Sediment transport and morphology changes in river mouths and estuaries

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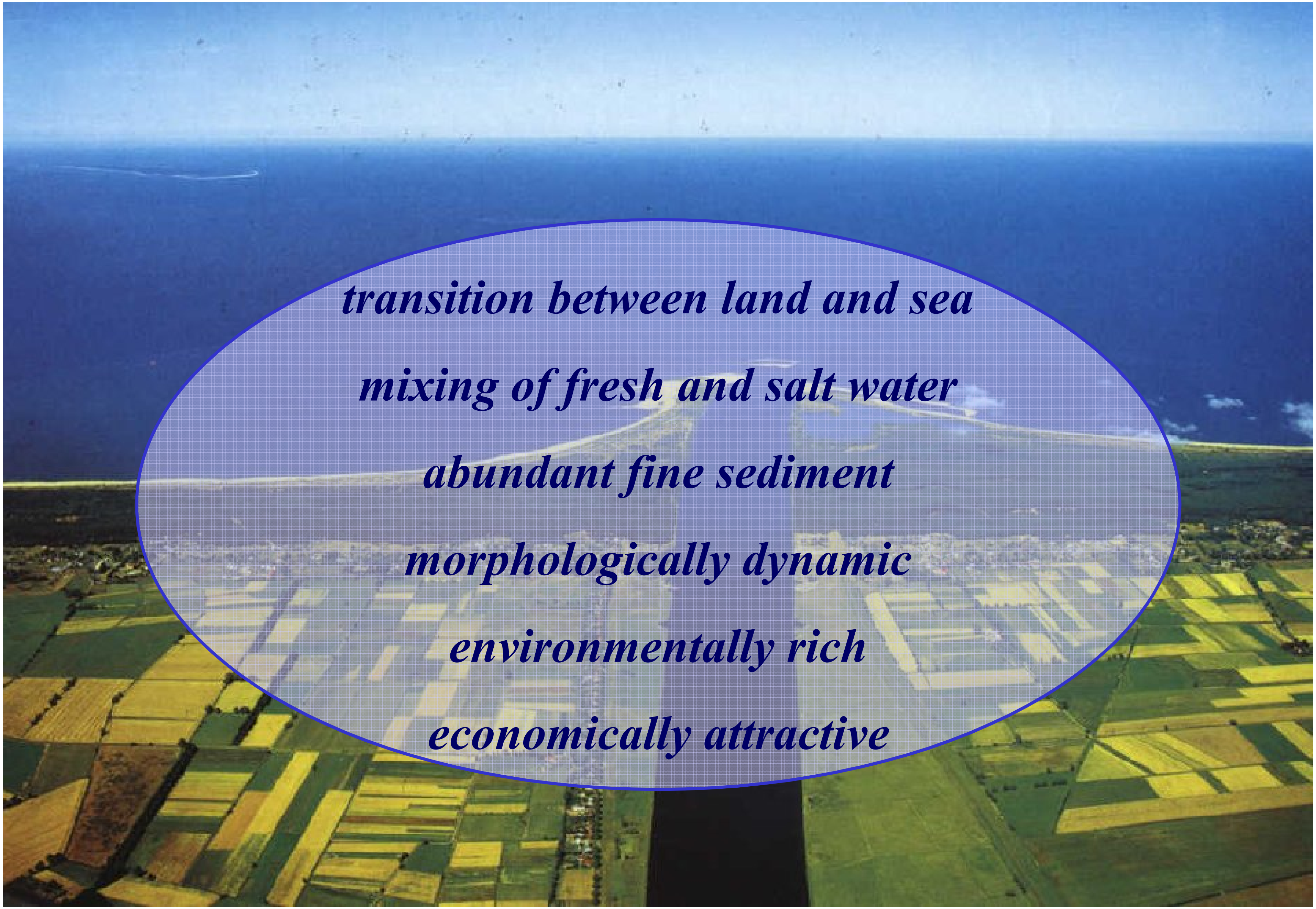
International Conference on the Dynamics of Coastal Zone of Non-Tidal Seas

Baltiysk (Kaliningrad Oblast), 30 June – 5 July, 2008

IBW PAN


transition between land and sea
mixing of fresh and salt water
abundant fine sediment
morphologically dynamic
environmentally rich
economically attractive

Scales of processes

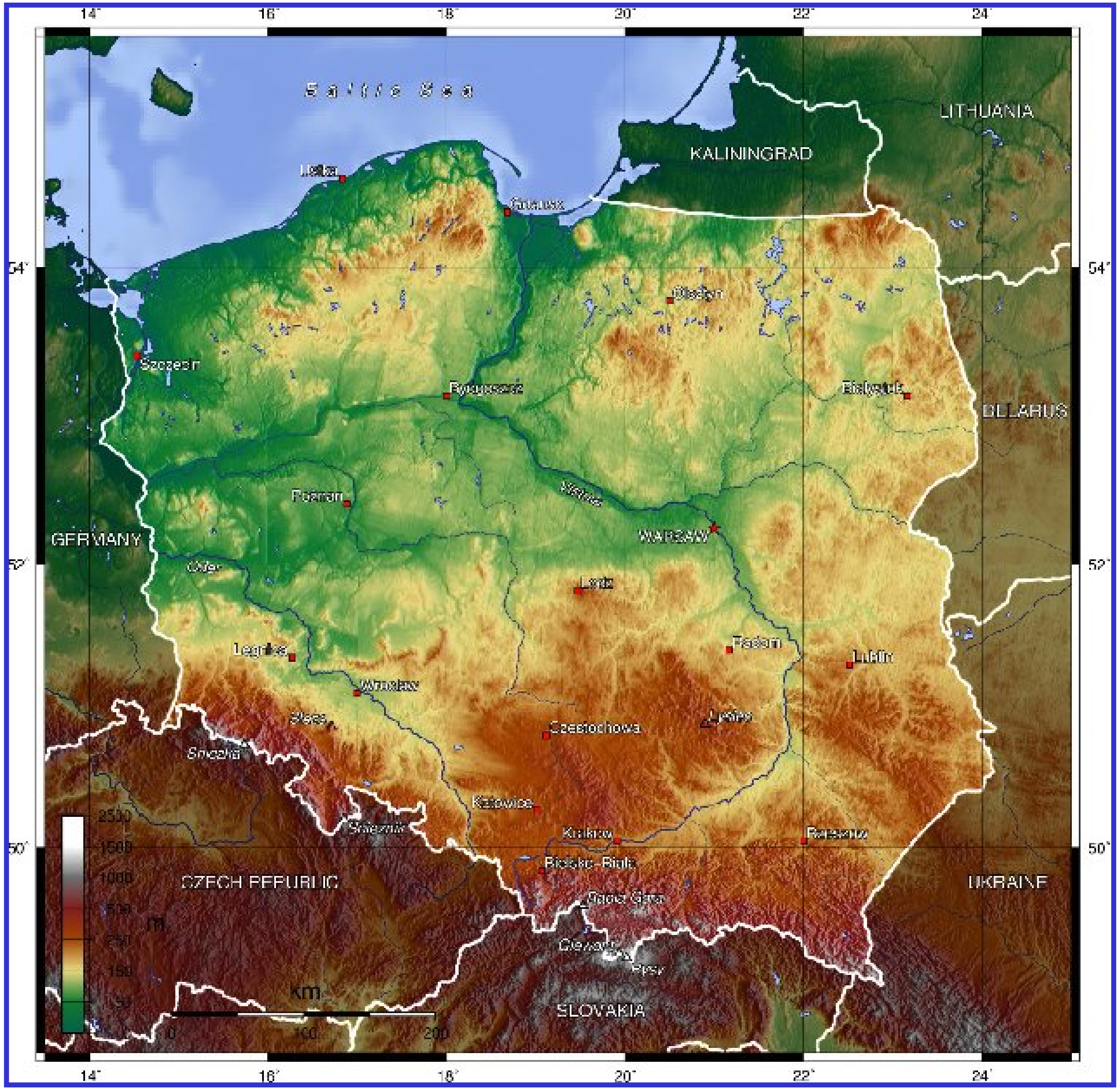
Micro-scale - concerning small scale flow, sediment transport (grain-grain, sand-mud interactions), morphological processes (bed ripples)

