Annex 45

Numerical Studies of Waves, Currents and Sediment Transport at the Marine Part of Deepwater Navigation Channel through the "Bystry" Arm of the Danube Delta and Model Verification based on Laboratory Modeling

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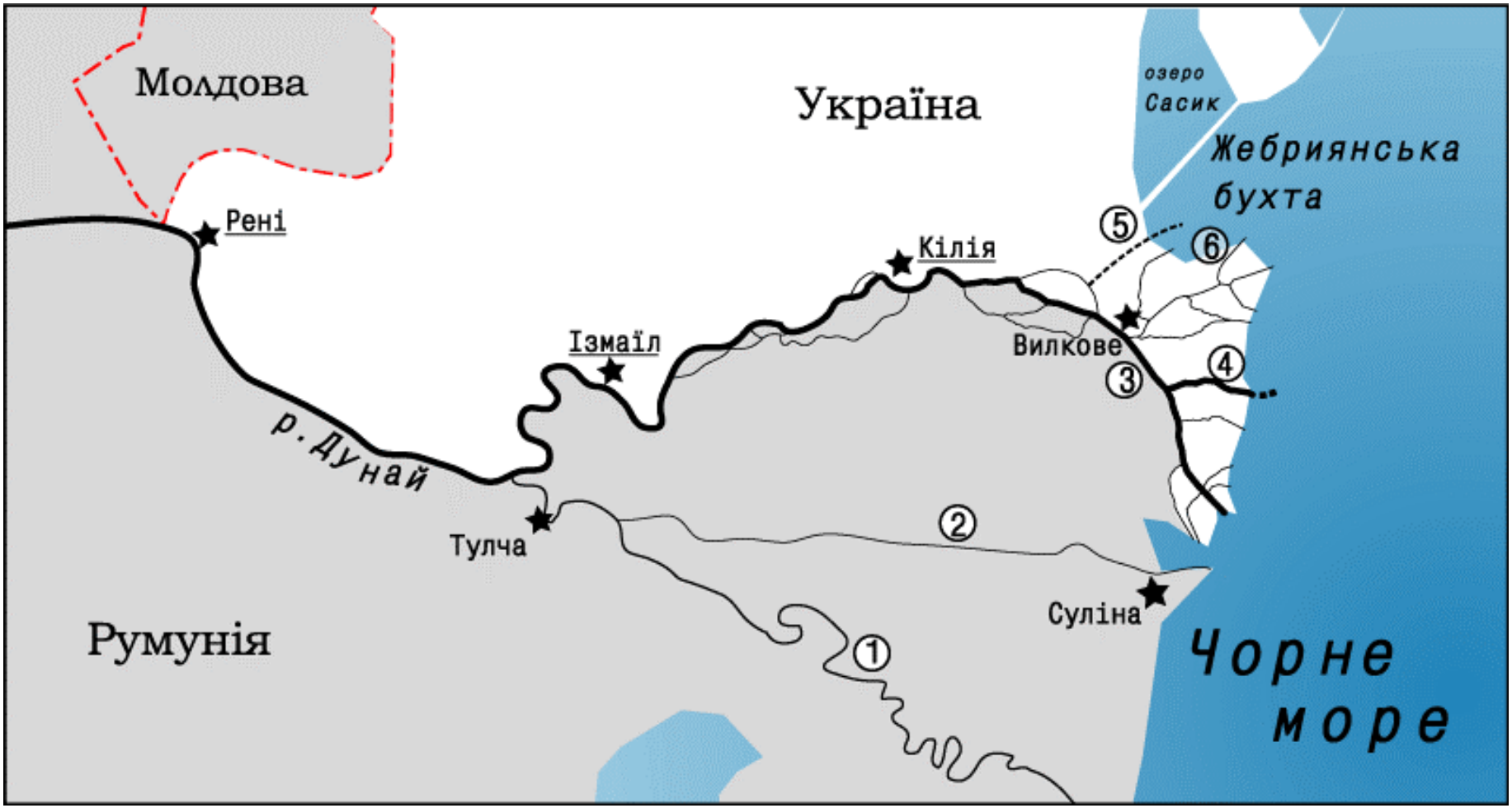
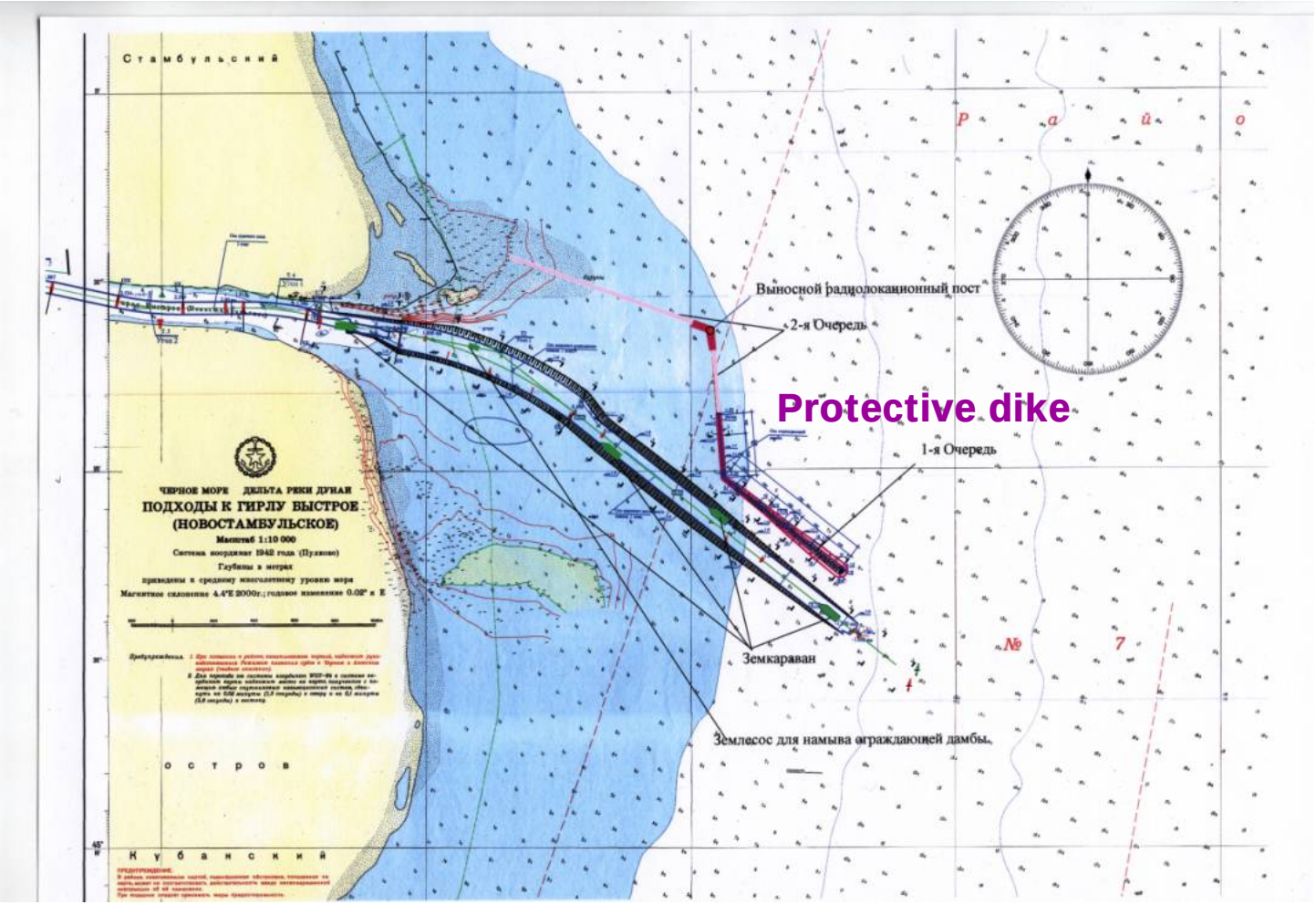
Team Leader- Dr. Vitaly Khomitsky
Engineering design and data processing: Institute "Richtransproect"
Team Leader- Eng. Iraida Golovina

Objectives of the study:

