Maritime Ireland / Wales
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Feasibility study of the use of digital cameras for water quality monitoring in the coastal zone

November 2001

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Maritime Ireland / Wales INTERREG Report NO.7
Measure 1.3: Protection of the Marine and Coastal Environment and Marine Emergency Planning

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Maritime (Ireland/Wales) INTERREG Programme 1994 - 1999

The EU Maritime (Ireland /Wales) INTERREG II Programme (1994 – 1999) was established to:

1. promote the creation and development of networks of co-operation across the common maritime border.
2. assist the eligible border region of Wales and Ireland to overcome development problems which arise from its relative isolation within the European Union.

These aims are to be achieved through the upgrading of major transport and other economic linkages in a way that will benefit the constituent populations and in a manner compatible with the protection and sustainability of the environment. The Maritime INTERREG area includes the coastlines of counties Meath, Dublin, Wicklow, Wexford and Waterford on the Irish side and Gwynedd, Ceredigion, Pembrokeshire and Carmarthenshire on the Welsh side and the sea area in between.

In order to achieve its strategic objectives the programme is divided into two Areas:

Sub-Programme 1: **Maritime Development:** transport, environment and related infrastructure (59 mEuro)

Sub-Programme 2: **General Economic Development:** Economic growth, tourism, culture, human resource development (24.9 mEuro)

The Marine and Coastal Environment Protection and Marine Emergency Planning Measure (1.3) has a total budget of 5.33 mEuro of which 3.395 mEuro is provided under the European Development Fund. EU aid rates are 75% (Ireland) and 50% (Wales).

The specific aims of Sub-Programme 1.3 are:

- to promote the transfer of information between the designated areas.
- to establish an in-depth profile of marine/coastal areas for conservation of habitat/species.
- to explore, survey, investigate, chart the marine resource to provide a management framework.
- to develop an integrated coastal zone management system.
- to improve marine environmental contacts and co-operation.
- to promote the sustainable development of the region.
- to improve nature conservation.

Joint Working Group

The Joint Working Group, established to oversee the implementation of Measure, consists of 5 Irish and 5 Welsh representatives.

Irish representation: Department of the Marine & Natural Resources, Department of the Environment & Local Government, Department of Transport, Energy & Communications, Local Authority and Marine Institute.

Welsh representation: National Assembly for Wales, Countryside Council for Wales, National Trust, Local Authority (Dyfed), Local Authority (Gwynedd).

This Report series is designed to provide information on the results of projects funded under Measure 1.3. Protection of the Marine & Coastal Environment and Marine Emergency Planning.

Feasibility study on the use of digital cameras for water quality monitoring in the coastal zone.

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Abstract.

The coastal zone is characteristically a turbid region of the sea with water clarity being an indicator of coastal dynamics. Turbidity affects water quality and aesthetic value. Previous investigations into water clarity in the Irish Sea have been conducted using imagery obtained from the Advanced Very High Resolution Radiometer (AVHRR). Good correlations were found between light reflectance and suspended sediment concentrations from this imagery.

In order to investigate suspended sediment concentrations in the coastal zone, an area where satellite imagery does not 'see well', scientists from NUI, Galway, UW, Bangor and Compass Informatics Ltd. undertook a feasibility study to investigate the possibilities of using both in situ and airborne digital cameras to monitor water clarity in the coastal zone. The digital cameras capture visible spectrum imagery with assigned values for red, green and blue light, thus making a quantifiable measurement of the up-welling light of different colours in a similar manner to the UW, Bangor Ocean Colour Sensor used in this project and a previous INTERREG Project (White et al.; 2000)

As suspended sediment concentrations were found to correlate well with in situ digital camera output values, it was anticipated that the camera would provide a successful method of monitoring Suspended Particulate Material (SPM) at fixed locations over a predetermined time period.

In practice aerial imagery did not prove to be a feasible method for SPM monitoring in the type of dynamic coastal environment under this particular survey. A combination of sun glint, sky reflectance interference, strong tidal currents and time lapse between imagery capture and in situ data collection made the calibration of images very difficult.

On the positive side, it was found that aerial imagery is ideally suited to observing coastal dynamical phenomena such as river plume development. These near shore dynamical processes cannot be monitored by satellite imagery and so aerial resolution and aircraft manoeuvrability are ideal for this type of coastal zone remote sensing.

1. Introduction.

In the INTERREG project " Water Clarity in the Southern Irish Sea" (White et. al; 2000), trends in suspended sediment load in the southern Irish Sea were assessed from 1987 –1997 using satellite remotely sensed imagery. A relationship between the water clarity (suspended sediment content) and the reflectance of visible light measured by the satellite was found. This allowed annual maps of light reflectance to be constructed and analysed for year-to-year changes in water clarity. Interannual changes in water clarity were related to changes in the mean annual wind strength over the region. In addition, a secondary finding arising from the project was the strong relationship between light of different colours up welled from the surface waters, and the water clarity, such that the ratio of up-welling red light to green varied linearly with the sediment content of the water. (Figure 1.1)

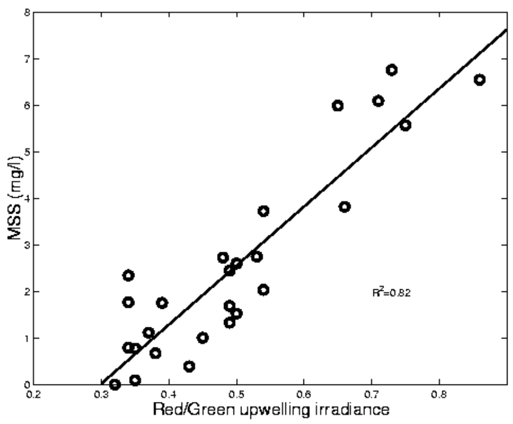


Fig. 1.1 Relationship between mineral suspended solids & the ratio of red & green upwelling irradiance as measured by SOS Ocean Colour Sensor in Southwest Irish Sea, Sept. 1998.

