

Chakib Biar

Geographic Information Systems for Modelling Sediment Transport and Deposition in Harbours

Abstract

The limit between the land and the sea is an unstable and vulnerable area. It is exposed to multiple aggressions and undergoes changes generated by hydrodynamic factors. Such factors cause erosion and depositions that may be harmful to the natural balance of any site or seaport. Therefore, constant tracking is necessary to determine and possibly control the evolution of the sea bed.

DRAPOR is a state-owned company in charge of navigation works maintenance in the seaports of the Kingdom of Morocco. It is seeking new possible ways to know in advance sea bottom levels in order to optimise dredging operations. Hence, the initiative to study the prospects of G.I.S. application in modelling sediment transport and erosion inside seaports. In various sections, this paper deals with sea phenomena that cause sediment transport. It also examines the mathematical models used for the purposes of sediment transport modelling, the general design of a prediction model for sand encroachments and erosions inside any seaport that is subjected to shoreline transit. Besides, in view of the necessity to give an example of integration of the various mathematical models in a Geographical Information System, an application has been developed with the Arcview G.I.S. 3.2 software using *AVENUE* language. Such application would make it possible to assess coastline evolution during the construction of a protection structure, namely a cross-shore jetty. The application hence made proved that the combination of mathematical models of sediment transport with a G.I.S. provides a tool that has management, analysis and processing capabilities and that is able to simulate coastline evolution after the construction of any coastal structure.

This article was first presented as a paper at the CEDA Dredging Days in Morocco, October 2002, and appears here in a slightly adapted version with permission.

Introduction

The sea coast is undoubtedly the area that has, at all times, stirred the interest of man if it were only for the fact that most countries were discovered, colonised and developed from the sea because navigation is the means of transport that man has mastered for a long time. No surprise then that the coastal areas have witnessed the erection of all kinds of structures first for economic and trade purposes, then, in more recent times, for tourist attraction purposes. Hence, man has come to know the techniques of maritime hydraulics when he learnt that the frontier between land and sea is most of the time particularly vulnerable and that it cannot be altered without special precautions being taken in advance.

Engineers found themselves quickly faced with some problems:

- sand encroachments which are very often a hindrance to the smooth operation of ports, and
- erosions with the conceivable consequences they can have on the various infrastructure built on the coast.

This paper lies within this perspective as it is aimed at assessing the potential uses of Geographical Information System (G.I.S.) applications in predicting the incidence of sand encroachments and erosions by means of mathematical models of sediment transport in harbour areas.

EROSION AND SEDIMENT DEPOSITION IN THE SEA

Under the action of waves, currents or wind, solid particles that form sediments may be snatched from the bottom of the sea and carried in suspension or on the seabed over more or less long distances to be deposited in still areas.

Diversity of coastline factors

Diversity of coastline currents

As they approach the shore, the waves generate various kinds of currents: currents of oscillation on the seabed, currents of translation in the boundary layer, currents of compensation in the body of water, long-shore currents in parallel with the shore. Under tidal action, currents may begin along the coast then change direction according to the time of tide. The winds have considerable impact on the coast currents. The speeds and directions of such currents are, in general, closely linked to the wind climate but with some delay.

Morphological diversity of the seabed

The shape of seafloor profile is significant for the problems of sediment transport owing to hydrodynamic action and so are the nature and thickness of mobile sediments that cover the rocky substratum.

Sediment diversity

There are two configurations of sediments:

- cohesive sediments: the cohesion of sediments results in that particles tend to form rudite in which the particles stick to each other;
- non-cohesive sediments: Non-cohesive sediments contain coarser sediments which are not subjected to any interaction and which can, therefore, move independently from one another.

Behavior of sediments under the action of waves

Sediment transport perpendicular to the coastline

As they are suspended in the waves orbit movements, solid particles may be displaced inside the profile.

They are carried towards the coast in the currents of translation or they are swept from the shore by the breaking waves. The coarsest sediments build up to form a swash near the breaking waves while the finer sediments can be scattered in the open sea by the currents of compensation. The movement inside the profile entails erosion of the coast as well as accretion of the small seabeds during storms and vice versa when the weather is fine.

Sediment transport in parallel with the shore

Under the action of oblique waves, a wave current originates and goes along the coastline forming a real "littoral river" comprised between the coast and the surf zone. The current is likely to carry considerable suspended loads or bed loads which were taken from the sea floor by the current of translation or from the coast by the wave.

J. Larras (1955) considers that an acceptable estimation of the speed of the wave current may be obtained by taking:

$$V = 2.6 \times \left[\frac{g H^2 i \sin(2\alpha)}{T} \right]^{1/3}$$



Chakib Biar (left) receiving the IADC Award from Mr Peter Hamburger; Secretary General of the IADC.

