# Safeguarding of Venice

# Safeguarding of Venice
## Sauvegarde de Venise
## Rettung von Venedig

**Ida Brøker HEDEGAARD**
Research Eng.
Danish Hydraulic Institute
Hørsholm, Denmark

Ida Brøker Hedegaard, born 1958, received her M.Sc. in 1982 and her Ph.D. in 1985 at the Technical Univ. of Denmark. Since 1985 she has been employed at DHI as a research engineer in coastal sediment transport.

**Karsten MANGOR**
Chief Eng.
Danish Hydraulic Institute
Hørsholm, Denmark

Karsten Mangor, born 1947, received his M.Sc. degree at the Technical Univ. of Denmark in 1972. Since his employment at DHI in 1974, he has mainly been engaged in sedimentation and coastal problems. Since 1988 K. Mangor has been the head of the Coastal Section at DHI.

**Giovanni CECCONI**
Civil Eng.
Consorzio Venezia Nuova
Venezia, Italy

Giovanni Cecconi, born 1954, received his civil engineering degree at the Univ. of Padua. For nine years he was involved in field surveys and hydrological studies. Giovanni, now at Consorzio Venezia Nuova, is responsible for the coordination of studies for interventions for the safeguard of Venice against flooding and for the restoration of lagoon morphology.

SUMMARY
The present paper partly describes reasons for the increasing need, through the last century, for safeguarding Venice, and the political discussions and decisions which have taken place in the period from the last sixties when public realized the risk of flooding. It recalls the comprehensive plan for safeguarding and restoration of the Lagoon. Further a brief presentation of parts of the studies carried out to secure an optimal design of the new works is given. This part focuses on the effects on the evolution of the famous beaches of Venice and the morphology around the three inlets which connect the Lagoon and the Adriatic.

Sauvegarde de Venise

Résumé
L'article décrit les raisons du besoin accru, au cours des cent dernières années, pour la sauvegarde de Venise et l'établissement d'un plan général pour le sauvetage et la restauration de la Lagune. Il rappelle les discussions et décisions politiques qui ont eu lieu dès la fin des années soixante, lorsque le public a réalisé le risque d'inondations. Quelques études sont présentées. Elles permettent d'assurer le projet optimal des nouvelles constructions. L'article traite des effets du développement régional sur les fameuses plages de Venise et la morphologie autour des trois bras de mer qui relient la Lagune et l'Adriatique.

Rettung von Venedig

Zusammenfassung
Der vorliegende Artikel beschreibt die Gründe für die während des letzten Jahrhunderts gestiegene Notwendigkeit von Schutzmassnahmen für Venedig und den umfangreichen Plan zur Rettung und Wiederherstellung der Lagune. Er nimmt die politischen Diskussionen und Entscheidungen der Zeit seit den späten sechziger Jahren wieder auf, als die Oeffentlichkeit das Risiko einer Ueberflutung erkannte. Einige Studien werden vorgestellt, die ausgeführt wurden, um den Entwurf der neuen Kunstbauten zu optimieren. Behandelt werden die Auswirkungen auf die berühmten Strände von Venedig und die Morphologie um die drei Wasserarme herum, die die Lagune mit der Adria verbinden.

## 1. INTRODUCTION

In connection with the safeguarding of Venice against flooding, a consortium of Italian engineering companies, the Consorzio Venezia Nuova (CVN), has been given concession by the Italian government to develop a comprehensive plan for saving Venice. The CVN has chosen DHI to assist them in many of the hydraulic and environmental aspects of the project.

The project involves the construction of combined storm surge barriers, locks, and refuge ports at the three inlets, additional jetties and breakwaters for the protection of the barriers as well as coast protection and beach nourishment works along the barrier islands.

DHI has during the period 1988-1990 undertaken the First Phase of the Study: Venice Lagoon - Inlet Stability and Impact of New Works.

- Morphological Study.

  The main purpose of this is to establish a general understanding of the morphological processes of the area insuring that the mathematical modelling is covering all important processes. Furthermore a detailed programme was established for the two other elements of the study: The Mathematical Modelling and the Field Campaign.

- Field Campaign.

  The purpose of the field campaign is to establish a detailed description of all relevant data, such as: wind, waves, currents, tides, bottom conditions and suspended sediments serving as input and detailed calibration basis for the mathematical modelling. The field campaign has covered two winter seasons of 4 months duration each during the winters 1988/89 and 1989/90.

- Mathematical Modelling.

  The main purpose of the phase I modelling has been to demonstrate the capability of the modelling setup and to establish a sound basis for the detailed planning of the final second phase, which is planned to be executed in 1991.

  The mathematical phase II modelling includes 2-dimensional modelling of waves, currents and sediment transport patterns as well as bed level changes in the areas close to the inlets. Furthermore the littoral transport conditions along the littorals will be modelled. Finally special study programmes of siltation in refuge ports and locks as well as scour/sedimentation investigations for the gate structures will be performed.

This paper describes the historical development of regulatory works, the effects on the morphology, the plans for future protection works and presents the mathematical tools used for investigation of the effects of the new works on the morphology around the inlets and along the littorals.

## 2. DESCRIPTION OF THE MORPHOLOGY OF VENICE LAGOON AND THE HISTORIC DEVELOPMENT OF REGULATORY WORKS

The Venice Lagoon is located in the NW-ern part of the Adriatic. The Lagoon is separated from the Adriatic by sand spits, tidal inlets and barrier islands as follows: Cavallino Beach, the NE-ern sand spit, Lido Inlet, the N-ern tidal inlet, Lido Island, the N-ern barrier island, Malamocco Inlet, the middle tidal inlet, Pellestrina Island, the S-ern barrier island, Chioggia Inlet, the S-ern tidal inlet, Sottomarina Beach, the S-ern sand spit.

Before men started to regulate the inlets and to protect the barrier islands, the system of sand spits, tidal inlets and barrier islands was quasi stable, due to the general sediment transport pattern of the area, which is SW-ward littoral drift Northeast of the lagoon and N-ward drift South of the lagoon. However, from the human point of view the natural system caused severe problems to habitation and navigation as follows:

- The tidal inlets were wide, shallow and constantly changing causing difficulties to the navigation
- The low barrier islands were often breached during storm surges causing damages and loss of property and lives.

