PART IV

The Venetian Coast

San Giorgio Island and Venice Lagoon

Test Section of Venice
Barrier being Transported to Lido Inlet

CHAPTER 138

DEVELOPMENT OF THE VENICE MORPHOLOGICAL SYSTEM

P.SILVA(*) and A.MOL(**)
(*)Technital S.p.A. (Verona, Italy)
(**)Grabowsky & Poort (The Hague, Holland)

ABSTRACT

The peper discusses the morphologicel development of the Venice Legoon since 1850 end, on the besis of enelyses of the system, presents models to simulate large scele development of the lagoon end of verious sub-besins.

The morphological development consists mainly in e continuous erosion of the selt-mershes and shellow erees, end e filling of cenels. Also a generel loss of sediment from the legoon wes observed. The mein causes were identified in engineering structures like jetties, dredging of artificiel cenels end meintenence dredging.

These works resulted in e disequilibrium of the neturel hydraulic system. In eddition, loss of biologicel protection in shellow arees, due to pollution, hes contributed.

Models were prepared on basis of time end partially everaged concentretions of sediment in shallow arees and cenals. Avereging wes carried on over e full year.

This approech faciliteted the building of models of verious complexity, which were found to be useful tools in the enelysis of the effectiveness of remediel meesures.

1. HISTORICAL BACKGROUND

The lagoon of Venice is a salt water basin connected to the Adriatic Sea by three inlets (see fig. 1). Sediments range from silt in the inner areas to fine sands close to the inlets. The conditions in the present lagoon have been heavily influenced by man; since the Middle Ages significant human intervention has changed the brackish estuary into a saline lagoon which interacts only with the Adriatic Sea. This saline system was in relative equilibrium in the period 1600-1850.

Fig.1 - MAP OF 1970

Fig.2 - MAP OF 1810

Since 1850 engineering works including inlet control structures, dredging and land reclamation (fig. 2) and changes in the ecological system due to urban, agricultural and industrial discharge, have brought the system to a state of disequilibrium which, in the last 20 years, has accelerated changes in the lagoon.

Significant erosion is observed in the shallow area, while natural channels are silting up. Salt marshes are disappearing at an increasing rate (compare fig. 1 and 2). The ecological system is out of balance as indicated by excessive algal growth and the disappearance of many species.

The changes of the morphology also determine negative consequences on human activities, causing difficulties to navigation in natural channels and an heavier wave attack against the defences of villages and agricultural land (fig. 3).

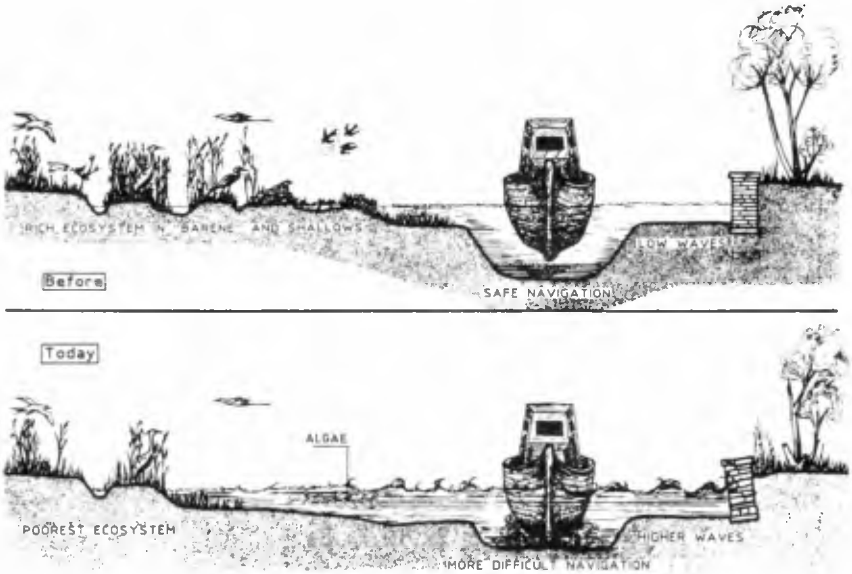
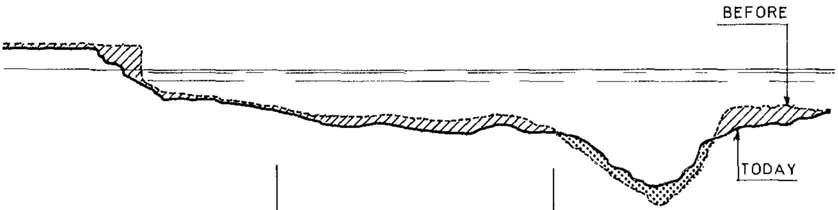