Two problems were found with the satellite monitoring methods of water clarity;

- the irregularity of useful imagery with seasonal bias in the number of cloud free images
- the course resolution of satellite images which did not allow measurements within 1km of the coastline or very shallow water.

It was thought that a digital camera flown at a low altitude above the sea's surface might allow monitoring of water clarity in the near coastal zone if an appropriate calibration for the camera could be found. This is because a digital camera takes a digital picture with assigned values for the red, green and blue light in the picture. The camera, therefore, makes a quantifiable measurement of the up-welling light of different colours in a similar manner to the Bangor Ocean Colour Sensor used in the INTERREG Project. Modified digital cameras have been used previously to map the coastal zone, for example, the mapping of the Irish Coastline during the Marine Research Measure programme 1994 – 1998. (Hyland, 2000)

To investigate the use of digital cameras in this way, NUI, Galway and the School of Ocean Sciences (SOS) UW, Bangor, together with Compass Informatics Ltd., undertook a feasibility study to investigate the possibilities of using both in situ and airborne digital cameras to monitor the water clarity in the near coastal zone.

2. Aims & Objectives.

The aim of the project was to determine the feasibility of using an airborne digital camera as a tool for remote sensing and consequent monitoring of water column constituents, such as suspended particulate material (SPM), in coastal waters within 1km of the shoreline.

Within this overall aim, objectives included:

- To collect relevant in situ sea-truth measurements of suspended particulate material (SPM), chlorophyll & dissolved organic material (yellow substance) using traditional methods and proven optical instruments (SOS Ocean Colour Sensor and Secchi disk), while capturing images of the water column from just below the sea surface using a customised Sony digital Mavica MVC-FD 73 Camera.
- To concurrently capture imagery of the coastal survey area using a Kodak Digital Science 460 colour camera flown on a light aircraft at a specified height.
- To develop relationships between SPM, chlorophyll and yellow substance measurements and optical instrument measurements, and the Red, Green & Blue output values of the in situ and airborne digital cameras.

3. Approach.

3.1. Partnership.

The three partners involved in the project were the Department of Oceanography, NUI, Galway (NUIG), the School of Ocean Sciences, University of Wales, Bangor (SOS) and Compass Informatics. All three partners provided complimentary skills to the project, NUIG providing water samples, instrument and image data analysis, SOS providing the colour sensor and in situ digital camera along with an excellent knowledge and experience in marine optics, and Compass Informatics providing the georectified aerial images from the airborne camera.

All three partners were involved in the fieldwork, SOS ensuring correct deployment of optical instruments, NUIG conducting water sampling and capturing in situ imagery and Compass Informatics providing concurrent flyover aerial imagery. The tasks of analysing water sample data, optical data, in situ digital imagery and georectified aerial imagery were undertaken at

NUI, Galway. Prior to fieldwork, experiments were carried out at SOS, Bangor with the involvement of NUI, Galway, in order to establish a methodology for using both digital cameras.

Exchange of expertise and ideas between NUIG and SOS was continued throughout the data analysis process. Compass Informatics provided invaluable advice with image georectification and correction.

3.2. Background Experiments.

Experiments were carried out in SOS, Bangor in order to establish the most effective method of:

- Capturing digital imagery using the in situ handheld camera
- Establishing relationships between the red and green output values and measured SPM concentrations.

It was found hat in order to avoid reflectance from both the sky and sea surface, images needed to be captured from just below the sea surface where these problems would be avoided.

A device was built using a piece of plastic pipe approximately 6 inches long with a fitted inner cushion, which attached snugly around the lens of the camera, excluding all light from the lens except the light through the end of the pipe. Once the device was attached to the camera, images were captured by placing the tip of the pipe just below the sea surface, thus enabling it to capture the true colour of the water column while avoiding any interference from the surface.

SPM measurements were carried out over a two-week sampling period in order to establish a relationship between these concentrations and the red and green output values of the digital camera. These experiments proved to be successful demonstrating that there exists a relationship between the digital camera red and green O/P values and SPM concentrations. For individual images, mean red and green values were examined. The green channel was the principal component and displayed greatest brightness values in almost all images. The red channel was a minor component and brightness values fluctuated according to SPM concentrations. This fluctuation of red channel O/P values was due to greater backscatter of longer wavelength light in areas of high SPM concentration. By examining the difference between the green and red O/P values we can observe the fluctuation of the red component in relation to the green principal component. These values were obtained for all imagery and plotted against sea-truth measurements of SPM to reveal the direct relationship between the green-red (g-r) value and SPM concentration. . The smaller the difference value, the greater the red component and hence the greater SPM concentration. Values ranged from 30-39 (digital camera units, dcu) in the more heavily SPM concentrated areas (SPM = 10mg/1 +) to values in excess of 50 dcu in water columns with SPM concentrations under 6mg/l.

3.3. Methodology.

After initial tests at SOS, the main fieldwork portion of the project consisted of two elements running concurrently:

Fieldwork: The establishment of an in situ data set to provide optical data for the Arklow Harbour survey area from which to calibrate the aerial imagery.

Aerial Imagery: The capture of aerial imagery of the Arklow Harbour survey area over a specified time series and at a specified altitude.