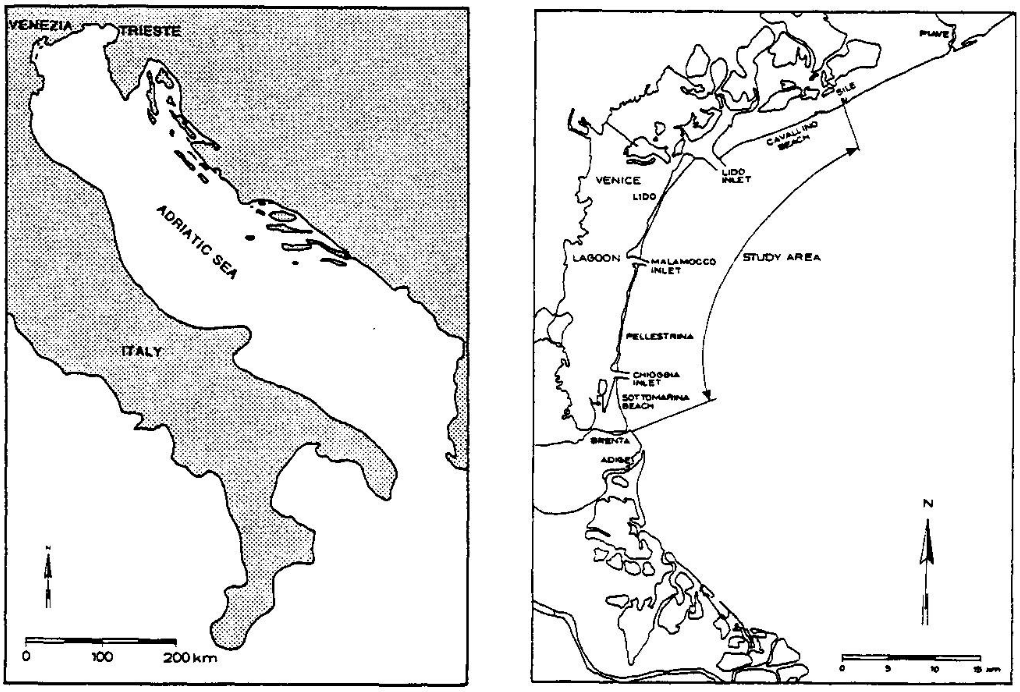


Fig. 1. Location maps: Adriatic Sea and Venice Lagoon with adjacent coasts

- The Lagoon suffered from sedimentation due to rivers discharging sediments into the lagoon.

As early as from the 14th to the 17th century the rivers were diverted around the lagoon to discharge direct into the sea.

Flooding of Venice has been documented since the 16th century. At that time a flood was an extraordinary event. The protection of the Lido and Pellestrina Islands as well as Sottomarina Beach by seawalls, the so-called Murazzi, started already at that time. From the middle of the 19th century of the following very large mitigating measures were initiated:

- Very large inlet jetties were constructed in all three tidal inlets.
- Navigation channels were dredged.
- The old seawalls at the barries islands were reinforced.

Most of these works were finished at the beginning of the 20th century.

The introduction of the jetties blocked the littoral drift completely, causing accumulation Northeast of the Lido Inlet north jetty at Cavallino beach and South of the Chioggia Inlet south jetty at Sottomarina beach. This trapping of sand increased the general erosion along the barrier islands. Furthermore sand was accumulated in the northern and southern ends of the barrier islands in the lee areas of the long jetties, which further added to the general erosion. This erosion raised the demands for reinforcement of the seawalls and groyne fields especially along the central part of Lido and Pellestrina. However, as no sand was supplied to the suffering beaches, and as the transport of sand away from the central parts of the islands continued, the beaches have been completely eroded away in these areas exposing the sea walls directly to the wave attack.

By the construction of the inlet jetties, the cross-section area of the inlets was drastically decreased, which caused an increase in the tidal currents in the inlets, which again resulted in erosion in the inlets and nearby lagoon shoals. This erosion started in the late part of the 19th century and ceased around 1950, when the equilibrium cross section were reestablish. During this period the inlet erosion amounted averagely approx. 700.000 $m^3$/year. Most of the eroded sand was jetted with the ebb currents out into the Adriatic, from where some of it was transported towards the littoral zone. By this mechanism, the starvation of the barrier island beaches was to some extent mitigated up to around 1950.

Around 1925 the development of the industrial suburb, Mestre, located at the mainland opposite Venice, accelerated, which did also the demand for groundwater. The groundwater was extracted from layers of sand and clay extending to the underground of Venice. This caused the whole area to subside. Adding to this man-induced subsidence the natural subsidence and the eustatic sea level rise results in a total subsidence of Venice of approx. 25 cm since the turn of the century. The continuous development in the lagoon area involved other large changes during this century, of which the most important are:

- Large reclamation works, mainly in the Mestre area.
- The construction of closed fish ponds.
- Dredging works in the industrial zone and in the canals amounting to $19 \cdot 10^6$ $m^3$ during the years 1952-60.
- Dredging of the large Canale dei Petroli from Malamocco inlet to Mestre, $31 \cdot 10^6$ $m^3$ during the years 1961-69.
- Increasing pollution of the lagoon.

This very drastic development within the fairly small and vulnerable lagoon area caused a series of problems to be more and more evident during the 1950'ties. The most important problems faced by the Venice community at present are:

- The frequent flooding of Venice.
- The deterioration of the lagoon morphology and ecology.
- The erosion of the barrier islands.
- The decreasing socio-economic conditions in Venice.

The requirements by the public for the solving of the above problems have gradually developed. This process will be described in the following.

## 3. THE MATURING OF THE SAFEGUARDING PROJECTS

Public opinion started to be well aware of the risk of flooding after the terrible storm surge in November 1966 with 1.2 m of water in San Marco Square and, more recently, in 1986 with almost one meter. Since the beginning of the century the yearly frequency of flooding has increased of around 6 times, reaching a value of 40 times a year.

The flooding of November 1966, which lasted about 24 hours, gave the evidence of the vulnerability of the city, and contributed to increase the on-going inland migration of the young population in search for better job opportunities. After the 1966 flooding the scientific community started an intense process for finding solutions along a line deeply influenced by the well accepted idea that the increased frequency of flooding and the higher water levels had been produced by human interventions such as: the extraction of groundwater, the reclamation works, the dredging of navigation channels and the construction of closed fish ponds.

