Paper presented at the 22nd Asian Conference on Remote Sensing, 5 - 9 November 2001, Singapore.

WATER QUALITY IN COASTAL WATERS

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KEY WORDS: Remote Sensing, Coastal Waters, Water Quality, Shallow Water

ABSTRACT: The aim of this work is to introduce the potential of satellite-based remote sensing data to agencies responsible for monitoring and managing water quality in the coastal zone of Western Australia. There exists a knowledge and/or expertise gap between satellite data providers and potential end users. This project aims to close the gap by developing a fundamental management tool that will be geographically transferable around the State and Australian Coastal Zone and which will be able to provide information at local, regional and statewide spatial scales, as required for management. We expect to provide management agencies with the ability to monitor anthropogenic impacts on the coastal zone (eg. nutrient-rich wastewater intrusions, industrial and urban discharges, river and estuarine outflows) as well as monitor the long-term trends in water quality indicators over local to regional scales.

1. INTRODUCTION

Western Australian contains arguably some of the most pristine coastline in the world. It includes a number of World Heritage Listed Marine Reserves. The near-coastal ocean waters also support billion dollar fisheries and multi-million dollar tourist attractions. Oil and gas is mined, processed and transported within the coastal zone. Intensive mining and agricultural activities take place along the West Australian coast and have the potential to impact the coastal zone through unexpected run-off or seepage of chemicals. Legalised and controlled addition of treated waste to the coastal zone affects the quality of coastal waters and the benthic habitat within what are considered acceptable bounds. It is incumbent on a number of local, state and national agencies, to monitor and maintain the Australian coastal zone. Currently it is common for agencies to carry out or commission intensive, in-situ, field campaigns to directly monitor water quality in specific locations. This practice is invaluable for determining first-hand characteristics of the water column and benthic communities. In-situ sampling is however unable to monitor large areas of ocean on a near-daily basis because of the relatively expensive and labour intensive nature of the process.

Satellite-based remote sensing provides the potential for monitoring the complete Western Australian coastal zone on a near-daily basis. Sea surface temperature (SST) and ocean colour data are captured by a number of polar orbiting satellite-mounted instruments. These data are downlinked and archived in Perth by the Western Australian Satellite Technology and Applications Consortium (WASTAC). WASTAC comprises Curtin University of Technology, CSIRO, the Department of Land Administration (DOLA), and the Bureau of Meteorology.

The potential exists for the various coastal-zone-monitoring agencies to utilise satellite data for the routine monitoring of large regions of coastal waters. A long-term archive of remotely sensed data is being developed and processed to provide agencies with an overview of the natural variations and extremes in water quality indicators. This knowledge will help improve the detection of extreme events in the presence of natural variation.

In-situ sampling of coastal waters is, and will continue to be, carried out not only to continue the record of in-situ measurements, but also to provide ground truthing for the remotely sensed data. In-situ sampling, by its nature, provides point samples, whereas remotely sensed data provides a parameter “averaged” over the extent of the instantaneous field-of-view of the sensor.

The current project, funded by the Natural Heritage Trust’s Coasts and Clean Seas (CCS) programme, aims to develop products based on remotely sensed data that provide an indication of water quality to the end users. One complicating factor affecting the quality of ocean colour data is the proximity to shore. Reflectance from the substrate in shallow water is known to affect remotely sensed geophysical products such as chlorophyll concentration and diffuse attenuation coefficient. Also, near-shore waters are often classed as Case 2. This means the standard Case 1 algorithms may produce erroneous results. In-situ optical measurements as well as computer

modelling of radiative transfer are being used to investigate development of improved ocean colour products for the shallow Perth coastal waters.

The possibly overwhelming volume of remotely sensed data will be distilled down to simple water quality products. Agencies will be able to access the water quality indicators via the internet (Lynch and Fearns 2001a). The tool is not expected to replace current in-situ monitoring practices, but rather provide a quick view of near-real-time conditions with the potential of alerting the monitoring and management agencies to situations that may require further investigation.

This paper presents an outline of some of the ground truth data collected off Hillarys boat harbour north of Perth, as well as some of the data associated with the archive of remotely sensed SST and ocean colour data (Lynch and Fearns 2001b). We also review the next stage of work required to fulfil the aims of this project.

2. STUDY LOCATION

Fig. 1 shows the extent of the region selected for this study. The region extends from 30° south to 35° south and 113° east to 116° east. Also shown in Fig. 1 are the Coasts and Clean Seas (CCS) study sub-regions. These were selected to provide indications of near-coastal as well as off shelf water quality parameters derived from remotely sensed data.

