Developing a Seabed Resurvey Strategy:
A GIS approach to modelling seabed changes and resurvey risk

A. M. Bakare, J. G. Morley, R. R. Simons

Department of Geomatic Engineering, University College London, Gower Street, London WC1E 6BT, United Kingdom
Telephone: +44 (0)20 7679 2741
Fax: +44 (0)20 7380 0453
Email: a.bakare@ge.ucl.ac.uk

1. Introduction

The application of GIS systems to environmental contexts is well established with a multitude of examples (see Goodchild *et al*, 1993). It has only recently been applied in coastal and marine environments, which present challenges due to the dynamic nature of the spatial and temporal environment, the lack of data and issues of accuracy and scale (Wright and Bartlett, 2000). It still has not been utilised to evaluate the forces that determine sediment transport in connection with the volume moved, the resulting changes in the seabed morphology and relevant application factors. Examples of potential applications include maintaining navigation safety and evaluating risk to offshore cables and pipelines.

Sediment on the seabed is in a constant state of flux as a direct response to the forces exerted by hydrodynamic, meteorological and physical conditions in the form of tides, storm surges and waves. The amount of sediment material that is moved is further influenced by the physical characteristics of the sediment and water column. Therefore an understanding of the transport characteristics, seabed morphological response and interaction with factors specific to an application (such as coastal population density) is frequently required for planning and management decisions in the marine environment.

The problem directly addressed by this project is that faced by bodies responsible for resurveying areas of seabed to maintain navigation safety in British territorial waters. Survey areas and re-survey frequencies are currently determined from qualitative knowledge of sediment movement and navigation intensity (IHMC, 2004) and there is a need to quantify this approach so the information can be ascertained more easily by an end-user.

2. System Development

A survey decision tool has been developed which dynamically couples a GIS (ESRI ArcGIS) to a numerical sediment transport model (SEDTRANS05), a current model (POLPRED) and a wave dataset for the West Gabbard wave buoy (obtained from the WaveNET service). The methodology employed utilises the GIS as the principle mechanism to undertake the morphological modelling and navigation risk assessment to enable a re-survey decision. The GIS is used to acquire the modelling inputs, initiate the sediment transport calculations, distribute the calculated sediment flux to predict bed height changes, analyse the risk posed to navigation and visually display the results.

In order to evaluate the functionality of the tool it has been applied to a study region off the east coast of Norfolk between Caister-On-Sea and Orford Ness, within a bounding box where the coordinates for the northeast and southwest corners are 52.736N, 2.475E and 52.065N, 1.556E (WGS 84) respectively, Figure 1. The seabed within the selected site comprises of a number of sand banks and deeper channels; the analysis was undertaken for the period between March 2001 and June 2004.