IADC Award 2002

Presented at the CEDA Dredging Days, Casablanca, Morocco October 22-24 2002

For the first time ever, the CEDA Dredging Days, were held outside of Europe in Casablanca, Morocco. As part of this conference, an award for young authors was presented by the International Association of Dredging Companies (IADC) to Mr Chakib Biar. Mr Biar received his degree with honours as a Surveyor Engineer from the Hassan II Agronomic and Veterinary Institute in Rabat, Morocco. He worked for a year with the dredging company Drapor developing under the ArcView GIS a module for the modelling of bottom changes in harbours and during dredging.

Each year, at selected conferences, the IADC grants awards for the best papers written by authors younger than 35 years of age. At each of these conferences, the Paper Committee is asked to recommend a prize-winner whose paper makes a significant contribution to the literature on dredging and related fields. The purpose of the IADC Award programme is "to stimulate the promotion of new ideas and encourage younger men and women in the dredging industry". The winner of an IADC Award receives US\$1000 and a certificate of recognition, and the paper is then published in *Terra et Aqua*.

Where:

- H Amplitude of the breaking wave
- i Beach average slope (expressed in its tangent)
- α Obliqueness of the waves from the open sea to the shore
- T Wave period

Various studies have shown that shoreline transit of fine sand depends on the result of the wave transport and may be expressed as follows:

$$Q = \left[(Kg/c) \right] \times H^2 T \quad f(\alpha) t$$

Where Q is the cubic-metre volume carried by the wave at an amplitude H (in metres) and over a period T (in seconds) showing in beds ranging between 15 and 20 m an obliqueness (α) to the coastline and over some time T (in seconds).

The various expressions used for the function $f(\alpha)$ are: $\sin(7\alpha/4)$, $\sin(2\alpha)$, and so on, while the term (Kg/c) describes the coefficient of sand transport and remains approximate to $0.4 \cdot 10^{-5}$ for the finest-grained sand of 250 microns, and to $0.2 \cdot 10^{-5}$ for coarser sand of 1 mm.

Impact of maritime works on shoreline transit

The overall scheme of shoreline sand transit may show a significant transport activity in the surf zone which acts as a center of attraction of sediments where the largest quantity of material will be suspended and may later be carried in the general direction of the wave current.

Depending on the position of a maritime works in relation to the surf zone or, more accurately speaking, the swash, shoreline transit may be intercepted in whole, deviated along the works leading to a very confined concentration of sediment transport or will finally be very slightly disturbed by the works if it is located very near the coast.

Works erected at great depths

Such works are likely to hinder most of the transit activity and may be illustrated by three seaport types:

1. Seaport allowing shoreline transit (Figure 1).
The accumulations along the secondary jetty depend on the configuration of the coastline and the general direction of the dominant waves. After secondary accumulation along the jetty is done, sediments may reach the entry passage and clog it during storms.
2. Seaport in the opposite direction to shoreline transit (Figure 2).
Accumulations in the windward zone are relatively slight in view of the transit. A good part of the deposit is scattered in the open sea where they accumulate in small beds areas. Along the secondary jetty and the passage of entry to the port, sedimentation

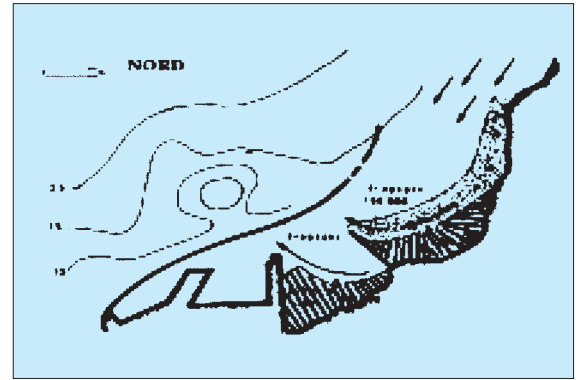


Figure 1. A seaport allowing shoreline transit (Migniot, 1977).

Figure 2. A seaport not allowing shoreline transit (Migniot, 1977).