A law was passed to stop the extraction of groundwater and in the following years the antropic contribution to subsidence disappeared. Further, a full set of drastic morphological interventions were proposed in order to reduce the propagation of the tide inside the lagoon with very little attention to the beneficial effects of the permanent tide flushing on water quality. These interventions included permanent restriction of the inlets and their complete closure, permanent reopening of fish ponds and removal of reclaimed areas and separation of Venice from the artificial navigation channel of Canal dei Petroli by means of a dike. Other proposals were related to the local defence of the city, such as artificial lifting of the ground level including buildings etc., confinement of the small city islands which constitute Venice.

The "period of proposal" lasted seven years till 1973 and produced no other practical intervention apart from the very important one of stopping groundwater extractions. During the evaluation process of the various drastic solutions the need of more information on the hydraulics and morphology of the lagoon was well recognised both by the decision makers and the public. In 1973 the government tried to address the problems for the safeguard of Venice with the first special law for Venice and, in 1975, with the guidelines for the application of the law.

The defence against flooding had first priority, the ecosystem and the port were considered secondary resources not to be damaged in an irreversible way.

The idea of floating gates at the three inlets originated from the 1970 call for proposals issued by the national Research Council. In 1975 the Minister for Public Works issued another call for proposals and in 1981 the feasibility project for the defence of the lagoon against flooding was completed by a group of leading experts. The proposed barriers consisted of permanent structures reducing the areas of the inlets coupled with a row of floating gates.

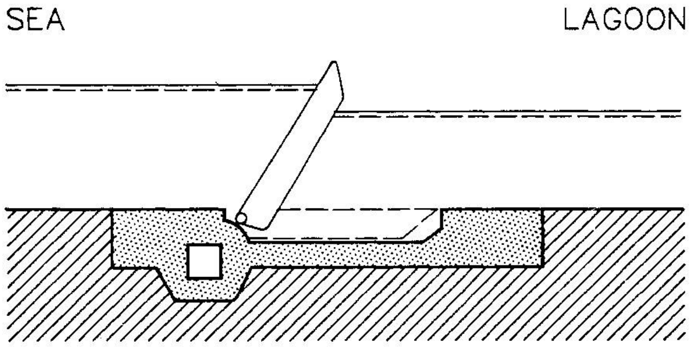


Fig. 2. Sketch of the proposed floating gates.

The feasibility project of 1981 was approved by the Greater Council of Public Works with a list of requests for further investigation, particularly on the impact of the permanent structures on tidal flushing. Only in 1984, with the second Special Law for Venice, the defence against flooding was associated with the need of intervention for environment restoration of the lagoon. The Law suggested that the ecosystem should be studied as a whole and the various interventions should be coordinated by the State through a private technical organization, the Consorzio Venezia Nuova, under the control of Magistrato alle Acque, a 500 year old Venetian institution responsible for the government of the lagoon system. Together with the protection against high water the law defined other objectives, including the protection of the littorals, the restoration of the ecosystem, the morphological re-equilibrium of the lagoon, the check on the feasibility of excluding oil tankers from the lagoon.

During the first 5 years of life Consorzio Venezia Nuova has developed a comprehensive plan of studies. A result of these studies has been the completion of the preliminary project for the new works at the inlets, the so-called REA project. The project has been developed taking into account a vast series of specific provisions that emerged from the long political and scientific work which led to the Special Act of 1984.

The institutional decisions and ruling can be divided into two main groups.

The first group contains the more general provisions requested by the public opinion according to which the work ought to maintain characteristics of an experimental nature, of reversibility, phasing and flexibility, search for the most suitable means to protect and strengthen commercial port activities and the local fishing industry, bear in mind the possibility of gradually replacing oil tanker traffic in the lagoon with oil pipelines and respect the natural, artistic and monumental heritage of the areas (no superstructures or intermediate piers).

The second group contains specific provisions which are conservative criteria in order to avoid all the potential negative impacts of the work on the lagoon morphology and water quality: No significant change in the volume of water exchanged between sea and lagoon, no significant change in the distribution of the flow rates between the three inlets and their relative canals, no appreciable alteration in sediments transported along the littorals, no significant change in the cross section area of the inlets, guaranteed access to the lagoon ports through the openings for commercial boat, fishing boats, passenger ships and pleasure crafts.

During 1990 the REA project has been discussed by the City Council, the region and the State and, at the end of the process, Consorzio Venezia Nuova has been asked to proceed with the completion of the project.

The attitude of public opinion towards the project has been influenced by a four year period without relevant high water and with noxious algal blooms. The scientific evidence of the risk of high water such as the one of 1966 and the need of protection barriers took second place, after the emerging need of interventions for pollution control. The requirement was put forward by the politicians that the gate operation must not increase the content of nutrient from the inland watershed in the lagoon.

The 1989 REA project is a great improvement completely different from the ideas of 1974 and from the proposal of 1981. Part of the merits goes to the public opinion who promoted the integration of the restoration of the lagoon environment in the project, but the price paid is very high because Venice is still under the offence of flooding, and it will remain in this situation during the next ten years which will be necessary for the completion of the works.

## 4. HYDROGRAPHIC CONDITIONS IN THE NWern PART OF THE ADRIATIC

In the north western part of the Adriatic Sea there are two dominant wind systems - the Bora coming from east north east and the Scirocco coming from south east. The coastal areas off Venice Lagoon are strongly influenced by the waves and currents induced by these two wind systems. The fine sand ($d_{50\%}$ = 100-200$\mu$) which constitute the beaches and coastal areas are transported along the adjacent beaches towards the area of interest - and trapped by the large jetties at Lido and Chioggia inlets. Apart from the extreme storm events, where the transport rates in the coastal zone are very high, the strong currents though the inlets due to the tide influence the development of the bathymetry - especially close to the inlets. The tide in this area is semidual (i.e. two cycles per day) with a typical range of 1 m at spring tide, and typical currents speeds in the inlets up to 2-3 knots.

## 5. MATHEMATICAL MODELS

A setup of mathematical models must include the relevant phenomena which determines the development of the morphology in the areas. These are wave conditions along the coasts, currents driven by tide, wind and, in the nearshore zone, waves, and the corresponding sediment transport capacity.