Meso-scale - sub-system elements (individual channels, shoals in one sub-basin of a coastal lagoon)

Macro-scale - sub-system as a whole (e.g. formation of channel patterns within an estaury)

Mega-scale - the system as a whole (e.g. behaviour of an entire lagoon system)

Vistula River and its estuary



length - 1047 km

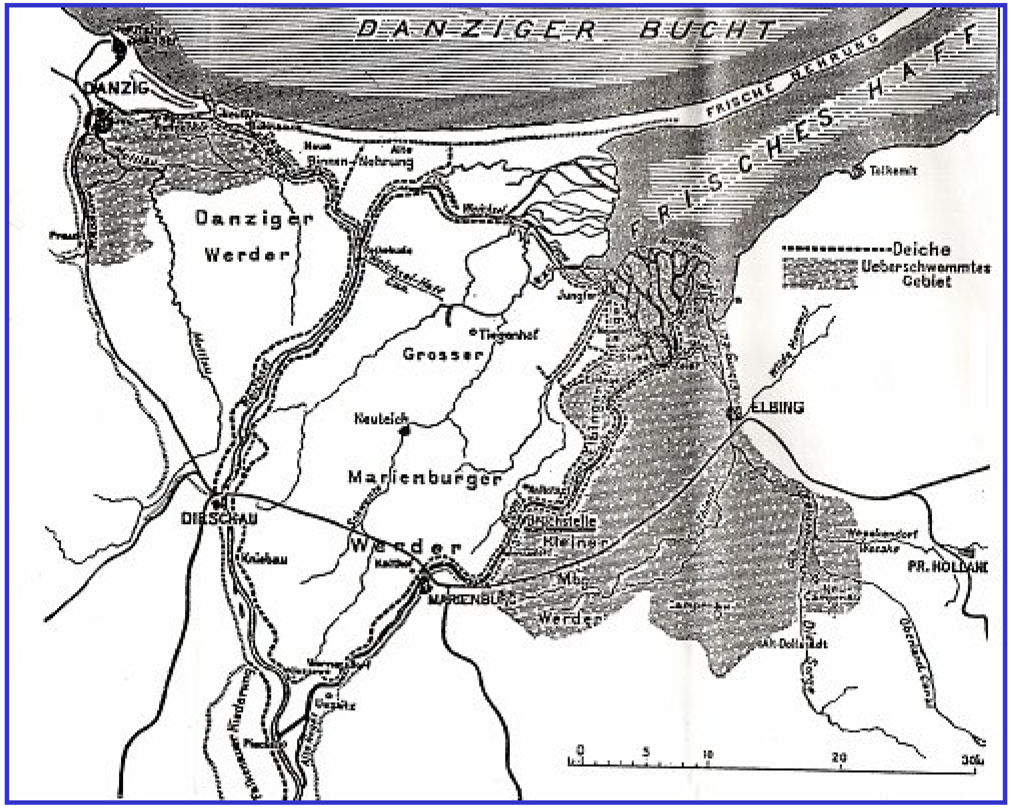
catchment - 194 000 km^2

Q_{mean} - 1080 m^3/s

Q_{min} - 253 m^3/s

Q_{max} - 7840 m^3/s

Vistula River mouth - history

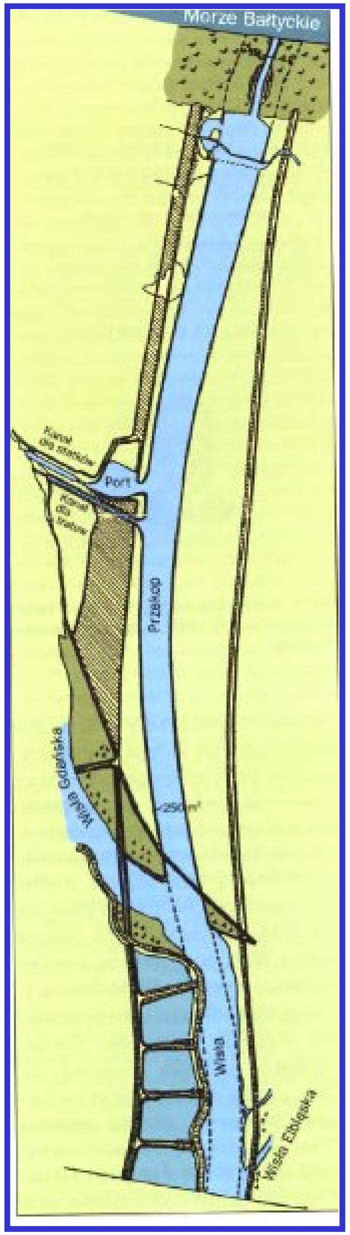


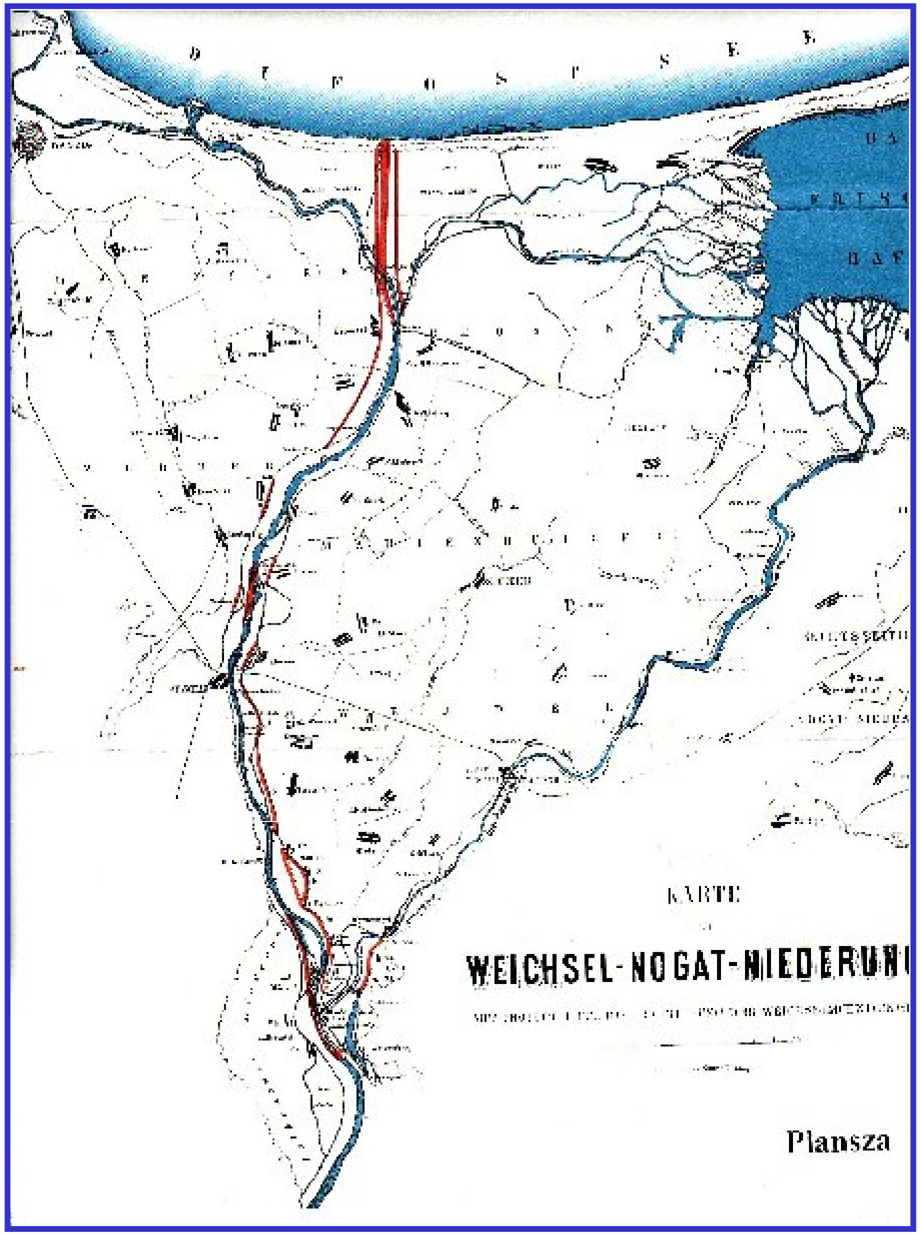
XVIII century

1700, 1706, 1709, 1713, 1717-1721, 1736-1738, 1742, 1744-1745, 1749, 1761, 1764-1765, 1780, 1782, 1785, 1789, 1794, 1813, 1816, 1829, 1855

~10000 inhabitants lost houses
cost of damage: 30 mln Preussian mark
(~120 mln USD today)

