# GIS methods to improve numerical model grids and bathymetries


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## Abstract

*Hydrodynamic models usually require management of large quantities of georeferenced information. This paper describes GIS methods for improving spatial inputs of a numerical model. Hydrodynamics and salinity of the Guadiana Estuary were simulated using the finite volume model MOHID with a boundary fitted curvilinear grid. GIS tools were used to pre-process the model grid and bathymetry. The water domain was extracted from an orthophoto map using unsupervised classification of the image after principal component analysis on the spectral bands. The large amount of bathymetric measurement points was decreased using a spatial regular pattern. Missing bathymetry data in some very shallow parts of the estuary were estimated from the orthophoto map using correlation between existing data and spectral band values. The use of GIS tools to produce model inputs proved to be a valuable aid increasing substantially the model accuracy.*



Keywords: GIS, bathymetry estimation, orthophoto, hydrodynamic model, Guadiana Estuary


## 1 Introduction

Estuarine hydrodynamic models usually require management of large quantities of georeferenced information. Geographic Information System (GIS) tools can help to prepare, manage, analyze and display all these data, during the input and the output phases.

The Guadiana Estuary is a rock-bound estuary located at the southern Iberian Peninsula, between Portugal and Spain (figure 1). Under different conditions the estuary can be stratified, partially mixed or well-mixed. The estuary extends for about 80 km from the mouth upstream and is prolonged offshore by a submerged delta. The estuary has an average depth of about 5 m (Garel 2009). Numerical models have already been applied to the Guadiana Estuary for simulation of hydrodynamics, salinity and sediment transport. Previous simulations were performed with rather coarse Cartesian grids (Lopes 2003) and covered only the lower half of the estuary. The hydrodynamics and salinity of the estuary also have been simulated using coarse triangular grids (Oliveira 2006).

The main objective of this work is to develop GIS based techniques to improve the setup of hydrodynamic models. The Guadiana Estuary, Portugal, is used to demonstrate the concept that can be generalized to other systems. Hydrodynamics and salinity dynamics of the Guadiana Estuary were simulated using a 2D configuration in MOHID Water Modelling System, based on a boundary fitted curvilinear grid. MOHID simulates flow and water properties in surface water bodies solving the shallow water equations by the finite volume method. MOHID includes GIS dedicated software, which handles spatial and temporal variable data in specific formats required or produced by MOHID (Braunschweig 2005).

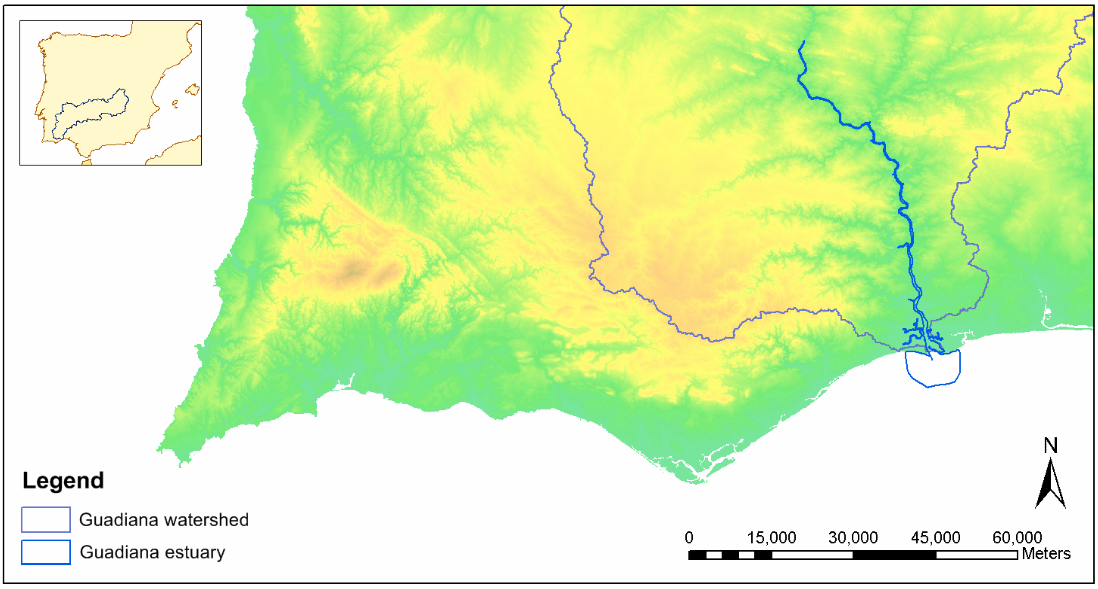


Figure 1. The Guadiana Estuary and drainage basin

This paper describes water domain extraction for spatial discretization in the section 2 and bathymetry processing and determination techniques in the section 3.

