Applications of GIS and Web delivery of coastal monitoring data in shoreline management

Bradbury AP, Cooper T and Mason TE
Channel Coastal Observatory, UK

Abstract
Effective planning and implementation of shoreline management requires high quality, long-term, time-series data sets to predict long-term coastal evolution and to determine design conditions for coastal protection and flood defence projects. This paper discusses development of a large-scale regional coastal monitoring programme, designed to provide coastal process data for improved understanding of environmental forcing factors, such as waves and tides, and the response of the shoreline to these conditions. GIS and web delivery aspects of the programme are highlighted. Demonstrations are provided of applications to deliver (a) real time wave and tidal data (b) on-line GIS and (c) analytical databases, in support of flood and coastal defence management.

1. Introduction
Historically, data for flood and coastal defence management has been collected and managed by Local Authorities and the Environment Agency in a piecemeal and uncoordinated manner, within the southeast of England. A coordinated initiative has resulted in the development of the South-East Strategic Regional Coastal Monitoring Programme; this has been designed to inform shoreline management decision-making at both operational and strategic levels (Bradbury et al., 2002). The £8 million DEFRA grant aided programme is funded initially for a period of 5 years, and covers about 1000km of coastline, stretching from the Isle of Grain in Kent to Portland Bill in Dorset. The management framework for the southeast regional programme, established in 2002, makes provision for collection, management and analysis of a wide range of coastal process data. Numerous coastal data sets are collected within a systematic risk based framework; these include topographic and bathymetric surveys, aerial photography, LIDAR, wave and tide data. This paper focuses on management, initial analysis and delivery of these data sets.

1.1 Data Management
The extent of the project area and the vast quantity and range of data types present a complex challenge, to provide consistent and robust data management. The data management programme must deal adequately with the following data types.

<table>
<thead>
<tr>
<th>Generic data form</th>
<th>Specific data types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time series point data</td>
<td>Wave, tides, currents</td>
</tr>
<tr>
<td>Time series profile data</td>
<td>Beach profiles, bathymetric profiles</td>
</tr>
<tr>
<td>Time series 3d spatial data</td>
<td>Beach surveys, Bathymetric surveys, terrain models</td>
</tr>
<tr>
<td>Time series 2d tiled spatial data</td>
<td>Aerial photographs, LIDAR, isopachyte plots, maps</td>
</tr>
<tr>
<td>Raw unprocessed data</td>
<td>All data sets</td>
</tr>
<tr>
<td>Point control data</td>
<td>Static GPS network observations</td>
</tr>
</tbody>
</table>

Table 1 Data types produced within the coastal monitoring programme

A consistent survey specification has been established for each data type within the programme and rigorous quality assurance procedures established to ensure compliance...
with these specifications; this minimises variability of data quality across the region, and also with time. A series of procedures have been introduced, for each data type, to undertake data quality checks. Once the data have successfully passed the quality assurance, it can then be loaded into an archive for storage. This archive is driven by a comprehensive meta-database.

During design of the programme, legacy data sets have been considered and where appropriate new measurement programmes co-located to extend the length of historical time series. These sites often present a problem however, as the standards of data collection and management may be somewhat different to the new programme specification. Analysis of legacy data sets has identified that many of these sets are not wholly compatible with each other, for analytical purposes, because of variations in: accuracy, precision, datum, transformation and measurement techniques. It is crucial therefore that adequate description of these variables is presented within the metadata, to enable informed decisions to be made of the appropriateness of the data for each possible application.

The meta-database is a key element for successful data management. It functions as a link between the data archive and the end user. To maximise the flexibility of the system, the meta-database has been established as an on-line tool, accessible via the Internet. The programme ethos is such that data is to be made freely available. Every user must register before uploading or downloading data to and from the archive and must login thereafter. The continued free provision of these data sets relies on demonstration of demand for the product and data downloads will be logged to determine demand and usage for the various data sets. This approach also provides control of the data upload to the system.

