	12.7

Feb-01	22.1	8.2	10.5	13.2
Mar-01	22.2	14.1	9.7	14.9
Apr-01	21	19.3	8.8	15.5
May-01	18.8	41.7	7.5	24.6
Jun-01	16.8	58.7	5.9	22.8
Jul-01	15.1	66.0	5.0	22.1
Aug-01	13.9	61.3	4.9	18.0
Sep-01	13.8	66.6	5.9	19.6
Oct-01	14.5	74.8	6.7	23.2
Nov-01	15.8	67.0	8.0	20.3
Dec-01	17.2	38.8	9.3	19.4
Jan-02	18.5	22.9	9.8	18.4
Feb-02	19.5	9.5	10.0	18.4
Mar-02	20.1	8.9	9.6	17.4
Apr-02	19.9	6.1	8.9	14.2
May-02	19	27.6	7.6	15.2
Jun-02	17.2	39.2	6.0	17.2
Jul-02	15.1	60.2	5.4	20.8
Aug-02	13.5	45.7	5.8	21.7
Sep-02	13.4	40.5	6.8	22.6
Oct-02	14.1	22.3	7.3	23.1
Nov-02	15.8	26.9	8.2	19.9
Dec-02	17.3	19.0	8.2	18.3
Jan-03	19.2	21.5	9.6	15.6
Feb-03	20.4	29.6	9.4	14.3
Mar-03	20.8	30.0	9.7	11.7
Apr-03	20.1	28.5	8.6	10.8
May-03	18.7	30.9	7.4	14.4
Jun-03	16.8	62.1	5.6	18.5
Jul-03	14.9	65.0	5.0	23.1