## 2 Spatial Discretization

A numerical model requires the discretization of the continuous space using a computational grid. Grid orthogonality is important for minimizing computational error. In estuarine models the correct description of the shoreline is a major issue because it influences strongly the results. In the traditional Cartesian grid the shoreline is discretized by steps producing a very rough description of the real geometry. In addition a large number of inactive cells are always present occupying the computer memory and increasing computational time. On the other hand, boundary-fitted curvilinear grids fit the coastline precisely, have few unused grid cells and allow higher precision in narrow parts of the domain and lower precision in the parts of less interest. This type of grid is particularly well suited for long and narrow meandering rivers like Guadiana. MOHID GIS provides a grid generator that produces structured nearly-orthogonal curvilinear meshes. Producing such grid requires a meshing domain polygon, which should follow the shoreline, and the opposite land polygon to input non-computing areas.

In the present application the available coastline data from NOAA was rather old and didn’t cover the entire estuary. Manual digitizing of a long estuary is very time-consuming. Therefore an alternative method to obtain the shoreline was needed.

There are many methods developed for water body and shoreline extraction from satellite imagery, including various classification methods. But none of the developed algorithms are accepted as universal and most of them are application specific, so precise separation water from land is still a challenge (Nath 2010). Existing methods usually require presence of infrared bands. The spectral reflectance of water in visible and especially in infrared bands is very different from the land features, so it helps a lot for water bodies determination. But for a small estuary the image should be of very high resolution and quality. In high-resolution ortophotos the infrared band is usually missing and sometimes only RGB photos taken by aircraft are available for the modelling area.

In this work the water domain was extracted from an orthophoto map by unsupervised classification. Several orthophoto maps were tested, and finally the image obtained from Google Maps was selected due to several advantages: recent image with clear water, free of clouds, not too small or too high resolution (4.75 m pixel), taken not at extremely high flood or low ebb, no sun glints.

The best result was achieved with unsupervised classification of the image based on Principal Component Analysis (PCA) using IDRISI Andes software[1]. Several classification methods including supervised classification were tried for the red, green and blue bands, but they did not show good results. Then PCA for the three spectral bands was performed. Almost all the information from the three bands was included into the first principal component (table 1). However, some information in the second component was related especially to the water body and turned out critically important for classification (figure 2). After performing PCA the method CLUSTER in IDRISI was applied to the three principal components instead of the initial bands. Twenty classes were obtained and then reclassified as land, water and very shallow water (figure 3).

Table 1. PCA result

| Loading | PC 1 | PC 2 | PC 3 |
|---|---|---|---|
| Band 1 | 0.995042 | -0.095441 | -0.028001 |
| Band 2 | 0.997767 | -0.023890 | 0.062365 |
| Band 3 | 0.991061 | 0.132534 | -0.015253 |
| % var. | 98.886068 | 0.972918 | 0.141017 |

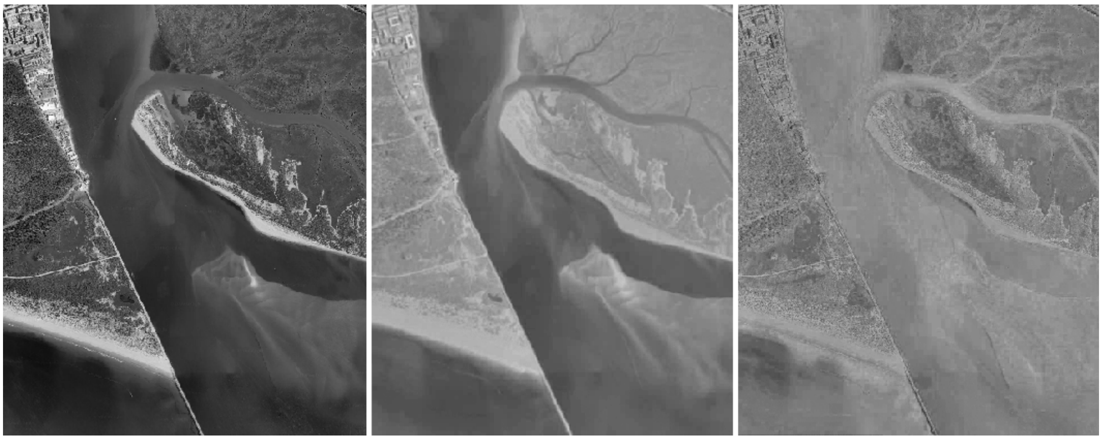

Figure 2. The three principal components, from PC1 (left) to PC3 (right).