Metadata systems have historically been established to a wide variety of standards. The project vision is to provide a system that is compatible with other meta-databases that conform to international standards. The database system was initially designed using the American FGDC Standard, which comprises a comprehensive set of pre-defined fields; this links seamlessly with the new ISO19115 and the next generation of the meta-database will be modified to be compliant with this standard. The raw format of the FGDC metadata standard comprises a total of about 200 pre-defined fields of which 22 are compulsory fields. Filling these fields for many thousands of data sets presents a laborious task, yet the majority of fields provide valuable information for one user or another. Given the scale of the metadata forms some practical measures are necessary to encourage effective and efficient use of the system. Simplification of the metadata population process is needed to provide data managers with a sensible and practical approach. The approach adopted provides the opportunity for auto filling of a significant proportion of the fields; this is dealt with by the XML metadata code. As a series of key data sets are to be collected on a regular basis, and to a common quality controlled specification, many of the fields can be filled automatically, on the basis of the specification standards. A series of part filled templates have been prepared therefore, for each principle data type e.g. for topographic surveys, wave data, bathymetric surveys etc. This provides a manageable number of fields to be filled manually and ensures that no valuable information about the data set is lost.

Many of the fields are common to the project specification and can be automatically filled on the basis of a single template, for example all data is recorded to a common datum and geo-referencing system. Certain fields are auto-filled by automatic software interrogation of standard format files. For example, the geographical extent fields are automatically extracted from the files; this particular process is particularly useful since each of the
thousands of files will vary. There is particular advantage in automating this process, since manual input of numeric coordinate data is often subject to human error. The following criteria were used to assess each metadata field, in conjunction with each type of data set:

- Ensure that all compulsory fields are completed.
- Determine whether each metadata field is applicable to the specific data type.
- Determine which fields are common to the programme specification, for the purpose of auto-filling to a common template.
- Determine which fields can be auto-filled by automated interrogation of the data set to be loaded to the system e.g. date of collection, bounding coordinates of data set.
- Identify fields that can be auto-filled on the basis of a single entry of the end users’ personal login details e.g. name, organisation, contact details.
- Identify those fields that can be filled to a template on the basis of a single survey methodology e.g. survey instrumentation, survey vessel etc.
- Identify fields that must be hand filled.

This approach has enabled a series of template forms to be developed that require minimal end user input. Although considerable programming effort has been required to develop the meta-database, it will provide a robust and simple to use application. The application has been developed, by using XML to build all elements of the meta-database; this presents many advantages over alternative programming approaches, particularly by reducing the amount of programming code to be written. Importantly, XML schema are used to validate each entry for each field; this ensures that appropriate entries are entered in all relevant fields. A simple front end provides the end user with an easy to use interface for file upload and metadata entry. The user has to fill in one metadata form for each uploaded data set. The metadata information provided by the user is stored together with the data.

The automated approach to completion of metadata records for programme standard specification data sets works extremely efficiently. Legacy data sets present a significant problem however. In many instances no metadata exists and in other instances the data collection standards are very different. In such instances the only option is to customise metadata forms for each data set; this is inevitably very time consuming. Provision has been made for development of template forms for these types of records, but the process of loading metadata-attributed data from legacy data sets is considerably more cumbersome than for standardised data sets.

The online search engine for retrieval of files is based upon a series of keywords, to define data types, dates and locations. The XML documents are structured and all fields can be queried just like a database. Any particular metadata field can be queried therefore. Certain data can also be queried with the aid of GIS front end spatial querying on the project website. For example, spatial definitions of shoreline management units have been established by attributing GIS polygons with keyword and coordinate data (Figure 1).

Similarly, selected online point data can also be accessed via a GIS front end, for example survey control network points, wave and tide data. The user is able to browse the on-line meta-database by using a number of keyword queries, e.g. the type of data set, location and date of data collection. A list of available data sets provides the user with a selection, which can be downloaded straight from the archive.
2. Data delivery
A wide range of data types are collected within the programme. Selected examples of these are discussed in context with web data delivery and management below.