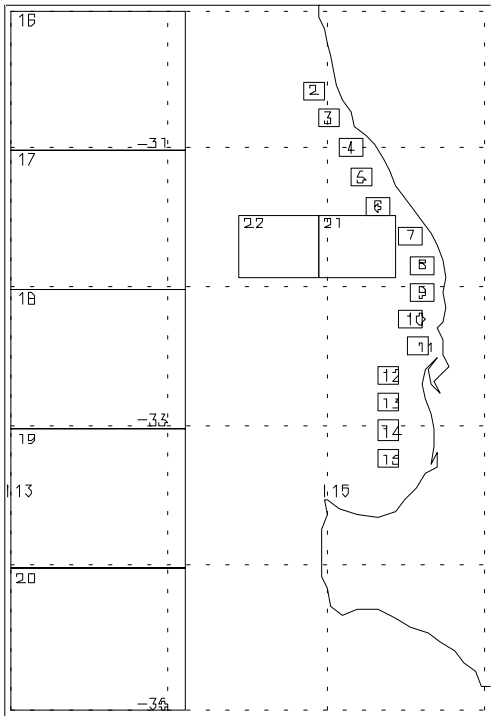


Figure 1. Coasts and Clean Seas study sub-regions.

The Hillarys transect is operated from Hillarys boat harbour along a transect running east-west at 31° 49.9′ south, with 10 sampling stations beginning at a near-shore station, H0, then one station every 5 km out to a station 40 km from shore, H40. The transect extends from the coast through sub-region 14. The near shore station is situated in the Hillarys Marine Park. An 18.5 m dive boat is chartered. Sampling cruises are scheduled to be conducted approximately every six weeks.

3. RESULTS

A number of different in-situ measurements are made at each of the Hillarys Transect sampling stations. As well as those measurements outlined below, phytoplankton samples are collected and analysed to provide an indication of phytoplankton species and phytoplankton abundance. Members of Fisheries WA have also been present on the Hillarys cruises with the aim of collecting and studying zooplankton. CSIRO researchers have provided water sampling and temperature validation equipment, as well as some post-cruise water sample analysis.

3.1 Temperature

A number of in-situ temperature measurements are made at each station. A bucket sample of water is drawn and a mercury-in-glass thermometer used to measure the near surface bulk temperature. Underway temperature measurements are made using a thermistor to measure the temperature of continuously pumped near-surface water. A calibrated thermistor suspended near (below) the waters surface is also used to measure water temperature at each sampling station.

Water temperature profiles are collected using a Scientific Data Logger (SDL). The SDL is lowered on a rope to the sea floor. The instrument logs measurements of temperature, salinity and depth.

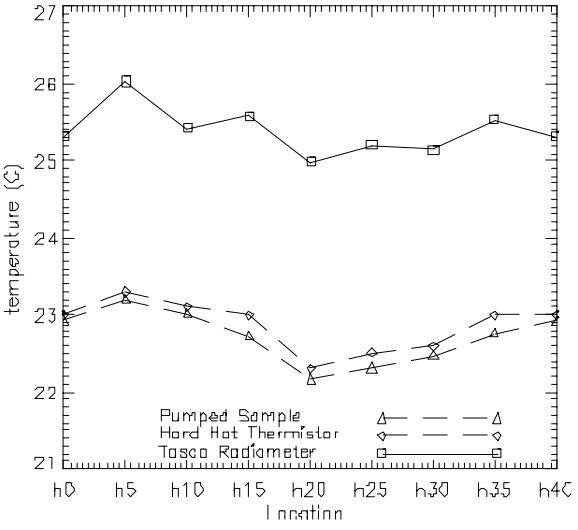


Figure 2. Tasco radiometer derived SST, thermistor and underway temperatures for 15th March 2000. The Tasco radiometer derived SST estimate often appears higher than the other in-situ SST measurements.

