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Krk Submarine Outfall: Prediction of effects on a marine ecosystem

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1) The problem

A structure such as submarine outfall, aquaculture or subsurface marine structures must not be located in *Posidonia* beds, other protected or endangered communities + zonation rules must be observed.

The problem becomes to design the shortest submarine outfall to satisfy the law i.e. that 200 m off-shore from the nearest public beach, the concentration of TCB, FC and FS must be smaller then 5000, 1000, 1000 /l.

The TCB at the source may be up to 10^13 TCB/l.

2) Brooks approach: an iterative procedure over three steps:

a) The initial dilution, D1, during which waste water forms a cloud above the source;

b) Secondary dilution, D2, during which waste water disperses through the water column into the area;

c) Extinction, D3 - bacteria die during transport in the sea.

The total ‘dilution’ is: TD = D1 * D2 * D3.

CD is the critical dilution needed. Hence, if:

TD > CD the submarine outfall may be shortened,
TD = CD the length of the outfall has been found
TD < CD the outfall must be longer.

An iterative procedure solves the problem if D1, D2 and D2 are given as functions of ambient conditions: bathymetry, seawater density structure, currents, light intensity, seawater state (temperature and salinity), wastewater characteristics, outfall characteristics and the type of bacteria.

In Brooks approach functions are approximations to the solution selected beyond the worse case and hence the outfall is likely to be longer than needed. MAP even worse.

How much longer ?

This is difficult to estimate precisely without detailed data. Our search for the data yielded miserable results. We examined “a lots of data” around submarine outfall of Rijeka – the best data set: 3 stations, visited 10 times during summer.

Ad hoc estimates

For D1 one calculates the height to which the cloud is going to rise during initial dilution. This is usually 10 to 20 meters.
If the outfall is at 50 m depth, this means that the initial cloud rises to 30 m below the surface. This layer is then assumed for secondary dilution. If the layer is of a homogeneous depth, and the Brooks approximation is good, then the outfall length would be calculated correctly.

If the layer toward the coast is of a decreasing depth (regularly), then: How far from the coast is the depth of 30 m ?
If it is further from 200 m, the outfall is too long, if it is closer than 200 m, it is too short.

The estimate may easily be double the required length – Especially using MAP's recommendation. One outfall costs from 1 to 2 M $. Croatia is building about 50 new outfalls.

The numerical method

The alternative is to follow a FE or FD approach and integrate the equations of motion to get as good as possible approx. to the 3+1 dim currents field. Given the fact that the approx. of the bathymetry is better captured by FE: it should be used. Bussinesq with hydrostatic approx. is:

$$\frac{\partial v}{\partial t} + v \cdot \nabla v + w\frac{\partial v}{\partial t} + f \times v = -g\nabla\zeta - \frac{g}{\rho_o}\int_z^\zeta \nabla_h \rho dz + \nabla(A_h \nabla \cdot v) + \frac{\partial}{\partial z}(N_m \frac{\partial v}{\partial z})$$

The transport equation for salt (and temperature):

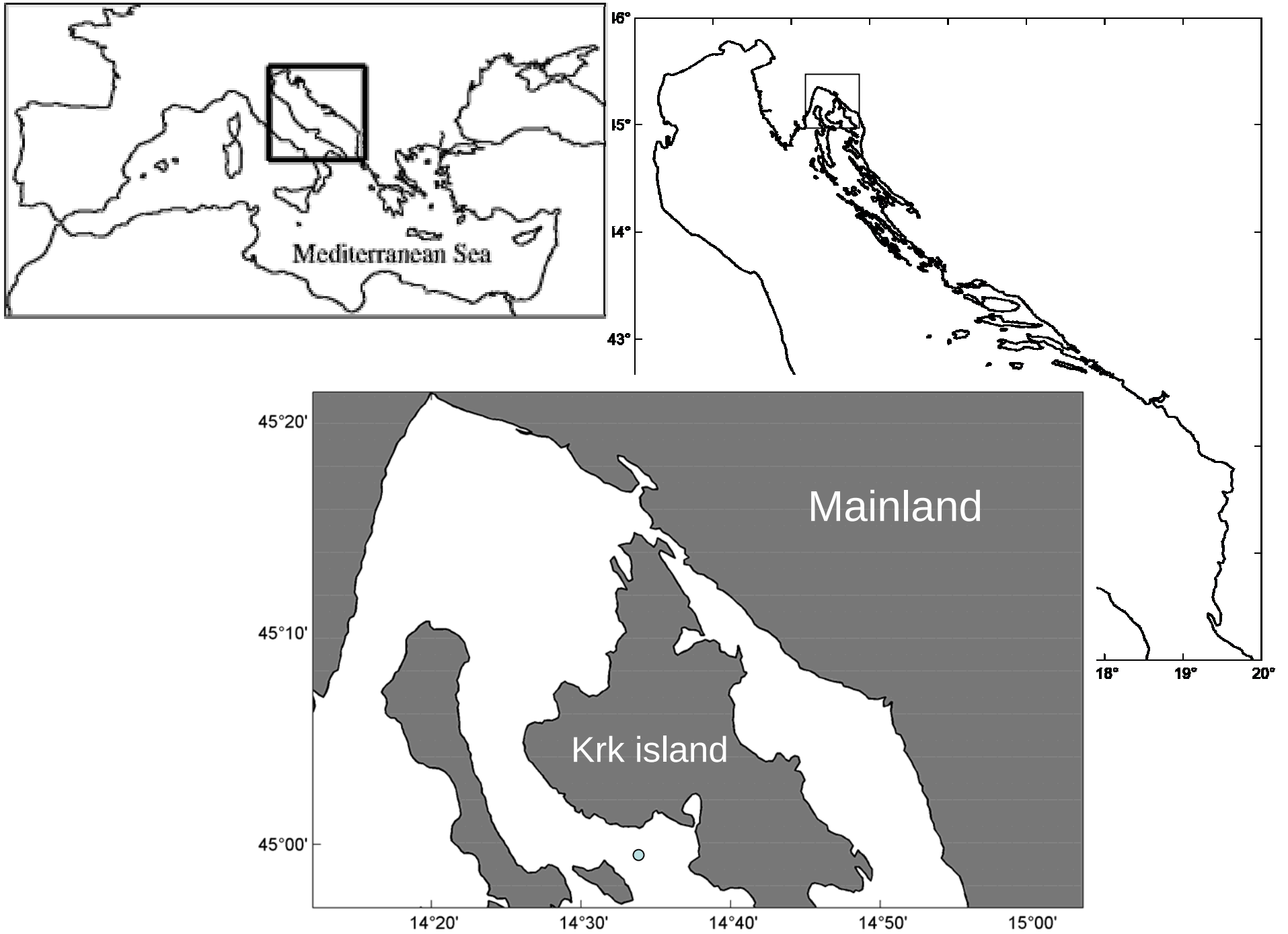
$$\frac{\partial C}{\partial t} + v \cdot \nabla C + w\frac{\partial C}{\partial t} = \nabla(A_h \nabla \cdot C) + \frac{\partial}{\partial z}(N_h \frac{\partial C}{\partial z}) - r \cdot C$$