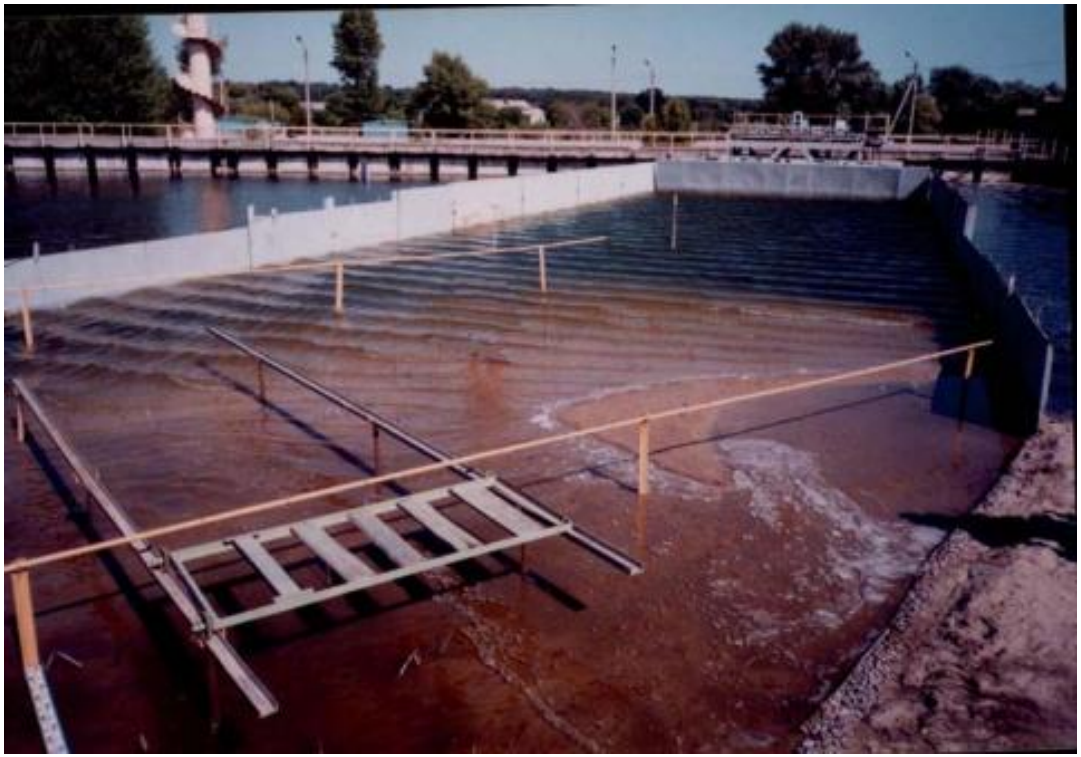
- to set up the contemporary modeling systems for the simulation of wave, currents, sediment transport and bottom erosion/sedimentation for the area of the marine approaching channel at the mouth of the arm Bystry;
- to verify and to calibrate the models on the basis of the data of the laboratory experiments fulfilled in 2002-2004 by the Institute of Hydromechanics of NAS;
- to implement the modeling system for the assessment of the impacts of the navigation channel and designed protective dike on the sediment transport and littoral processes in the project area.



The construction of Deepwater Navigation Channel (DNC) in the Bystry arm of the Danube Delta has started in 2003. The whole project provides the development of the navigation channel Danube- Black Sea in Ukraine which ensures the passage with the draft 7.2 m. The first phase of project, that was finished in August, 2004, provides the passage with the draft 5.85 m. The second phase of the project is under preparation.



The marine part of the DNC - the approaching channel, length 3.30 km, which is passing through the sea sand-bar at the mouth of the Bystry arm . Within phase two the jetty will be constructed to protect the channel from the littoral drift from the North and North-East – that are main directions of the sediment transport in the area.



3D scale model with movable bottom of the marine area of the mouth of Bystroe was constructed in the experimental wave tank of the Institute of Hydromechanics. The wave tank length is 43 m, width 27 m, water depth 0.9 m. It is fitted with a piston-type wave generator and with a pump to simulate the currents from the river mouth. The directions of the incoming waves can be changed by the re-location of the wave generator, The set of the automatic wave gage devices provides the measurements in the up to the 10 points of the wave tank The currents were measured by the micro-propeller meters.

Mathematical Models :

The numerical modeling was provided on the basis of the 2-D hydro&morpho- dynamics modeling code ***COASTOX***, that was used for this task as a set of the following modules.

HWAVE – the module describing wave diffraction, refraction and transformation on bottom inhomogeneities and currents on the basis of hyperbolic approximation of mild slope equation, which is more widely appreciable than parabolic approximation and more computational efficient then an elliptic one. The numerical engine of the module is based on the 4-th order finite difference scheme.

CUR – the module describing nearshore 2-D currents, which radiation-stress terms are calculated on the basis of the outputs of HWAVE model. The numerical engine is based on the TVD scheme, computationally efficient for the calculation of the flooding and drying of coast under long wave (tides, wind surf) impacts.

SED - the module of the simulation of the sediment transport in which the suspended sediments are simulated on the basis of the finite-difference solution of 2-D advection – diffusion equation and the bottom sediment transport calculations are provided o the basis of a library of the most widely used popular semi-empirical formulas (van Rijn, Bijke and others).

MORPH – the module of the simulation of the morphological transformation of coastal zone based on the mass balance equation, on the basis of the sediment fluxes, calculated in the SED module. MORPH management submodel is responsible for the execution of the model chain "waves- current- sediments – morphodynamics- waves" etc.

Input data for Laboratory and Mathematical Modeling :

Directions of high storm waves

North: Waves of 1% probability of exceeding at isobath 10 m

Height H= 1.9 m, period T=3.7 sec

North East: H= 2.9 m, T=4.7 sec

East : H= 2.9, T=4.6

South East : H= 3.0, T=4.7

Total days per "no ice cover period" of year (330 days) with the wind speed higher than 10 m/s (climate data Ust-Dunaysk)

North : 3.05

North East. 1.46

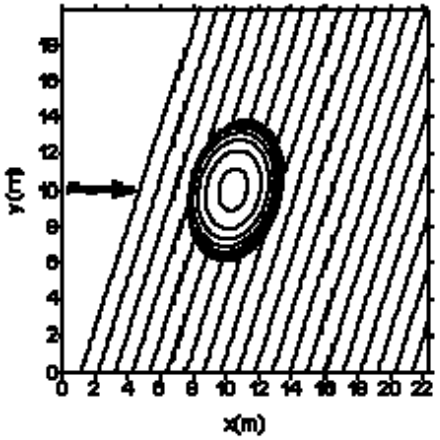
East : 0.47

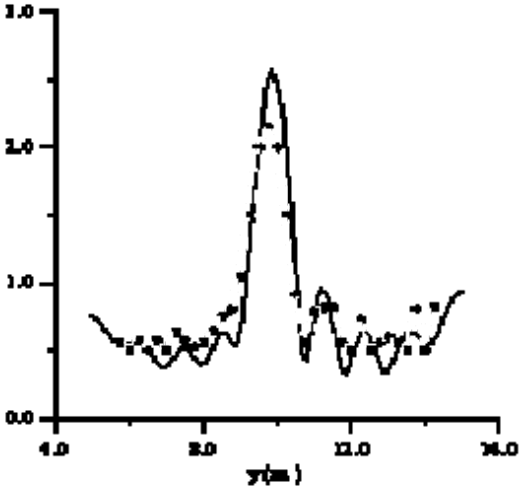
South East : 0.20

The water discharge from Bystry at 1560 m3/sec was selected as the typical "high flood" discharge with the "mean high" values of the sediment influx into the marine part of the Danube Delta with the suspended sediment concentration at 0.53 kg/m3 A mean grain size of the suspended sediments in the river flow is 0.02-0.04 mm with the increasing of the fraction of sand at 0.15 mm during and after the floods.

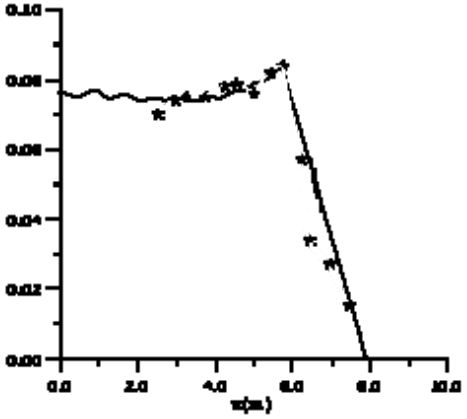
Laboratory experiment was provided for the above flow parameters without the modeling sediment flow from the river, only water flow

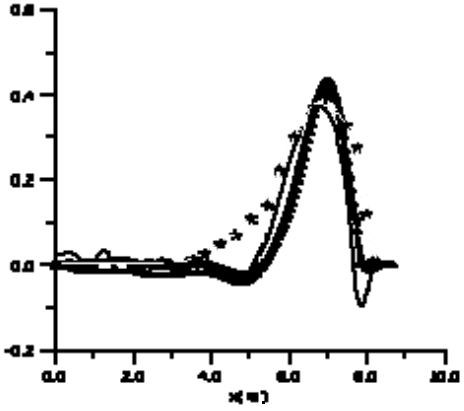
The models were tested on the basis of the international recognized data sets (some examples below) and were implemented earlier in the various applications for the coastal engineering and environmental protection projects in Ukraine and other countries.