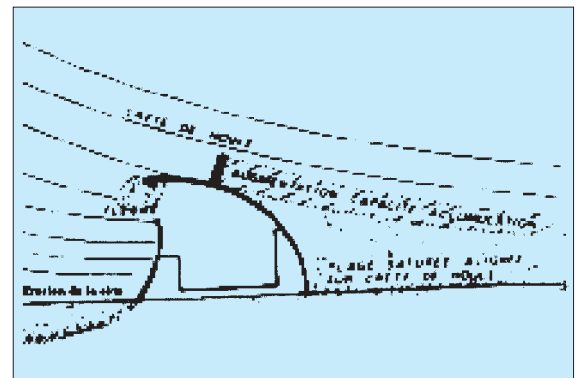
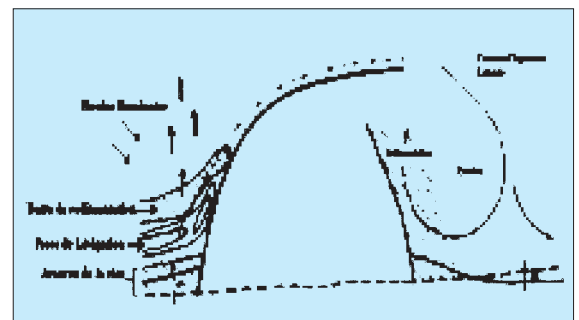
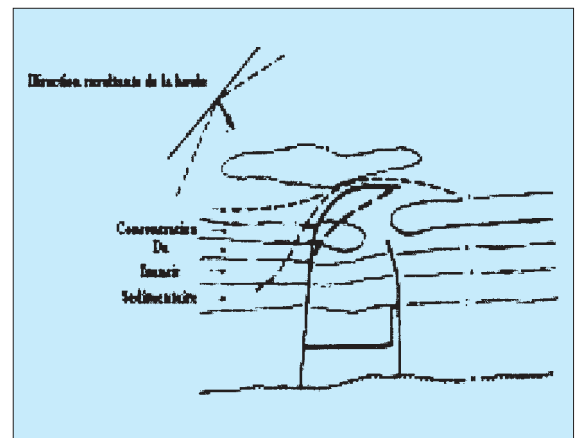


Figure 3. Seaport accumulating the shoreline transit (Migniot, 1977).

Figure 4. Seaport set-up at a medium depth (Migniot, 1977).



occurs due to the supply of the swell side-to-side expansion current which originates in the area protected by the seawall.

3. Seaport accumulating shoreline transit.

When the beach is saturated and becomes aligned with the crest of the wave (Figure 3), sands will pass over the works to form a rise in front of the pass unless shoreline transit is stopped with the works completed at 1.0 or 1.5 km from the port.

Works set up at medium depths from 5 to 7 m (Figure 4)

Such works would form a tight screen to shoreline transit in the whole small beds area. The sediments that move ordinarily in that area will hence be deviated seaward and increase the amount of solid flow into the swash. In order to take in the excess amount of solid flow, the depths in that part of the swash will decrease to create an equilibrium between the possibilities of tidal transport at that spot and the quantities of sediment supply.

Works set-up near the coast at low depths

Such works have only a very limited effect on shoreline transit inside the swash. The entry passage can be protected only from the material transported into the sea by the foreshore. Protection of the entry passage must not be too heavy as it is likely to create a zone of expansion of the wave that carries sediment supply.

MATHEMATICAL MODELS OF SEDIMENT TRANSPORT

From the point of view of physics, phenomena related to sediment transport in the areas near the coast and the morphological changes the coast goes through (erosion and sedimentation) are all subjected to hydraulic and hydrodynamic forces. Therefore, any design, construction or operation of a coastal structure must be based on a comprehensive study of such factors.

Depending on the degree of turbulence and on the power of the long-shore current, there are two kinds of sediment movement:

1. Bed Load Movement formed by the grains that roll on when they come into contact with the sea bottom or move in little successive hops and touch the bottom from time to time.
2. Suspended Load Movement when the carrying fluid, namely water, contains a high concentration of sediments as it nears the bottom which rapidly decreases towards the surface.

Formulating models of sediment transport

There are three models of sediment transport examined:

- the general equation of bed variation;
- mathematical bed load models; and
- mathematical suspended load models.

The General Equation of Bed Variation

The mathematical relation that predicts coastline or depth development in a coastal area subjected to considerable sediment movement is derived from the mass conservation principle of moving grains.

By defining the aggregate volume of the sediment load along the horizontal directions x and y by q_{sx} , q_{sy} , q_{bx} , q_{by} , where s = "suspended load" and b = "bed load" ($[q]=m^3/m/s$) while, for a pseudo-horizontal bed, the bed variation dependent on time ∂_b is given by (Christopher, 1984):

$$\frac{\partial \delta b}{\partial t} + \frac{\partial (q_{sx} + q_{bx})}{\partial x} + \frac{\partial (q_{sy} + q_{by})}{\partial y} = 0$$

Mathematical Bed Load Models

This kind of transport concerns only a thin area beneath the bed. In case the bed is smooth, the thickness of this area approximates $(2-3)D_{50}$ where D_{50} is the average diameter.

DUBOYS suggests a simple and practical relationship to quantify the bed load:

$$q_b = x \cdot \tau_b \cdot (\tau_b - \tau_{cw})$$

where x is a dimensional factor whose value depends on the size, geometry and specific weight of sediment grains.

$$\tau_{cw} = \tau_b \left(1 + \frac{1}{2} \left(\frac{\zeta \hat{u}b}{U} \right)^2 \right)$$

Where:

- τ_b Bed shear stress exerted by the current only.
- $\hat{u}b$ Speed of the wave current near the bed.
- ζ Dimensionless factor depending on the coarseness of the bed.

Mathematical Suspended Load Models

Depending on the shape and dimension of sediments as well as the turbulence of flow, sediment transport may occur without sediments touching the bed.