3.3.1. Fieldwork.

Fieldwork was carried out in one survey at Arklow Harbour, Co. Wicklow on August 29th, 2000, using an easily manoeuvrable rigid inflatable boat. The survey was conducted over a 4-hour period, with 19 stations occupied within the area. The location of the survey area is shown in Fig. 3.1

In situ measurements provided optical data for the Arklow Harbour survey area from which to calibrate the aerial imagery. An attempt was made to sample stations in a rectangular grid in order to obtain an even spread of stations and maximum coverage of the survey area. In order to carry out the calibration of the aerial imagery, optical parameters affecting water colour and clarity were measured.

These parameters included:

1) Ocean colour Sensor (OCS)
2) Secchi disk depth.
3) Suspended sediment, gravimetry from surface samples.
4) Chlorophyll, from flourometry.
5) Dissolved organic material (yellow substance) from spectrometry.
6) In situ digital camera with customised attachment.

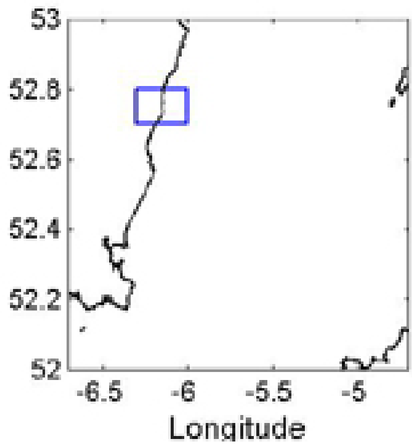


Fig. 3.1. Arklow Harbour survey area, Southwestern Irish Sea.

The SOS OCS was deployed at each station, facing downward in the water column, measuring the upwelling light only. By examining the upwelling colour ratios, a change of colour intensity could be detected from station to station. The actual irradiance values were not examined. Secchi disc measurements were taken at each station to determine water column turbidity and to make rough estimates of colour change. Suspended particulate material, chlorophyll and yellow substance were measured from water samples collected in situ and analysed in the laboratory using the traditional methods of gravimetry, flourometry and spectrometry respectively.

The in situ digital camera was equipped with a customised attachment on the lens, which enabled images to be captured just below the sea surface, excluding any light that might infiltrate the image from above the surface. This eliminated any sky reflectance or sun glint, which would affect the colour & intensity of the image. At each station site, three images were captured at three different exposures in order to determine whether or not varying levels of exposure affected the red, green & blue light intensity proportions.

In Situ Image Analysis.

In situ Imagery was analysed using Adobe Photoshop. Only visible imagery was used for analysis. Plume was very evident in aerial imagery. Red, Green and Blue output values were examined and averaged for each image. The average Green – Red (g-r) output values were plotted against SPM, chlorophyll and yellow substance concentrations. The g-r output values were also plotted against R/G values from the SOS Ocean Colour Sensor and Secchi depth measurements.

3.3.2. Aerial Imagery.

Aerial Images were captured using a Kodak Digital Science 460 colour camera fixed on a support frame to the outside of a light aircraft, a Cessna 172. This camera provided high-resolution imagery with a pixel array of 3060 x 2063, and a resolution of 40cm when flown at 4000 ft. An image with 40cm resolution covers an area of 1224m by 814m.

Aerial images were captured over a 2-hour time period concurrently with the in situ fieldwork. Communication with the aircraft was via mobile phone and a sampling procedure was decided whereby images would be captured at half hour intervals between 2pm and 4pm. These included images captured at two different altitudes 2,000 ft & 4,000 ft, and in three formats, Visible spectrum, Visible with polariser attached to reduce sun glint and surface/sky reflectance, and Colour Infra Red. In all, almost 50 images were captured over the course of the sampling procedure. Images were georectified and mosaiced by Compass Informatics.

River plume development is evident over the course of the 4-hour sampling period. The weaker currents at low water are obvious in the first 3 images as the structure of the plume is quite well defined. The turning of the tide and stronger currents during flooding are evident in image 4 & 5 as the plume and it's boundary front disperse. These observations and images demonstrate the suitability of an airborne camera as a valuable tool for high resolution remote sensing of dynamical phenomena in the coastal zone. Research into the use of the camera for this purpose is currently continuing as a Masters research project in the Dept. of Oceanography, NUI Galway.

Image Capture.

Below is a time series of visible imagery captured at 4,000 feet altitude over a 4-hour sampling period.

Flyover 1: 2pm.

Flyover 2: 2.30pm.

Flyover 3: 3pm.

Flyover 4: 3.30pm.

Flyover 5: 4pm.

Imagery of River Avoca plume development evident over the course of the 4-hour sampling period. Tide ebbing for flyover 1, 2 & 3. Turn of the tide and flooding evident in plume dissipation during flyover 4 & 5.

Aerial Image Analysis.

Airborne Imagery was also analysed using Adobe Photoshop software. Images captured at 4,000 ft in the visible spectrum were used for analysis in this study. Station sites were identified using the South Pier Head in Arklow Harbour as a ground control point. Images captured at 4000 ft and 2000 ft had resolutions of 40cm and 20cm respectively assuming a level flight with the camera perpendicular to the sea surface.

As the aerial images were captured over a time series of approximately two hours, a grading system was developed where stations were placed in one of three grades A, B or C according to the time frame within which the station was sampled in relation to the time the aerial imagery was captured.

Grade	Time of in situ Station Sampling
A	Up to 10 minutes either side of aerial capture.
B	Between 10 – 20 minutes.
C	20 minutes +.

Individual stations were sampled from the aerial imagery by examining a $20m^2$ area of sea surface surrounding the station position. Within this $20m^2$ area averages of Red, Green and Blue output values were obtained from the image histogram and a mean Red, Green and Blue values for each station was obtained. This procedure was repeated for sea surface areas of $30m^2$, and $100m^2$.

