2.2.5 The development and validation of algorithms for remotely sensing case II waters

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Introduction

Coastal embayments and estuaries are important ecosystems containing a number of critical habitats and resources that are important for sustaining fisheries and ecosystem health. Although there has been a wealth of new knowledge generated over the last decade about these ecosystems, the spatial and temporal patterns of biological and physical processes are not fully mapped or understood. Remotely sensed data offer a unique perspective on these processes because of the synoptic view over time and quantitative algorithms that can be used to extract geophysical and biophysical information from them.

In this study, the approach taken in retrieving benthic cover type and bathymetry from remotely sensed imagery is to derive an algorithm from an in-water radiative transfer model. The model includes the spectral reflectance of benthic cover, the water column constituents (Chlorophyll-a, Coloured Dissolved Organic Matter and Suspended Sediments) and the bathymetry. The model permits the hyperspectral observations to be formally inverted using a non-linear optimisation scheme to yield a benthic classification, the bathymetry and the concentrations of in-water constituents.

Aims/Objectives:

The aims of this PhD research were to,

1. Develop and validate a coastal water reflectance model that will permit the simultaneous retrieval of the concentrations of in-water constituents (Chl-a, CDOM, SS), water column depth as well as the composition of the seafloor, from remotely sensed data.
2. Acquire *in situ* hyperspectral data from SRFME field programs to permit the testing of the coastal water reflectance model.
3. Implement the coastal water reflectance model to appropriate satellite/aircraft data sets and compare the retrieved products to *in situ* data.

Model Approach

A coastal water reflectance model that incorporates the reflectance spectra of three common benthic types, found off WA coastal waters, was developed based on the work of Lee *et al*, 1999. In their work, they have demonstrated that their model can retrieve concentrations of in-water constituents and depth to a relatively high accuracy. Essential to their model was the use of the spectral shape of the sea bottom and only sandy bottom environments were studied. The question is can this model approach be used to retrieve the contributions of more than one bottom type, namely sand, seagrass and brown algae, and hence generate a bottom classification map? The validity of the coastal water reflectance model with the inclusion of the three benthic types has been explored in this PhD research and the results are summarised below.

Model Evaluation with Synthetic Data

A large database of remote-sensing reflectance spectra corresponding to a range of water depths, bottom reflectance spectra and water column properties was constructed. The remote-sensing reflectance spectra were generated using the Hydrolight radiative transfer numerical model, which provides an exact solution of the radiative transfer equation for the given input conditions. The Hydrolight simulated reflectance database provides a particularly useful means of evaluating the retrieval capabilities of the coastal water reflectance model. It permits comparison between model-retrieved parameters with the corresponding Hydrolight inputs.

The coastal water reflectance model was applied to each generated reflectance spectrum incorporating the Levenburg-Marquardt optimisation scheme. The scheme involves adjusting the model parameters until the difference between the model spectrum and Hydrolight reflectance spectrum reaches a minimum. Once a minimum is reached the model parameters are considered derived.

Comparison between the model-retrieved bottom coefficients of sand, seagrass and brown algae and the Hydrolight input coefficients show very promising results. Figures 2.16a, b and c display the retrieved bottom weighting coefficients of sand, seagrass and brown algae (Square symbols), corresponding to the bottom type used in the Hydrolight simulations, respectively. The dotted lines represent the reflectance value at the 550nm centre wavelength for the corresponding bottom type spectrum used in the Hydrolight simulations. In these graphs, it is evident that for a sandy bottom type (Figure 2.16a) the coastal water reflectance model retrieved bottom weighting coefficients of sand, B_{Sand}, equivalent to the Hydrolight input value and zero for both the seagrass, $B_{Seagrass}$, and brown algae, $B_{Brown\ Algae}$, coefficients. For simulations where the bottom type input was seagrass (Figure 2.16b), the model returned $B_{Seagrass}$ values comparable to the Hydrolight input value and zero for the sand and brown algae coefficients. For the brown algae case (Figure 2.16c), the model returned $B_{Brown\ Algae}$ values close to the Hydrolight input value and zero for B_{Sand} and $B_{Seagrass}$.