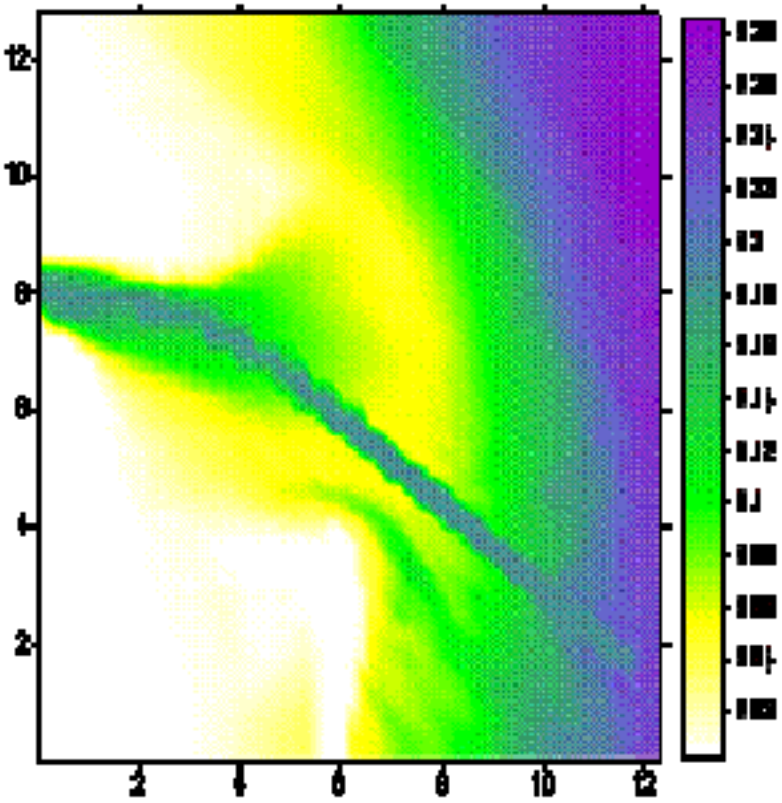
Model comparison with “Delft Hydraulics” laboratory data (Berkhoff,1982) on wave height transformation above the shoal

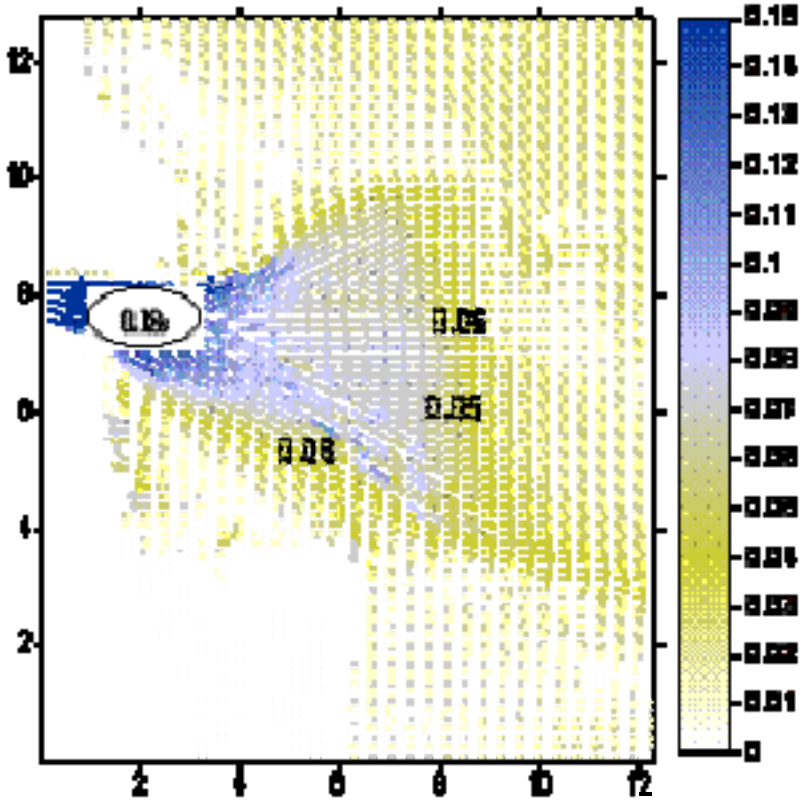




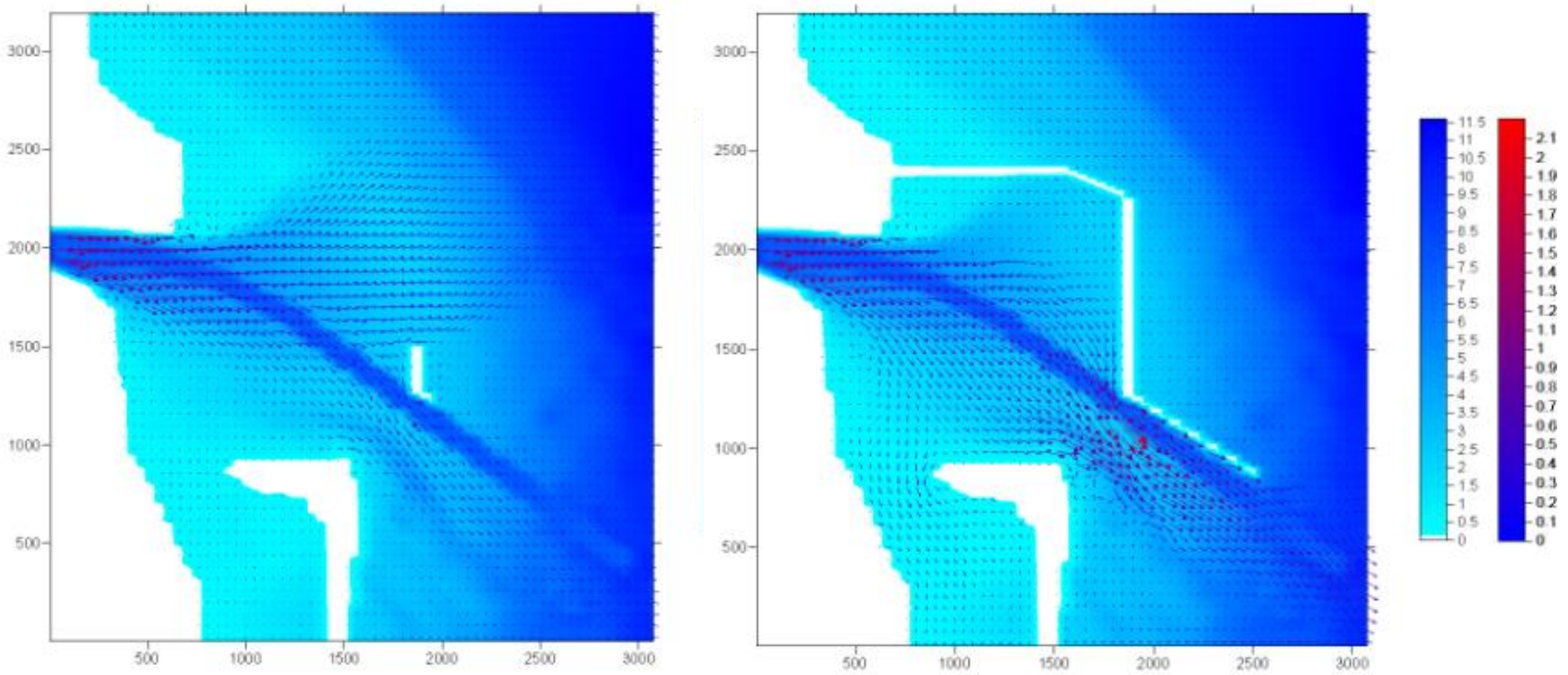
Model comparison with the laboratory data (Visser, 1984) on water elevation in the surf zone (wave set up) and the distribution of the velocities of wave generated alongshore currents

Simulated and recalculated from the laboratory experiments river driven currents in “no waves conditions”

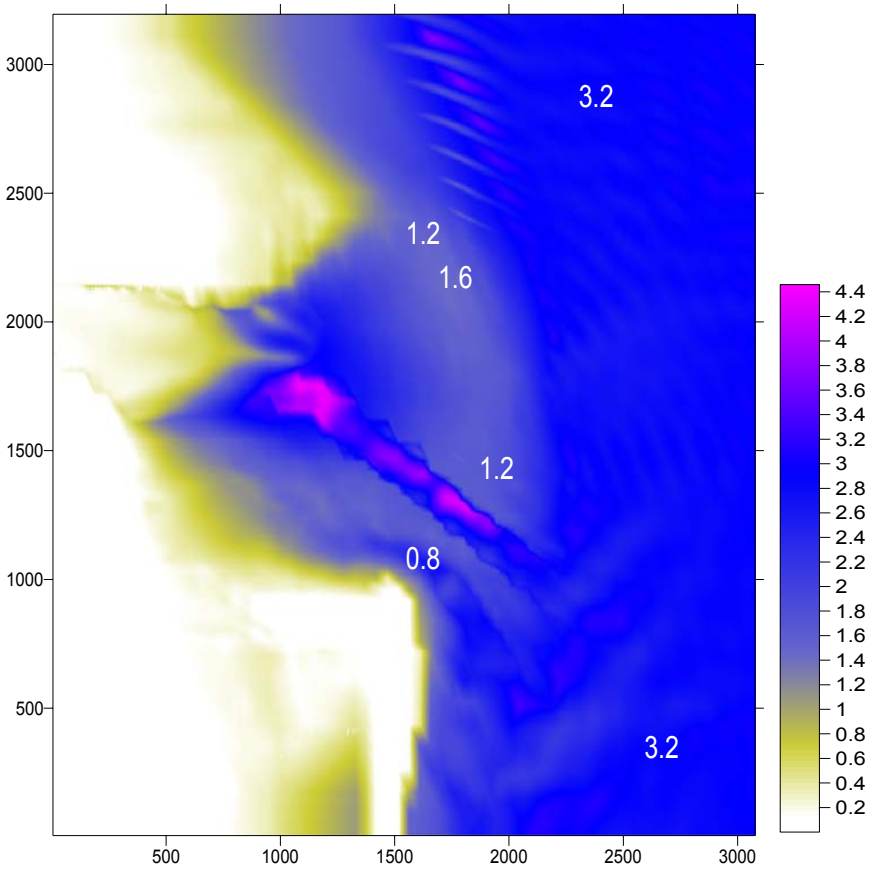




Simulated river driven currents in “no wave’s conditions” after the construction of the “short dike-2004” and long designed jetty