4. Results.

4.1. Traditional Methods – In situ constituents and optical instruments.

Due to the presence of the Avoca river plume forming at the mouth of Arklow Harbour, the optical properties of the stations within the plume differed from those stations outside the plume. This was due to an abundance of yellow substance, which is characteristic of land derived river plume water. Typical absorption spectra of yellow substance were measured for both plume and non-plume stations and examples of both are shown in Figures 4.1a & 4.1b. As a result of the different optical characteristics, data was divided into two data sets:

1) Non-Plume Stations.
2) Plume Stations.

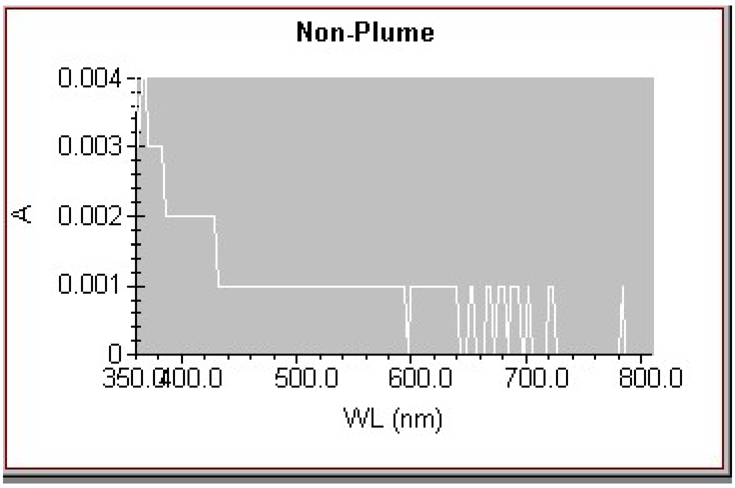


Figure 4.1a. Absorption spectra of non – plume Water.

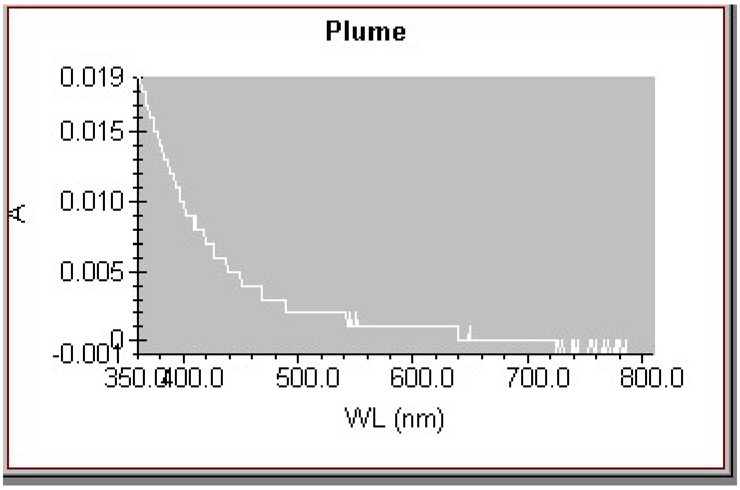


Figure 4.1b. Typical absorption spectra of yellow substance evident in plume waters.

Non-Plume Stations.

SPM concentrations were plotted against Secchi depth (Zd) measurements and red / green colour sensor ratios (R/G) for calibration purposes. Strong correlations were observed between SPM & Zd, with $R^2 = 0.74$, and indicated that sediment concentrations increased as Zd decreased. Strong correlations were also observed between SPM & R/G ($R^2 = 0.86$) and indicated that as sediment concentrations increased, the red reflectance increased due to backscatter of red light by sediment. Strong correlations again observed between R/G & Zd ($R^2 = 0.87$) indicated that as water turned redder, turbidity increased. These trends were as expected and indicated consistency in traditional methods of SPM measurement.

Plume Stations.

Due to the absorption spectra of yellow substance in plume waters, trends associated with SPM were not observed at plume stations. Correlations between SPM, Zd & R/G were either poor or contrary to expectation indicating that waters optically affected by high yellow substance concentration need to be examined as a separate data set.

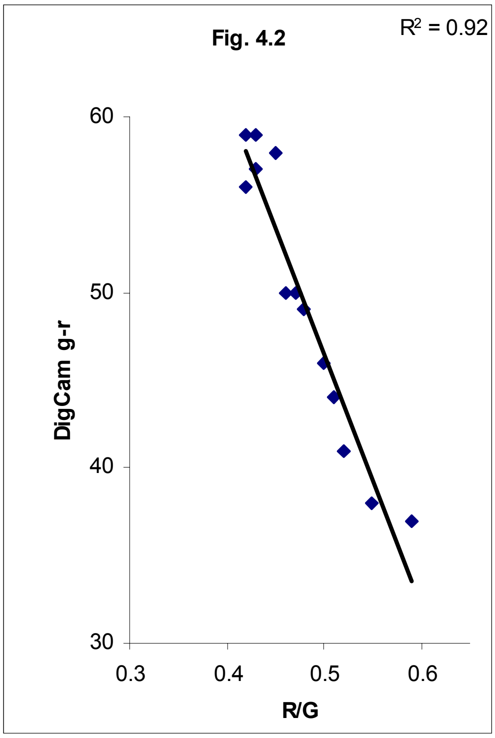
4.2. In Situ Digital Camera – SPM relationship.

Non-Plume Stations.

Strong relationships have been found between the OCS O/P values (R/G), Secchi depth (Zd) and suspended particulate material, and the insitu digital camera imagery for non-plume station data. R/G values from the Ocean Colour Sensor were plotted against green-red output values from the insitu imagery and a strong relationship was identified with $R^2 = 0.92$ indicating increase in digital red component as OCS observed red irradiance increased (Figure 4.2). SPM concentrations were plotted against the green-red (g-r) output values from the imagery and again a strong relationship was identified with (R^2 = 0.71, Figure 4.3). Strong relationship was found between Zd and g-r O/P values, with R^2 = 0.77. (Figure 4.4).