Fig. 3 - EFFECTS OF MORPHOLOGICAL CHANGES

Erosion and sedimentation patterns for the lagoon are available from 1900 onwards and information on inlets and coastline since 1800. The morphological changes over these time periods correlate well with significant engineering works such as inlet control structures and dredging of navigation channels. Figure 4 presents the main findings on the basis of analyses of bathymetric maps.



REDUCTION OF "BARENE" SURFACE

1930	72 Km^2
1970	48 Km^2
1990	45 Km^2

DEEPENING OF SHALLOWS

(mean depth)

1930	0,60m
1970	0,75m
1990	0,95m

SEDIMENTATION OF NATURAL CHANNELS

1970	→ 1,5 million m^3/year
1990	

Fig. 4 - MAIN PHENOMENA

2. ANALYSIS OF CAUSES

Section 1 described a significant change of the geometrical parameters of the lagoon, due to change in the morphological equilibrium. These changes have been caused by an imbalance of the total sediment budget of the lagoon (input-output, see fig. 5) and by an internal sediment redistribution (fig. 6). A detailed analysis, comprising all possible phenomena, followed by order of magnitude estimates, has resulted in the following most probable causes.

The first historical change to the sediment balance was caused by the diversion of rivers directly to the sea between 1500-1600 which reduced the sediment input by roughly 700,000 m^3/year.

The main reason for this diversion was siltation of the lagoon. Since that period, the lagoon found a relative equilibrium, with only a slow reduction of the area of salt marshes (being former river deltas). From 1850 the jetty construction has reduced sediment input from the sea. Estimated reduction was 300,000 m^3/year.

Particularly since 1970 there is evidence that the average sediment content of outflowing water has increased. The reasons are: the reduced resistance forces due to pollution (disappearance of biological protection) and the increase of active forces (shipping, fishing).

"Apparent" sediment loss was caused by subsidence of lagoon bottom due to water exploitation close to Marghera. This has been stopped since 1970.