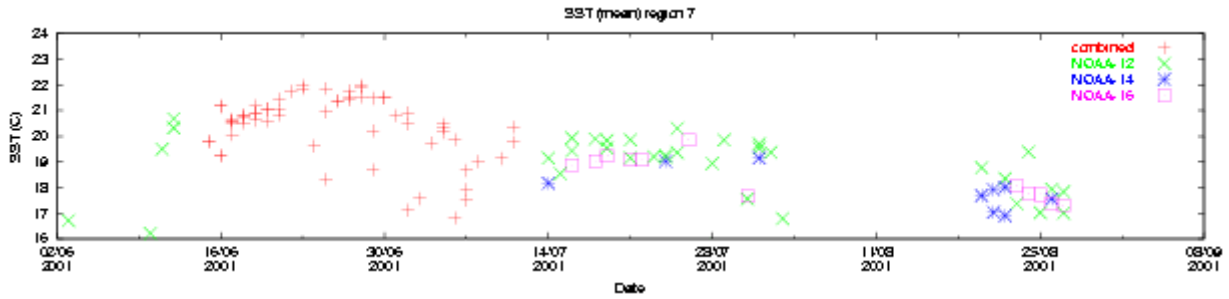


Figure 3. Sample SST data as displayed on the CCS web site. Some of the data are separated by NOAA satellite, the combined points include NOAA 12, 14 and 16 data. The SST data include all night and day passes. Standard SST algorithms have been applied, and standard quality control procedures implemented. It appears that the spread of data is mainly due to the effects of thin cloud or other atmospheric effects.

A hand held Tasco radiometer is used to measure the skin temperature of both the bucket sample and the water near the boat. The Tasco hand-held wide-band radiometer measures radiance centred on 10.19 micron. Radiance at this wavelength is a function of the radiance emitted by the sea surface and the downwelling sky radiance reflected by the sea surface.

The Tasco radiometer is calibrated, using an on-board portable black body, for variations in operating temperature and scene temperature. Results to date however have indicated the Tasco-radiometer-derived skin temperature may not be a reliable validation temperature measurement (McAtee 2000, personal communication). Fig. 2 shows the Tasco derived SST, thermistor and underway temperatures for 15th March 2000.

Sea Surface Temperature may be measured from a satellite-borne sensor. NOAA/AVHRR radiance data are downlinked and archived in Perth by WASTAC. These data are accessed every night and processed to SST products. Associated statistical data are calculated and used to update graphs that are posted on an internet web site (Lynch and Fearns 2001a). In principle this process could be carried out as soon as the NOAA/AVHRR data are received, thus providing near real time SST information for the Perth region. Fig. 3 shows a sample of recently collected NOAA/AVHRR SST data. The data include night and day SST values derived from NOAA 12, 14 and 16 satellites. The scatter in retrieved temperatures appears to be due to atmospheric effects such as the presence of thin cloud which is not detected with the standard cloud-clearing algorithm.

3.2 Chlorophyll

Depth integrated water samples are collected on-station. These are drawn from the surface to the sea floor, or to a maximum depth of 18 m. These depth-integrated samples are filtered immediately and processed the next day in a laboratory to determine chlorophyll concentration. Both spectrophotometric and fluorometric techniques are employed. Fig. 4 shows in-situ chlorophyll measurements for 15th March 2000.

A Turner Designs flow-through flourometer is used to estimate underway chlorophyll concentration. This instrument is subjected to calibrated samples on a regular basis.

The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) is an ocean colour sensor that has been operationally transmitting data since October 1997. Top-of-atmosphere radiance measurements are made on a near-daily basis over the coastal waters of Western Australia. These measurements enable estimates of such water properties as chlorophyll-a concentration and diffuse attenuation coefficient of light at wavelength 490 nm, K_{490}. The level of accuracy specified by NASA for the SeaWiFS chlorophyll-a product is ± 35%.