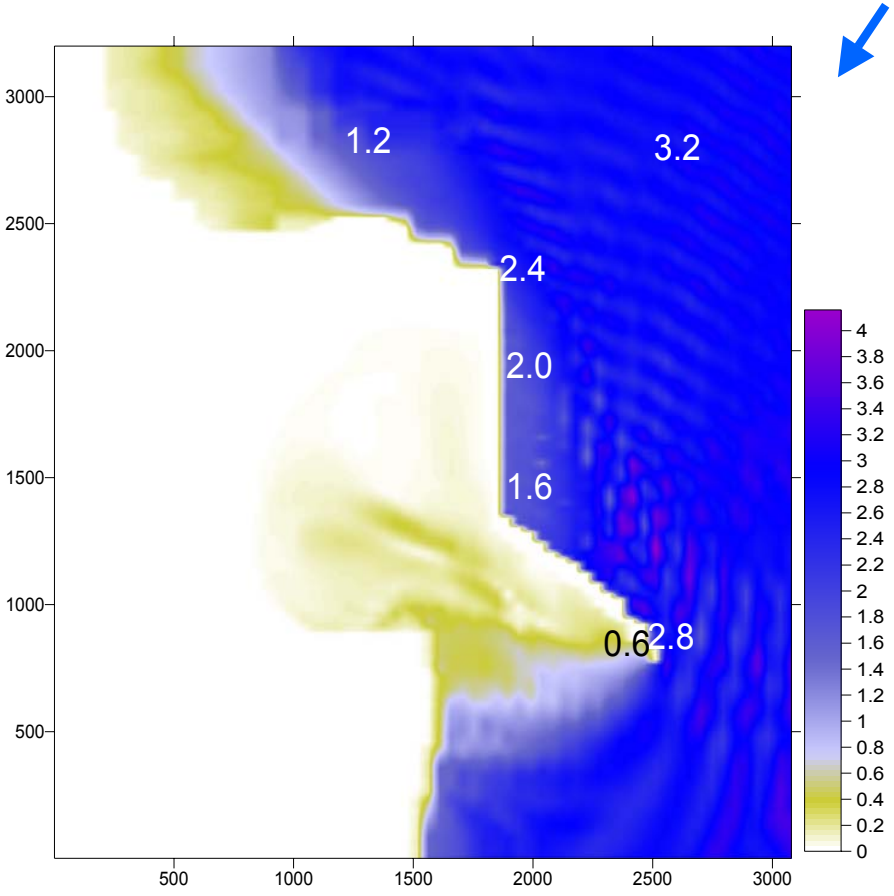


Wave heights numerically simulated and recalculated from the measurements in the wave tank (white numbers)

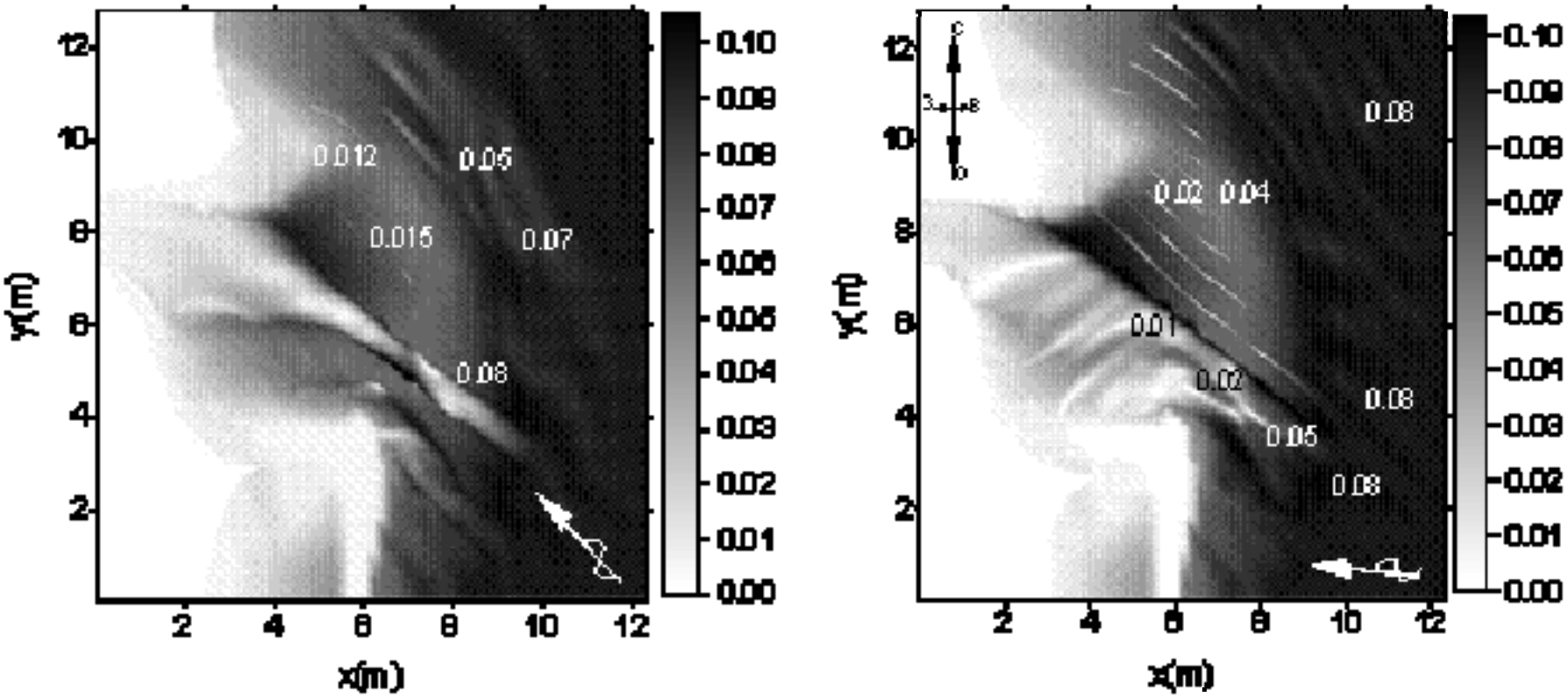


Navigation channel without jetty

Incoming waves from NE (37 degree)