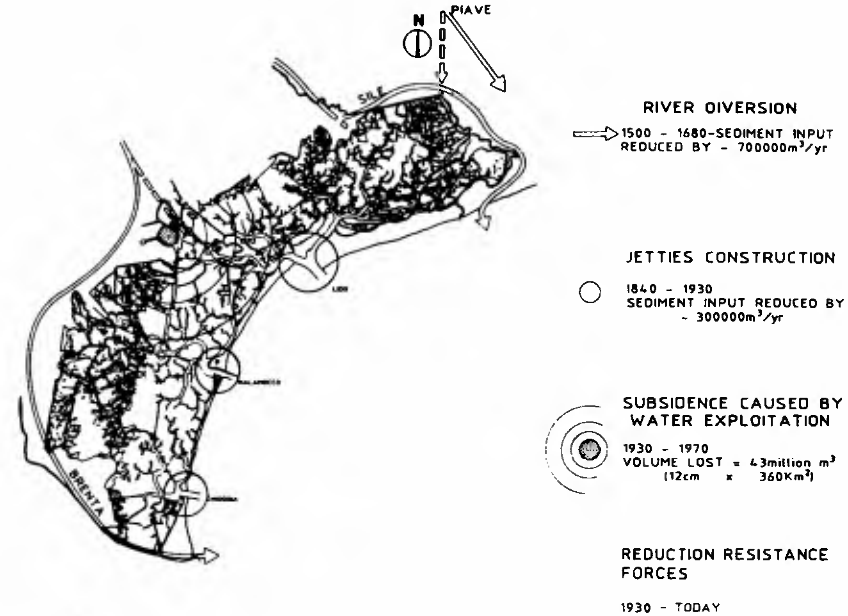


Fig.5 - MAIN CAUSES: GLOBAL "VOLUMETRIC" BUDGET

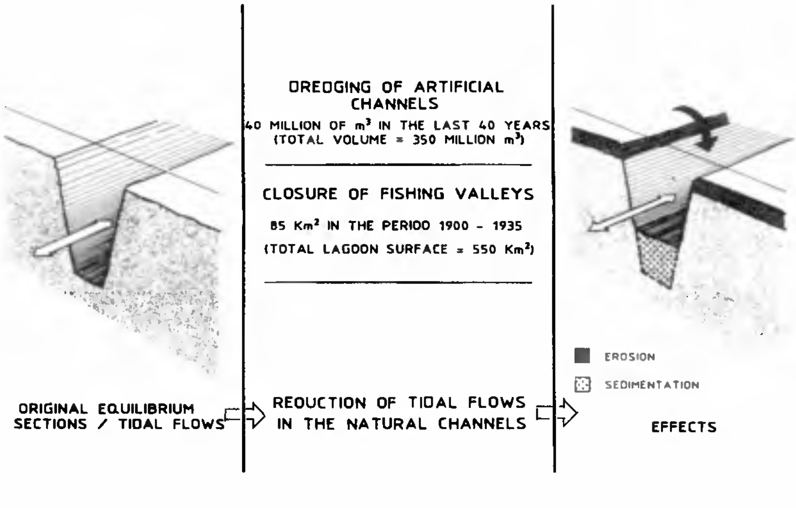


Fig. 6 - INTERNAL SEDIMENT REDISTRIBUTION

Another important element is the redistribution of sediment in the lagoon: erosion of shallow water areas and saltmarshes at the same time as sedimentation of natural and artificial channels have been found.

The main phenomena are:

- imbalance of hydraulic system due to dredging of artificial channels, increasing velocity in shallow areas and reducing velocity in natural channels;
- closure of fishing valleys reducing tidal volume, and then the velocities in the channels.

As a result the channels function today as sediment traps (see fig. 6).

3. STABILITY OF LAGOON CHANNELS

The lagoon channels have been remarkably stable since 1600 after the rivers were diverted. Comparison of maps available since 1910 show only slight changes due to natural causes. Meandering and geometrical profile characteristics (depth-width ratios) are noticeably similar. Total cross-section generally depends upon tidal volumes flowing though the cross-section, according to relations resembling similar laws for tidal inlets (see References (3) and (5)). An analysis was carried on following an approach developed by Marchi (Ref. (4)), who analytically developed a formulation equal to the Jarret relation for inlets.

This relation allows the introduction of the bottom characteristics using the Strickler coefficient. As the bottom characteristics of the various channels were measured, the relation between discharge and cross section was calculated. It was found that, since smaller channels had a smaller D_{50} of bottom sediment, on a logarithmic paper the new relation was within a similar band to the Jarret relation. Table 1 presents both relations, while figure 7 shows empirical plots of lagoon channels; the discharges were calculated using a finite elements hydraulic model.

In the Lido area (where no artificial dredging has been carried out) channels were found to follow the theoretical relation according to Marchi. The other lagoon channels, were found to have too large cross sections. This historical development however should a gradual decline towards the theoretical equilibrium, following the Marchi approach.

Hence, also for lagoon channels a general relation exist between tidal volume and cross section, or, as a general hypothesis one may say: lagoon <u>tidal volume</u> has a direct relation to <u>volume of lagoon channels</u>.