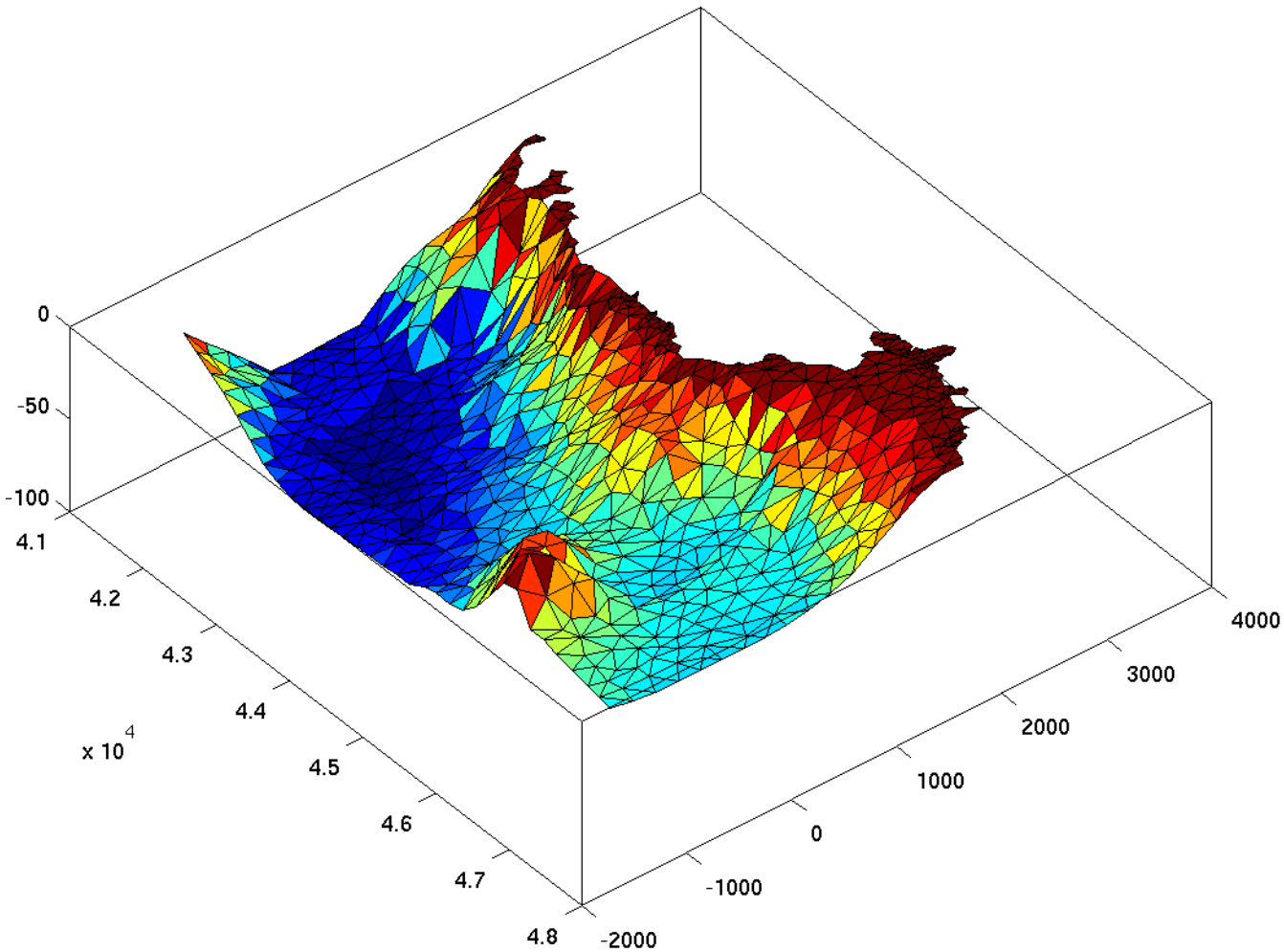
The transport equation for bacteria concentration C:

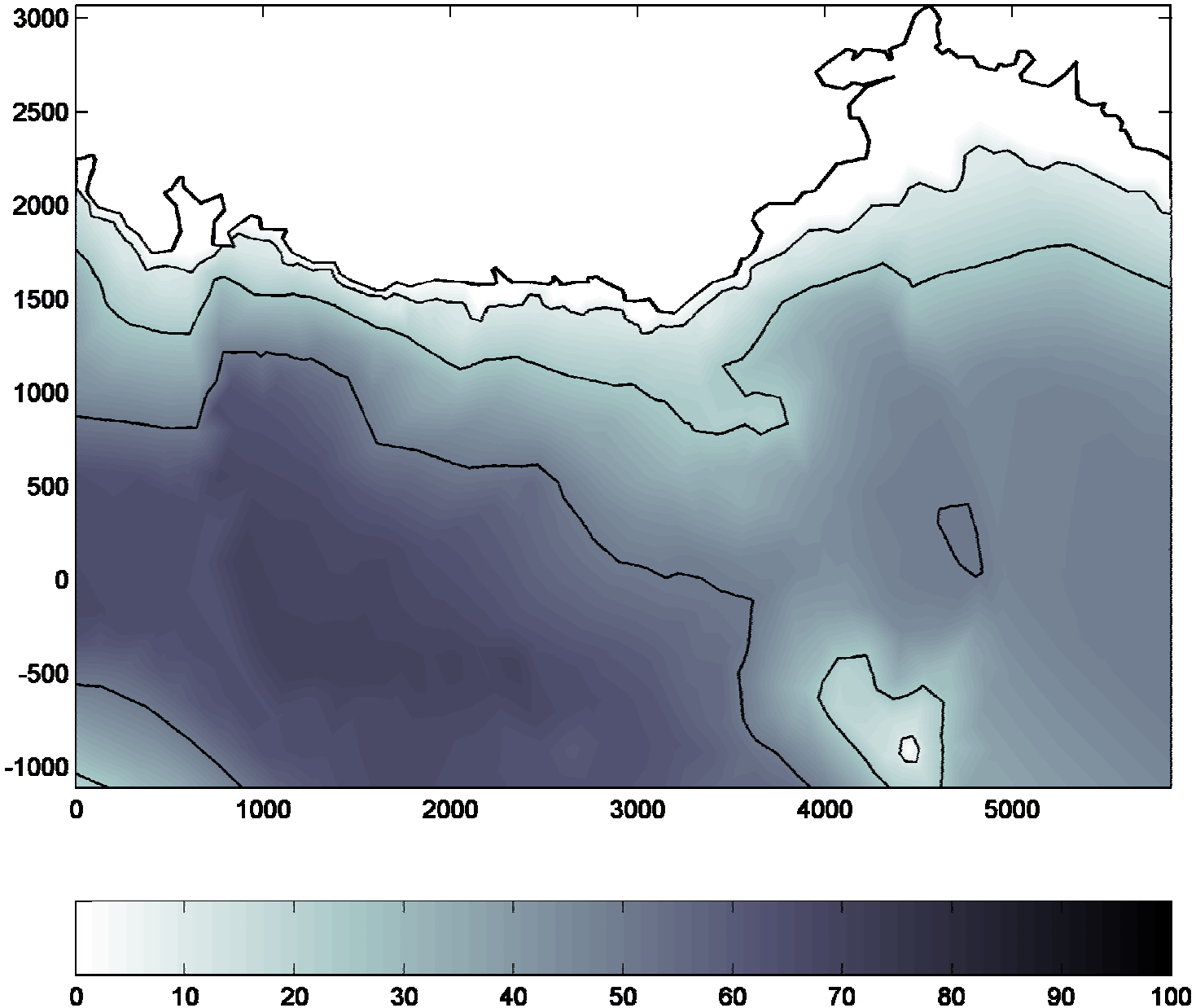
$$\frac{\partial C}{\partial t} + v \cdot \nabla C + w \frac{\partial C}{\partial t} = \nabla (A_h \nabla \cdot C) + \frac{\partial}{\partial z} (N_h \frac{\partial C}{\partial z}) - r \cdot C$$

where r is a decay rate.

Discretize with high spatial and time resolution (10 s).
Use variable density of the mesh (from 100 m to 7 m).


Mediterranean Sea
16°
15°
14°
43°
18°
19°
20°
45°20'
45°10'
45°00'
Mainland
Krk island
14°20'
14°30'
14°40'
14°50'
15°00'