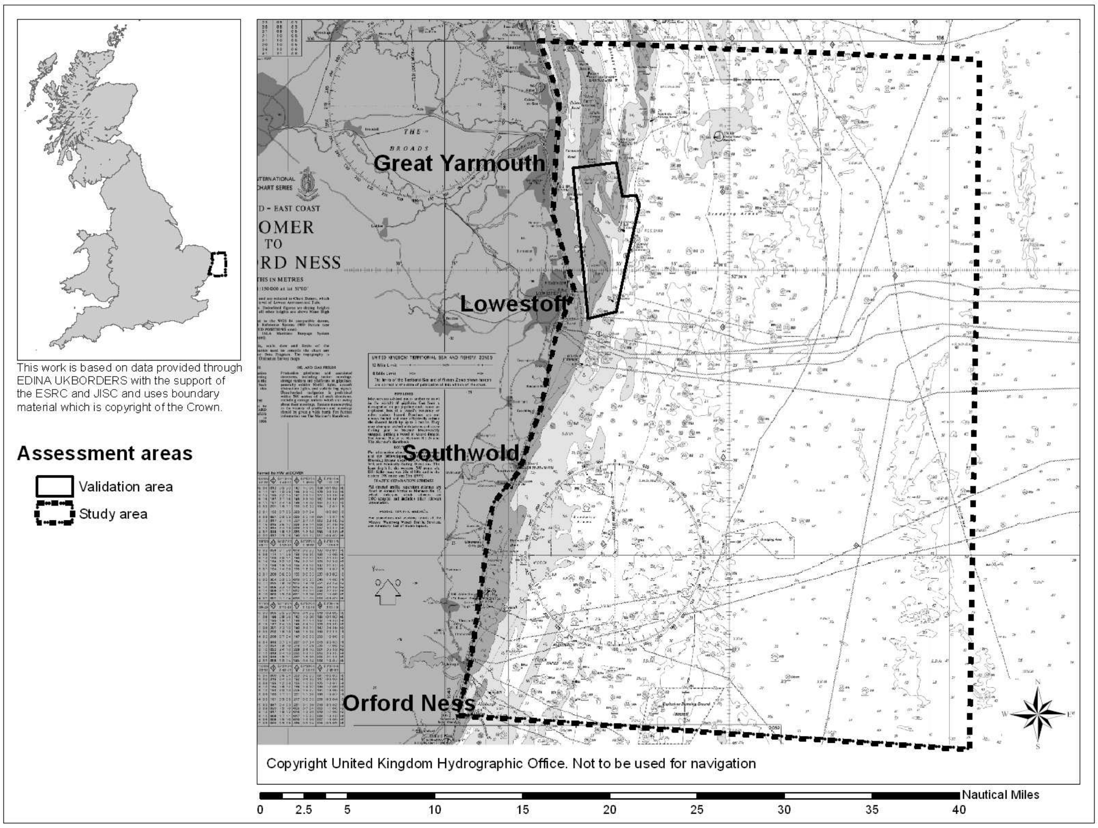

Figure 1: Study and validation areas in the Southern North Sea.

A fixed grid spatial data structure was used to represent and acquire the input data necessary for the sediment transport calculation. The data required included the current height, magnitude and flow direction from POLPRED, wave period, height and direction from the wave dataset, seabed depth from bathymetric data of the site and seabed sediment characteristics from a geology chart. Due to the point-based nature of SEDTRANS05 the flux prediction was calculated on a cell by cell basis. Tests within the GIS were then used to query the flux direction and then relocate the sediment between cells updating both the loosing and receiving cells with the resulting volume and seabed height. In addition checks were used within the tool to update the seabed height input into the transport calculation when the height of any individual cell evolved beyond a defined magnitude. The transport calculation and redistribution were repeated at regular time intervals for the assessment period.

The modelled seabed bathymetry and height change, vessel draft and clearance characteristics were reclassified to obtain risk levels based on defined user criteria thereby enabling a standard across sites. Risk levels for the seabed change were determined by evaluating the seabed bathymetry with the predicted height change so that areas with a significant height gain and a relatively shallow water depth posed the greatest risk. The navigation risk levels were ascertained by comparing the seabed bathymetry with the vessel drafts, so that areas with low clearance beneath the vessel provided the greatest risk. The two risk datasets were then evaluated together to identify the locations that required re-survey because of the risk posed to navigation, which were displayed in the GIS.

3. Implementation Results and Validation

The results from the model identified localised sediment gain on the sand banks within the validation area. The sediment increase occurred predominantly above the 5m depth contour relative to a base reference at the top of the bank at 1m. Changes were also observed for the region between the 5m and 10m contours with gains and losses both occurring. The seabed below the 10m contour was dominated by loss in the seabed height, Figure 2a.

The locations predicted to experience change were assessed in relation to the seabed bathymetric data for the validation area observed from field surveys of the site. The results showed that the coupled seabed change model was correctly identifying locations in the real world that were undergoing change. However it was under-predicting the magnitude and lateral extent of the change, Figure 2. This is most likely due to the limitations of the model in that storm surges are not included as a hydrodynamic input and a single set of wave values are used to represent the wave activity in the study region instead of varying spatially. This is because storm surges are known to move large volumes of sediment in the Southern North Sea and the study area (HR Wallingford, 2002 and Van der Molen 2002). Additionally, wave characteristics evolve as they move into shallow water through shoaling and refraction thereby influencing the transport volume (Sleath, 1984 and Soulsby, 1997).

Figure 2: Predicted and measured seabed height change for the validation area between 2002 and 2003 at 150m resolution, height change is in metres. A) Prediction using the Van Rijn (1993) formula and rook case distribution and B) Measured difference.

Analyses of the locations identified for resurveying showed that the tool was also identifying the area of seabed that posed the greatest risk to navigation, which was between the 5m and 10m contours, Figure 3. However the decision tool was not identifying the full extent of the risk because of the under-predictions described earlier.