This requires that the speed w_f at which grains fall be lower than the turbulence vertical component.

The dimensionless factor that defines such requirement is the factor z^* (Christopher, 1984):

$$z^* = w_f / (\beta \cdot K \cdot U \cdot u^*)$$

Where:

- β Ration (current scattering/viscosity)
- K Von Karman constant (≈ 0.4)
- U Average flow speed
- u^* Speed of abrasion depending on the current (waves + currents)
- $u^* = \sqrt{(\tau_{cw} / \rho)}$

The equation that defines suspended sediment transport in a quasi-horizontal flow is expressed as follows:

$$\frac{\partial c}{\partial t} + \frac{\partial(cu)}{\partial x} + \frac{\partial(cv)}{\partial y} - w_f \frac{\partial c}{\partial z} = \frac{\partial}{\partial x} \left(\epsilon_h \frac{\partial c}{\partial x} \right) + \frac{\partial}{\partial y} \left(\epsilon_h \frac{\partial c}{\partial y} \right) + \frac{\partial}{\partial z} \left(\epsilon_v \frac{\partial c}{\partial z} \right)$$

In accordance with the definition of concentration, c defines the volume of sediments in mixture volume unit (grains + water). The suspended load is given by the integral depending on the degree of depth:

$$Q_{SX} = \int_{-h+a}^0 UC.DZ, \quad Q_{SY} = \int_{-h+a}^0 VC.DZ$$

The integration is restricted to a distance a above the bed that is equal to the thickness of the area where transport is carried out on the seabed.

The average concentration of sediments in such area is:

$$c_a = q_b / (a \cdot u_a)$$

where u_a represents the average velocity of the bed load.

At a distance a from the bed, the rate of sediment deposition is given by the product $w_f \cdot c$. The erosion rate is given by the product $\epsilon_v \cdot dc/dz$

$$D = W_F C / Z = -H+A, \quad E = -\epsilon_v \cdot DC / DZ / Z = -H+A$$

The distribution of the coefficient of vertical scattering is given depending on the vertical distribution of viscosity v_v :

$$\epsilon_v = \varphi \cdot \beta \cdot v_v$$

Where:

- β Dimensionless factor ($2 > \beta > 1$) that describes the variance in behavior between fluid and particles in a stirred environment.
- φ Dimensionless factor that describes the impact of a significant concentration of sediments on the hydrodynamic forces.

Recent research suggest that a ϵ_v value can be assigned to the upper half of the depth, a constant that is equal to $\epsilon = \epsilon_{max}$

For a given distribution of $\epsilon(z)$, the concentration $c(x, y, z, t)$ over an h depth is given by:

$$c(z) = c_a \left(\frac{h-z}{z} \frac{a}{h-z} \right)^{z^*}$$

The $c(z)$ function is defined in the range $z = 0$ to $z < h-a$.

To calculate the z^* factor, the formula of logarithmic series distribution of $u(z)$ speed is given by:

$$u(z) = \frac{u^*}{k} \ln \left(\frac{h+z}{z_o} \right)$$

k coefficient depending on the environment

with $z_o = k_s/33$ and z is measured from the surface down to the bed ($k_s =$ absolute bed roughness equal to half the height of the bosses).

The aggregate load is hence defined by the sum $q_t = q_s + q_b$.

Shifting the coastline

Any obstruction (groins, seawalls, and so on) that lies in the way of solid sediment transport driven by the dominant wave results in an accumulation on the « windward » side of the groins and in an erosion of the “lee” side (Figure 5).

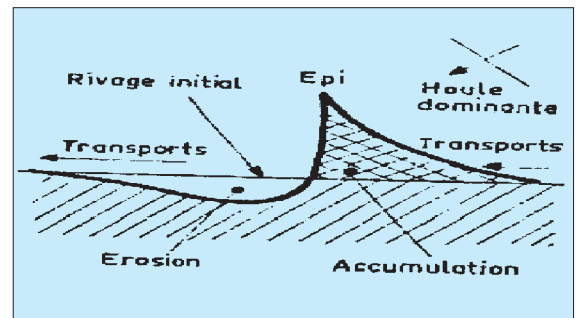


Figure 5. The impact of an obstruction on the coastline (Bonnefille, 1982)..

Penlard-Considère’s theory allows the computation of the coastline development in the area of accumulation on the basis of some hypotheses which have proved to be true in the case of pebble beaches. Those basic hypotheses are as follows:

- The characteristics of the wave are constant over time.
- The flow of solid sediments in an abscissa section x depends only on the amplitude H_{br} and on the angle φ_{br} between the breaking wave and the local coastline: $Q = f(H_{br}, \varphi_{br})$
 $Q_{br} = -\varphi'_{br} + \tan^{-1}(dy/dx)$; $H_{br} = H/k$

- k Wave breaking coefficient
- H Amplitude of the incident wave
- φ'_{br} Angle between the breaking wave and the x axis

If $y(x,t)$ is the coastline ordinate depending on x and on time t , the evolution of y in relation to time is:

$$dy/dt = (1/h) \cdot (dQ/dx)$$

The result of the computation of the values of $y(x_v, t_r)$ and $Q(x_v, t_r)$ in typical areas defined by indices i , in horizontal space x and in temporal space t .