Table 1 - Discharge/section relations

Jarrett (1976) $\Omega = K1\ Q^{K2}$

$K1 = 9 \times 10^{-4}$

$K2 = 0{,}85$

Q = mean max discharges in a spring tide

Ω = cross-sections

Marchi (1989) $\Omega = [n^2\ \gamma\ b^{1/3}/Ks\ T^2\ \tau_{CR}]^{3/7} \times Q^{0.857}$

b = channel width

Ks = Strickler coefficient

T = tidal period

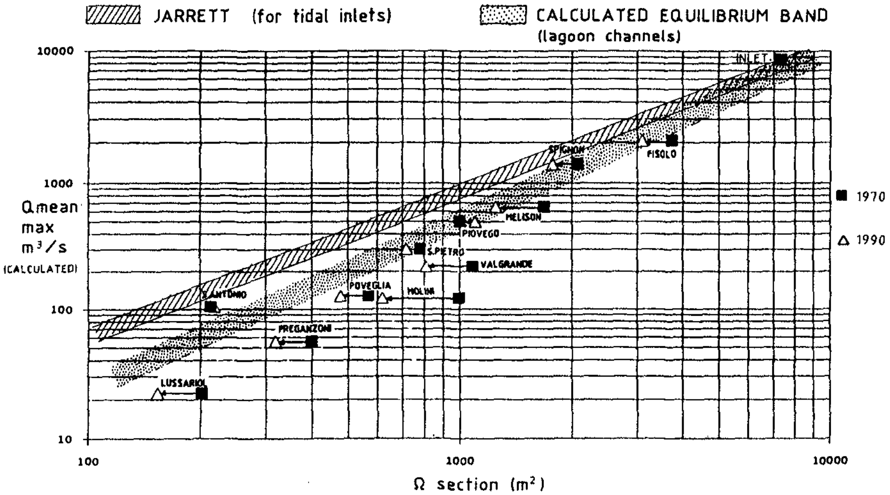


Fig.7 - Q/Ω RELATIONS, EXTRAPOLATED TO INTERNAL CHANNELS

4. MEASUREMENTS AND ANALYSIS

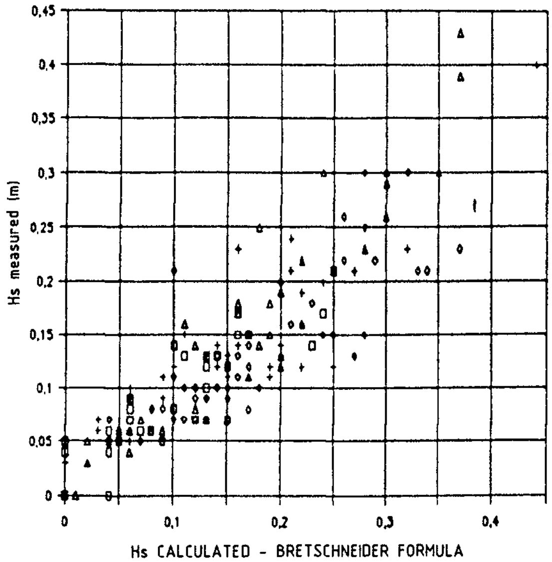
In order to verify various hypotheses a measurement campaign was carried out. It was performed by Danish Hydraulic Institute and Ecomar on behalf of Consorzio Venezia Nuova. The main objectives were to assess:

- relation between wind, waves and meteorological component of water levels;
- relation between sediment concentration and waves/currents;
- effects of shipping upon sediment concentration.

Three fixed stations with sensors (to measure wind, velocity, waves) and sediment samples were installed in shallow areas and used for a period of one year. During the same period, a campaign was carried out by boat to establish the spatial variation of parameters, and to analyse the conditions in the channels.

The analysis of results lead to the following conclusions:

- wind-waves relation were similar to Brethschneider relations (fig. 8);
- sediment-wave/current relations (figures 9 and 10) could well be correlated using the Bijker formula, reducing in the lagoon the found concentration by a factor 5 to consider the conditions of not breaking waves and the silty to fine sand environment.



Note: The different symbols are referred to different areas of measurements.