The classified image was vectorized in ArcGIS 9.3 software[2] and processed using ArcToolbox. The amount of small polygons appeared due to pixel-based classification was decreased by the Aggregate tool, finally leaving only one large polygon for each class. These polygons were generalized and smoothed using the Simplify tool (figure 3). The result also needed some manual editing in several places with orthophoto defects.

[1] *IDRISI is a geographic information system and remote sensing software developed at Clark University*.
[2] *ESRI 2009. ArcGIS Desktop: Release 9.3. Redlands, CA. Environmental Systems Research Institute*.

Figure 3. The classification result (left) and vectorized water class (right).

Finally the resulting polygon was imported into MOHID GIS and the curvilinear grid was generated in this domain. The grid dimensions were 2209x122 cells and the cell size varied from 10 m to 70 m inside the estuary and up to 300 m at the outer submerged delta.

## 3 Bathymetry Processing

The grid obtained in the previous section was used to produce a gridded bathymetry using interpolation. In estuarine modelling the quality of bathymetry is essential to ensure good model results; therefore several pre-processing methods were developed using GIS tools.

The data from different sources were integrated with transformation of different initial coordinate systems into WGS84 system. Historic bathymetric data was complemented with Sonar bathymetric surveys. This surveying method produces very large amounts of data; thus techniques are needed to cluster the information, prior to its interpolation. The measured points were first separated using ArcGIS into groups by a regular net of hexagons (figure 4). The diameter was chosen 2 m, to be several times smaller than the smallest grid cell but about 10 times larger than average distance between Sonar points. Then an average x, y, and bathymetry value was calculated for each group (hexagon) using a developed Python script. Before this outliers were removed by comparing each point inside hexagon with the initial average.

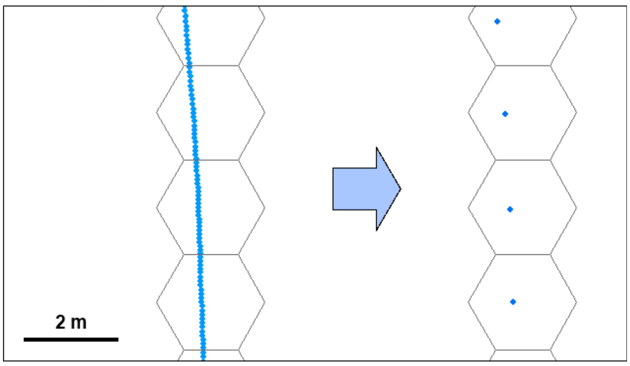


Figure 4. Aggregating bathymetry (initial data on the left and the result at the right side)

Sonar surveys always display gaps in the shallow parts of the estuary. Such areas are very dynamic and often experience quick and significant changes in bottom shape, so acquired data become old rather quickly. Since the water is usually clear and the depth is small in those areas, sunlight reflected from the bottom can be detected by a satellite or aircraft. The recorded light intensity depends on the water depth, attenuation coefficient for its wavelength in this water, and the reflection coefficient of the bottom. Thus it is possible to extract water depth information from satellite images of clear shallow areas. This possibility has been examined by many authors for about 40 years (Lyzenga 1978). Most of the authors prefer determining water depth from multispectral satellite imagery by various complicated equations based on optical laws. However, all those equations have several parameters to be tuned empirically using some known bathymetry points. These tunable coefficients partially represent attenuation and other local water properties. Generally, the relationships between depth and optical signal are sensor and site specific (Stumpf 2003). So, in this work bathymetry was estimated from the orthophoto map by simple statistical method using correlation between existing data and spectral band values. The same image obtained from Google Maps was selected due to high water clarity on this image. The bathymetry points for the analysis were chosen in the clean shallow area, with values shallower than 8 m depth, where the relation between bathymetry and color was strong (figures 5, 6). A script in Python was developed to read georeferenced raster cell values correspondent to the bathymetry points using GDAL library. Light attenuation exponentially growths with increasing depth so the relationship between bathymetry and bottom reflectance is not linear (Lyzenga 1978). The log-transformation for the bathymetry values was used to achieve linearity.