The above results demonstrate the potential for the coastal water reflectance model to distinguish between sand, seagrass and brown algae. Figure 2.17 shows the comparison between Hydrolight input depth and model-retrieved depth from the simulations. The results indicate that the model-retrieved depth agree very closely with the input depths for the simulated depth range.

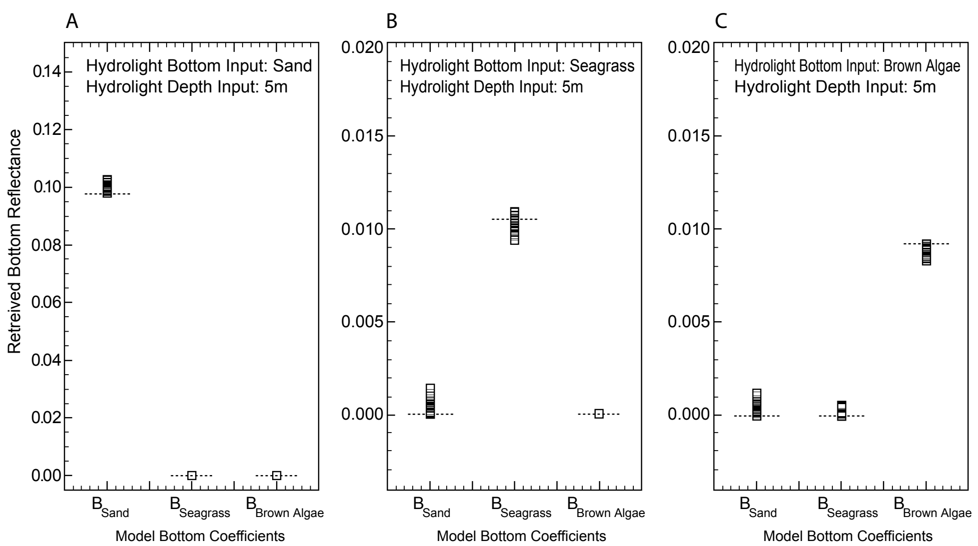

Figure 2.16: Model retrieved bottom coefficients, B_{Sand}, $B_{Seagrass}$ and $B_{Brown\ Algae}$ over Hydrolight bottom input spectra, a) sand, b) seagrass and c) brown algae.