Plume Stations.

Due to the presence of yellow substance, correlations between digital O/P and R/G, and digital O/P and Zd displayed trends contrary to those displayed by non-plume stations. Yellow substance displays greatest absorption in the blue and uv end of the visible spectrum with an exponential decrease toward the red end of spectrum, and the plume water possessing completely different optical properties to the non-plume water. This feature was particularly evident when deploying the Secchi disc. Although the water colour appeared much browner and darker within the plume, one would expect the Secchi disc measurements to be quite small due to the buoyant nature of the river plume the Secchi disc penetrated beneath the shallow draft of the plume to the non-plume water beneath. So the inverse relationship in Figure 4.5 illustrates that although the water was a darker colour, it's clarity penetrated to similar depths as non-plume waters, thus darker appearance of water was indeed due to dissolved substance optical properties and not particulate material.



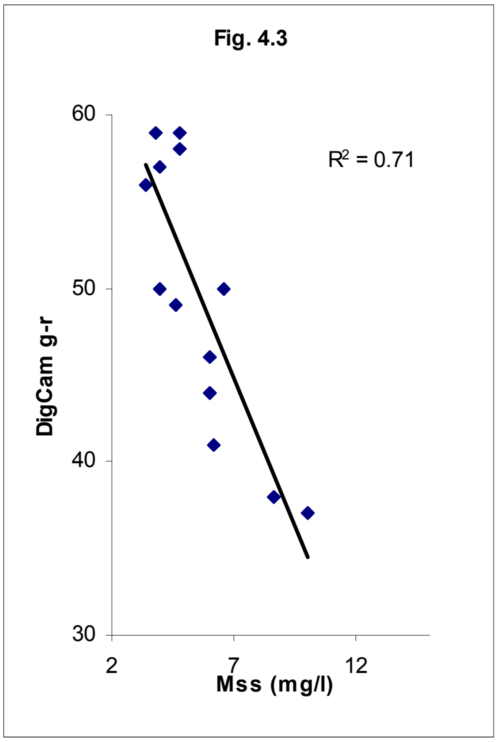
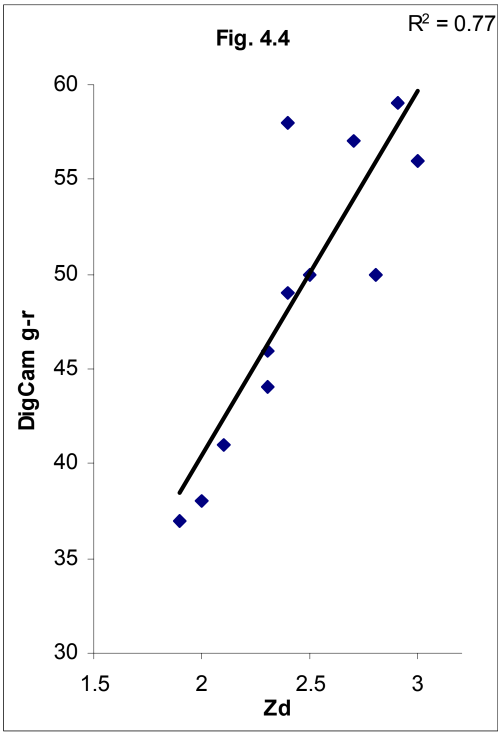


Fig. 4.2 Comparisons of Ocean Colour Sensor with in situ camera O/P.

Fig. 4.3 Comparisons of MSS with in situ camera O/P.



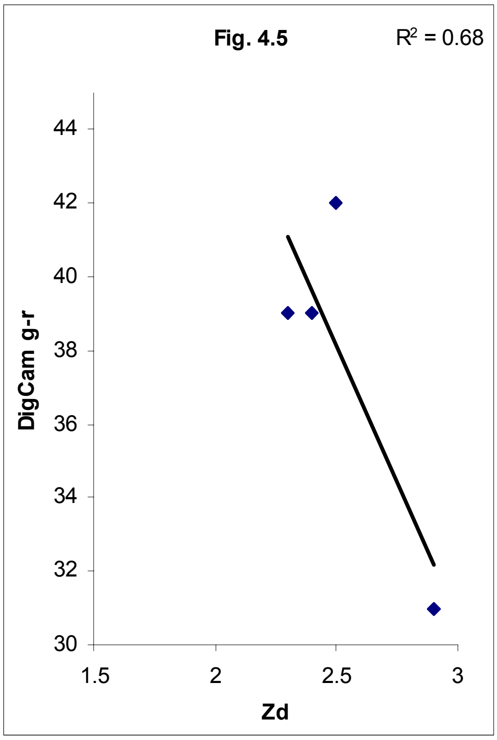


Fig. 4.4. Non-Plume: Comparisons of Secchi depth with in situ camera O/P

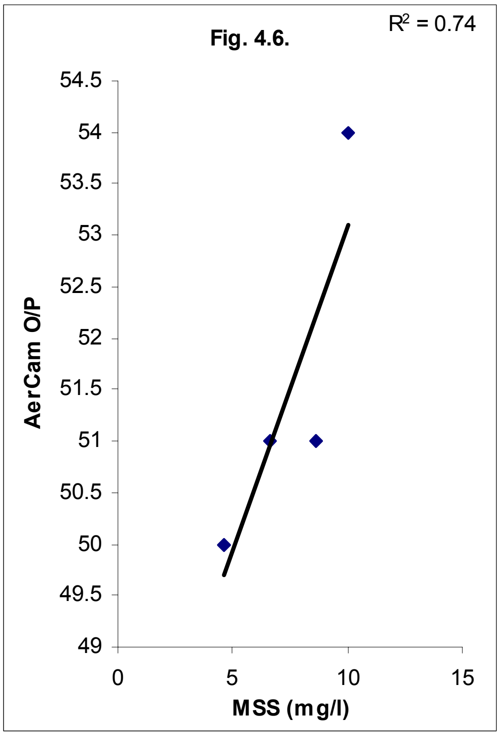
Fig. 4.5. Plume: Comparisons of secchi depth with in situ camera O/P