0
-50
-100
4.1
4.2
4.3
4.4
x 10^4
4.5
4.6
4.7
4.8
-2000
-1000
0
1000
2000
3000
4000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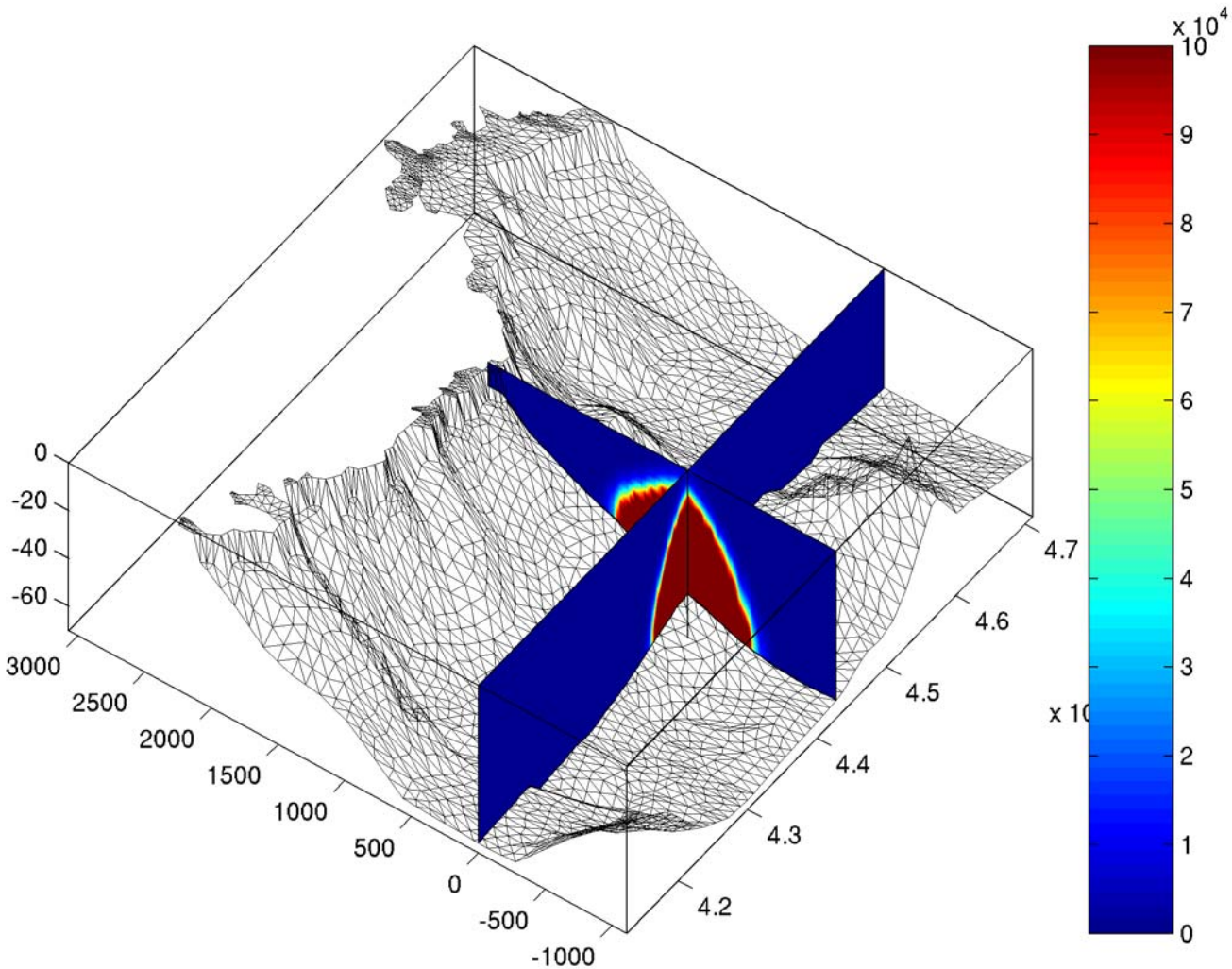
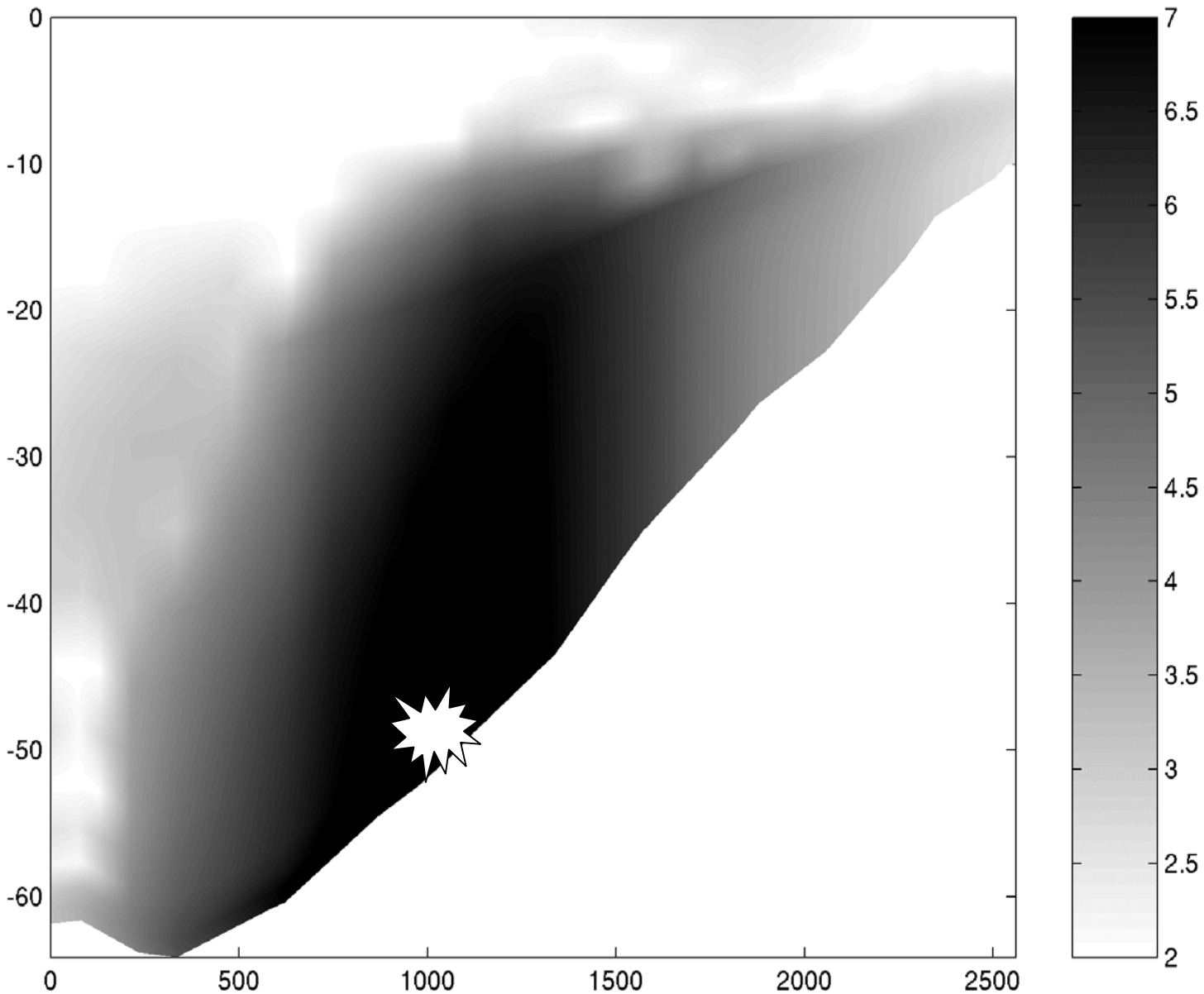
2500
2000
1500
1000
500
0
-500
-1000
0
1000
2000
3000
4000
5000
0
10
20
30
40
50
60
70
80
90
100