Regulation 1890 - 1895

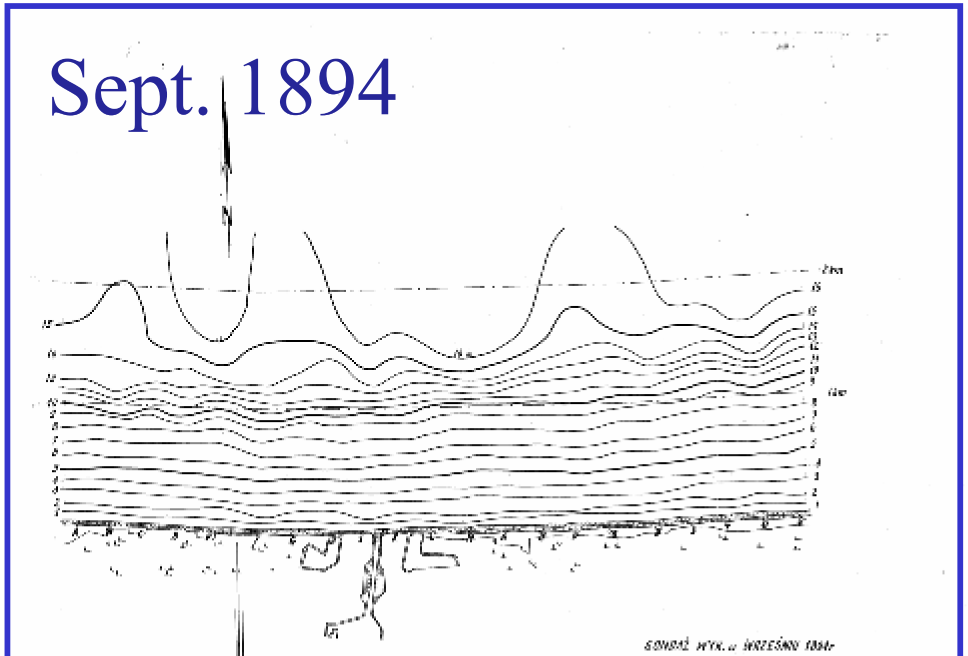




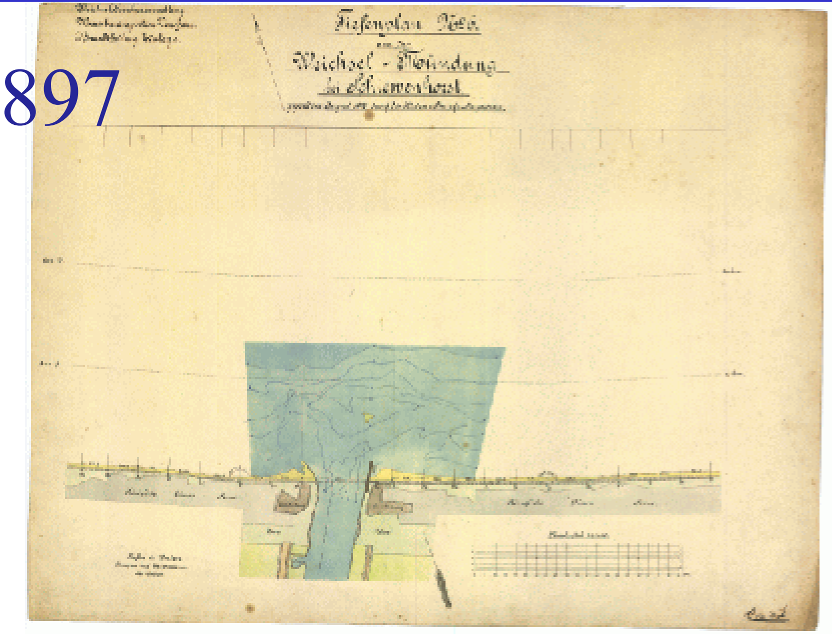
opening

<u>31.03.1895</u>

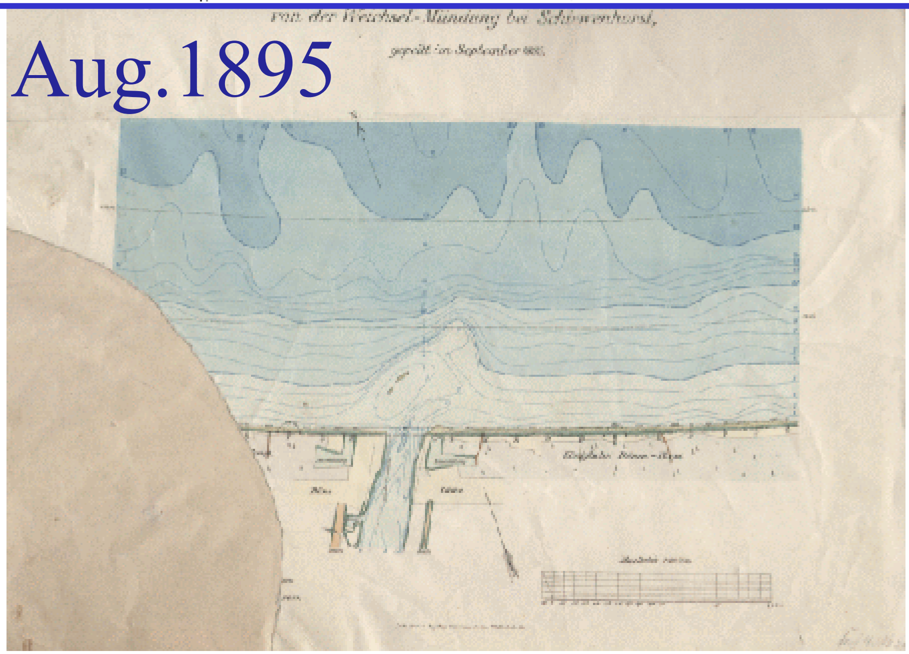
Regulation – short term consequences



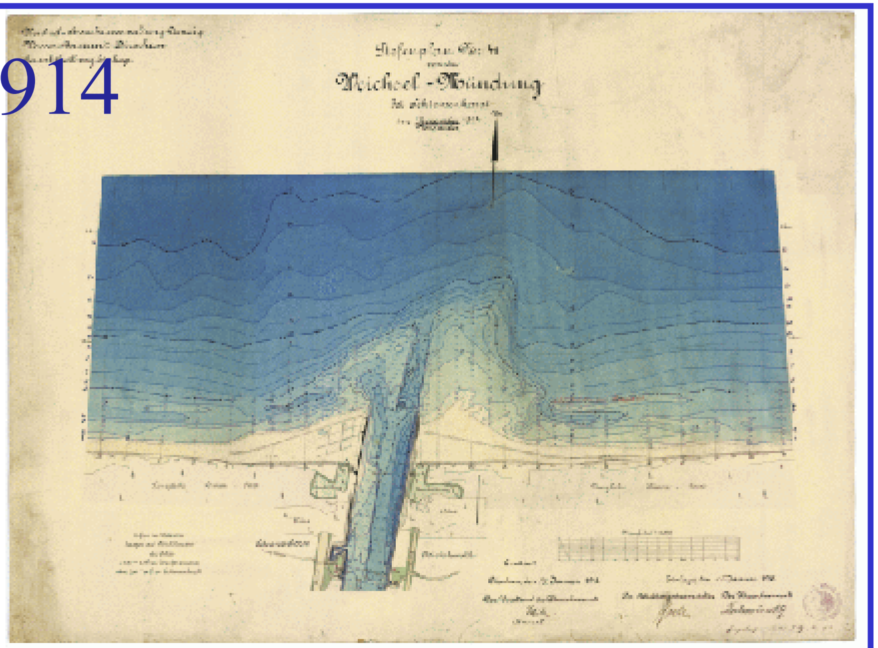
Sept. 1894



1897