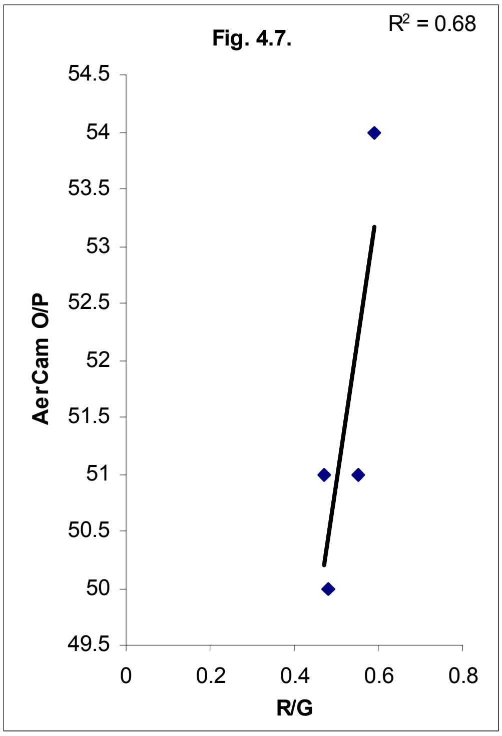
4.3. Airborne Camera – In Situ Camera – SPM Relationships.

Non-Plume Stations.

Aerial digital imagery values were taken from 20m^2 area of sea surface surrounding station positions, 30m^2 and 100m^2 areas. These g-r O/P values were plotted against SPM concentrations, Ocean Sensor R/G, Zd and in situ digital imagery g-r O/P values. No correlation was found between SPM and aerial O/P (R^2=0.03), R/G and aerial O/P (R^2=0.01), Zd and aerial O/P (R^2=0.001) and in situ O/P and aerial O/P, (R^2=0.12). The 30m^2 and 100m^2 area sample sites also displayed very weak correlations with R^2 values very similar to those of the 20m^2 area sample sites.

Graded stations displayed different results when plotted individually. For Grade A stations over a sample area of 20m^2, correlations were observed between SPM and aerial O/P (R^2=0.73), R/G and aerial O/P (R^2=0.68), Zd and aerial O/P (R^2=0.52) and in situ O/P (R^2=0.48). Although these correlations appear good, trends are directly opposite to trends observed in in situ digital O/P data. In short, the aerial camera is operating in reverse for Grade A station data set (Figures 4.6 & 4.7).





Grade A Stations.

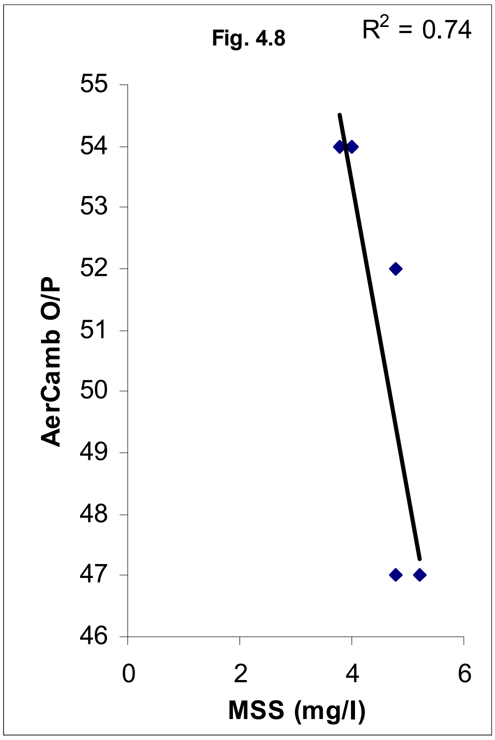
Fig. 4.6. Comparisons of MSS with aerial camera O/P

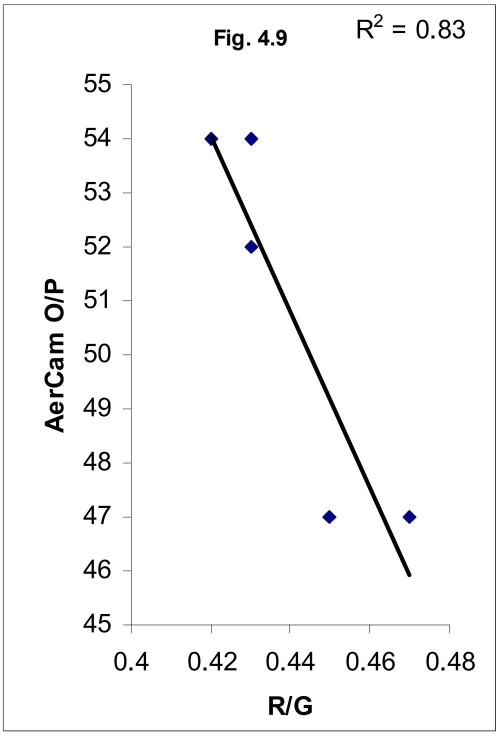
Fig. 4.7. Comparisons of (OCS) R/G with aerial camera O/P

For Grade B & C stations combined over a sample area of 20m^2, trends observed concur with trends observed by the in situ digital imagery with SPM and aerial O/P (R^2=0.74), R/G and aerial imagery (R^2=0.83, Zd and serial imagery (R^2=0.48, Figures 4.8 & 4.9). The 30m^2 sample area data showed very similar trends and values to those for 20m^2 sample area data. The 100m^2 sample area data showed very little relationship, as this sample area was probably too large with station sites overlapping with the plume and each other.