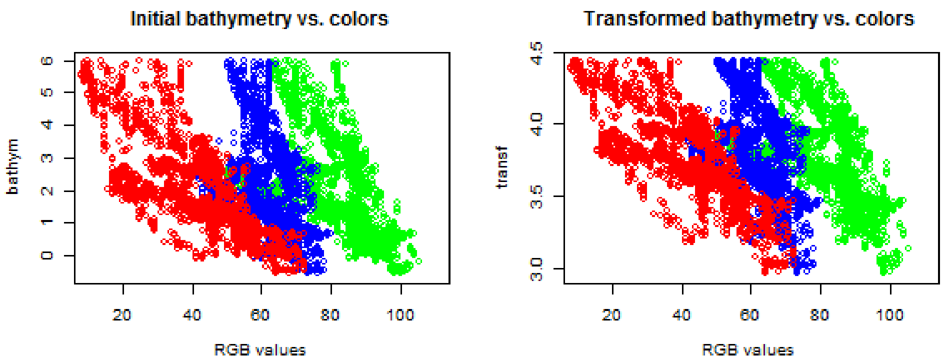


Figure 5. Relationships between bathymetry and color intensity.

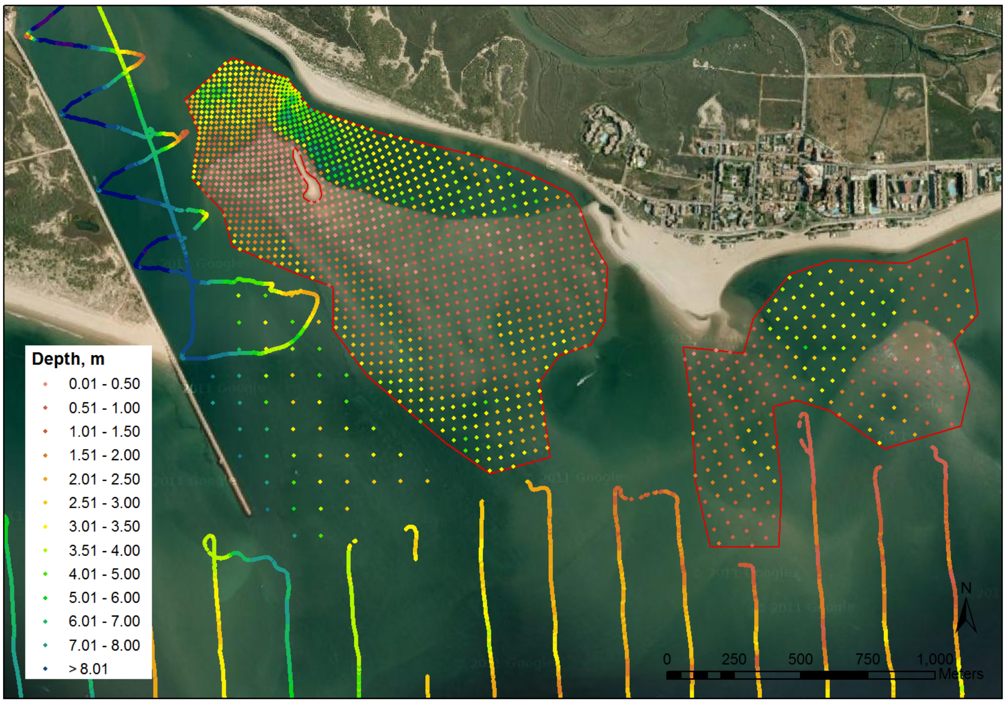


Figure 6. Estimated bathymetry.

A multiple linear regression was performed for the three bands in the form of the equation 1. Then the result was returned to the normal bathymetry scale by inverting the transformation.

$$Bathymetry = a + b * R + c * G + d * B \quad (1)$$

Where:

R, G, B – red, green and blue digital numbers of pixels,

a, b, c, d – coefficients.

The bathymetry data were separated into two subsets: 75% for regression and 25% for accuracy evaluation. R-squared of the regression was 0.73 and RMSE was 0.6 m. The regression result was used for determining bathymetry in the data-missing areas. The point locations for estimation, shown in figure 6, were selected in very clean shallow areas (marked by red outline) at the centers and corners of cells of the computational grid. The values of estimated bathymetry are very close to the topographic zero at the points located almost on the shoreline, increasing the confidence in the method. Afterwards the final computational bathymetric grid was interpolated by triangulation.

The hydrodynamic model results were validated using in-situ measurements in several places in the estuary. All the techniques contributed to an improvement of the model results quality.

## 4 Conclusion

The objective of this work was to improve the setup of hydrodynamic models by GIS based techniques. Validation of the model with different scenarios proved that good quality of the spatial input data is critical for having good model results. The use of GIS tools to produce curvilinear grids and accurate bathymetric data proved to be a valuable aid to modelling, improving the model results when compared with techniques used in previous simulations.

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