x 10^4
10
9
8
7
6
5
4
3
2
1
0
0
-20
-40
-60
3000
2500
2000
1500
1000
500
0
-500
-1000
4.2
4.3
4.4
4.5
4.6
4.7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-10
-20
-30
-40
-50
-60
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2500
7
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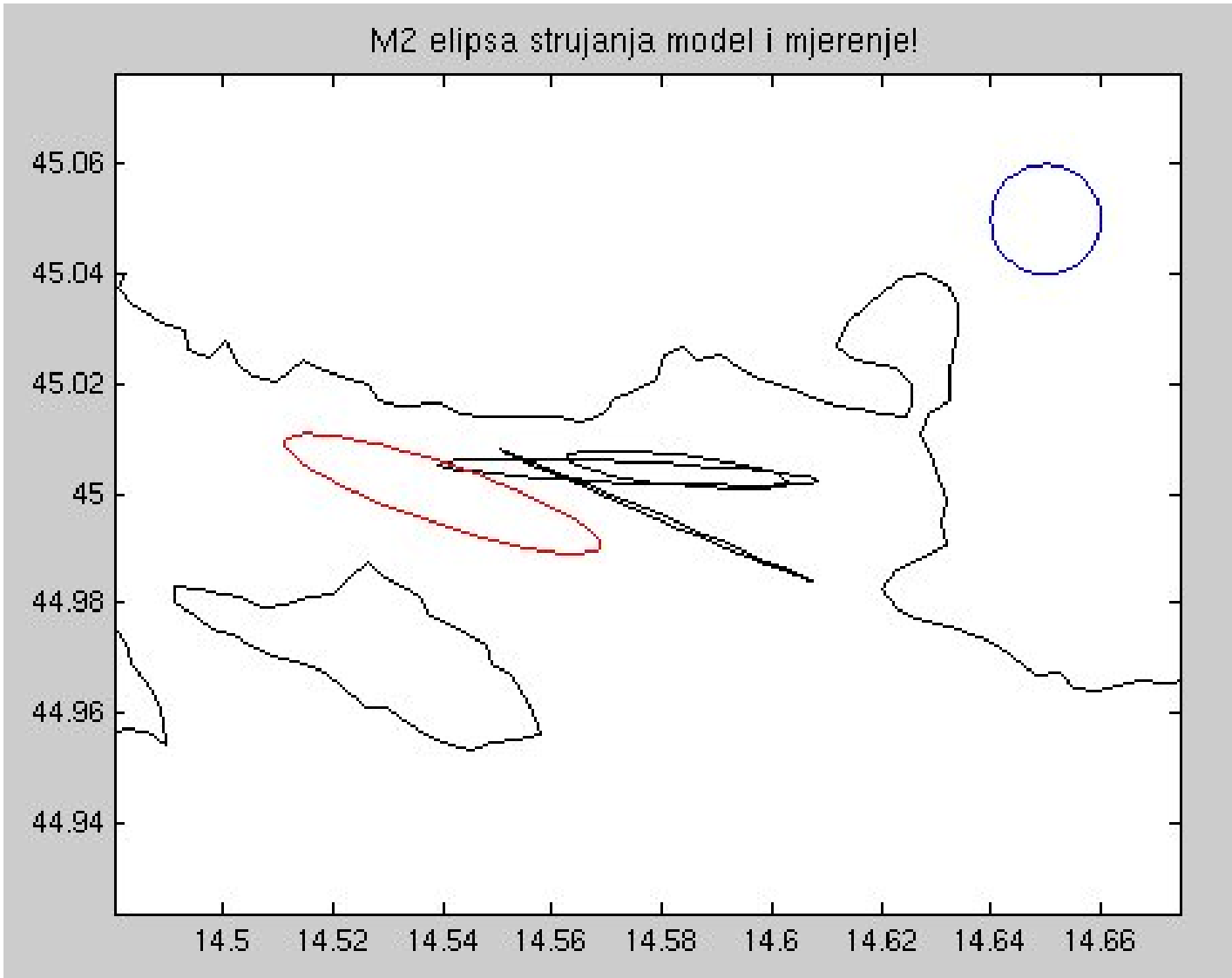
5
4.5
4
3.5
3
2.5
2


M2 elipsa strujanja model i mjerenje!
45.06
45.04
45.02
45
44.98
44.96
44.94
14.5
14.52
14.54
14.56
14.58
14.6
14.62
14.64
14.66

What other effects are important ?

1) Eutrophication of the Rijeka Bay

With the inflow, the eutrophication increases (below 5 %).

2) Hypoxia on the bottom

Depending on the pretreatment, but not likely.

3) Displacement of benthic organisms

Yes. In the vicinity up to 200 m. Wastewater is rising, we do not expect it to move along the bottom.

VERIFICATION ?