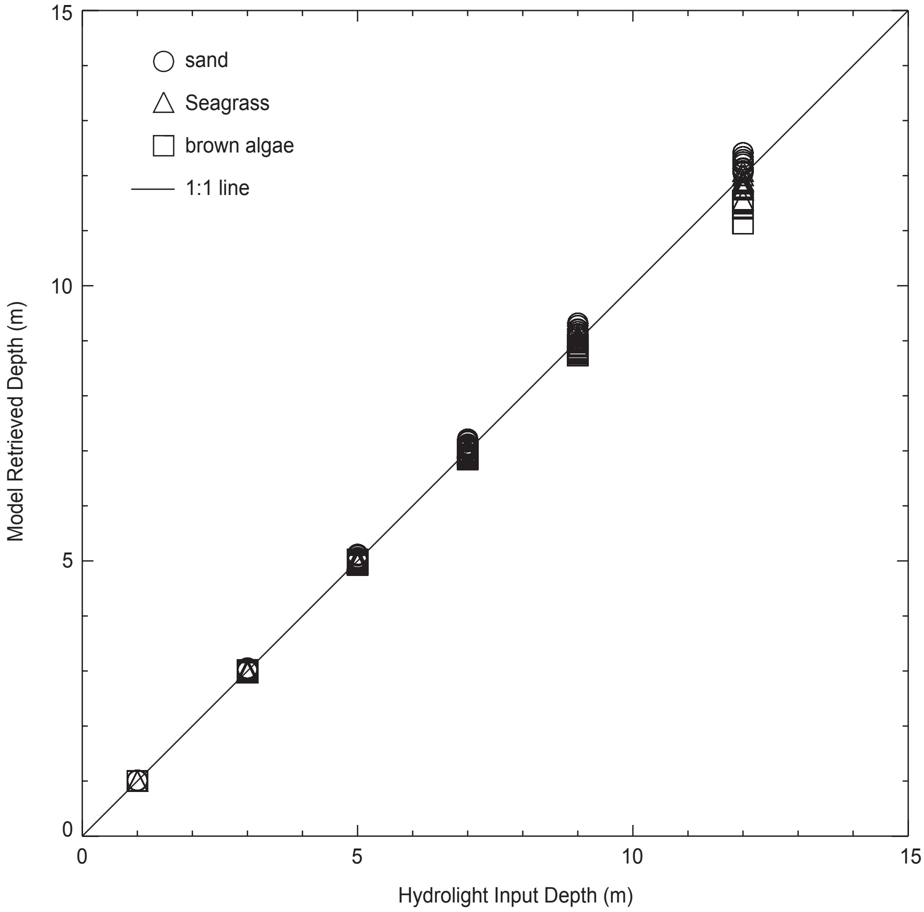

Figure 2.17: A comparison scatter plot of Hydrolight input depth against model-retrieved depth over the various simulated bottom types.

Model Application to Hymap Imagery

Two flight lines of HyMap (HyVista Corporation) spectral imagery over Jurien Bay were captured on 23rd of April 2004 to study the possibility of bottom type retrieval from shallow, coastal waters. The study area selected for evaluation in this PhD research encompasses a small portion of the recently designated Jurien Bay Marine Park, located approximately 300km north of Perth, Western Australia (Figure 2.18). The bottom composition within this selected region is highly variable, composed largely of sediment, seagrass and pavement/reef. The most commonly found sediment is white carbonate sand. The dominant seagrass species is *Posidonia australis*. Small pockets of the seagrasses *Amphibolus griffithii* and *Halophila ovalis* also occur in this region. The brown algae, *Sargassum.* sp. and *Ecklonia*, are very abundant in this region and reside mainly on the reef and pavement areas with varying density. Occurring in much sparser growth is the fleshy and coralline red epiphytes. These epiphytes attach themselves onto seagrass shoots and also survive independently over the pavement/reef areas.

The topography of the area is also highly variable and includes extensive shallow water areas with depths ranging 1m to 15m.

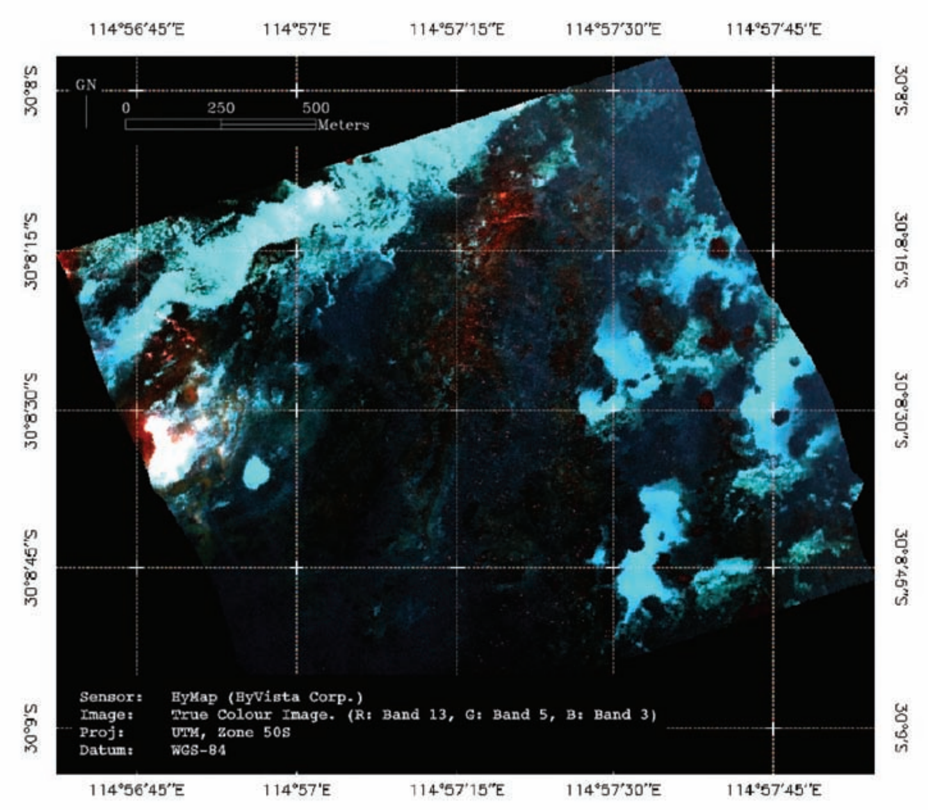

Figure 2.18: A true colour representation of the HyMap captured image over the "Scientific Reference Zone". The colour variation within the image scene is due to spatial changes in water attenuation (depth) and benthic cover.