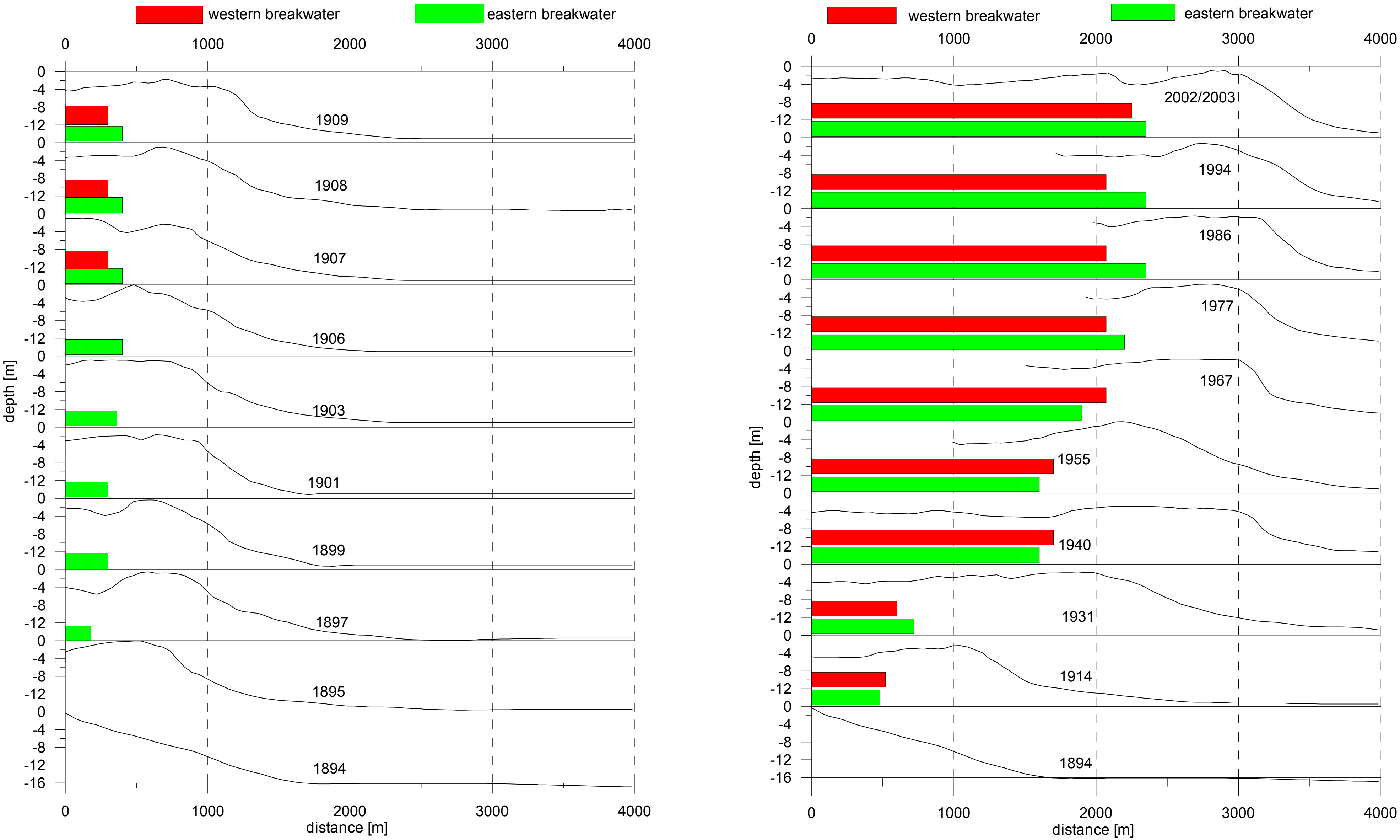


Aug.1895

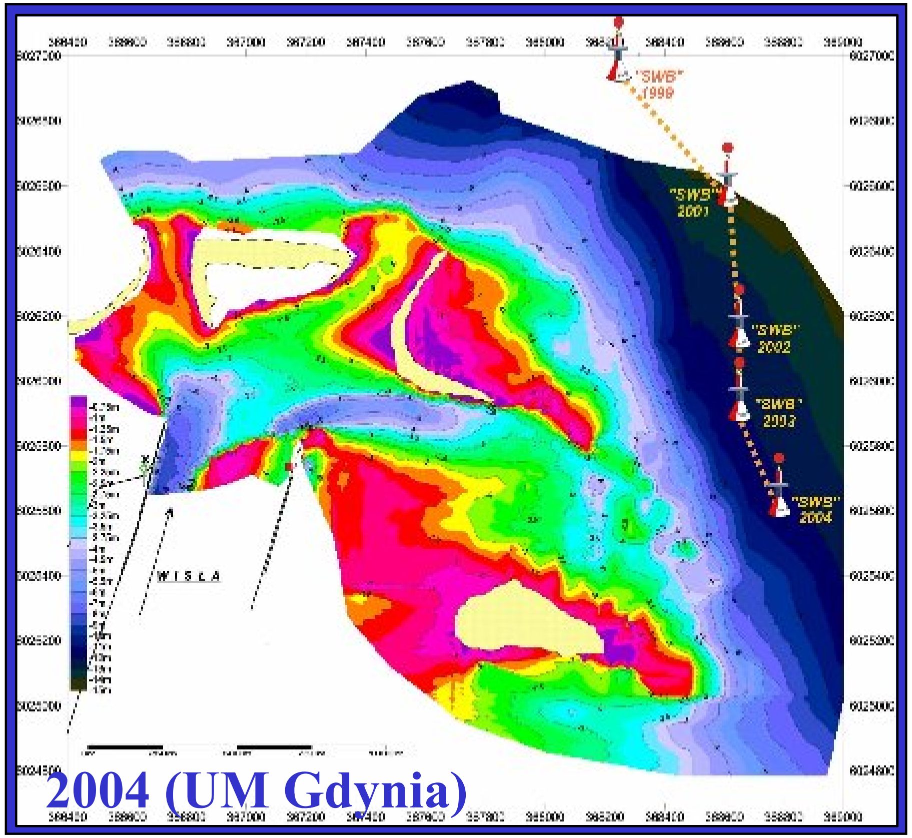


1914

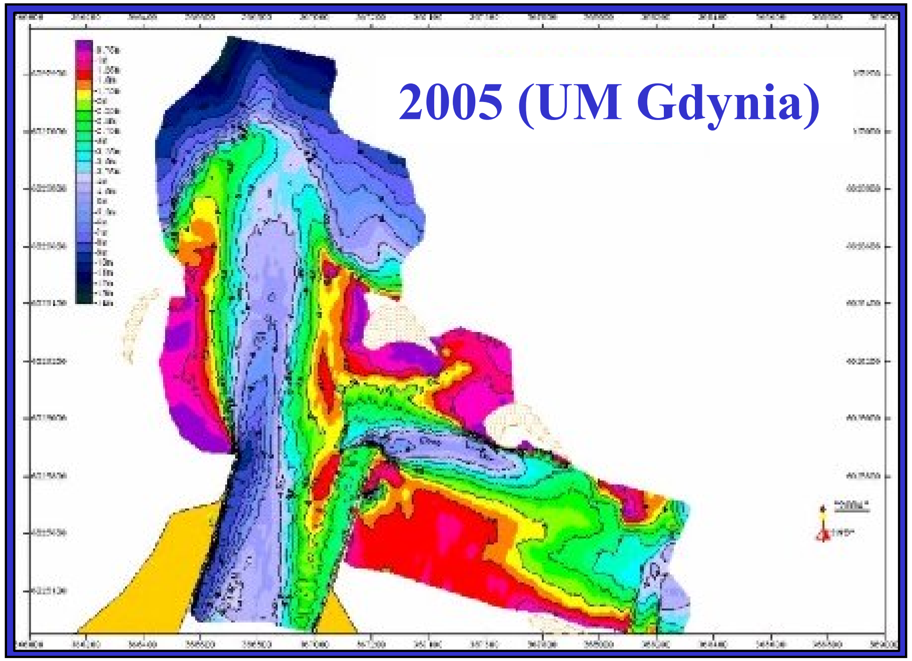
Regulation – jetties elongation



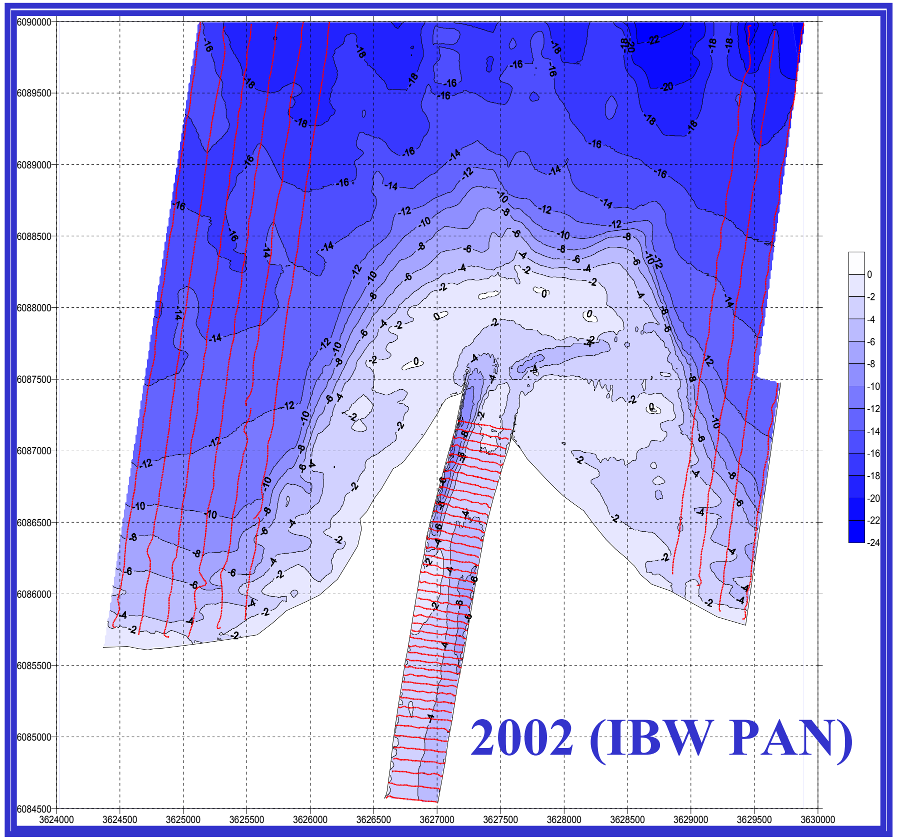
Bathymetry of the Vistula outlet



2004 (UM Gdynia)



2005 (UM Gdynia)



2002 (IBW PAN)