The equations that have to be resolved successively and repeatedly are:

$$\varphi'_{brj} = -\varphi'_{brj} + TAN^{-1} \left(\frac{Y_i^n - Y_{i-1}^n}{\Delta x} \right),$$

$$Q_i^{n+1} = f(H_{brj}, \varphi_{brj}),$$

$$Y_i^{n+1} = Y_i^n + \frac{(Q_{i+1}^n - Q_i^n) \Delta t}{\Delta x \cdot h}$$

GEOGRAPHIC INFORMATION SYSTEMS

According to the definitions given in *Le Petit Larousse*:

- A *System* is “a combination of components brought together to form a whole”.
- An *Information* is “an element of knowledge that can be encoded to be kept, processed or communicated”.
- *Geographic* means “that is relevant to geography and aiming at describing the surface of the earth”.

In this instance, the term “system” means in general an *information system* with information science being “the science of automatic and relational processing of information as a vehicle of knowledge and communication using hardware and software”.

However, such a purely structural description does not clearly define the idea of G.I.S. especially as compared to automatic mapping systems as, in fact, “a *Geographic Information System* is a group of numeric data which are geographically located and structured inside an information processing system equipped with functional applications that allow the building, modification, questioning and map representation of the data base in accordance with semantic and spatial criteria”.

USE OF G.I.S. IN THE MANAGEMENT OF COASTAL AREAS

As a response to the value that the coast has taken on and to the propagation of protection works, new coast management techniques have emerged based on the discipline called Integrated Coastal Zone Management (ICZM). That subject brings together a number of specialised disciplines with the participation of coastal zone specialists, biologists, social scientists, and so on.

Basic concepts of Integrated Coastal Zone Management

This discipline is based on the structuring and coordination of the various activities and resources available in the coastal zones with the purpose of ensuring its development on the economic, environmental and social planes.

An ICZM plan puts forward an all-inclusive solution that guarantees a balanced development in various fields such as:

- protection of the coast and the shoreline;
- agriculture and fishing;
- housing developments, infrastructures, industries, navigation and public utilities;
- conservation of the natural heritage, and so on.

Advantages of Geographic Information Systems (G.I.S.)

The main hurdle in any coastal zone management plan is the huge quantity of data that have to be processed in order to help the specialists find the most adequate political and social solution to achieve development. It is within such context that Geographic Information Systems are called on to draw benefit from their capabilities of collection, analysis and processing of loads of data.

Here are some examples of the kinds of data that may be integrated in a G.I.S. within the framework of an ICZM plan: charts, aerial photographs, satellite pictures, river lines, vegetation species, sediment types, population density, climate, pollution sources, development areas such as seaports, cities, and such. Now, it is clear that G.I.S. are a powerful tool whereby various types of data can be collected, structured, organised, and processed before being finally handed down to various experts who can use them easily.

The use of Geographic Information Systems to manage and analyse the various data from various disciplines gives experts a tool with which they can:

- edit charts;
- lay down basic conditions;
- manage data;
- identify problems and their causes;
- generate prediction models;
- simulate data for the calibration of digital models;
- assess the impact of any management plan;
- generate management scenarios; and
- report results.

MODEL FOR THE PREDICTION OF SAND ENCROACHMENTS AND EROSIONS IN SEAPORTS

This model is intended to optimise the dredging operations by improving the predictions concerning the volumes that have to be extracted as well as the areas of action (Figure 6).

Data analyses

Port-relevant data

- (a) Bathymetric Mapping: A bathymetric mapping is the basis of simulation of the action of hydraulic and hydrodynamic factors.
- (b) Material Characteristics: Knowing the physical and