Two types of model complexes have been applied during the first phase of mathematical modelling:

- MIKE, two-dimensional wave-, current and sediment transport models, S10, MIKE21.HD, MIKE21.ST
- LITPACK littoral drift and coast line evolution models.

All the models in the two dimensional model complex operate in a rectangular grid with constant grid spacing. The wave model S10 is a refraction model for monochromatic unidirectional waves. MIKE21.HD is a dynamic depth integrated current model in which currents driven by wind, tide, breaking waves can be modelled. In MIKE21.ST the wave and current fields found by S10 and MIKE21.HD are utilised to calculate a sediment transport field averaged over the tidal cycle and the corresponding initial bed level changes. In MIKE21.ST the sediment transport as function of the local wave, current and bed material parameters are calculated by a detailed intra wave period model, see Fredsøe et al. (1985) and Deigaard et al. (1986). An overview of the model complex applied for calculation of the initial bed level changes are shown in Fig. 3.

LITPACK is a model complex for investigations of coastal processes of sandy beaches. LITPACK consists of a hydrodynamic module which calculates waves and longshore currents in the surf zone, a sediment transport module which calculate the longshore sediment transport by use of the same detailed sediment transport module as applied in MIKE 21.ST, and finally a one line model for calculation of coast line evolution.

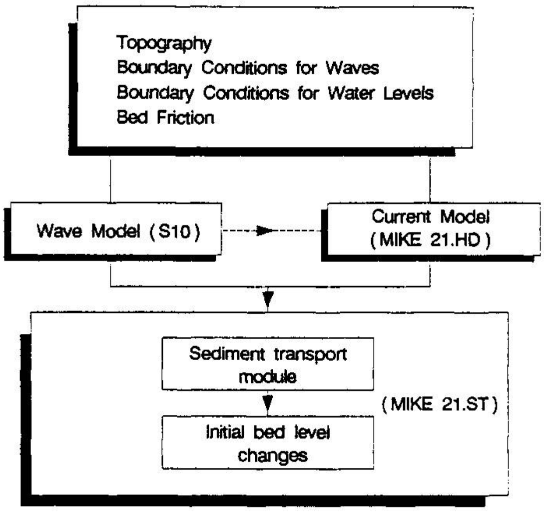


Fig. 3. Overview of the parts of the MIKE model complex used for calculation of initial bed level changes.

## 6. FIELD INVESTIGATIONS

There are 3 major purposes of field investigations in the area: 1) to collect general information of the local conditions, wind, waves, currents, bathymetry, bed material etc., 2) to collect data for calibration and verification of models which can then be applied for a larger range of conditions, 3) monitoring of a number of relevant parameters for documentation of the effect of the new works.

The field measurements include both long term recording of a number of parameters in fixed stations and intensive investigations of currents and suspended sediment.

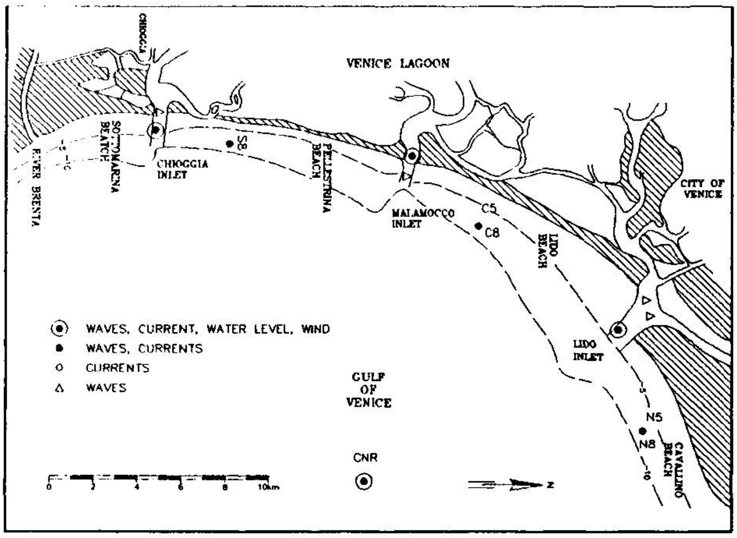


Fig. 4. Overview of fixed stations and recorded parameters.

The long term recording programme consists of 22 self-recording instruments in fixed locations in and off the three inlets. These locations and the measured parameters are shown in Fig. 4. The instruments used both for current and wave recording are electromagnetic meters while the pure wave meters use acoustic signals. All instruments are mounted 1-1.5 m above the bed. The sample rate varies between 1 and 3 hours.

For calibration and verification of the hydrodynamic models very precise information on water levels is needed. For this purpose the measurements mentioned above are supplemented by registrations carried out by Comune di Venezia of water levels in the three inlets every 5 min.

The above described long term recordings cover the period Dec. 1988 to April 1990. Apart from this, some of the instruments were deployed already in the period Sept. 1987 to April 1988 and some instruments are still maintained for monitoring purposes. The long term recordings are carried out by ECOMAR, Milan, Italy.

The intensive measurements concentrated on detailed investigations of current patterns around the inlets both under ebb and flood flow and calm and rough conditions and collection of data for calibration and verification of the sediment transport model, i.e. simultaneous measurements of suspended sediment, current profile, wave conditions, characteristics of bed material and suspended material.

The current investigations were carried out by float tracking and current profiling by an electromagnetic meter. A laser system, normally used for land surveying supplemented by a GPS system in large distances from shore (more than 2 km), was applied for positioning. The registration of suspended sediment was carried out by analysis of half litre water samples sucked from 0.05, 0.10, 0.30, 1.0 m above the bed. The grain size distributions of the sediment were determined by analysis of 25 litre samples sucked 0.1 m above the bed and of grab samples of bed material.

Examples of results

The data material is very comprehensive. As an example is shown an extract of collected data during two days with rough weather, mainly the 26th and 27th of March 1990. Fig. 5.A, B, C and D show measured significant wave heights and current speeds in the 3 offshore stations N8, C8, S8 and wind speed and direction at the CNR measuring platform.