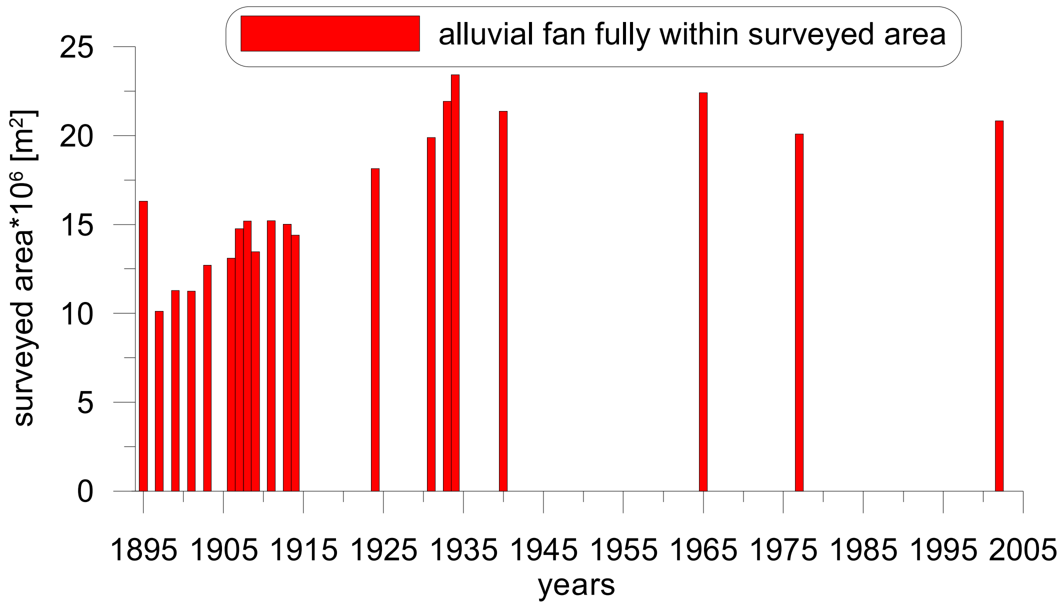
Regulation – present status

Development of marine alluvial fan

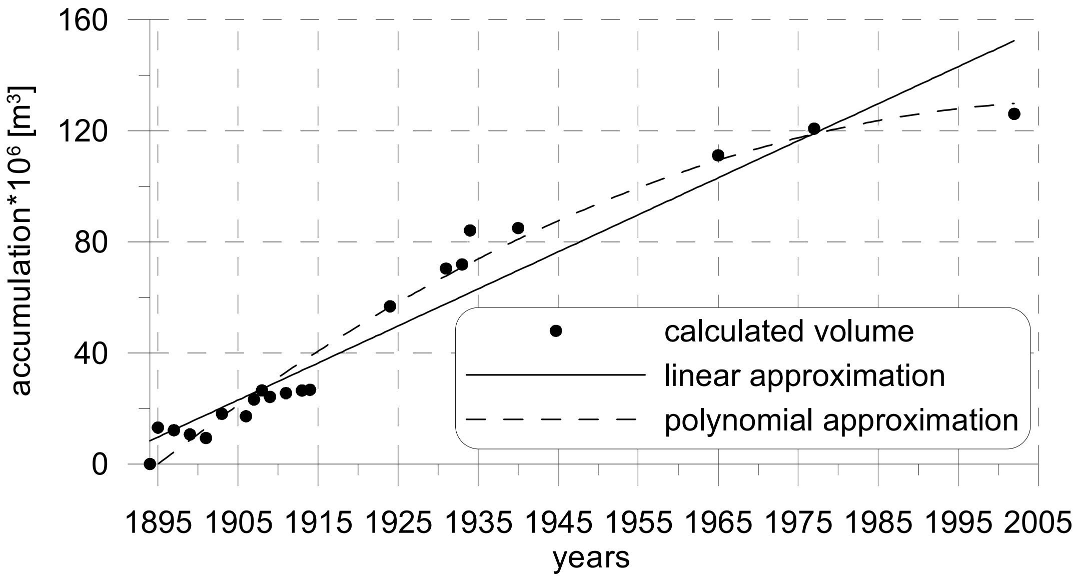
- *directly after cross-cut in 1895 (approx.10mln m^3)*
- *backward erosion of the river bed (ended in 30’s)*
- *cut-off of the Nogat branch in 1915*