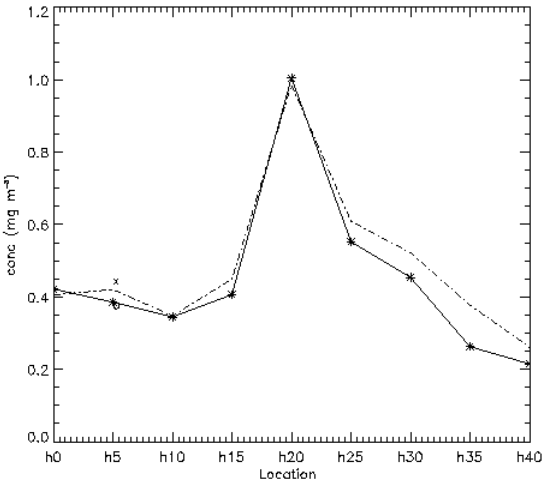
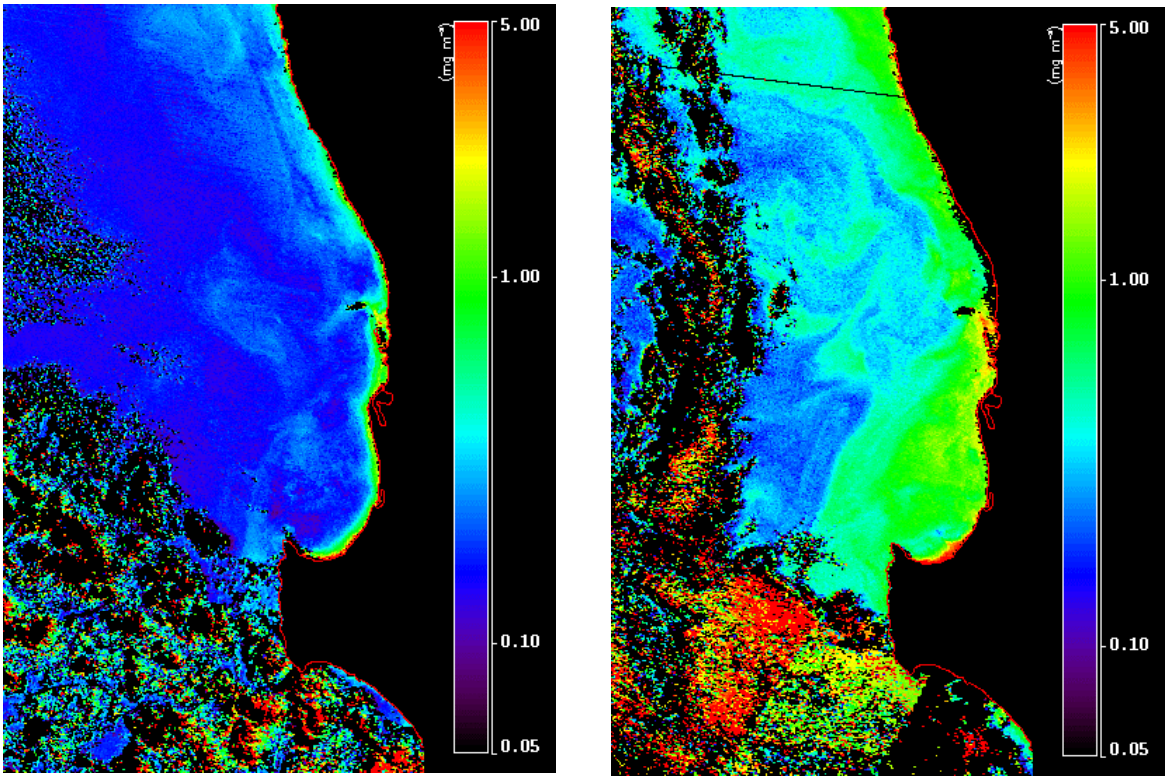


Figure 4. Fluorometric and spectrophotometric measurements of chlorophyll concentration for 15th March 2000 along the Hillarys transect. H0 is the near-short station, H40 is the 40km station.



SeaWiFS L1A data is obtained from the WASTAC archive and processed to L2 geophysical products. Data for the CCS study region is then extracted and remapped. Fig. 5 shows two SeaWiFS chlorophyll-a images, one for 13th December 1997, representing a typical summer chlorophyll distribution pattern, and 23rd June 1998, representing a typical winter pattern.

A number of standard statistical values are calculated for each of the sub-regions shown in Fig. 1 including mean, standard deviation, median, percentage of "good" pixels, and maximum concentration. Fig. 6 shows two sample plots of mean chlorophyll concentration for sub-regions 7 and 13 from 1st October 199 to 31st March 2000. There is a decrease in chlorophyll during the summer months and increase leading out of autumn.

The main feature apparent in all plots and images of chlorophyll concentration is the increase in concentration during the winter months. A study of the standard deviation of the chlorophyll data shows extremely high levels of variability over relatively short periods of time.

3.3 Attenuation of light: Profiling measurements of photosyntheticaly available radiation (PAR) are made and used to calculate K_{PAR}, the diffuse attenuation coefficient of PAR. Secchi depth, a measurement related to turbidity, is also recorded at each station. The routinely produced remotely sensed SeaWiFS attenuation product is K_{490}. To date we have not had the capability to measure K_{490} by in-situ means. It is not unreasonable however to expect a high degree of correlation between K_{490} and K_{PAR}. Fig. 7 shows the SeaWiFS K_{490} product plotted against the in-situ determination of K_{PAR}.