The coastal water reflectance model was applied to a small section of the image scene covering the "scientific reference zone" (Figure 2.18). Each pixel element within the atmospherically corrected reflectance data set, provided by HyVista Corp., was inverted by implementing the coastal water reflectance model in conjunction with a Levenberg-Marquardt optimisation scheme. The retrieved bottom weighting coefficients of sand, seagrass and brown algae were used to generate a false colour bottom type classification image, representing our results of benthic cover (Figure 2.19).

The classification image was constructed using the ENVI package distributed by Reasearch Systems Inc. (RSI). Model-retrieved bottom weighing coefficients of sand, seagrass and brown algae were related to the blue, green and red components of the ENVI colour table. From the Hydrolight modelling results, we anticipate that blue, green and red pixel colours of the classification image would represent benthic cover representative of sand, seagrass and brown algae, respectively. These results would only be valid for situations where only one bottom type is captured within the image pixel. For situations where the image pixel is occupied by two or more benthic cover types, we expect the model to retrieve bottom weighting coefficients such that a combination of the three bottom spectra (model) are utilized in the non-linear fit. For these instances, the values of the individual bottom weighting coefficients would be reduced and hence be represented by darker image pixels. Similarly, for the situations where the benthic cover type (eg, coral or rock) imaged within a pixel is spectrally different to the bottom type spectra utilized in the model, the model would retrieve a combination of bottom type weighting coefficients which best fits the imaged bottom type reflectance. This would result in pixel colours that are made up of a combination of blue, green and red.

The model-retrieved depth was used to generate a bathymetric map of the evaluation site and comparisons with hydro-acoustic sounding determined depths were made.