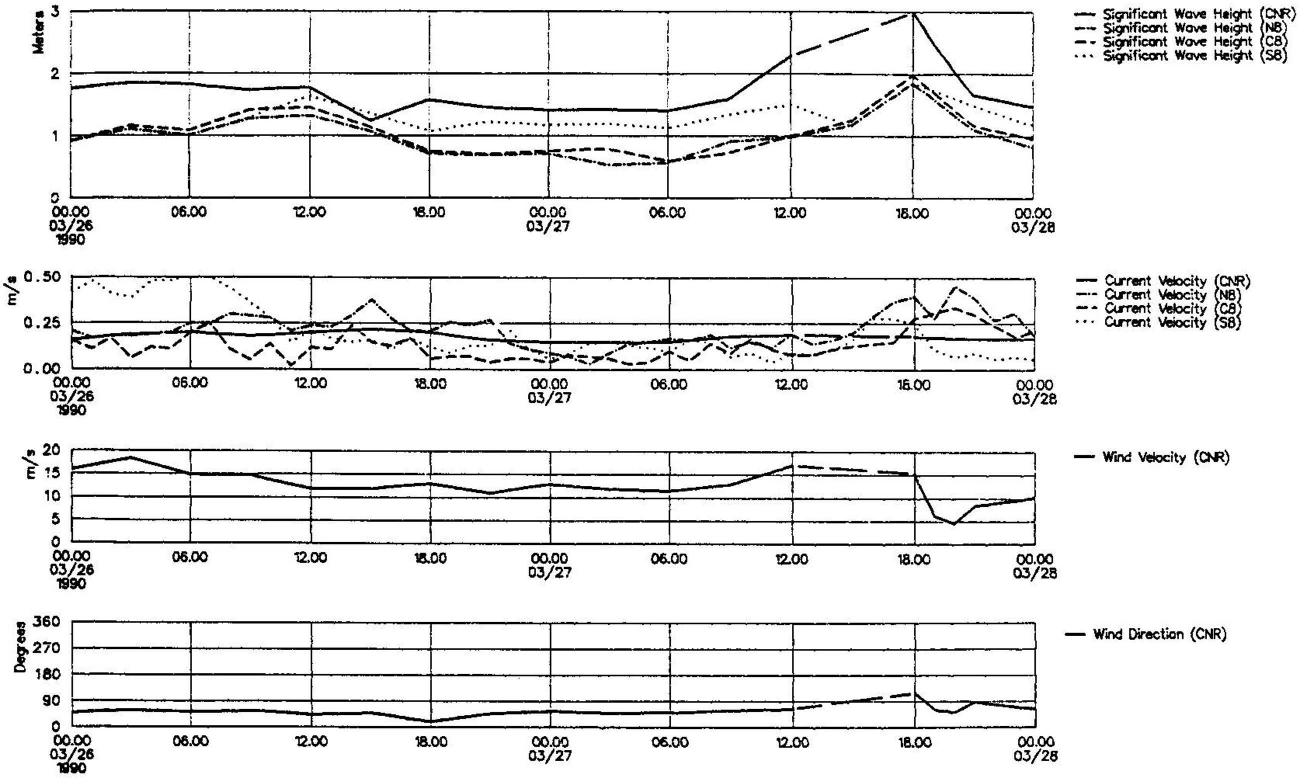


Fig. 5. Example of timeseries of measured waves, currents and winds.

The utility of these simultaneous measurements are obvious: verification of wave and current models, all kinds of statistic analysis and correlations between waves, winds and currents.

Fig. 6.A and B show two series of float tracks carried out on the 27th of March under ebb and flood flow and the water level registration from the inlets and the CNR platform. These detailed measurements supplement the long term measurements and are very useful for model verification. Note for instance the strong bending of the ebb flow jet due to the relatively strong wind driven southgoing current along the coast.

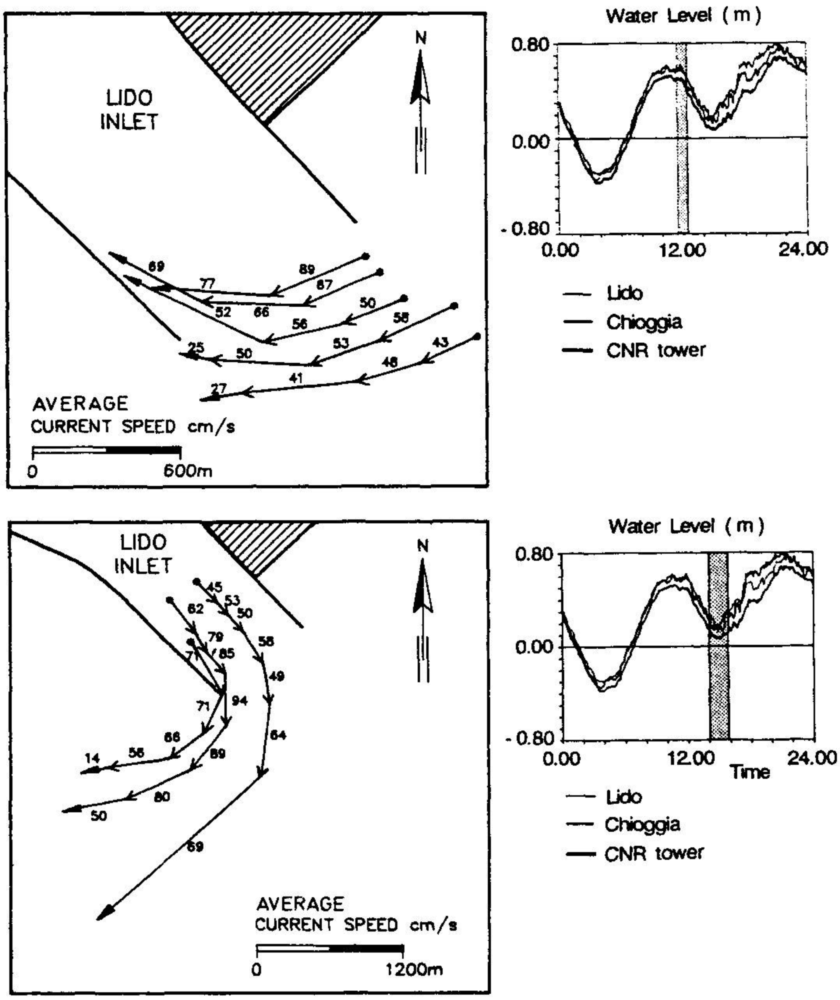


Fig. 6. Detailed investigation of current patterns around Lido Inlet.