- sedimentation supply by the river (0.6-1.5 mln m^3/year)
- sedimentation due to wave action
- erosion due to waves and local currents (100 000 –130 000 m^3/year)

Sedimentation of alluvial fan 1894-2003



period	mln m^3/year
1896-1920	1.9
1920-1945	1.6
1945-1970	1.0
1970-1995	0.4-0.6



<u>sediment size (*d_{50}*)</u>

0.55-1.0 mm - fan channels

0.25-1.0 mm - plateau of the fan

0.18-0.25 mm - coast adjacent to the fan

Modelling of rivers and estuaries

1-D approach

used to simulate the large-scale morhological changes in rivers and estuaries;

analytical solutions - simple schematized cases

numerical solutions - more realistic cases

e.g non-uniformity of bed material – number of size classes

Modelling of rivers and estuaries

2-DV approach

applied to predict transport rates, sedimentation and erosion in rivers, estuaries and coastal waters

in rivers – sedimentation in pipelines, tunnel trenches, settling traps for irrigation channels

2-DH approach

based on the depth-integrated equations of motion in combination with a sediment transport model

application: eg. bed evolution in a river bend

Modelling of rivers and estuaries

3-D approach - used for a wide range of horizontal scales (estuaries, coastal sea)

One-phase Models

- *passive scalar* hypothesis
- no fluid-particles interactions
- settling velocity of solid particles by empirics
- fluid-bed interaction by empirical formulas for deposit and erosion fluxes
- extra models for consolidation of solid particles

Two-phase Models

- no *passive scalar* hypothesis
- fluid-particles interaction
- settling velocity of solid particles by the models
- fluid-bed interaction by the models
- consolidation process included in the models

Modelling of Vistula estuary

The main goal:

to support regional administration (Regional Water Board in Gdańsk) with the concept to improve the navigation conditions in the river mouth (also in <u>winter conditions</u>)

The main effort focused on searching a solution which:

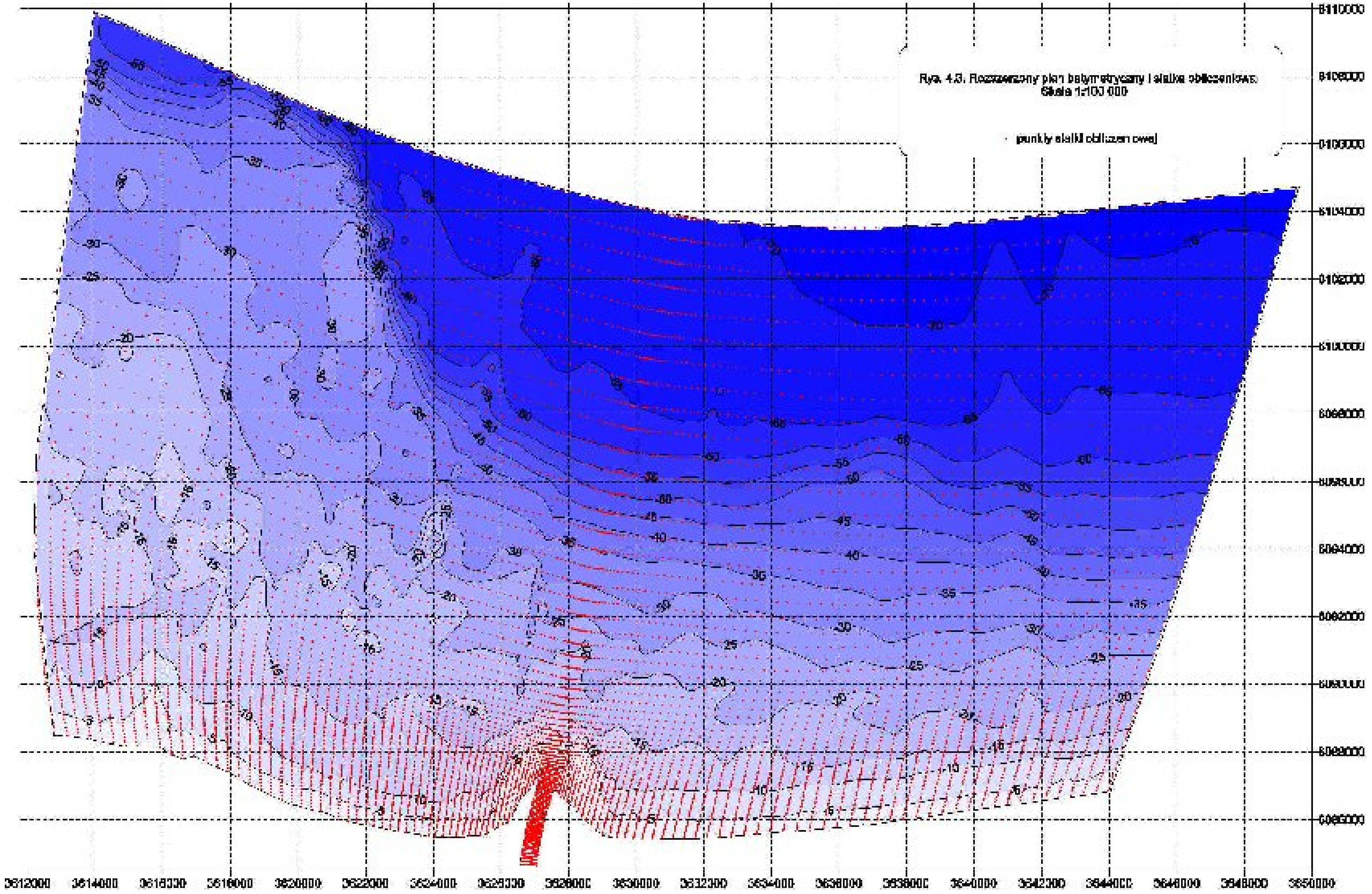
- enable concentration of the main channel into a relativel narrow channel,
- make use of natural capacity of river to self cleaning.