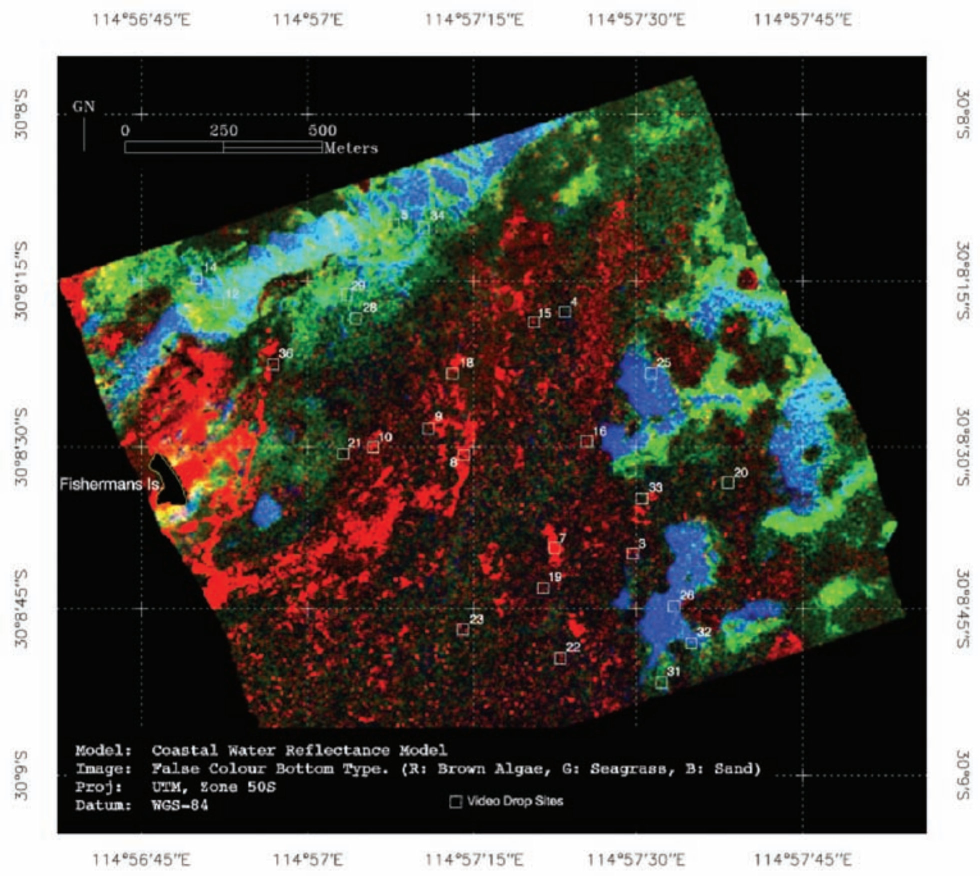

Figure 2.19: A false colour benthic cover representation of the "Scientific Reference Zone". Sand, seagrass and brown algae are represented by blue, green and red coloured pixels, respectively. Darker coloured pixels indicate a mixture of benthic cover. Locations of 26 ground-truthing stations are marked out as squares.

Benthic Cover Validation

To study the validity of the generated bottom type classification image, a SRFME field campaign was undertaken whereby video drops over 26 sites within the image scene (Figure 2.19) were deployed to identify the bottom composition. The location of the image pixels corresponding to the field sites were extracted and their colour was compared to the bottom composition identified with the video data (Table 2.2).

Table 2.2 A tabulated comparison of image (classification) pixel colour with the benthic cover identified in video footage over selected ground-truthing sites.

Station #	Pixel colour	Bottom cover identified in video drops
14	Blue	Sand
32	Blue	Mostly Sand/Patchy Halophila
26	Blue	Sand
25	Blue	Sand
12	Blue	Sand/Patchy Halophila
34	Blue	Sand/Patchy Halophila
29	Green	Sand/Halophila
28	Green	Sand/Halophila
5	Green	Seagrass(dense)/Sand
31	Green	Sand/Seagrass/Light Brown Epiphytes
21	Dark Green	Purple Sargassum/Seagrass/Brown+Yellow Epiphytes/Sand
33	Dark Green	Bare Reef/Purple Sargassum (Sparse)
20	Dark Green	Bare Reef/Purple Sargassum (Sparse)
4	Dark Green	Bare Reef/Purple Sargassum (Sparse)
10	Red	Sargassum (Dense cover)
8	Red	Ecklonia (Dense cover)
3	Red	Brown Sargassum/Brown Epiphytes (Dense cover)
7	Red	Ecklonia (Dense cover)
36	Dark Red	Ecklonia/Seagrass/Brown+Purple Sargassum
9	Dark Red	Purple Sargassum/Sand/Patchy Ecklonia/Epiphytes
19	Dark Red	Purple Sargassum/Sand/Patchy Ecklonia/Epiphytes
23	Dark Red	Purple Sargassum/Brown+Yellow Epiphytes
22	Dark Red	Purple Sargassum/Sand/Brown Epiphytes
16	Dark Red	Brown Sargassum
15	Dark Red	Purple+Brown Sargassum/patchy Sand

Referring to Table 2.2, we can see that blue pixels correspond to sandy bottom environments, green pixels were associated with mainly seagrass with some stations containing a small proportion of sand. Red pixels were associated with dense cover of the brown algae, *Ecklonia* and *Sargassum.* Dark green pixels were associated with mixtures of sparse brown algae and bare reef (rock). Dark red pixels were associated with mixtures of brown algae, sand and epiphytes.

These results are promising and demonstrate a potential for the coastal water reflectance model to provide benthic cover classification maps identifying sand, seagrass and brown algae, which are of interest to end users such as coastal water managers and environmental scientists.

Depth Validation

A historical hydro-acoustic data set of bathymetry was used to validate the model-retrieved depth. Image derived depths were co-located with the hydro-acoustic sounding depths and presented as a scatter plot (Figure 2.20). Figure 2.20 shows that depth retrieval capability of the model work well for the selected region. The mean difference in depth was calculated to be ~7%.