Plume Stations.

No correlation was observed between aerial imagery O/P values and any parameters within the plume, perhaps due to lack of concurrent sea truth data or sky reflectance problems.





Grade B & C Stations.

Fig 4.8. Comparisons of MSS with aerial camera O/P

Fig 4.9. Comparisons of (OCS) R/G with aerial camera O/P

4.4. Rudimentary System for in situ camera.

For the Non-Plume station data set, the positive relationships observed between the handheld digital camera and SPM concentrations mean that the camera can be used directly as an in situ method of SPM measurement once calibrations have been made with SPM concentrations and /or other optical instrumentation. A rudimentary system has been created in order to demonstrate how the camera could work in the field in conjunction with other methods for SPM monitoring. Table 4.1.

Method	Grade	Range
a) In situ Digital Camera	A	30 – 40
	B	40 – 49
	C	50 – 59
b) SPM mg/l	A	8 –10+
	B	6 – 8
	C	0 - 6
c) OCS R/G	A	0.55 – 0.59
	B	0.48 – 0.54
	C	0.40 – 0.47

Table 4.1

Results of each method were divided into three grades, A B & C. Each grade consists of a set of values within a specific range, unique to the individual method. This enables an estimation of SPM concentrations within a specific range either by using one method singly or by combining methods.

<u>Example:</u>

A g-r O/P value of 37 dcu was recorded using the in situ digital camera at station 8. By means of the rudimentary grading system, this value falls into Grade A where it can be observed that in this Grade SPM concentrations lie between 8 and 10 mg/l, and the SOS OCS O/P value is in the range 0.55+ (Table 4.2).

Station No.	DigCam G-R O/P	OCS R/G	SPM mg/l	Grade
1	45	0.52	6.6	B
2	58	0.45	4.8	C
3	46	0.5	6	B
5	55	0.47	5.2	C
6	50	0.47	6.6	C
7	44	0.51	6	B
8	37	0.59	10	A
9	38	0.55	8.6	A
10	41	0.52	6.2	B
11	49	0.48	4.6	B
14	50	0.46	4	C
15	56	0.42	3.4	C
16	59	0.43	4.8	C
17	57	0.43	4	C
18	59	0.42	3.8	C

Table 4.2

For this method to be useful the sample area in question would have to be optically uniform in order for a calibration to work and images would need to be captured under uniform conditions. This method could work for a relatively small sampling area (along a short stretch of coastline) where the optical properties do not change significantly.

5. Conclusions.

1. Variations in suspended sediment concentrations can be successfully monitored using an in situ digital camera with customised attachment enabling capturing of water column imagery from below the sea surface. Traditional methods of suspended sediment measurements can successfully calibrate this camera.

2. Visible Spectrum Aerial Imagery did not prove to be a feasible method of monitoring suspended sediment concentrations in the coastal zones due to sunglint and sky reflectance, which interferes with RGB O/P values. In addition, strong tidal currents and the time lapse between the capture of aerial imagery and ground-truth data collection make the calibration of the images extremely difficult unless a larger number of concurrent measurements are collected, but which means a significant increase in flyovers (and hence cost).

3. Aerial Imagery can be used effectively to monitor coastal dynamical phenomena such as river plume development and dispersion. These near shore dynamical processes cannot be monitored by satellite imagery.

6. Implications.

The results of this project have a number of important implications for the successful monitoring of suspended sediment in the nearshore coastal zone, the monitoring of coastal dynamical processes and overall environmental management of coastal zones. The initial objective of the project was to assess the feasibility of using an airborne digital camera as a tool for remote sensing and consequent monitoring of suspended sediment in coastal waters within 1km of the shoreline. The results of the project have indicated that there is no significant relationship between the airborne digital camera RGB O/P values and suspended sediment concentrations in the water column and so airborne imagery cannot successfully monitor SPM concentrations in a dynamical coastal area.

Conversely, in situ digital camera RGB O/P values show a strong relationship with suspended sediment concentrations. In this respect, the project has demonstrated a method of relating changes in RGB O/P data measured by an in situ digital camera to the water clarity. This camera would ideally be placed on fixed buoys over a predetermined time period. The strong relationship found is a significant finding of the work with a fundamental implication for future monitoring of water clarity. Calibration would need to be repeated for waters with varying optical properties.

Due to the high image resolution and flexible flight paths of the light aircraft, aerial imagery proves to be a successful tool for monitoring the coastal dynamical process of river plume development. Aerial imagery clearly distinguishes plume and non-plume water, and plume development is easily observed over the time series of images. In terms of coastal zone dynamical phenomena, the project has demonstrated a method of monitoring near shore dynamical activity, which proves impossible for satellite imagery to monitor.

7. Acknowledgements.

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8. Training.

Postgraduate training provided by the project included:

Lisa Feighery: M.Sc. thesis. 'Water quality monitoring in the coastal zone with a digital camera'. (NUI, Galway.)

9. References.

Hyland, E. (2000). Marine Research Measure Dictionary of Projects. 65pp.ISBN 1-902895-04-5.