4. PROPOSED DEVELOPMENTS

The concern of marine park managers is that remotely sensed data are not currently reliable in terms of monitoring the Perth marine parks. These parks are relatively close to the shore. We are implementing a number of "bottom reflectance" schemes to improve the near-coastal remotely sensed ocean colour products. These include a bottom correction scheme based on a Levenberg-Marquardt solution of a shallow water reflectance model (Lee et al. 1999). Also, an analysis of the "background" reflectance over the life of the SeaWiFS archive will be used to perform a retrospective correction. Fig 8 shows in-situ and remotely sensed chlorophyll concentration data for the length of

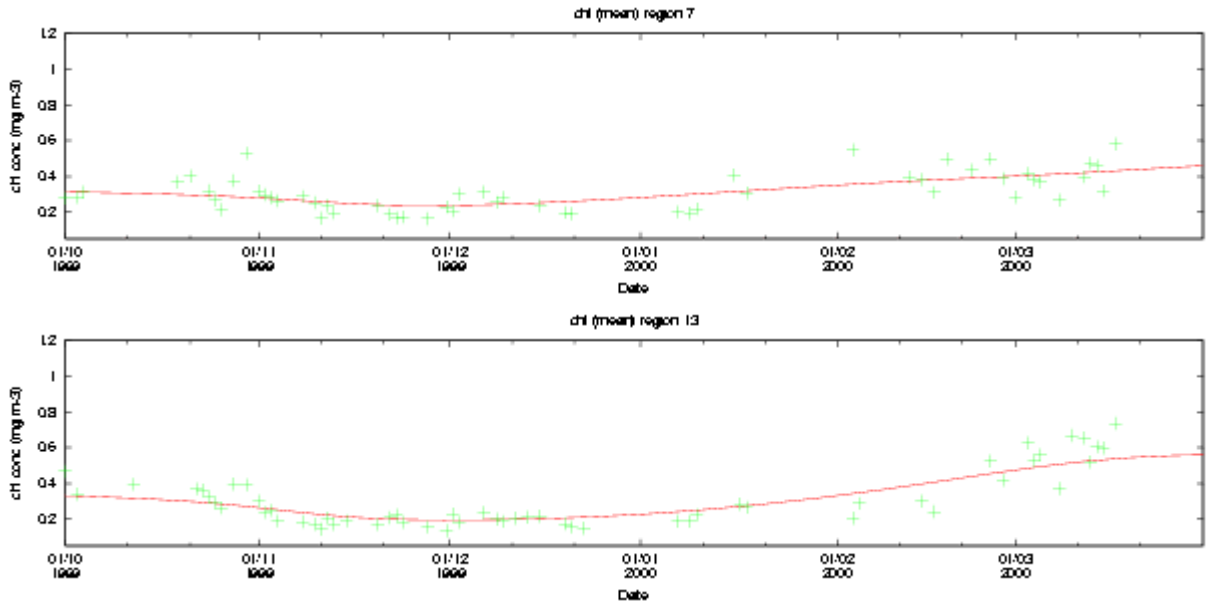


Figure 6. Mean chlorophyll concentration as determined by SeaWiFS data. The top plot shows data for region 7 and the bottom plot for region 13 (See Fig. 1). Each plot shows a six-month period from 1st Oct 1999 to 31st March 2000. The red curve is used to indicate the long-term average chlorophyll concentration.

the Hillarys Transect. The remotely sensed and in-situ results agree well in the water deeper than about 25 m (~155.6° longitude). In the shallow coastal water the remotely sensed product, as expected, is higher than the in-situ measurement.

Following the shallow water correction of the archive, analysis of the seasonal variation in water column properties, as well as inter-annual variations over different spatial scales will be used to determine characterises of significant events. When significant events occur they may be located and reported to relevant agencies.

SeaWiFS is not the only source of ocean colour data. It is currently however, the only locally received near-daily view of our coastal zone. Licence restrictions limit the use of SeaWiFS data to research activities. Ocean colour imagery derived from SeaWiFS data can not be posted on a publicly accessible web-site. Also, the 30-day decryption restriction imposed on SeaWiFS data means we can not provide near-real-time monitoring of the coastal zone. The installation of an X-band receiver in Perth late in 2001 will enable direct reception of MODIS data. We expect MODIS data to be used for subsequent near-real-time monitoring of the Perth coastal zone. High spatial resolution ASTER data is also available at very low cost, but the temporal and spatial coverage is significantly limited, therefore impractical for routine monitoring of the region.