Fig. 7. shows an example of measured suspended concentrations and current profiles in the position C5, see Fig. 4. on the 26th of March. These measurements are used for verification of the sediment transport model and for general establishment of a correlation between background concentrations of fines and wave and current conditions. For comparison Fig. 7. includes a distribution of suspended sediment calculated by the sediment transport model with the relevant parameters.

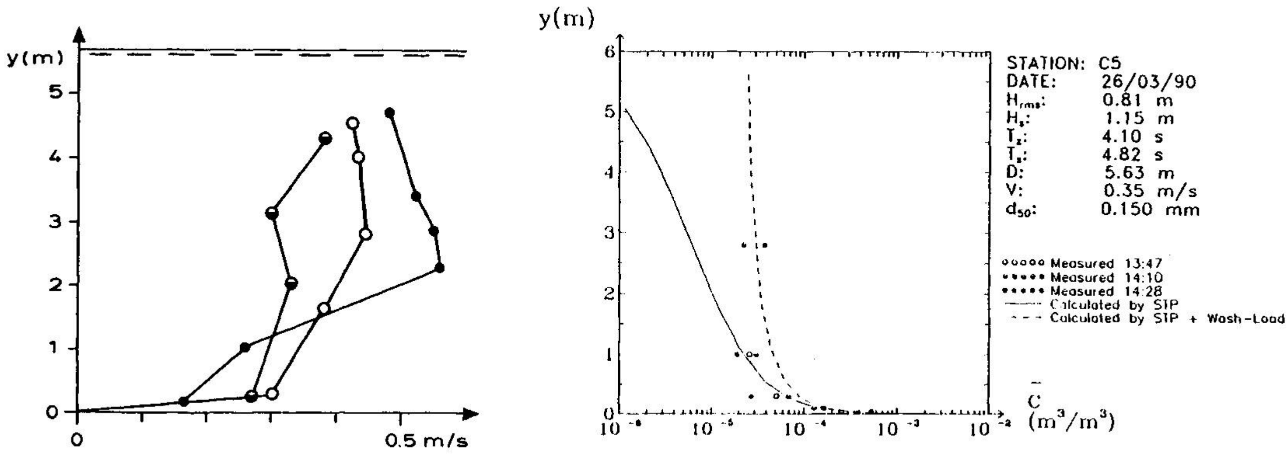


Fig. 7. Measured current profiles and measured and calculated suspended sediment profiles. C is volume of suspended sediment per volume of sediment and water.

## 7. PRELIMINARY RESULTS FROM MATHEMATICAL MODELS

The first phase of mathematical modelling included calculations of initial bed level changes in the two dimensional model complex MIKE and a first verification of the sediment transport and littoral drift model by simulation of the previous evolution of a stretch of the relevant coastline by LITPACK.

### Coastline Development by LITPACK

The most direct way of verification of the basic sediment transport model is comparisons as shown in Fig. 7 between measured and calculated suspended sediment profiles. Another very valuable verification of the sediment transport model are comparison of the coastline evolutions found by LITPACK and observations. Fig. 8 shows the observed and simulated coastline evolution north of Lido inlet during the period 1933-83. This comparison shows that the size of the calculated net littoral drift is reasonable.

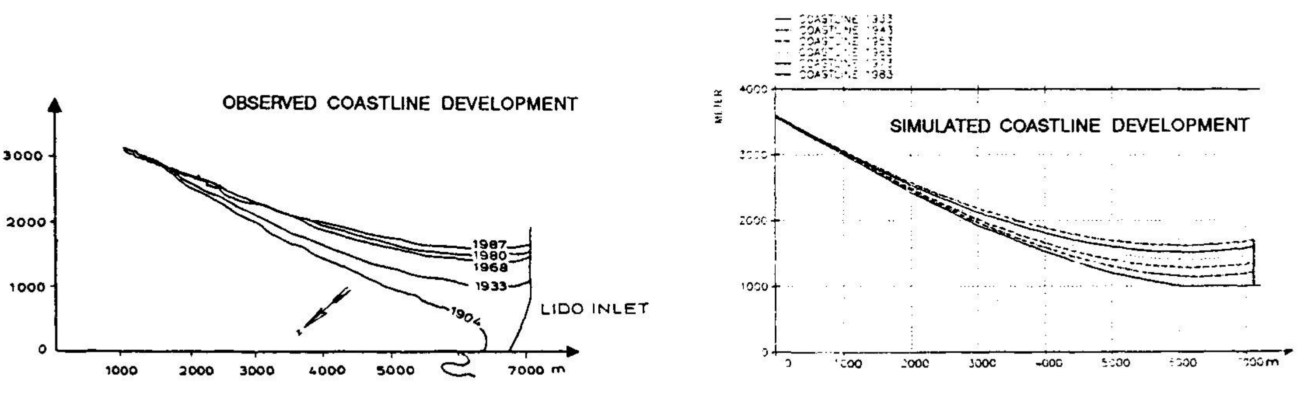


Fig. 8. Comparison of observed and simulated coastline evolution. Cavallino Beach.

### 2-dimensional modelling

Wave, current and sediment transport fields for a typical Bora and a typical Scirocco storm combined with a typical tide have been modelled. The simulations have been carried out for the actual layouts of the structures around the inlets and two proposals for future layouts. Further, the effects of closing the gates during the Scirocco storm have been investigated. The areas covered by the models are sketched in Fig. 9. In the so-called Regional Area wave, current and sediment transport fields are investigated in a 300 m grid. In the local model areas at Lido, Malamocco and Chioggia inlets, the sediment transport phenomena are studied in more detail. In these models the grid spacing is only 50 m.