2.1 Wave Data
Wave data are derived from two primary sources. A network of near-shore wave buoys, pressure, and step gauges provides real time data at 10 sites. Measured time series data are telemetered from the wave measurement sites to shore based stations and forwarded, via ftp link on a broad band connection, for immediate broadcast on the project website. A simple GIS map driven front end enables the end user to navigate quickly to the real time data (Figure 2). Wave statistics ($H_s$, $H_{max}$, $T_m$, $T_p$, direction and spreading) are calculated and non quality controlled updates provided every 30 minutes (Figure 3). Full spectral data sets are also recorded and stored, but these are not broadcast on the website.
Wave rider buoys are notoriously prone to damage by ships and occasionally break loose from their moorings when hit by ships; they are often difficult to locate when they break loose from the moorings. The real time web link provides the opportunity to track the position of the buoys via a GPS position signal that forms part of the buoy system and the analysis record. A new position is broadcast every 30 minutes and departures from a defined bounding box result in email and text alerts, triggered by the website software; this enables rapid mobilisation of search and retrieval vessels.

Figure 3. Example real time wave data from project web site.

The measured data is supplemented by a much denser network of synthetic wave data, derived for a further 42 sites: data are derived from an offshore hindcasting model and transformed to the near-shore sites using shallow water wave transformation models. The numerical models are also validated by the measured wave data at selected sites.

Real time wave data are used for a variety of applications, including determination of threshold conditions for post-storm topographic surveys, identification of trigger levels for maintenance, warning thresholds for flood forecasting systems, management of floating delivery plant for coastal engineering schemes and even for identification of suitable conditions for surfing. These operational applications are all informed via the XML applications within the web software, either by e-mail or text message alert, based upon simple threshold criteria. Data may also be used in conjunction with post storm beach profile surveys and empirical models, to assess the risk or increased vulnerability of a coastal defence following a major storm event.

A series of rigorous quality checks are made on the data sets and these are archived on a monthly basis. Subsequently, quality controlled data are transferred to an analytical database (SANDS) for determination of wave climate statistics such as probability distributions of wave height, period and direction; and determination of extreme wave conditions, by extrapolation of data using a 2-parameter Weibull distribution. Such data is typically used for determination of design conditions for new coastal engineering works. Clearly the data sets need to be of suitable length (typically at least ten years), before such an extreme analysis can be conducted with a reasonable degree of success. One of the legacy sites integrated into the new programme has suitable record length and an example extremes analysis is shown in Figure 4. In addition, the whole time series of wave height, period and direction are regularly used in coastal process investigations, typically to drive numerical models of sediment transport, which are subsequently validated with measured beach profile data.
2.2 Tide Data
In a similar manner to the wave measurement network, a real time tide gauge network is also under construction (Figure 5). Whilst this is currently more limited in extent, similar technology enables real time data to be broadcast on the Internet. Where suitable time series have been collected (typically one year per site) harmonic analyses of data sets are conducted to provide predictions of tidal elevations. The modelled predictions are broadcast simultaneously with measured data and can be used to identify the magnitude of surges.
developed for the Channel Coast than for some other parts of the country - the Solent is very poorly represented at present within these models. Real time measurements are therefore of considerable value in tracking surges (Figure 6). Data can also be used for validation of flood forecasting models and it is anticipated that the data will be used for development of the next generation of higher resolution (1km) surge prediction models. Real time data and predictions are presented for the Herne Bay tide gauge below (Figure 5). Note the storm surge event on 22 February.

<table>
<thead>
<tr>
<th>Time (GMT)</th>
<th>Elevation</th>
<th>Residual</th>
<th>Year</th>
<th>Highest</th>
<th>Lowest</th>
</tr>
</thead>
<tbody>
<tr>
<td>28-02-2004 19:56</td>
<td>3.170</td>
<td>-0.229</td>
<td>2004</td>
<td>6m</td>
<td>0m</td>
</tr>
</tbody>
</table>

Next HW: 05:51 GMT, 4.17m
Next LW: 23:41 GMT, 1.68m

![Figure 6. Real time tide measurement and prediction at Herne Bay](image)

2.3 On-line GIS

One of the aims of the Regional Monitoring Programme is to make coastal process data widely and freely available. The most cost effective way of achieving this is to provide on-line access to the data via the Internet. The first step in development of a browse-able online GIS is the delivery of a baseline digital orthophoto set, which is now operational within a Mapserver environment (Figure 7).