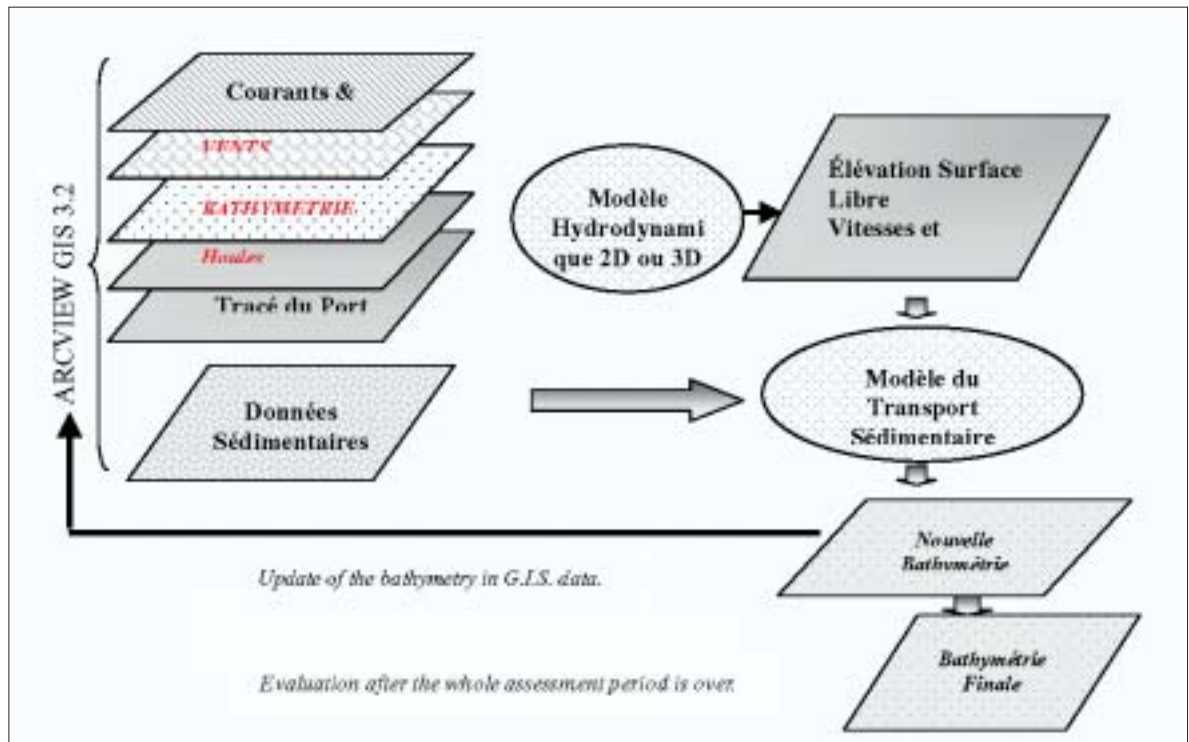


Figure 6. Design scheme of the prediction model of sand encroachments and erosions.

chemical characteristics of the materials that form the seabed allows the sampling of unstable and high-turbulence zones.

- (c) The Site Lay-Out Plan: The site lay-out plan represents the general infrastructure of the site (quays, jetties, coast, and so on). It serves as a basis for integrating the phenomena of refraction, diffraction, and currents reverberation on obstacles.

Oceanographic and meteorological data

- (a) Data Relevant to the Waves:

This is a comprehensive description of the three parameters relevant to the waves during the whole assessment period: significant amplitude, incidence angle and wave period.

- (b) Data Relevant to the Studies of Currents:

In order to assess the action of both the wave and the currents, it is necessary to have a detailed description of the direction together with the speed of propagation of all the currents on site.

Analyses and processing

Computation of the agitation of the free surface

It is a matter of resolving the hydrodynamics equations model that results in a regular grid where each point is marked with the elevation of the free surface, flow density, flow direction and propagation speed of water particles.

Simulation of sediment transport

Once wave agitation is defined on site, the directions and speeds of sediment flows can be made out. The loads of solids transported, whether seabed or

suspended loads, have then to be calculated using the DUBOYS equations. After that, sediment concentrations in movement are deduced at every site point. Eventually, the deposit rate D and erosion rate E are calculated in relation to the speeds and concentrations arrived at. The bathymetry hence reached replaces the original bathymetry and computations are resumed all over again.

It must be noted, though, that the G.I.S. is used all along this process. It takes care of:

- organising input data layers;
- managing the intermediate data in the data base;
- implementing the application if the G.I.S. software has a programming code, and
- laying out the results arrived at under separate themes which attributes show all information on the site development.

Bathymetry is reached all over the site and may be used:

- to sample the bathymetry relevant to the seaport zone;
- to define the areas where sand encroachments or erosion have occurred by comparing the original bathymetry and the bathymetry arrived at in the end;
- to sample the areas where the seabed exceeds the limits that ensure vessel access.