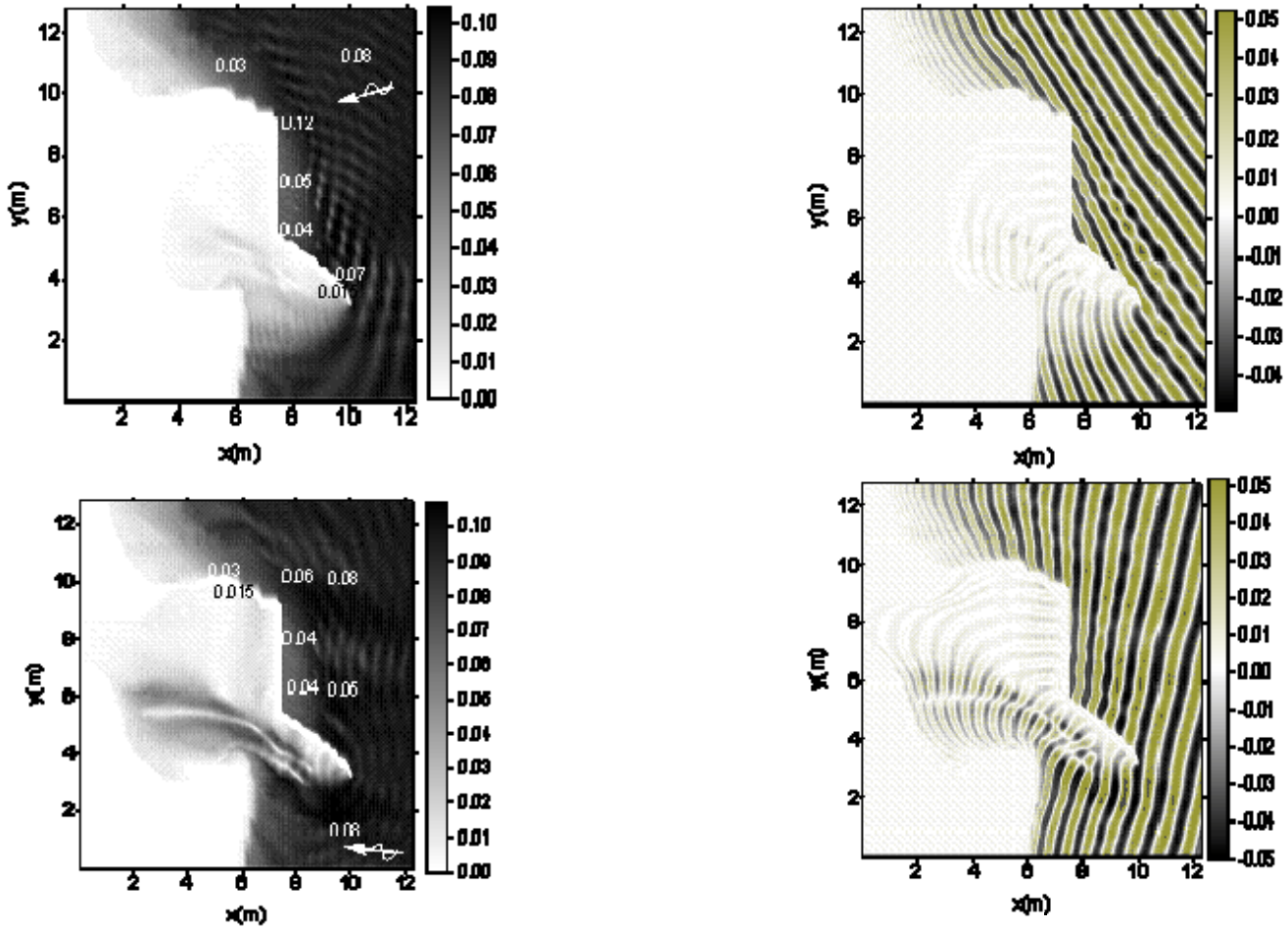
with designed long jetty



Wave heights simulated for the conditions of laboratory experiments

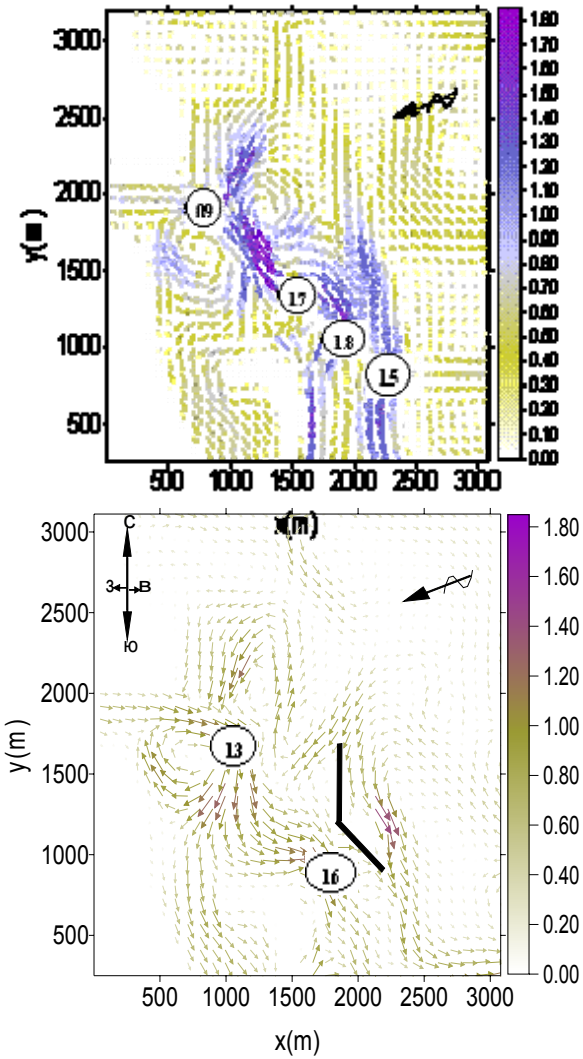
nd ESE waves without dike

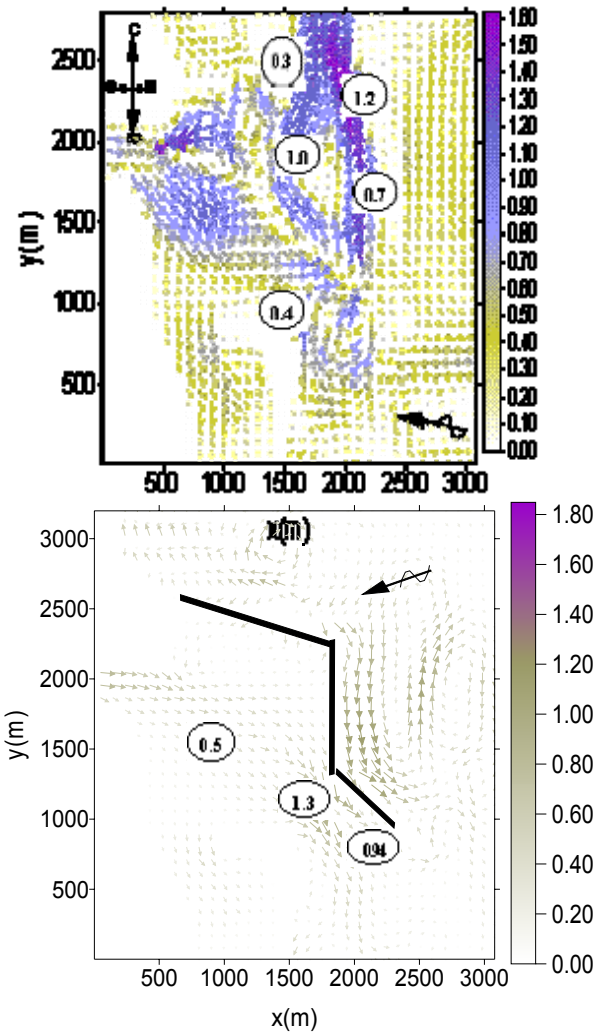
Wave heights and water surface elevation simulated for for the conditions of laboratory experiments



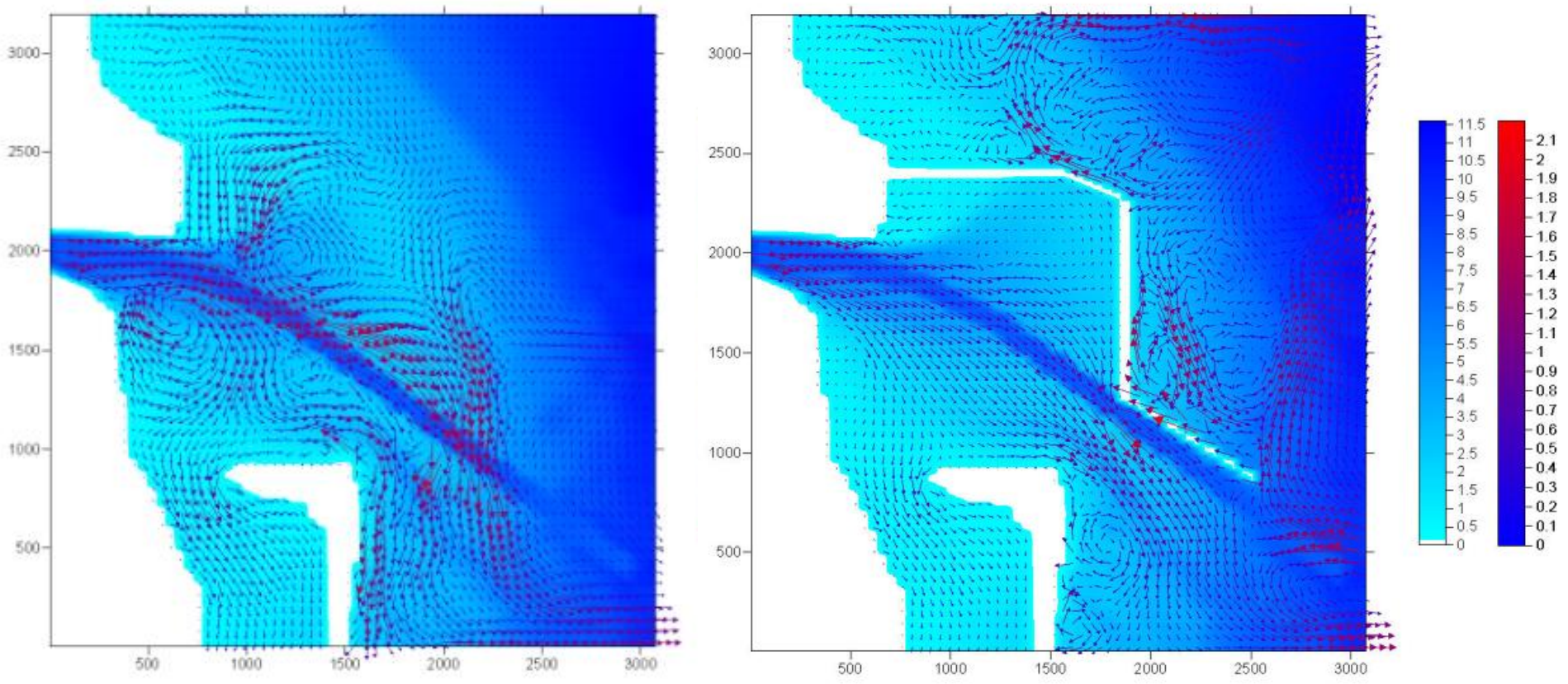
NE and ESE waves after long dike construction