Effect of an increased inflow of fresh water to the bay

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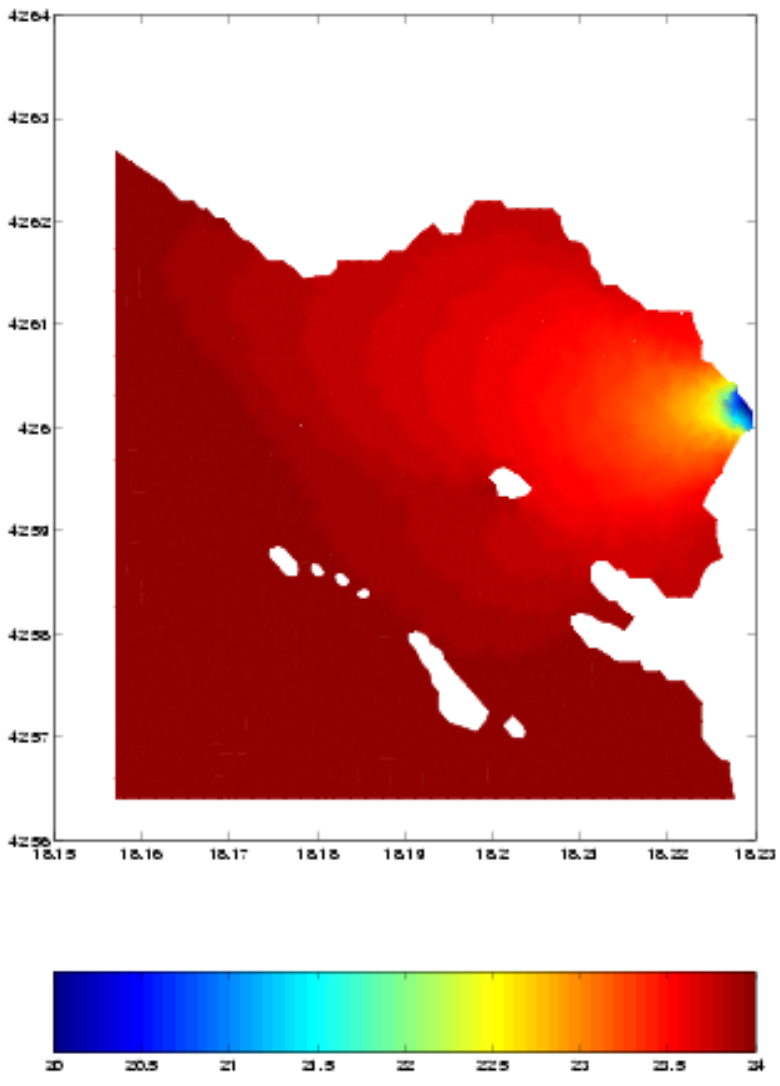
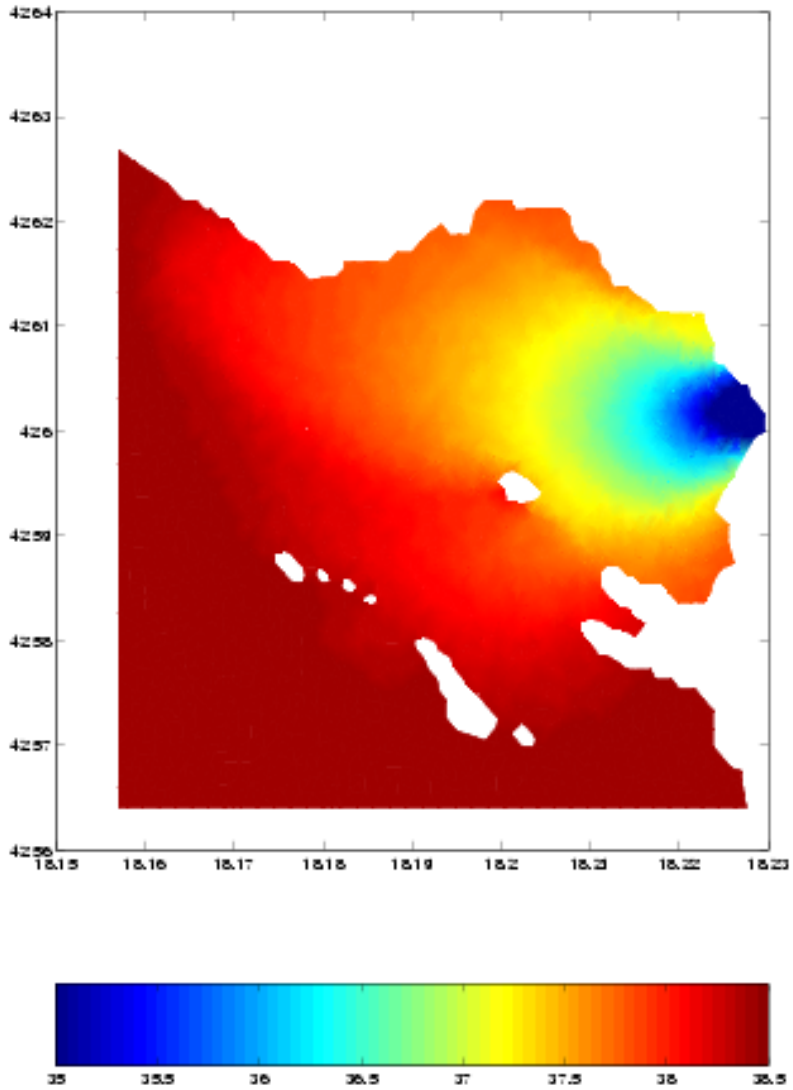
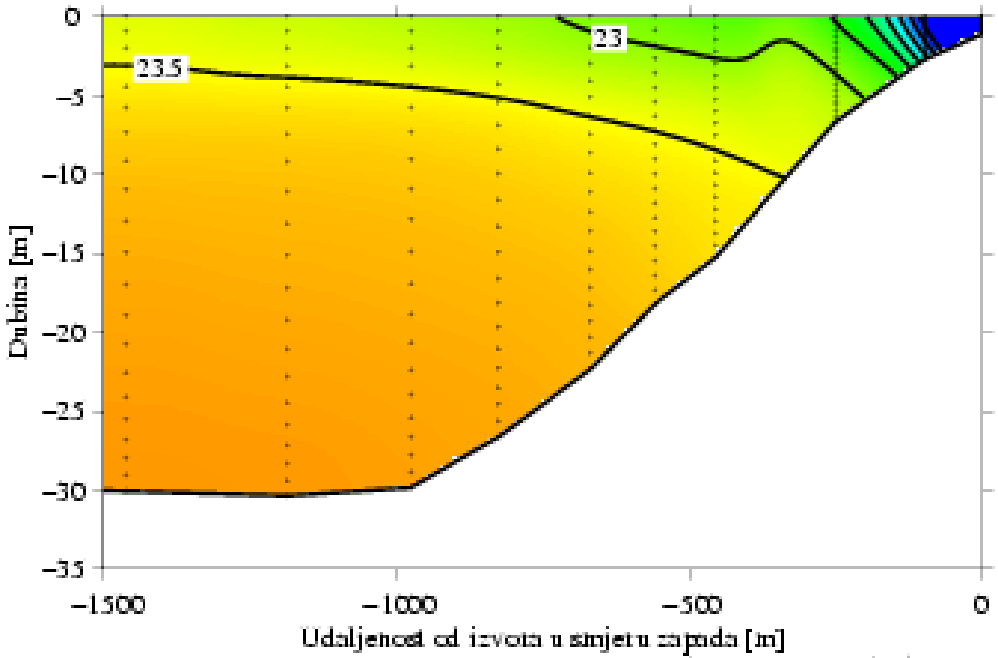