White M., S. Gaffney, D. Bowers and P. Bowyer (2000). Water Clarity in the Southern Irish Sea. Maritime Ireland/Wales INTERREG Report No. 4. 28pp. ISBN 1393 9025.

APPENDIX MARITIME INTERREG PROJECTS

The following co-operative projects and networks are supported under Measure 1.3 "Protection of the Marine and Coastal Environment and Marine Emergency Planning", of the Maritime (Ireland/Wales) INTERREG Programme (1994 – 1999):

Co-operative Projects

1. **Roseate Terns - The Natural Connection - A Conservation and Research Project linking Wales and Ireland**
   Irish Wildbird Conservancy / North Wales Wildlife Trust.
2. **Marine Mammal Strandings - A Collaborative Study for the Irish Sea**.
   National University of Ireland, Cork / Countryside Council for Wales.
3. **South West Irish Sea Survey (SWISS).**
   Trinity College Dublin / National Museum of Wales, Cardiff.
4. **The Fate of Nutrients in Estuarine Plumes.**
   National University of Ireland, Galway / University of Wales, Bangor.
5. **Water Quality and Circulation in the Southern Irish Sea**
   National University of Ireland, Galway / University of Wales, Bangor.
6. **Grey Seals: Status and Monitoring in the Irish and Celtic Seas.**
   National University of Ireland, Cork / Dyfed Wildlife Trust.
7. **Sensitivity and Mapping of inshore marine biotopes in the Southern Irish Sea (SensMap).**
   Ecological Consultancy Services (Dublin), Dúchas / Countryside Council for Wales.
8. **Marine Information System: Scoping Study (Phase I).**
   Marine Institute, National Marine Data Centre/ Countryside Council for Wales.
9. **Achieving EU Standards in Recreational Waters**.
   National University of Ireland, Dublin / University of Wales, Aberystwyth.
10. **Irish Sea Southern Boundary Study**
    Marine Informatics Ltd (Dublin) / University of Wales, Bangor.
11. **Marine Information System: Demonstration (Phase II).**
    Marine Institute, National Marine Data Centre / Countryside Council for Wales.
12. **Emergency Response Information System (ERIS)**
    Enterprise Ireland, Compass Informatics, IMES / University of Wales, Bangor.
13. **Risk Assessment and Collaborative Emergency Response in the Irish Sea (RACER)**
    Nautical Enterprise Centre (Cork), National University of Ireland, Cork, University of Wales, Cardiff.
14. **Critical assessment of human activity for the sustainable management of the coastal zone.**
    National University of Ireland, Cork / University of Wales, Aberystwyth.
15. **SeaScapes – Developing a method of seascape evaluation**
    Brady Shipman Martin, National University of Ireland, Dublin / University of Wales, Aberystwyth.
16. **Ardfodir Glan – Clean Coasts/Clean Seas**
    CoastWatch Ireland / Keep Wales Tidy Campaign.

Co-operative Networks

17. **Irish Sea Hydrodynamic Modelling Network**
    Trinity College Dublin / University of Wales, Bangor.
18. **CoAST - Co-operative Action - Sustainability Network**
    Dublin Regional Authority / Isle of Anglesey County Council.
19. **ECONET - Erosion Control Network**
    Enterprise Ireland / Conwyn County Council.
20. **Navigate with Nature**
    Irish Sailing Association / Centre for Economic and Environmental Development (UK).
21. **"Land Dividing - Sea Uniting" Irish Seas Exhibition**
    Irish Seal Sanctuary, ENFO / National Assembly for Wales.
22. **From Seawaves to Airwaves**
    West Dublin Community Radio / Radio Ceredigion CYF.
23. **BENSIS – Benthic Ecology Network**
    Trinity College Dublin / National Museum of Wales, Cardiff.
24. **Remote Sensing of Suspended Sediment Load in the Coastal Zone**
    National University of Ireland, Galway / University of Wales, Bangor.
25. **Paving the Information Highway**
    Ecological Consultancy Services (Dublin) / Irish Sea Forum, University of Wales, Bangor.
26. **Inland, Coastal and Estuarine (ICE) Journal**
    National University of Ireland, Dublin / Centre for Economic and Environmental Development (UK).

Maritime Ireland/Wales *INTERREG* Report Series (ISSN: 1393 – 9025):

1. Raine, R. and LeB Williams, P.J. (2000) –*The fate of Nutrients in Estuarine Plumes*. 31pp.
2. Newton, S.F. and O. Crowe (2000) *Roseate Terns – The Natural Connection*. 66pp.
3. Kiely, O, Ligard, D., McKibben, M., Connolly, N., & M. Barnes (2000) *Grey Seals: status and monitoring in the Irish and Celtic Seas*. 76pp.
4. White, M., Gaffney, S., Bowers, D., and P. Bowyer (2000) *Water Quality in the Southern Irish Sea*. 28pp.
5. Hill, M., Briggs, J., Minto, P., Bagnall, D., Foley, K. & A. Williams. (2001). *Guide to Best Practice in Seascape Assessment*. 58pp.
6. Bruen, M.P., Crowther, J., Kay, D., Masterson, B.F., O'Connor, P.E., Thorp, M.B & M.D. Wyer (2001). Achieving EU Standards in Recreational Waters (In Press).

Other *INTERREG-II* Publications

Wilson, J.G., Mackie, A.S.Y., O'Connor, B.D.S., Rees, E.I.S. & T. Darbyshire (2001). Benthic Biodiversity in the Southern Irish Sea 2: The South-West Irish Sea Survey - - *Studies in Marine Biodiversity and Systematics from the National Museum of Wales*. BIOMÔR Reports 2 (1): 10143.

For further information on the Maritime Ireland/Wales INTERREG-II Programme see

http://www.marine.ie/intcoop/interreg/

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