Currents, generated by the river flow and waves, numerically simulated and recalculated from the measurements in the wave tank (white numbers)





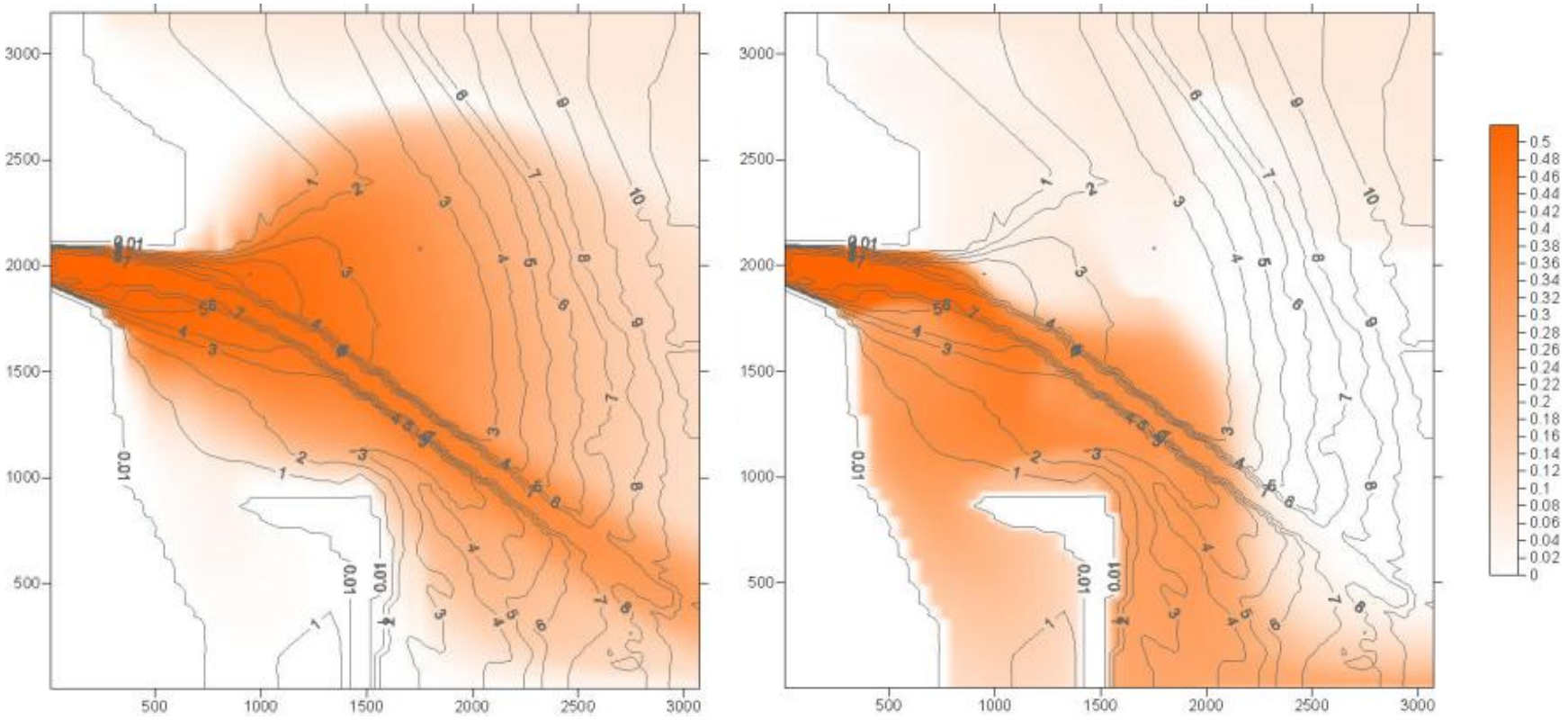
More detailed presentations of the currents fields in situation with and without the designed jetty and most frequent NE wave storm



Conclusion on waves and currents modeling :

- The measured in the wave tank and simulated wave fields before and after the construction of the jetty as also the measured and simulated fields of the wave & river driven currents are in reasonable agreements.
- Under wave storm impacts the significant transformation and increasing of the velocities take place in the area. Under most frequent NE waves impacts the currents with the velocities more than 1.5 m/sec are developing at the marine slope of the bar in the channel and two significant “jet currents” cross the channel at river slope and marine slope of the bar from N and NE respectively. After the long dike constructions these “jet currents” disappear and also will be diminished the intensity of longshore currents at east side of “Bird Cosa”
- In situations without storms the velocities between north-east end of the “Bird Cosa” and between the main coast and Bird Cosa will be slightly higher.
- The constructed in 2004 “short dike” did not provide significant impact on currents pattern in the area.

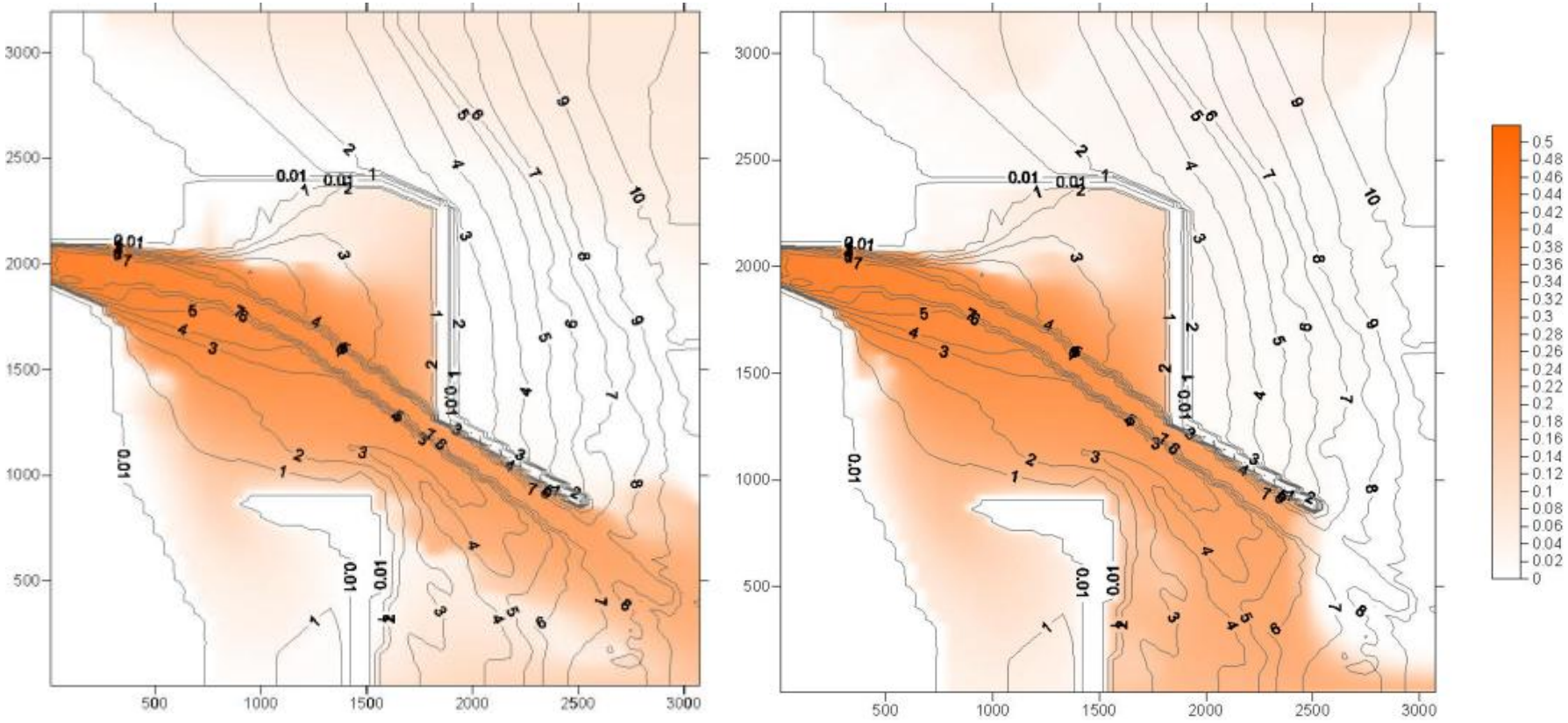
Suspended sediment (size 0.02 mm) concentration in the “no wave condition” and under NE waves without jetty