MODEL FOR THE PREDICTION OF COASTLINE EVOLUTION

Within a practical approach, an example of integration

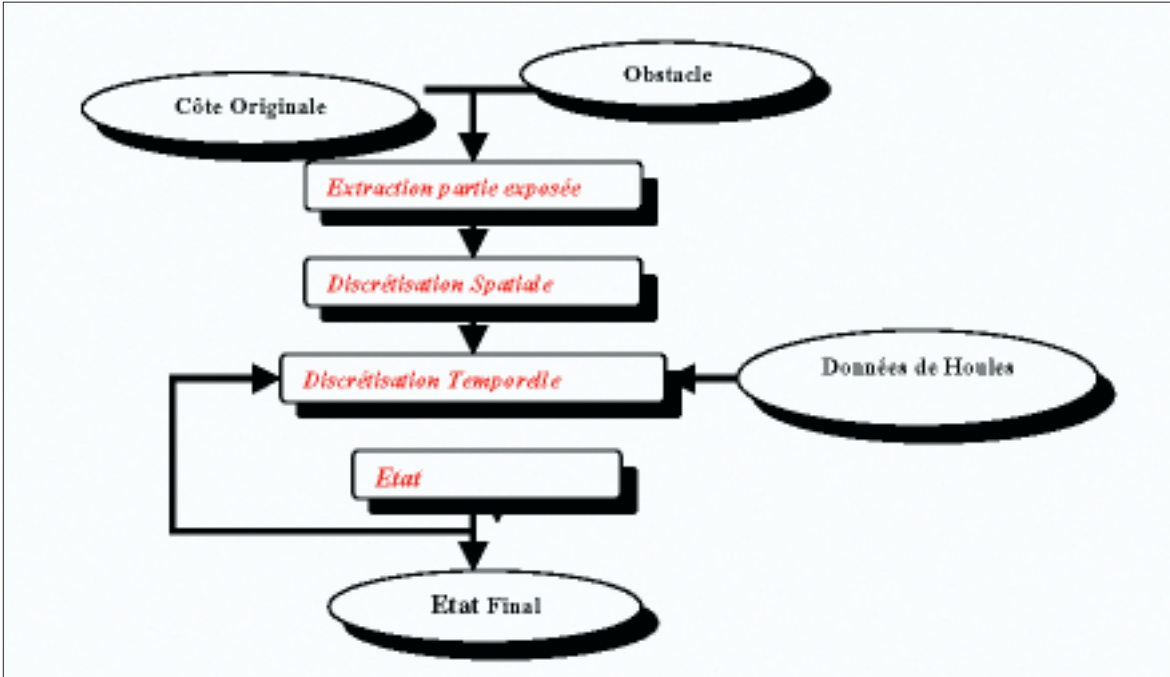


Figure 7. Design Scheme of the Prediction Model of Coastline Evolution.

of the various mathematical models and notions of marine hydrodynamics is introduced in a G.I.S. destined for the management of coastal areas (Figure 7). It concerns predicting the behaviour of the coastline under the impact of the construction of protection works (seawalls, groins, jetty).

About the area under study

Lying on the Atlantic coast, at 9°15' longitude west and 32°18' latitude north, the port of Safi is set up inside a large bay that shelters it from the south-west storms.

Results of the model of coastline evolution

The data used firstly in the model are shown in Table I below.

The results yielded by the model using those data are as in Figures 8 and 9.

The results given by the model are acceptable in consideration of the input data. It must be noted, however, that such evolution is computed bearing in mind that no dredging was carried out during the test period.

In order to have better results:

- data accuracy can be improved by dividing the assessment period in homogeneous data periods based on studies and statistics provided by the seaport operation and management authorities; and
- a comprehensive study of sediment dynamics in situ can be carried out in priority and a shoreline transport formula can be adapted.

Impact of temporal discretisation

Temporal discretisation (TD) requires dividing the total

duration of assessment into a series of equal intervals whose length is defined by the user. The smaller the discretisation is, the more logical the outcome of the assessment will be.

In Figure 10 are some examples of assessment using different parameters.

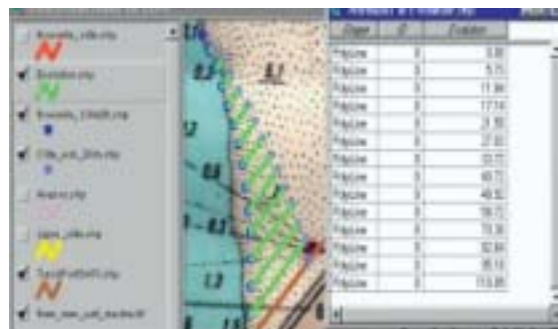


Figure 8. Evolution of shore points.

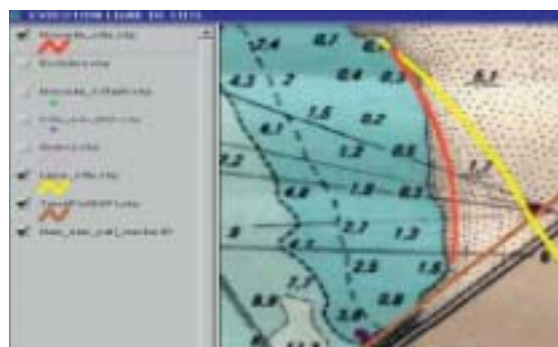


Figure 9. State of the coast after one year.

Table I. Data of the Coastline Evolution Model.