Vistula River in winter 2002/2003

alluvial fun in
winter

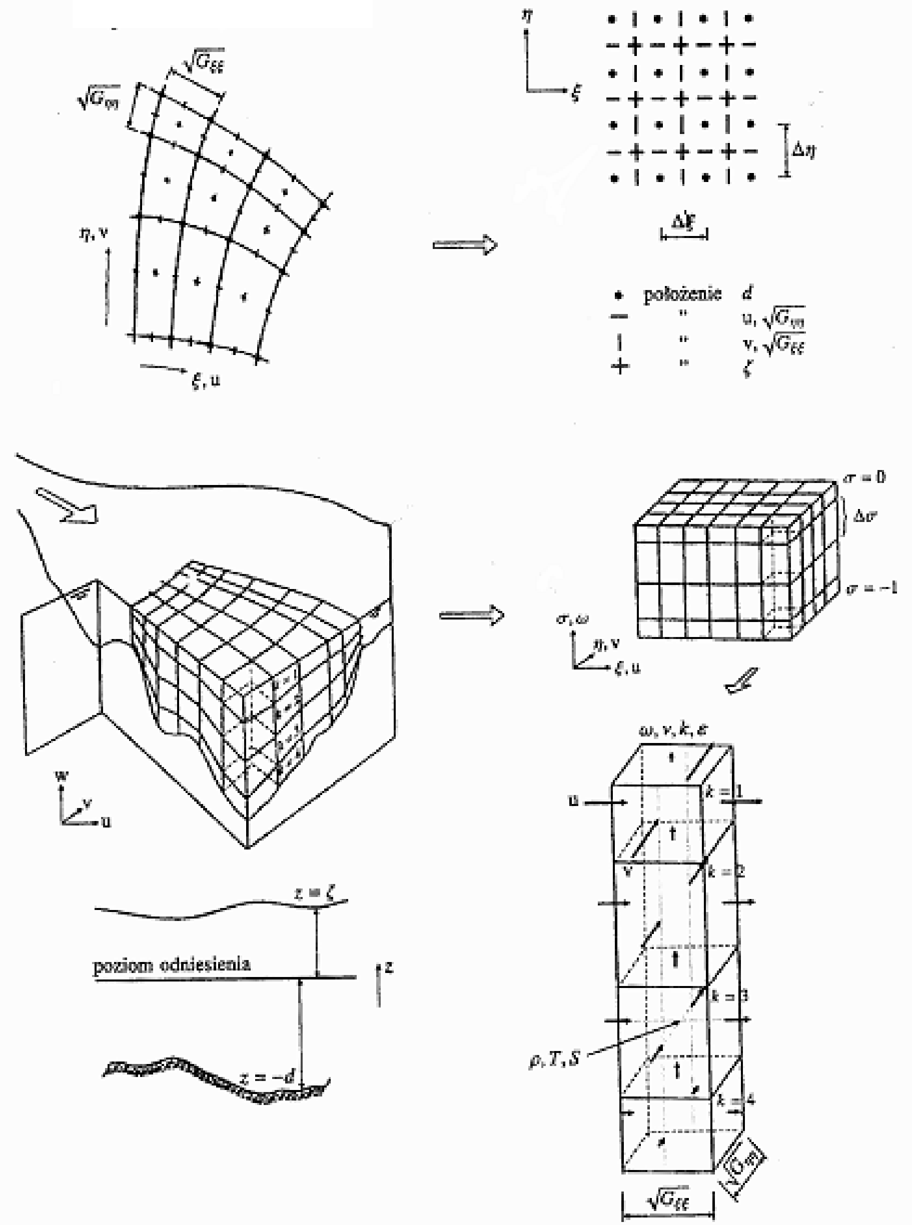
right river bank

Modelling of Vistula estuary

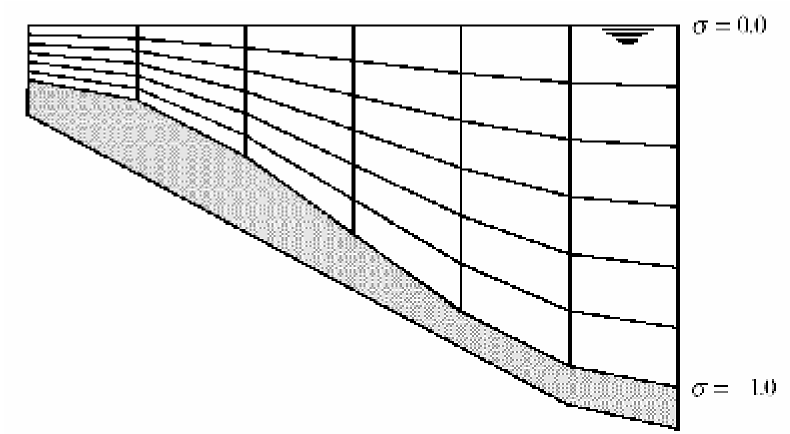


Delft3D

Physical space *Space after transformation*



- *Curvilinear orthogonal grid*
- *σ co-ordinates in vertical (Phillips, 1957)*



$$\sigma = \frac{z - \varsigma}{\varsigma + d} = \frac{z - \varsigma}{H}$$

d - depth below the reference level;

ς - free surface elevation above the reference level;

H= d + ς - total depth;

Characteristic discharges (m^3/s) in years 1951-1990

period	WWQ	SWQ	SSQ	SNQ	NNQ
XI	4460	1190	993	697	319
XII	3830	1470	968	649	253
I	4250	1450	1120	633	302
II	4530	1710	1520	725	324
III	6980	2620	1870	930	304
IV	7020	2690	1870	1170	489
V	4240	1860	1230	876	504
VI	7840	1670	1040	739	475
VII	5050	1470	919	651	335
VIII	6820	1530	887	619	300
IX	3390	1030	720	570	300
X	5500	1110	786	576	306
year	7840	3840	**1080**	419	253

Characteristic discharges (m^3/s) 1.11.2001 – 31.10.2002

period	WWQ	SSQ	NNQ
XI	1210	1070	932
XII	1140	927	660
I	3720	1300	764
II	4320	3220	2380
III	2920	2340	1820
IV	1820	1400	1070
V	1070	814	652
VI	1850	1290	770
VII	1170	816	643
VIII	1250	754	594
IX	730	541	483
X	1340	825	483
year		**1260**	

Average discharge with a given time of duration in years 1951-1990 [m^3/s]

% of years	**days in years**	**Discharge [m^3/s]**
1	**3.6**	**3840**
3	11.0	2850
5	18.3	2420
10	36.5	1900
15	**54.8**	**1600**
25	91.3	1280
50	182.6	882
75	273.9	640
85	310.5	545
90	328.7	488
95	347.0	422
97	354.3	392
99	361.6	342

Wave characteristics calculated based on wind conditions – depth 20 m

wind direction	wind speed [m/s]	frequency in year [%]	wave period [s]	wave height [m]
W	6 10 14 18	7.45 3.12 0.83 0.06	2.6 3.5 4.4 5.1	0.31 0.59 0.96 1.03
NW	6 10 14 18 20	5.15 1.95 0.64 0.012 0.008	5.6 5.8 6.7 7.5 8.4	1.03 1.10 1.63 2.18 2.74
N	6 10 14 18 20	2.91 0.91 0.25 0.012 0.008	5.2 5.6 6.7 7.4 8.2	0.97 1.21 1.76 2.31 2.71
NE	6 10 14	3.33 0.91 0.22	3.5 5.9 4.7	0.46 1.26 1.70
E	6 10 14	5.34 2.39 0.30	3.2 3.6 4.6	0.42 0.62 0.83