No waves

North-East waves

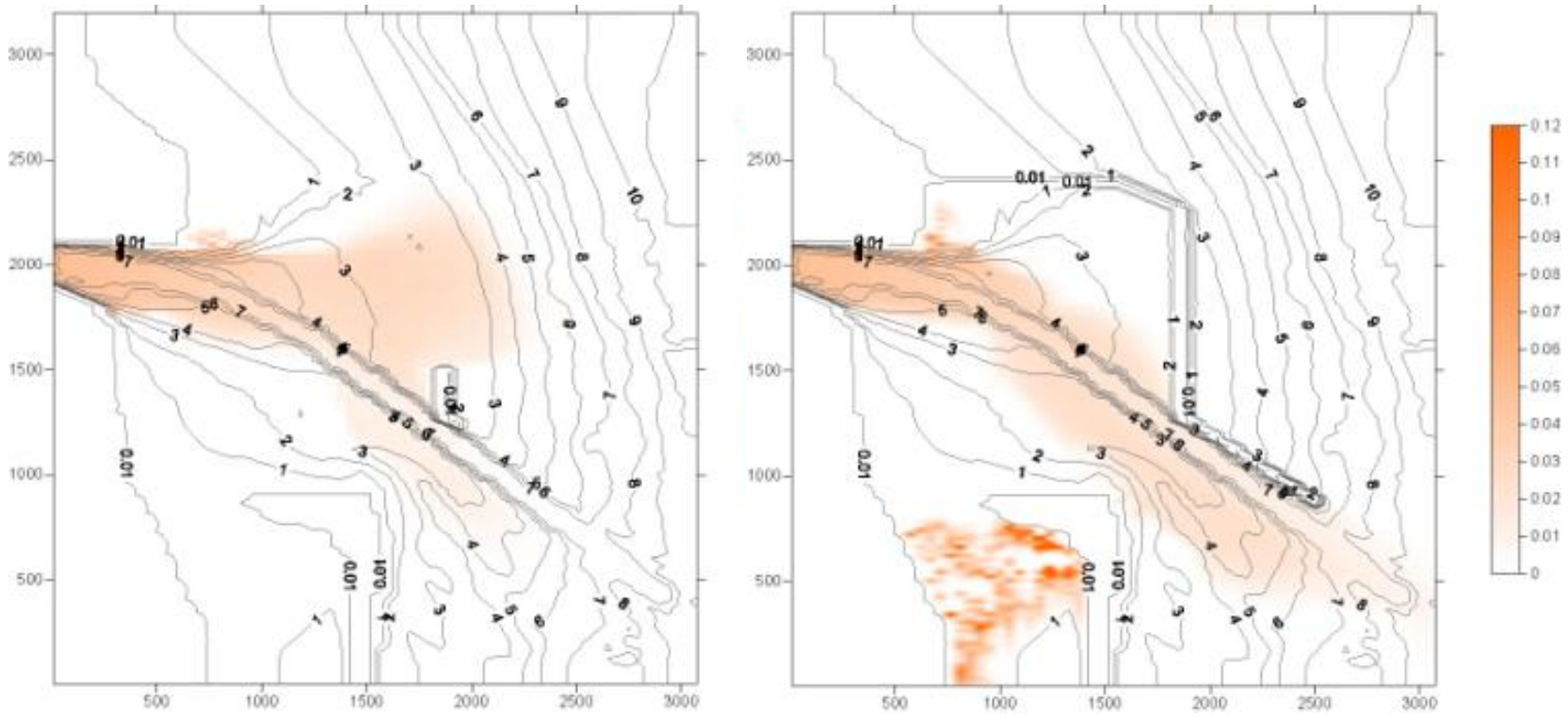
Suspended sediment (size 0.02 mm) concentration in the “no wave condition” and under NE waves with the designed jetty

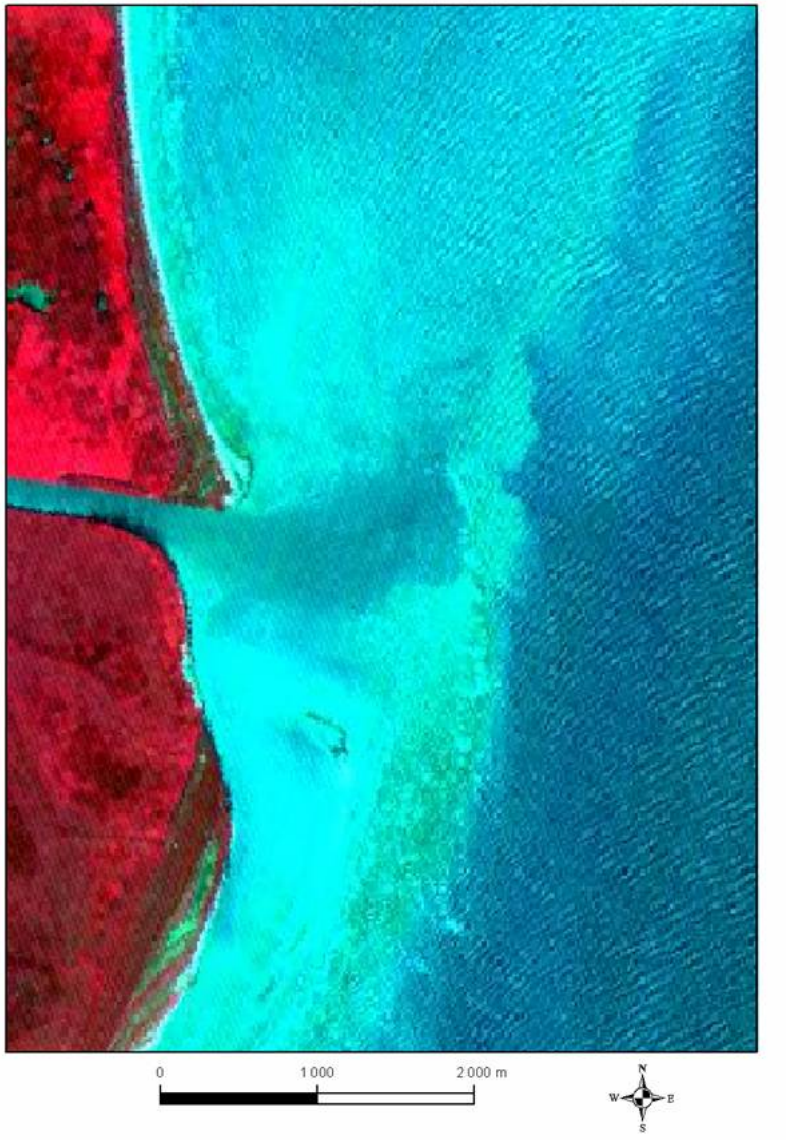


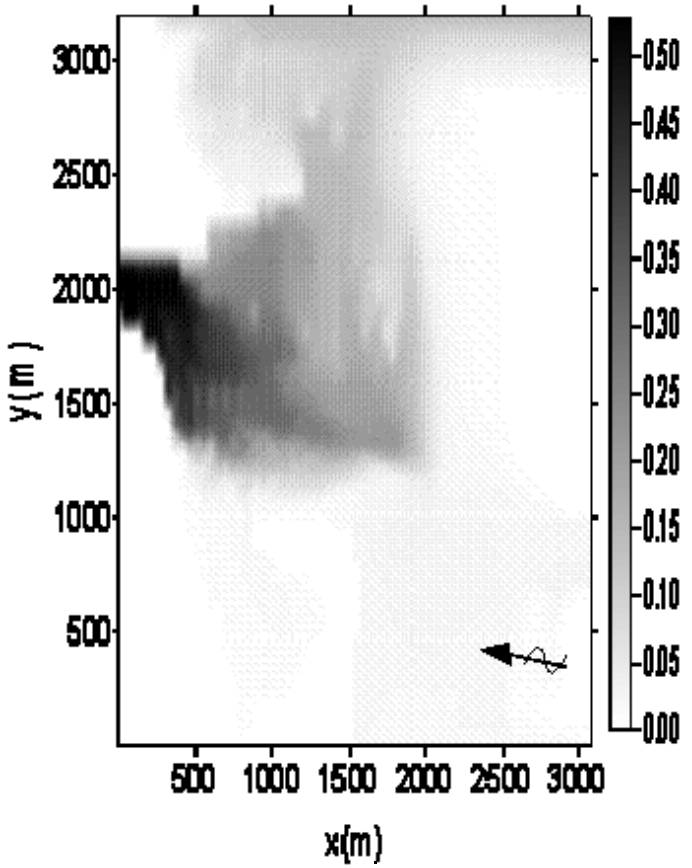
No waves

North-East waves

Suspended sediment (size 0.15 mm) concentration in the “no wave condition” with and without the designed jetty