A baseline low water aerial survey of the southeast coast has been completed. The data has been orthorectified using LiDAR and photogrammetric ground models derived from the aerial photography. The data has been coordinated by reference to an extensive ground control network of measured photo-control, fast-static GPS observations and using standard geoid models (OSTN02 and OSGM02) to transform the data from the GPS ellipsoid to national grid coordinates. Digital orthophotos are produced at a ground resolution of 25cm and are produced as 500m square tiles. High-resolution aerial photography for the entire coastal strip of the programme area can now be viewed on-line. Wavelet compression enables rapid on-the-fly delivery of the high-resolution imagery, which is held in a layer comprising 4GB of imagery. Basic navigation tools enable the user to zoom, pan and save images, but the tool kit is being rapidly expanded to provide more functionality.

The next aim is to add various other programme information layers to the aerial photography, e.g. location of beach profiles, Shoreline Management Unit boundaries,
defence type, managements strategy and geomorphology. Additional layers related to ongoing surveys are currently under preparation; these will include ground modelled plots of beach topography derived from detailed baseline beach surveys, LiDAR surveys of soft cliffs and estuaries and also bathymetric surveys of the nearshore zone. The beach surveys include separate layers for elevation and also feature coded sediment type. As the programme develops, difference models will be produced, showing changes to beach volume and identifying the location and extent of erosion and accretion between surveys.

![Figure 7. On-line digital orthophotos](image)

The on-line GIS is linked to the meta-database. This link (currently under testing) enables the user to download aerial photo tiles on-line, together with supporting metadata information for each photo tile. This approach will enable the user to browse for data, using: either keyword or numerical search queries; and also by navigating on a map front end to a particular stretch of coastline, to obtain a list of available data sets for the selected area.

3. Analytical GIS
A proprietary GIS - Shoreline and Nearshore Data System (SANDS), developed by Halcrow Group Ltd, is used for most the more detailed analysis work. SANDS is a monitoring and data storage GIS, developed for shoreline managers and coastal engineers, to analyse coastal data. It is particularly powerful for the analysis of point or profile located time series. SANDS databases have been established for each section of the coastline and local databases are held by many of the partner Local Authorities. The geographical front end has been populated with a series of data layers (Figure 8). Beach profiles, bathymetric profiles, LiDAR profiles and photogrammetric profiles, tidal time series, wave time series, modelled wave data and coastal-defence structure details are all stored within the GIS.
SANDS enables combined analysis of both shoreline responses (beach and bathymetric profiles) and also environmental drivers (wave and tidal data). Typical analyses run across the region includes establishment of critical and alarm threshold conditions for profile sites; derived from time series analysis of wave and tidal data. The threat of these conditions on destabilization of structures or overtopping risk is normally based upon assessment of threshold conditions in empirical predictive hydrodynamic models, run externally. Beach profile analysis (Figure 9) subsequently enables the user to relate changes in beach profile cross sectional area to a ‘master profile’ and defined alarm or crisis conditions. The ‘master profile’ could for example be a seawall linked to a section of bedrock underneath the beach material, or a simply an arbitrary profile. These changes can be plotted as a time series (Figure 10) with a trend line, thereby enabling predictions for the need for intervention to be identified.

Figure 8. SANDS database GIS front end

Figure 9. Beach Profile time series
4. Conclusions
A large-scale regional coastal monitoring network has been established to inform shoreline management planning and operational flood and coastal defence. Real time web tools have been developed to provide operational real time wave and tidal data via a GIS interface. An operational online GIS and linked metadatabase has been constructed and is undergoing continuous development. Combined analysis of environmental loading conditions and shoreline response is conducted off-line in a proprietary GIS.

5. References

6. Acknowledgements
The programme is funded with DEFRA grant aid and financial support from 31 partner local authorities and the Environment Agency. The meta-database and website applications have been developed in partnership with the GeoData Institute, University of Southampton, under the guidance of Jason Sadler.