Wave	Breaking Amplitude	1.5 m
	Period	9 seconds
	Incidence Angle to	50°
	Breaking Coefficient	1.25
	Depth of Influence	5 m
Spatial Discretisation	PAS	20 m
Temporal Discretisation	Interval for Discretisation	1 day
	Total Test Duration	365 days
Transport Formula	$Q (m^3) = (1/10000) * H_{br}^2 * T * Sin (7*\varphi_{br}/4)$	

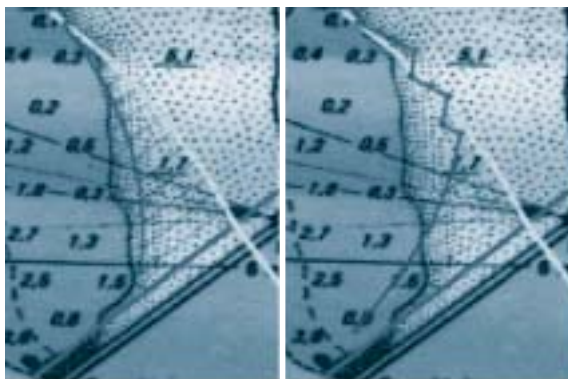


TD = 1 day and Total Duration = 365 days.

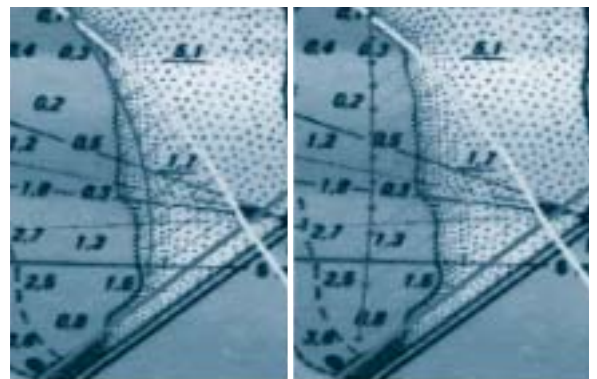


TD = 10 days and Total Duration = 1 year.

Figure 10. Evolution of the coastline with various temporal discretisation instances:

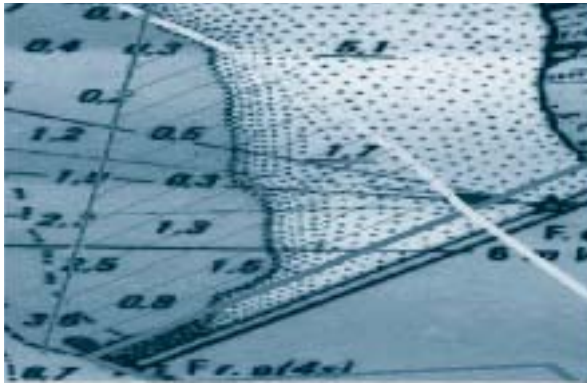


$H_{br} = 1.5$ m and $\varphi_{br} = 45^\circ$ (←) then $\varphi_{br} = 35^\circ$ (→)

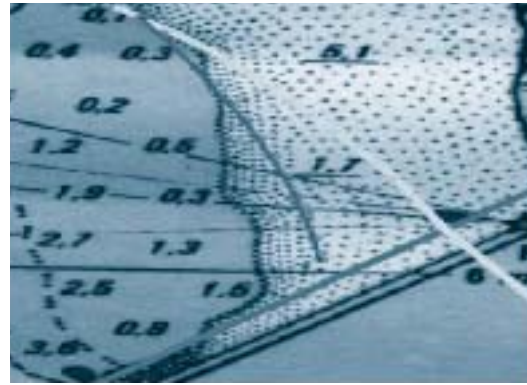


$H_{br} = 1.5$ m and $H_{br} = 3$ m (←) then $\varphi_{br} = 50^\circ$ (→)

Figure 11. Evolution of the coastline with various wave data.



$$Q_1(m^3) = (10^{-3}) * H_{br}^2 * T * \sin(7 * \varphi_{br}/4)$$



$$Q_2(m^3) = (10^{-4}) * H_{br}^2 * T * \sin(2 * \varphi_{br})$$

Figure 12. Evolution of the coastline with various transport formulae.

Impact of the wave data

Various results are presented in Figure 11 with various data to show the significant impact of the incidence angle and the amplitude.

Impact of the transport formula

The results reached using various formulations are shown in Figure 12.

It is observed that the solid transport formula is important and, therefore, it is necessary that it should be carefully worked out on the basis of statistical and dynamic study in the long run.

Conclusion

Sea phenomena, and more specifically sea coast phenomena, are too complex to be represented in a dependable manner using mathematical and empirical models. These models are the outcome of many a hypothesis and omissions of natural factors such as salinity and temperature. Progress in this field is still in process. However, unless the calibration of such models is based on long-term studies that are continuously updated, sound management of coastline zones development will remain doubtful.

Owing to their capability to manage and organise loads of data, which is their main asset, Geographic Information Systems (G.I.S.), are capable of modeling reality. By combining G.I.S. with the previous mathematical models, a powerful tool is created that is fully equipped to ensure sound management of coastal territory.

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