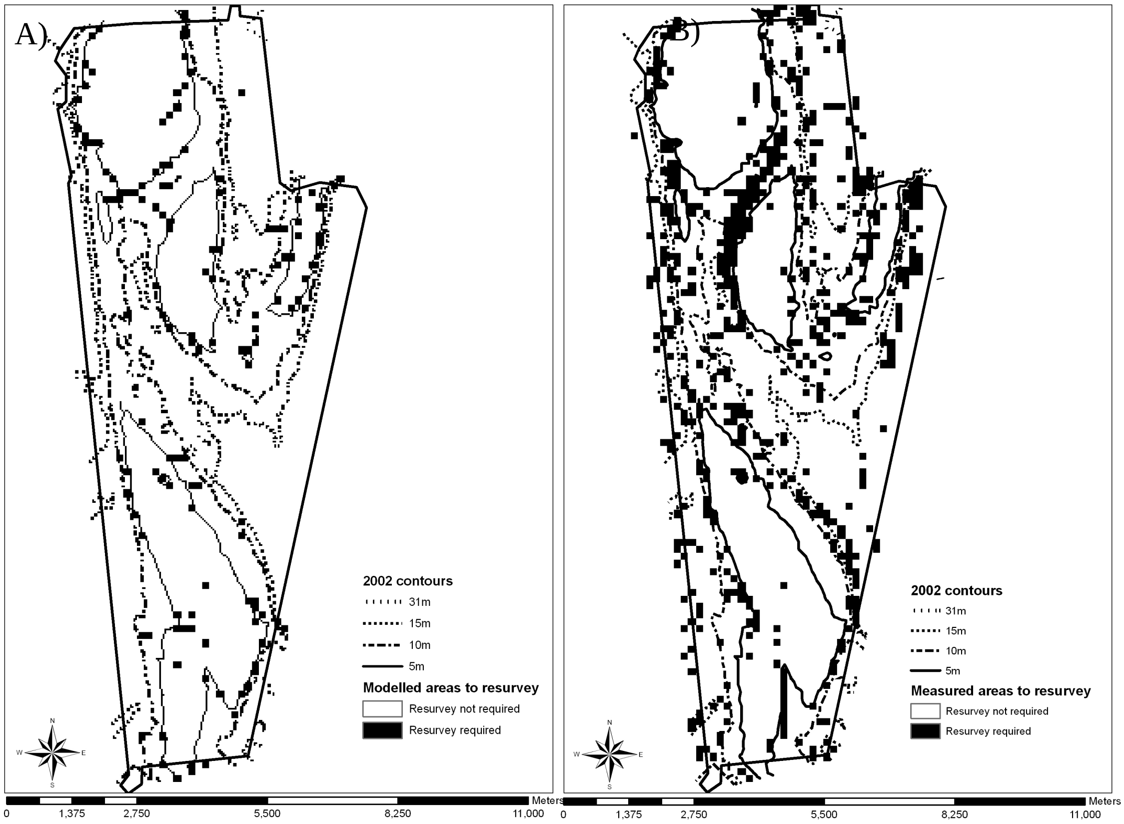

Figure 3: Seabed locations to resurvey based on A) predicted and B) observed changes in the seabed bathymetry, using the user-defined reclassification criteria.

A number of sensitivity tests were undertaken to evaluate the influence of input parameters on the prediction output which were assessed statistically. These included assessments of the sediment transport formulae, grid cell resolution, the prediction interval, sediment redistribution mechanism and the seasonal variation in transport.

- Five sediment transport formulae were investigated. The results showed that the Van Rijn (1993) bedload formula provided the best height agreement on the basis that it had the least statistical variance from the observed bathymetry.
- Two grid cell resolutions were evaluated, 500m and 150m (relating to the survey swath width). The latter provided a more accurate and precise prediction as the modelled result agreed with the observed change. Although the overall predicted degree of change was less than the observed, the height change value at the 150m resolution was only between factors two to five less than the observed case, Figure 2.
- Two time-step intervals were assessed, 3-hours and 1-hour. As anticipated the hourly time-step provided better results, which is primarily because less averaging of the tidal and wave characteristics occurred and the values were closer to reality.
- Two methods for sediment redistribution to the immediate neighbours of a cell using the direction calculated by the transport model were evaluated, namely the queen and rook cases for movement. The former involved sediment redistribution to one of eight neighbours surrounding a cell. In contrast the latter either moved sediment to a single cell or resolved the sediment flux between a pair of neighbours, thereby approximating a more realistic sediment flow across the seabed. Statistical analysis indicated that the latter approach provided marginally better results. This suggests that the under-prediction in the lateral extent of

seabed change is not solely due to the redistribution method and in turn implies that the representation of wave activity within the study area may be a significant contributing factor.

- The model accurately identified seasonal variation in the volume of sediment transported. The winter months (December to February) reported about half of the overall bottom change modelled for a year; this also coincides with research undertaken as part of the Southern North Sea Sediment Transport Study (HR Wallingford, 2002). Seabed height changes were also predicted in seasons 2 (March to May) and 3 (June to August) but to a lesser magnitude than season 1, while season 4 (September to November) modelled a similar pattern to the seabed change as season 1.

4. Conclusion

The coupling and analysis process undertaken during this project highlights the ability of the approach to predict sediment transport and change in bathymetry. However, the limitations of the results show the importance of accounting for surge and varying wave conditions, suggesting there is scope for further development.

The resulting survey decision tool and the outcome of the analysis indicate that a GIS is a viable and useful tool for managing and evaluating factors that determine sediment transport volume with issues specific to an application. In addition its capability to acquire and analyse disparate datasets and visualise the resulting outputs further supports its application as an end-user system in the marine environment.

5. Acknowledgements

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Biography

Anna-Marie Bakare is a first year doctoral student in the department of Geomatic Engineering (UCL). She holds a BSc (Hons) in Archaeology from the Institute of Archaeology (UCL) and an MSc in Geographic Information Science from the department of Geomatic Engineering (UCL). The research presented is a result of the MSc dissertation.