Fig.8 - WAVE HEIGHT IN THE LAGOON: MEASURED VS. CALCULATED DATA

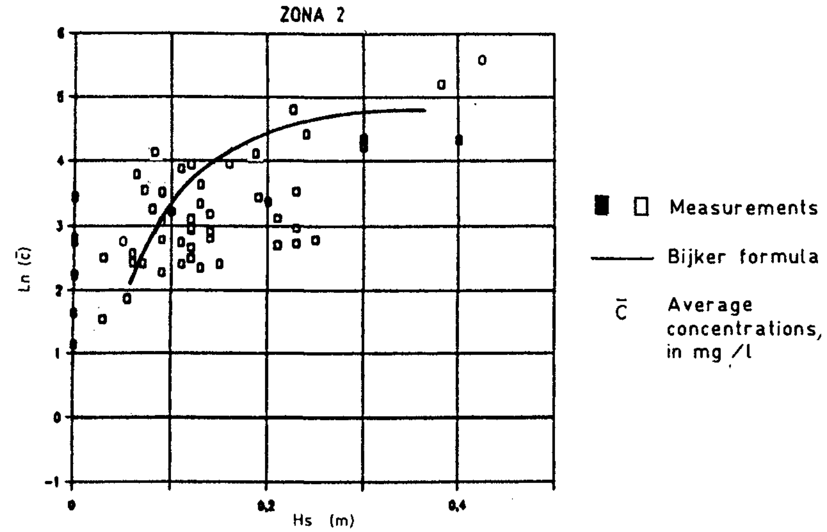


Fig.9 - SUSPENDED SEDIMENT CONCENTRATION IN THE SHALLOWS MEASURED VS. CALCULATED DATA

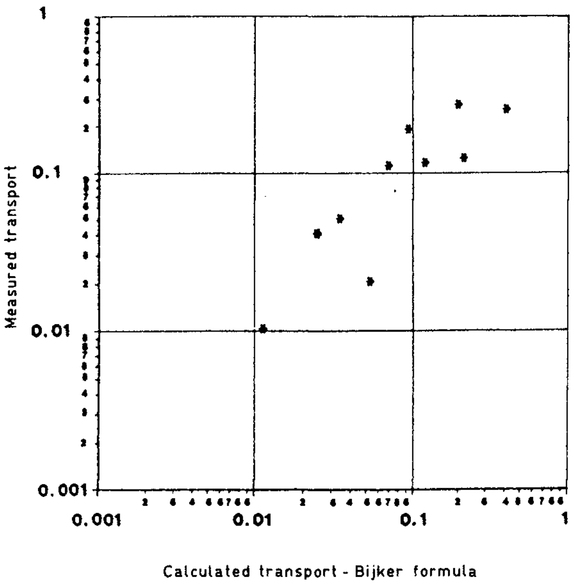


Fig.10 - LITTORAL TRANSPORT IN FRONT OF THE INLETS: MEASURED VS. CALCULATED DATA

5. MODELLING OF SEDIMENT BUDGET

As morphological processes have a large time scale a schematisation was proposed averaging the tide and wind effects over a full year, following the approach of Di Silvio (Ref. (2)). Yearly averages were calculated of all parameters affecting the sediment budget model (see Table 2). Velocities were calculated on the basis of a finite element tidal model of the lagoon. The yearly averaged concentrations were calculated on the basis of the Bijker formula. It was found that in the canals the velocity was the driving force, and in the shallows the wave action. After the calculation of the wave statistics from wind statistics, and the subsequent calculation of the sediment concentration statistics on the basis of Bijker, it was found that an approximate linear relation existed between mean sediment concentration and the mean water depth.

For modelling purposes a rooted vegetation coefficient was added to model biological protection by seagrasses and benthic fauna.

A first schematization was prepared on basis of a three cell model for each of the three basins Chioggia, Lido and Malamocco (see fig. 11).

Computer simulations showed that the 3-cell model was a useful tool capable of simulating main events utilizing calibration of parameters which were considered realistic on the basis of measurements (figure 12).