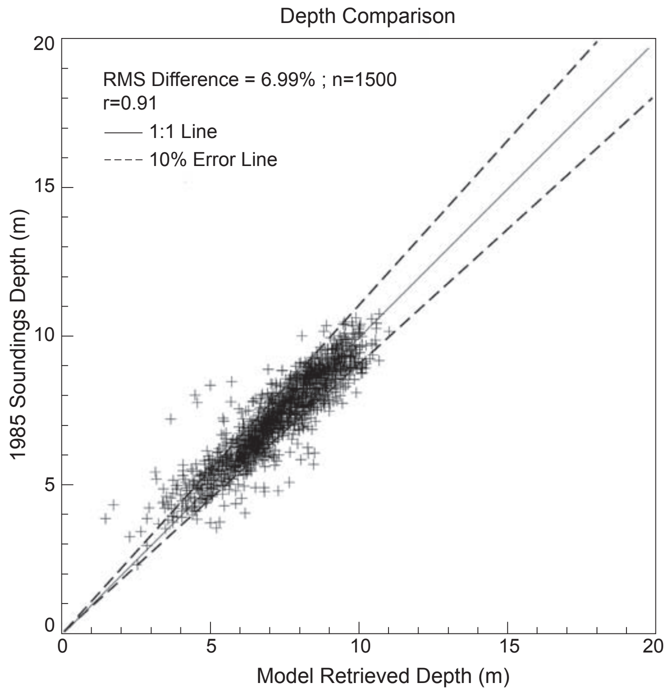

Figure 2.20: A scatter plot of the model-retrieved depth over the "scientific reference zone" compared with hydro-acoustic soundings.

Summary and Conclusions

A shallow water reflectance model that incorporates 3 bottom type spectra, typical of WA coastal waters, was developed during this PhD research. The model retrieval capabilities of bottom type were tested with a synthetic reflectance data set. The results indicate that the model has the ability to select the appropriate bottom type cover (sand, seagrass or brown algae) to water column depths ranging from 1 to 5m.

The model was then applied to HyMap reflectance data collected over Jurien Bay coastal waters. The model-retrieved bottom coefficients were used to generate a bottom type classification map identifying coverage of sand, seagrass and brown algae. A SRFME ground-truthing exercise was undertaken to validate the classification image. Comparison between *in situ* determined bottom type cover and model generated bottom type classification correlate well with each other, especially for dense cover of sand, seagrass and brown algae. The accuracy of the retrieved water column depth was evaluated by comparing historical hydro-acoustic soundings with the model-retrieved depth. The results indicate that the model is capable of estimating water column depth, accurate to around 10% up to depths of 15m.

These results are very promising and show potential for the routine mapping and monitoring of sea floor composition and bathymetry over coastal western Australian waters.

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References

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

List of Conference Presentations

Australian Marine Sciences Association, Fremantle, 10-12 Jul 02, "The Development and Validation of Algorithms for Remotely Sensing Case II Waters"

Australian Meteorological and Oceanographic Society, UWA, 10-12 Feb 03, "Hyperspectral Remote Sensing of Western Australian Coastal Waters"

SPIE - The International Society for Optical Engineering, San Diego, 3-8 Aug 03, "Hyperspectral Remote Sensing of Western Australian Coastal Waters"

Ocean Optics, Fremantle, 25-29 Oct 04, "Bottom Type Classification using Hyperspectral Imagery"

Australian Remote Sensing and Photogrammetry Conference, Fremantle, 18-21 Oct 04, "Characterisation of Seagrass Beds using HyMap Imagery"

Intended Thesis Submission Date: 24th of September 2007.

Publications

Klonowski, W., (2003). Hyperspectral remote sensing of Western Australian coastal waters, The International Society for Optical Engineering *5515,* 201-210.

2.2.6 Spatial, temporal and biogeochemical dynamics of submarine groundwater discharge in a semi-enclosed coastal basin

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Executive Summary

This PhD study applied a variety of field sampling techniques in conjunction with surface water hydrodynamic modelling to achieve a process-based understanding of spatial, temporal and biogeochemical dynamics of groundwater discharge in marine waters. Field investigations were carried out in Cockburn Sound, a semi-enclosed marine basin located approx. 12 km south of Fremantle, Western Australia. This site was selected in part for its topical relevance to Western Australian marine health, but also for the complexity of groundwater discharge dynamics that arises from complex interactions between chemistry, hydrogeology, bathymetry and oceanography.

Results indicated that groundwater discharge was highly spatially and temporally heterogeneic. Additionally, the availability of post-discharge groundwater in marine surface