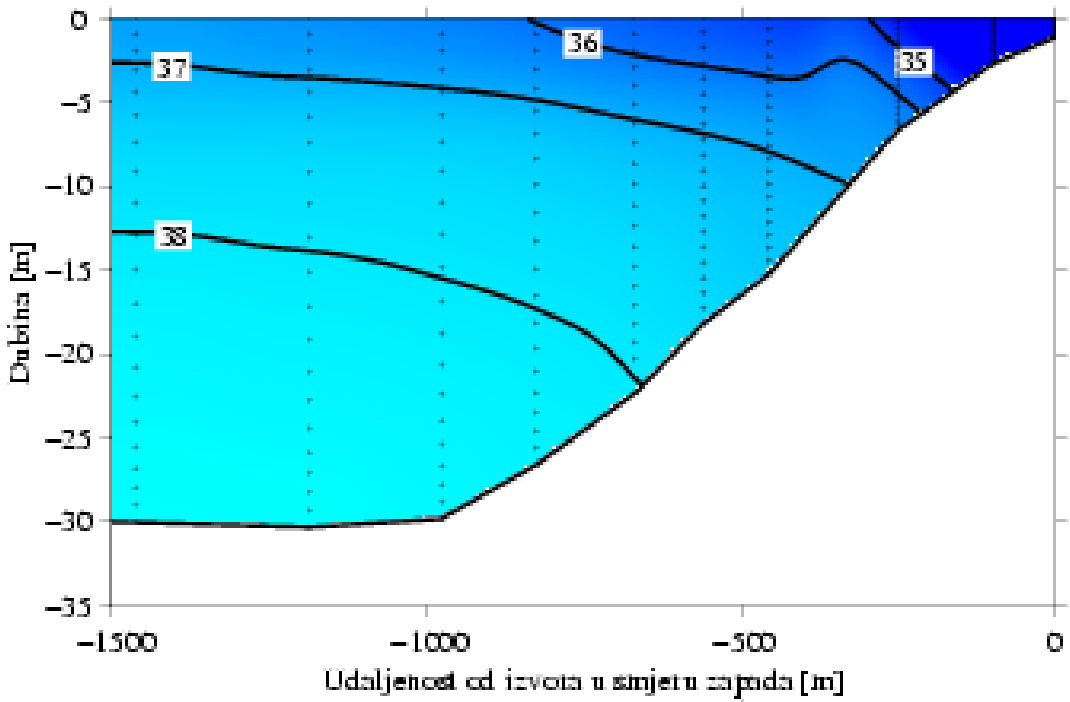


<= Vertical slice:

Temperature

Vertical slice: =>

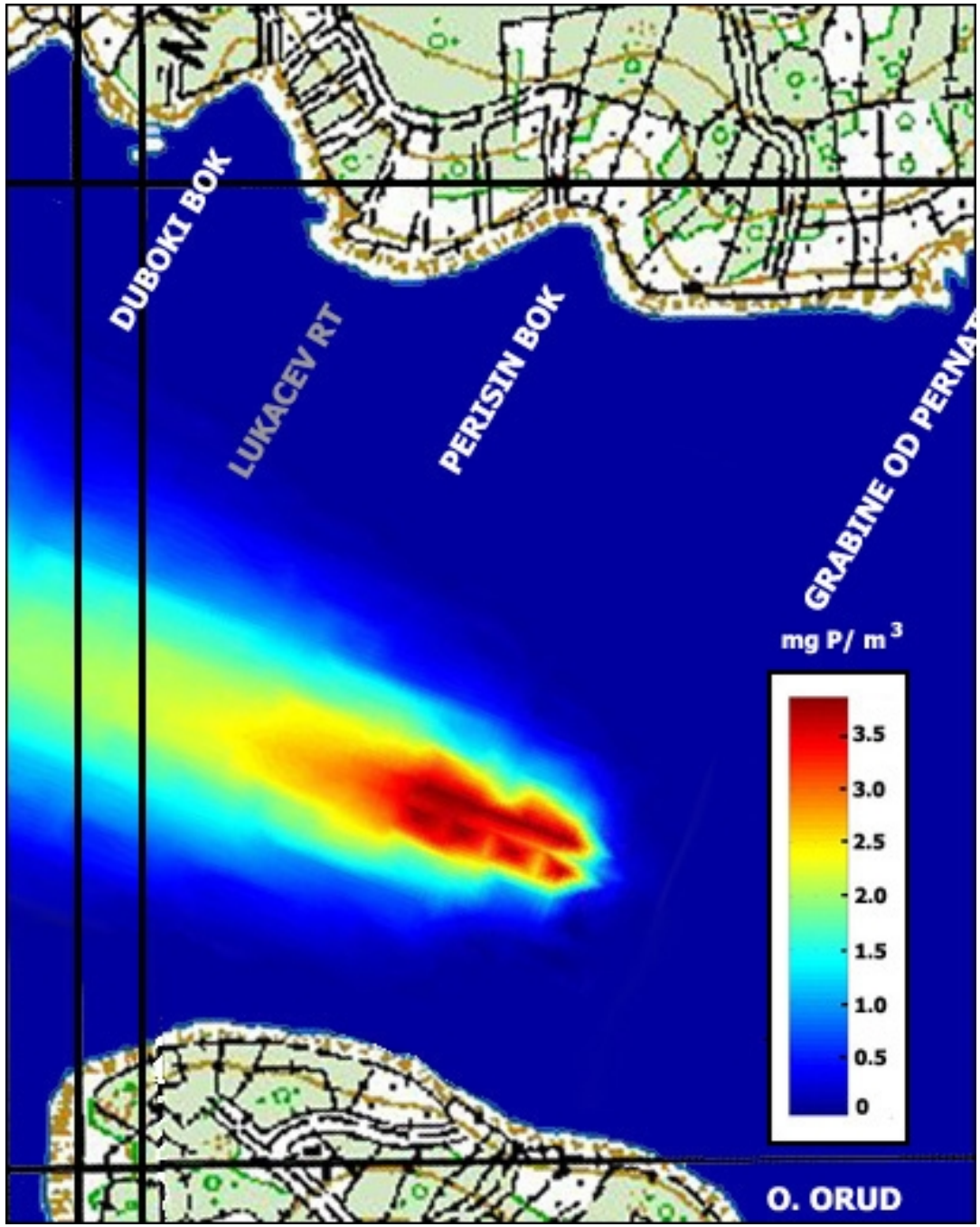
Salinity



Effect of an Aquaculture to the water column

Prediction of elevated P concentrations using a 3D model.

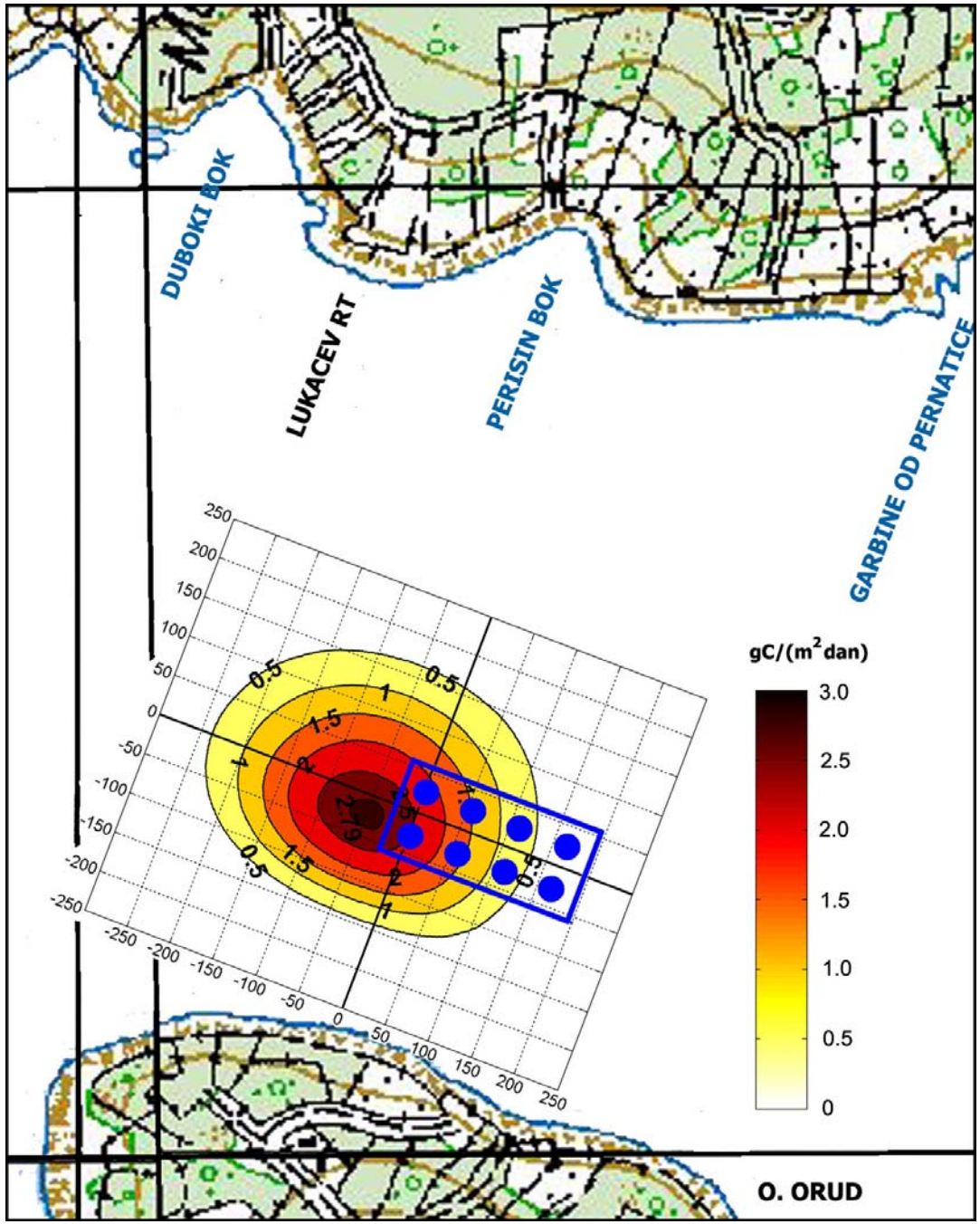
Surface =>



Effect of an aquaculture to the bottom

Prediction using 3 D model:

Influx to the bottom =>



Thank you !

A view to a cave. Depth 5 m. Courtesy of Donat Petricioli.