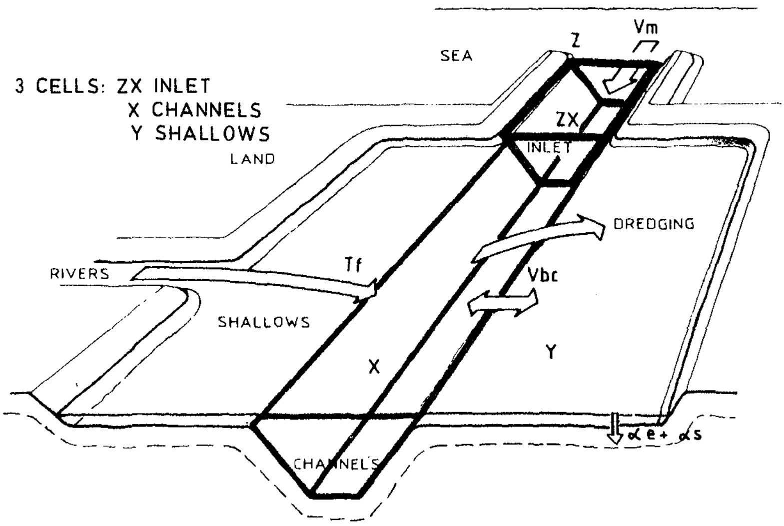


Fig.11 - THREE CELLS BALANCE MODEL

Table 2 - Balance model

Hydraulic flows	<---	2D finite element model
Bottom variations	<---	hydraulic flows x differences in mean concentration + volumetric changes for subsidence and eustatic rise + direct effects (dredging-river input)
Mean concentrations (averaged in space and in time)	<---	channels $x = C_1/d\ [C_2\ (Q_{med}/b\ .\ d)]^4$ shallows $y = C_w\ .\ C_v/d$ C_w = wave energy coefficient C_v = rooted vegetation coefficient

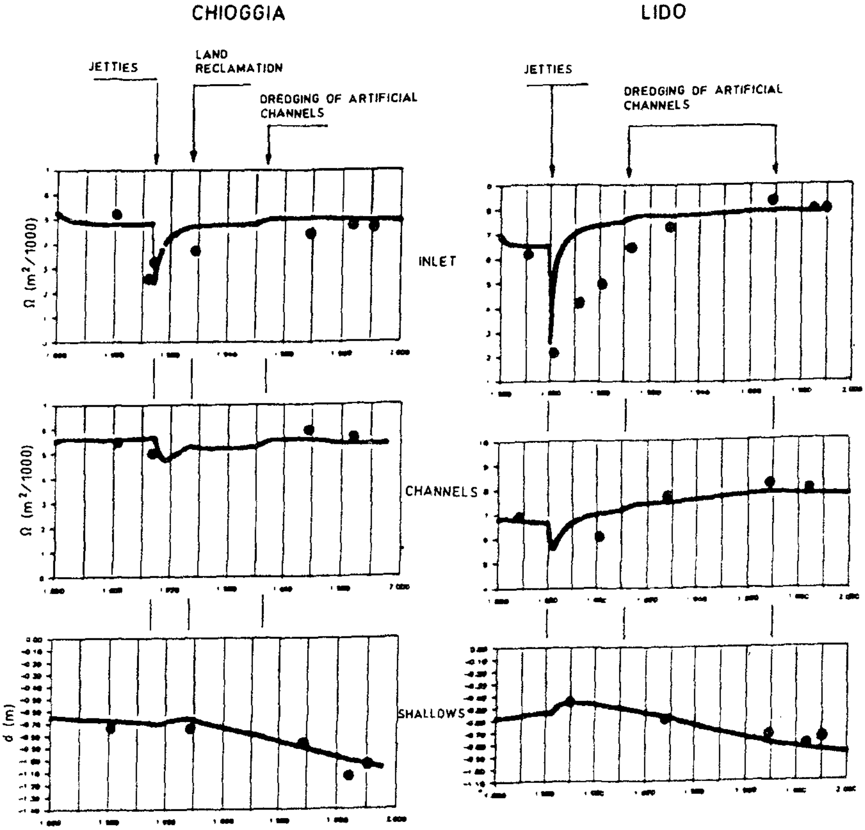


Fig.12 - 3 CELLS MODEL EXAMPLE OF RESULTS

In addition, a finite elements model was built dividing the lagoon into approximately 90 cells, to study the effects of the remedial measures, such as filling of artificial canals, nourishment of sediment, increase of biological protection, etc. Calibration of the model was carried out utilizing maps of 1970 and 1990. Parameters to be applied were within the range as measured during the field campaign, except for some complicated cells which were nodal points in the canal system around Venice.