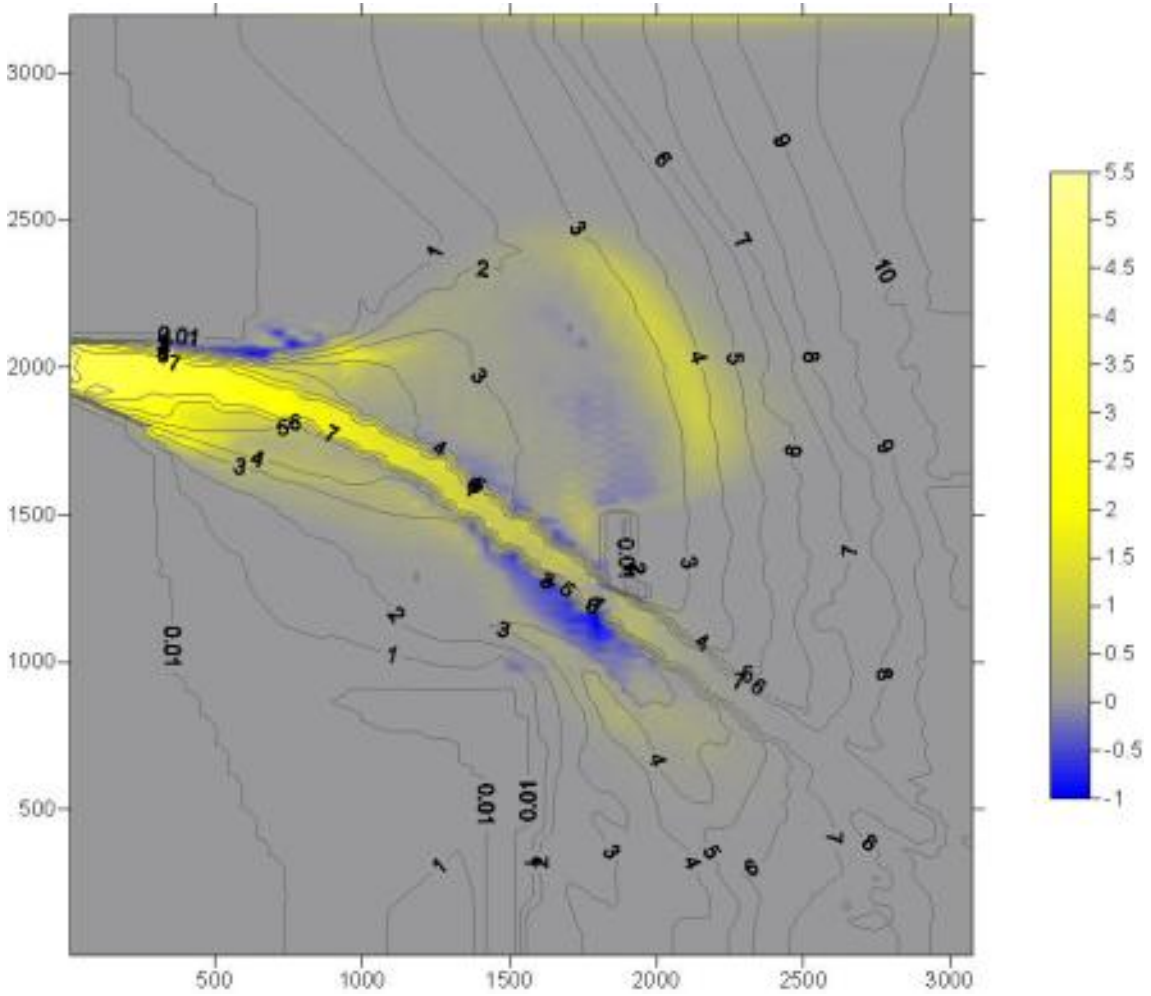




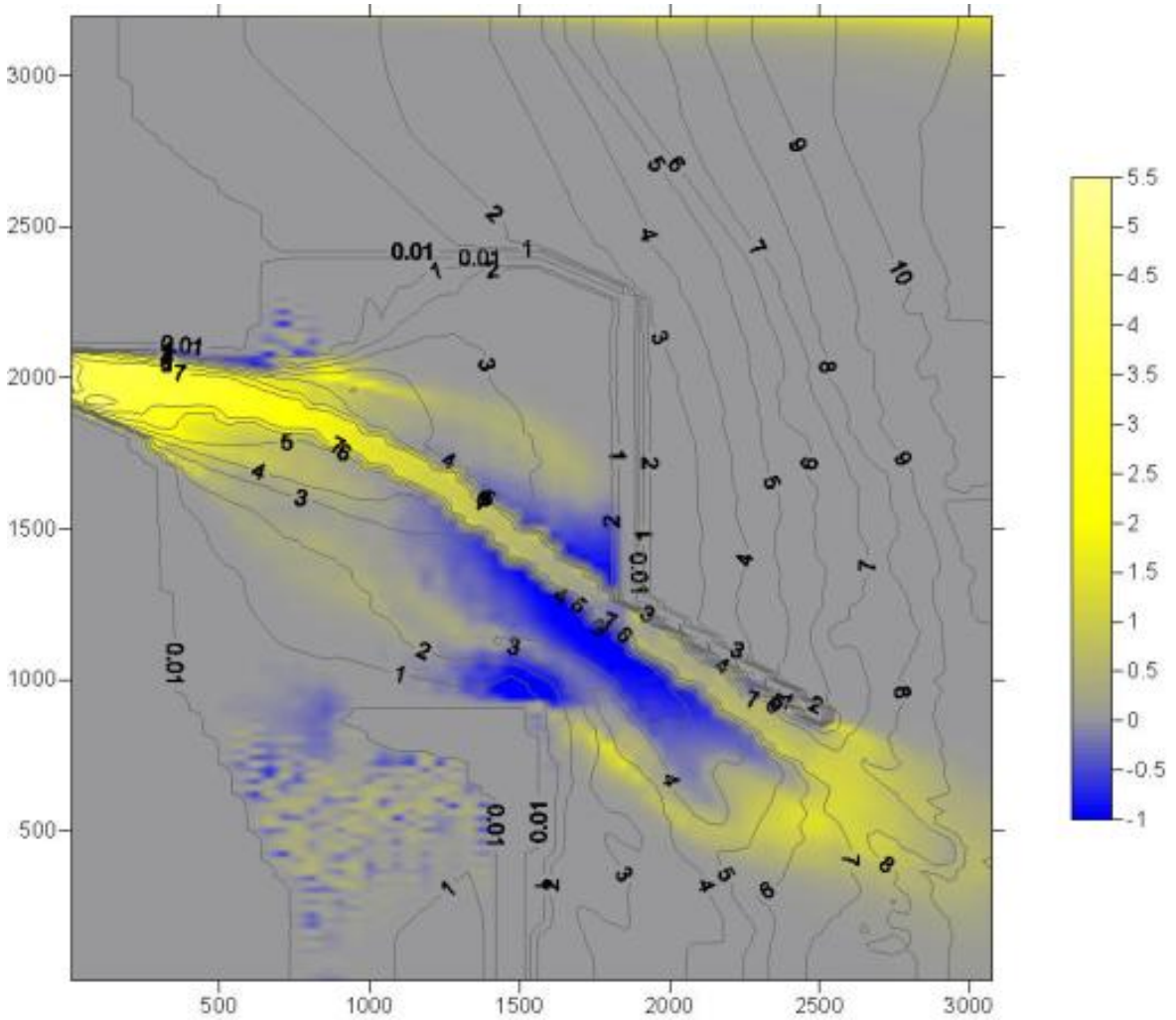


Simulated field of suspended sediments (d=0.02 mm) for the conditions of South-East- South waves and the satellite picture Terra (ASTER) 12.01.2001, which presents the image of river muddy water in the sea under the impact of South- East waves

Zones of sedimentation (yellow) and erosion (blue) for the suspended sediment size 0.15 mm concentration in the "no wave condition" for "short dike-2004" without jetty



Zones of sedimentation (yellow) and erosion (blue) for the suspended sediment size 0.15 mm concentration in the "no wave condition" for the long jetty



Conclusions :

- The comprehensive analyses of the wave fields and currents in the marine part the Deep Navigation Channel (DNC) was provided on the basis of laboratory and numerical models
- Sedimentation and littoral dynamics processes in the area of the bar are driven mainly by the sediment fluxes from Bystry and less are influenced by the marine sediments. Under the most frequent North and East- North waves the sediment from Bytry are propagated mainly southward, changing direction under much rare South- East waves
- Construction of the jetty will not prevent the sedimentation in the DNS at the river slope of the bar, because the jetty is designed at some distance from the DNC at this place. From other side any other construction – e.g. jetty at the slope of the DNC, two jetties from both side of DNC would provide the more significant impact on the coastal processes southward – erosion of the Bird Cosa (Island) due to the increasing of the currents in first case, and even more intensive erosion of the coast and the island in second case due to the cuts from the rivers sediment fluxes. Therefore the proposed configuration of the long jetty is not most efficient for the prevention of the sedimentation, however is most efficient for the prevention of the coastal ecosystems southward from DNC.
- The construction of the long jetty will prevent the formation of two the Northern alongshore currents that cross DNC during most frequent North Eats and North wave storms, intensifying the sedimentation of the channel in these areas, that was realy filled by sand after the end of the Phase1 of the project.
- After the constriction of the long dike it will be intensification of the water exchange between Bird Cosa Island and main coast and it will be re-sedimentation of the sediments eroded from the south slope of DNS to the east coast of Birds Cosa. Both processes will promote the stabilization Bird Cosa as a separate ecosystem.
- The main southward direction of the dispersion of the sediments released from Bystry will not be changed by the jetty, that prevent only northward propagation of the sediments in the bar area. Therefore the construction will not have significant impact on the littoral processes in the area from DNS to Ukrainian- Romanian Border
- The rare southward propagation of the sediments under impact of SE wave storms will not influence significantly the coastal erosion in this area, because main North- South alongshore sediment current in the North- West part of the Black Sea will compensate here the lack of the Bystry's sediment
- The jetty will promote the "pushing" of the Bystry sediment to the end of the jetty – i.e. into the area of the depth 8-9 m. From here the sediment will be transported southward by the North- South alongshore current without significant changes in the natural intensity of this process.