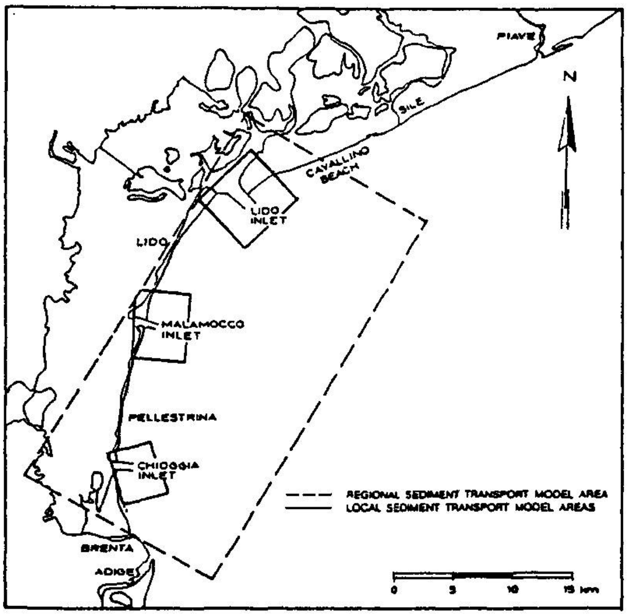


Fig. 9. Overview of Model Areas.

An example of results produced by the model complex is illustrated in the Fig. 10.A - D. This example treats the local area around Chioggia inlet for the existing constructions and strong Scirocco wind conditions, $H_s \simeq 2.8$ m, tidal range 0.8 m.

Fig. 10.A shows the bathymetry of the area. The grain size of the bed material is a very important parameter for the sediment transport calculations and is digitized in a similar way and used as input to model complex.

By the wave model S10 the wave field is calculated. The results are illustrated in Fig. 10.B, in which isolines for significant wave heights are shown. The time varying current field is calculated by the hydrodynamic model MIKE21.HD. The driving forces included in this simulation are wind, tide and variation in the radiation stresses (wave driven currents). As an example the current field at maximum flood flow is shown in Fig. 10.C.

The sediment transport field averaged over the tidal cycle has been calculated based on the wave field, the current fields and the grain size distribution. The calculated average transport field is shown in Fig. 10.D.

It appears that the wave driven currents along Sottomarina carry large amounts of sediment. This so-called littoral drift is responsible for the evolution of Sottomarina Beach, which advances ~ 6 m/year. Close to the southern jetty a large counter clockwise current vortex appears. This wave-driven current pattern occurs because the wave fronts are refracted around the shoal SE of the inlet. The sediment transport rates along the jetty increase strongly from outside to inside the surf zone. Because the breaking waves are able to carry more sediment in suspension than the non breaking waves. The net transport in the inlet appears to be close to zero in this case. This is because the current speeds during ebb and flood flow are found from the current simulations to be nearly identical.

The duration per year of the conditions simulated in this example is estimated at 1.8 day/year - assuming that this condition represents all strong Scirocco wind cases. From the above described sediment transport field the initial bed level changes per year corresponding to Scirocco wind are determined. These calculated bed level changes are illustrated in Fig. 11. The bed level changes reflect the variations in the transport capacities. Along Sottomarina Beach the decrease in littoral drift leads to large deposition areas. The counter clockwise current and sediment transport pattern south of the jetty leads to erosion where the transport capacity is increased due to the increase from outside to inside the surf zone in the amount of suspended sediment. Inside the inlet no net erosion is seen because the transport capacity is identical during ebb and flood. The erosion NE of the inlet takes place during ebb flow where the ebb flow jet passes this area. The pattern SE of the inlet occurs due to the shoal. Erosion takes place where the water depth decreases in the current direction and deposition takes place where the current has passed the shoal and the water depth increases (north of the shoal).

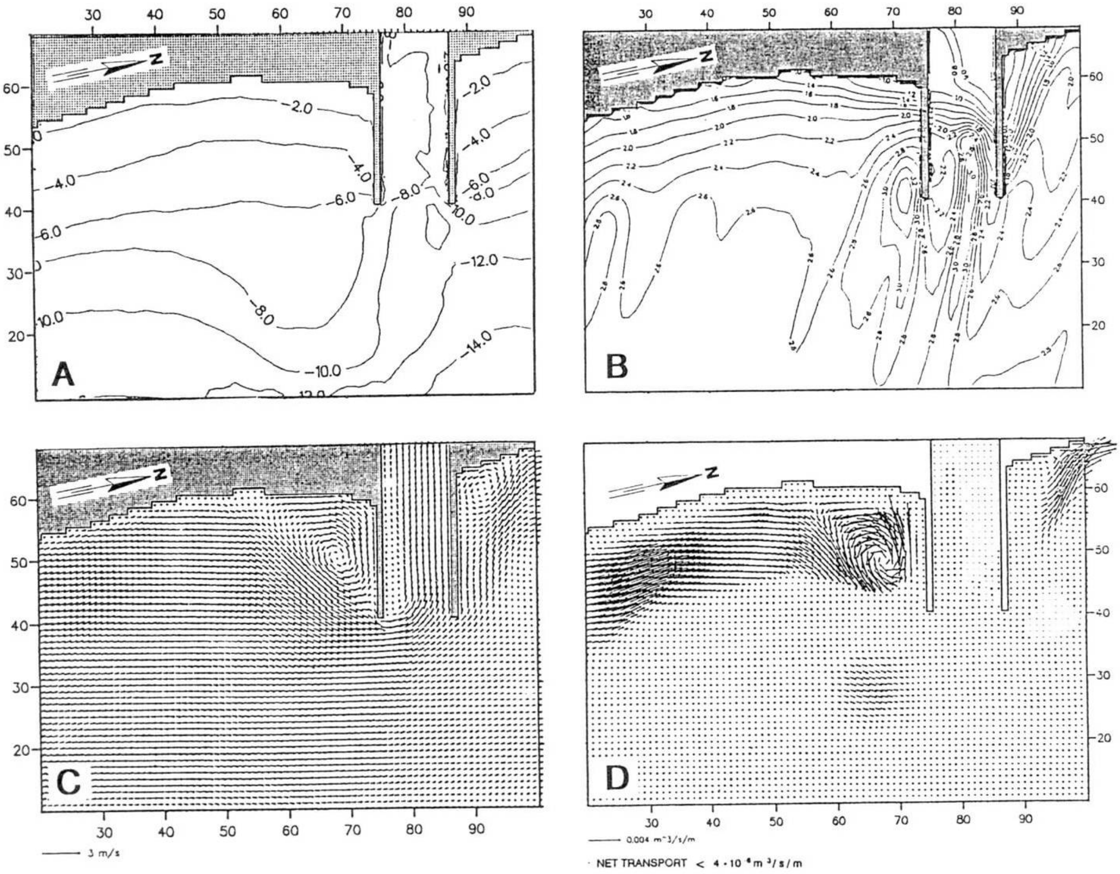


Fig. 10.A Bathymetry
10.B Wave heights
10.C Current pattern at maximum flood flow
10.D Sediment transport field averaged over the tidal cycle