Figure 13 presents the validation, demonstrating that the trend on virtually all cells is in agreement with reality. Figure 14 presents a forecast, without any measures, and with filling of artificial canals.

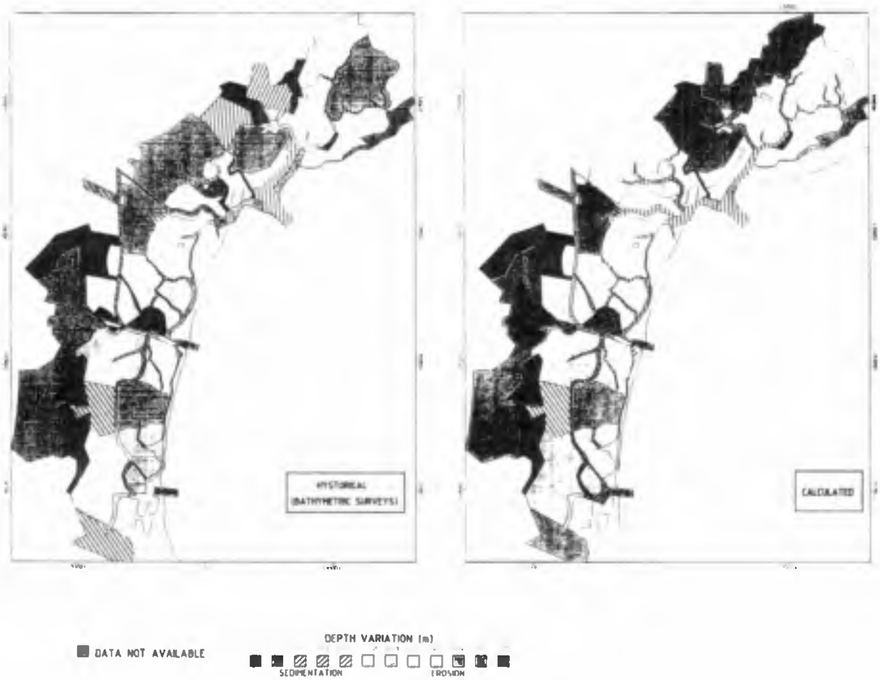


Fig.13 - MULTICELL BALANCE MODEL - VALIDATION

Fig.14 - MULTICELL BALANCE MODEL - PREDICTION

6. DISCUSSION

1. It is believed that the causes of the morphological disequilibrium in the lagoon have been identified. Nevertheless the effects of the huge algal growth in lagoon is not investigated in detail. The main occurrence is in the Lido basin, where it may have a stabilizing effect or even reduce depths due to deposits of organic material.

2. A major uncertainty is the effect of biological protection (benthic fauna, seagrass). The loss of this protection in large parts of the lagoon is undoubtedly due to pollution (biological, chemical) but also due to intensive illegal fishing. Although no figures are available, there are signs that large areas of the lagoon are frequently disturbed by heavy systems installed on fishing boats, destroying all biological protection and increasing mean sediment concentration.

3. The schematizations are all based upon granular material. However, in the lagoon stirring-up and deposit conditions will be different, and the models are not necessarily able to forecast adverse developments.

4. The models may oversimplify certain phenomena and are not able to include effects such as asymmetric tides. Nevertheless, calibration was easy and it is believed that the dominant phenomena are modelled.

7. REFERENCES

(1) Bruun P. (1978). "Stability of Tidal Inlets - Theory and Engineering". Elsevier Publ. Co.

(2) Di Silvio G. (1989). "Modelling the morphologicl evolution of tidal lagoons and their equilibrium configurations". 23rd IAHR Congress, Ottawa (Canada).

(3) Jarret J.T. (1976). "Tidal Prism-Inlet Area Relationships". GITI Report 3, US Army Coastal Engineering Research Center, Ft. Belvoir, VA.

(4) Marchi E. (1989). "Sulla stabilità delle bocche lagunari a marea". Presented at Accademia dei Lincei, 9/12/1989.

(5) O'Brien M.P. (1969). "Equilibrium Flow Area of Inlets on Sandy Coasts". Journal of Waterways and Harbours Division. American Society of Civil Engineers.