5. CONCLUSION

We are able to observe changes in SST, chlorophyll concentration and K_{490} in near coastal waters in the Perth region using remote sensing methods. Ground truthing provides confidence in the remotely sensed products. Near-coastal shallow water products are not reliable, however seasonal and shorter term changes are observed in the near-coastal waters. We believe this information, although not necessarily accurate in terms of absolute calibration, is still however useful in some situations for observing coastal processes and spatial extent of observed features.

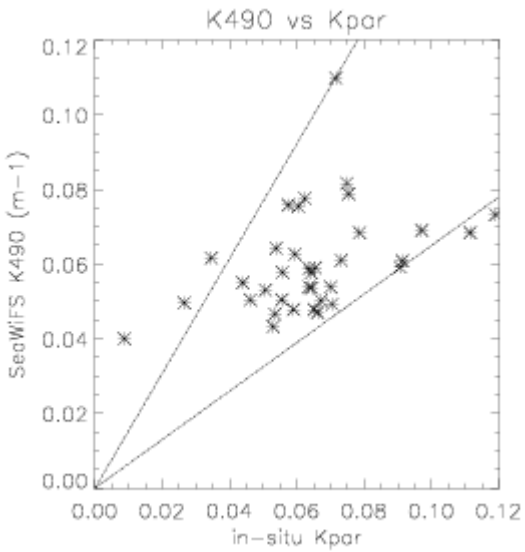


Figure 7. Comparison between SeaWiFS derived K_{490} data and K_{PAR} based on in-situ PAR measurements. The two lines on the plot represent a range of ± 35%. These results are based on measurements made during an earlier study funded by a FRDC grant

Remotely sensed images of the Perth coastal waters provide a graphic display of the interactions between different water masses along the coastline. In-situ sampling within a marine park may highlight an event, such as an algal bloom. Remote sensing provides a view of the spatial extent of such a bloom. Sometimes a single image, or a time series of images, may be used to locate the origin of such a bloom. SeaWiFS images have been used to show the link between a coastal outfall and an extensive distribution of relatively high chlorophyll concentration water extending many tens of kilometres from the outfall.

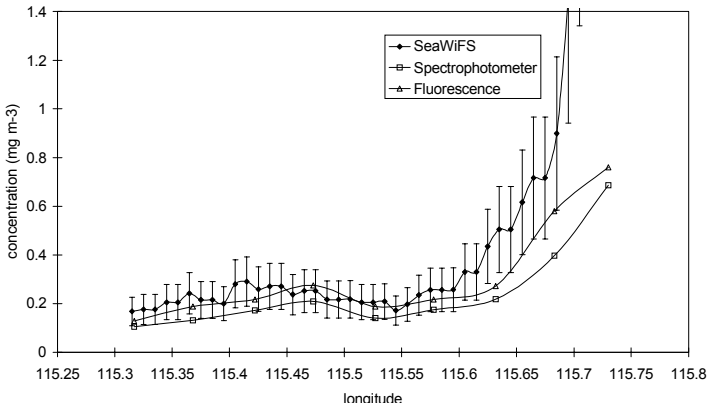


Figure 8. Sample chlorophyll data for the Hillarys Transect for 19th January 1998. These data were collected as part of a FRDC funded project. The error bars indicate the 35% uncertainty associated with the SeaWiFS Case 1 chlorophyll product.

As the archive of satellite data grows we will be able to develop a long-term overview of the coastal water quality baseline conditions in the Perth waters region. An increased understanding of spatial variability down to marine park scales, and temporal variability over monthly, seasonal and annual time scales, will allow management authorities to better assess possible impacts due to natural and anthropogenic influences.

Acknowledgement

This research is made possible due to the generous assistance of the Natural Heritage Trust's Coasts and Clean Seas Fund, CSIRO, Department of Land Administration (DOLA), Bureau of Meteorology, WASTAC, Fisheries Western Australia and numerous student volunteers.

References

Lee, Z., Carder, K., Mobley, C.D., Steward, R.G. and Patch, J.S., 1999. Hyperspectral remote sensing for shallow waters: 2. Deriving bottom depths and water properties by optimization. Applied Optics, 38 (18), pp. 3831-3843

Lynch, M.J. and Fearns, P.R., 2001a. Coasts and Clean Seas Research Project 9814, web-based report, Curtin University of Technology *http://rssrg.curtin.edu.au/research/sat_ocean/oc/CCS/ccsmain.html*

Lynch, M.J. and Fearns, P.R., 2001b. A baseline study of Perth coastal waters, International Geoscience and Remote Sensing Symposium, Sydney, Australia, July 9-13, 2001.