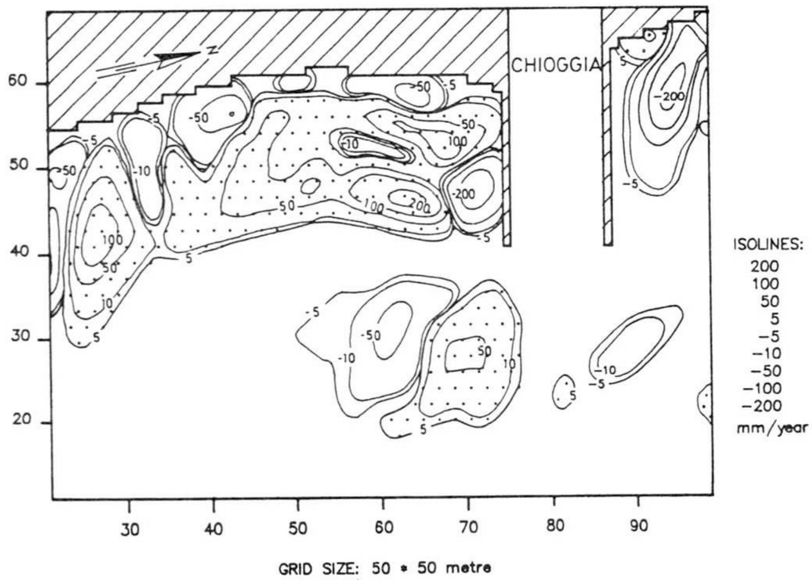


Fig. 11. Calculated Initial Bed Level Changes per Year corresponding to Strong Scirocco Wind.

Preliminary estimates of the impact of the new works

From the first phase of mathematical modelling it seems that the effects of the new works are concentrated relatively close to the inlets. The most important changes are found in cases where the future layouts include offshore breakwaters. In these cases sedimentation will take place in the sheltered areas between the inlet mouth and the breakwater. Further a proposed offshore breakwater at Chioggia seems to increase the area along the Sottomarina beach with shelter for the north easterly waves. This means some increase in the accreation immidiately south of the southern jetty.

In Malamocco and Chioggia inlets the simulations of the present layout show an ongoing erosion in the inlet mouth and a corresponding deposition far away where the current speeds decrease. This so-called 'flushing effect' disappears when the gates are closed. The closing of the gates during all rough Scirocco wind conditions therefore reduces the natural erosion in the inlet mouth. Furthermore, the preliminary simulations draw attention to the ongoing deposition near the inlet mouth of Lido due to littoral drift along Cavallino Beach.

Future investigations

The first phase of mathematical studies has shown that the very large jetties constructed during the last century to secure the navigation has changed radically the sediment transport pattern in the area and has caused the ongoing erosion along the Lido and Pellestrina beaches. The preliminary calculations have shown that the new works only influence the overall morphology of the littorals slightly compared to the existing man made interference in nature. However, there is, evidently, a need for restoration of the beaches and of cause the local areas around the new barriers will be influenced both by the structures themselves and by the closures of the gates. Further, it is very difficult to build refuge ports and locks in areas with strong currents and large amounts of suspended material without facing siltation problems.

The second phase of studies therefore focuses on these problems. It is planned to investigate the effects on the bathymetry of gate closure in a number of different wave and current conditions in the local model areas around the three inlets. The very delicate exchange of sediment through the inlets will be studied by use of both numerical models and collected field data in an attempt to estimate the net erosion or deposition in the lagoon. Based on measured and calculated amounts of suspended sediment and currents at the entrances to the planned refuge ports and locks, the siltation in these basins will be estimated and the optimal design will be chosen.

Further, the future investigations include study of design of an artificial, wide beach along the Lido, which suffers from lack of sand and which could be an even more attractive place to go for the many tourists who visit Venice. Along the Pellestrina the problems are more serious because the foreshore has been totally eroded and in long stretches the only protection of the lagoon is a seawall. In the nearest future different protection schemes for the Pellestrina will be investigated.

8. REFERENCES

/1/ Studio 1.4.1. Studio con modello matematico degli effetti indotti sui litorali dagli interventi alle bocche di porto della laguna di Venezia. January 1988. Performed by TEI S.p.A. for CVN.

/2/ Studio A.1.3 Relievi Correntometrici Nelle Zone di Mare Antistante Il Cordone Litoraneo. 1989. Performed by ECOMAR.

/3/ Venice Lagoon. Inlet Stability and Impact of New Works. Field Campaign - Study A.1.3. Intensive Field Measurements. Periods: 22/11-1988 - 12/1-1989, 2/3-1989 - 7/3-1989. Field Report 1, DHI, September 1989.

/4/ Venice Lagoon. Inlet Stability and Impact of New Works. Field Campaign - Study A.1.3. Second phase. DHI, 1990.

/5/ Study B.7.3. Study of Impact of New Works on the Stability of the Inlets and the Littorals: Progetto Prelininare delle Opera alle Boccha, Ch. 9 and 10. Performed by Technital.

/6/ Venice Lagoon. Inlet Stability and Impact of New Works. Study B.7.3, Phase 1. DHI, March 1990.

/7/ Studio C.5.1 - Monitoraggio dell'idrodinamica alle bocche e sul litorale - I fase. Preformed by ECOMAR. 1989, 1990.

/8/ R. Deigaard, J. Fredsøe, I. Brøker Hedegaard: "Mathematical Model for Littoral Drift", Journal of Waterways, Port, Coastal and Ocean Engineering, Vol. 112, No. 3, 1986.

/9/ R. Deigaard, J. Fredsøe, I.B. Hedegaard: "Suspended Sediment in the Surf Zone". Journal of Waterway, Port, Coastal and Ocean Engineering, Vol. 112, No. 1, 1986.

4 April, 1991 / 1006-4/9101.bem

Leere Seite
Blank page
Page vide