Modelling of Vistula estuary hydro- and lithodynamics

I – zero option – present situation

II – flushing

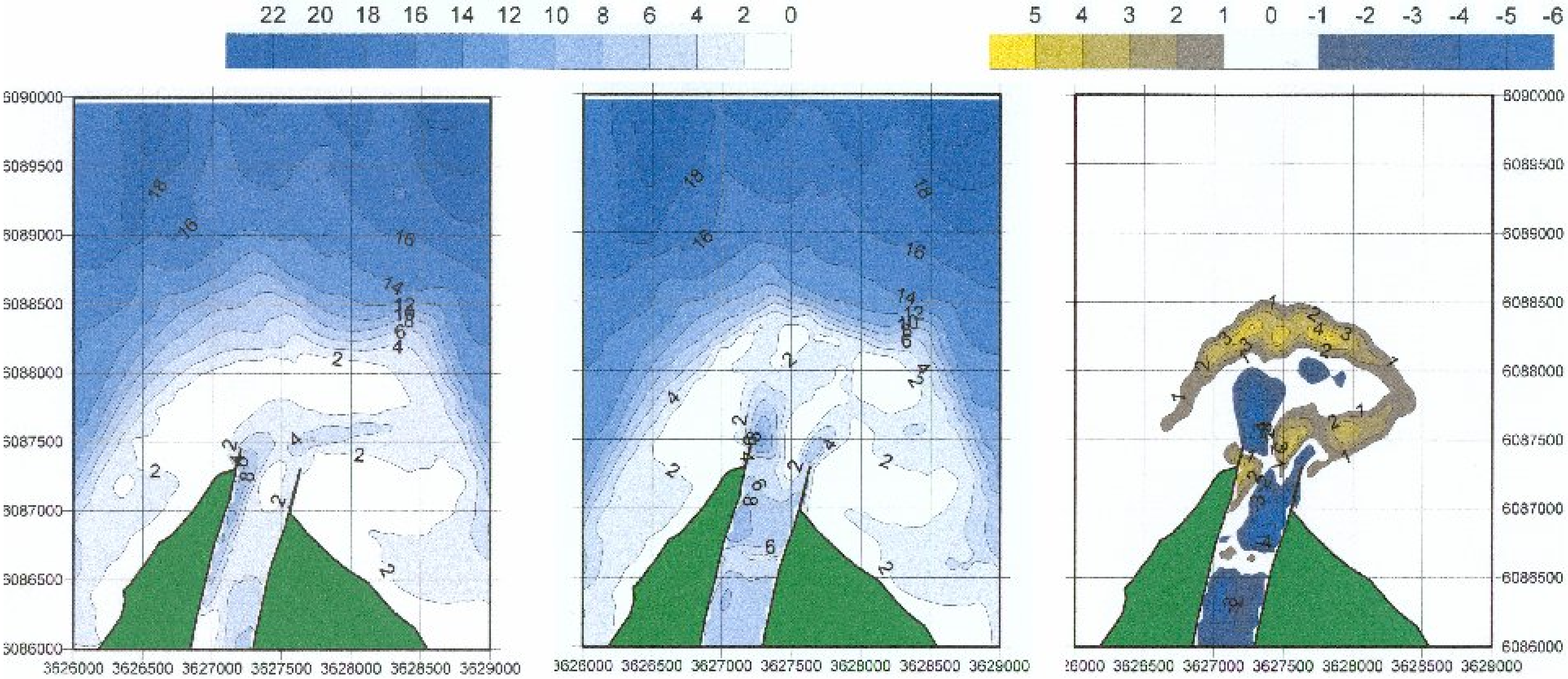
III – execution of narrow deep channel

IV – extension of two breakwaters as parallel constructions

V – extension of two breakwaters as contructing constructions

VI – construction of eastern breakwater

I – present situation

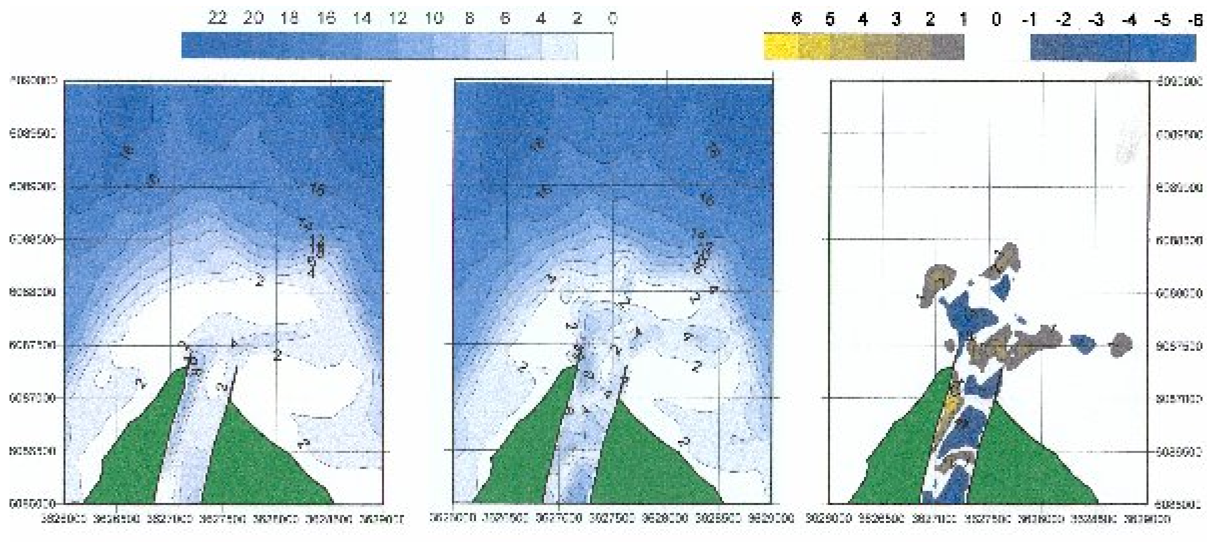


iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

Breakwaters – present situation

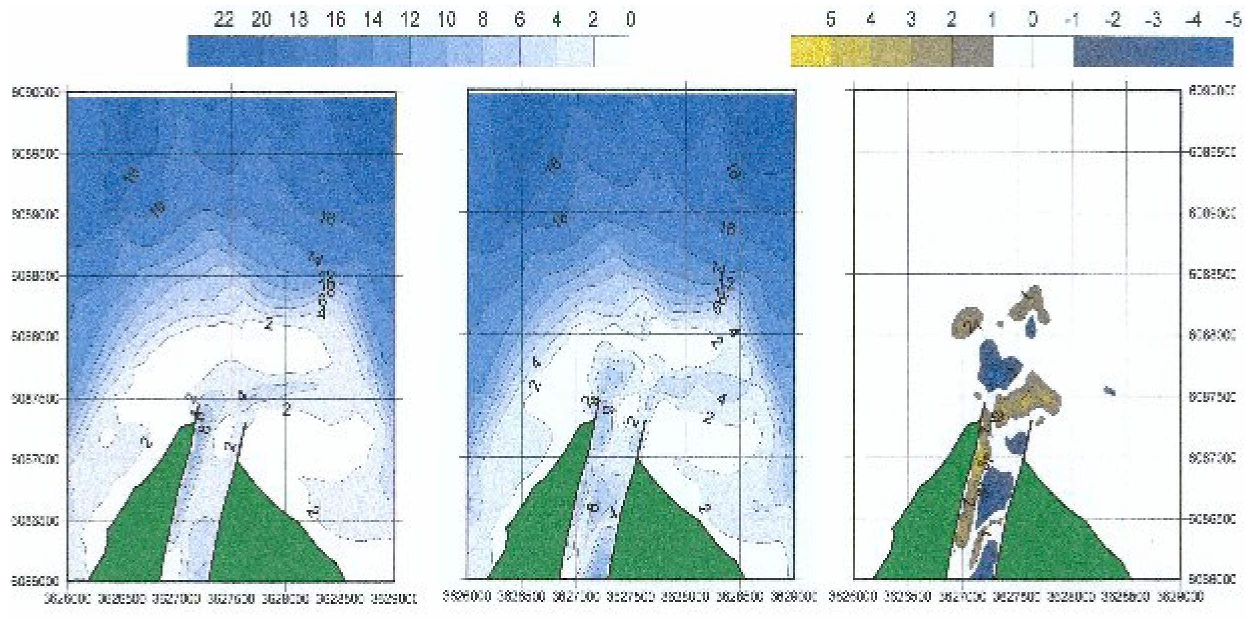
Mean annual discharge in 2002 – 1 year calculation

II - flushing



iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

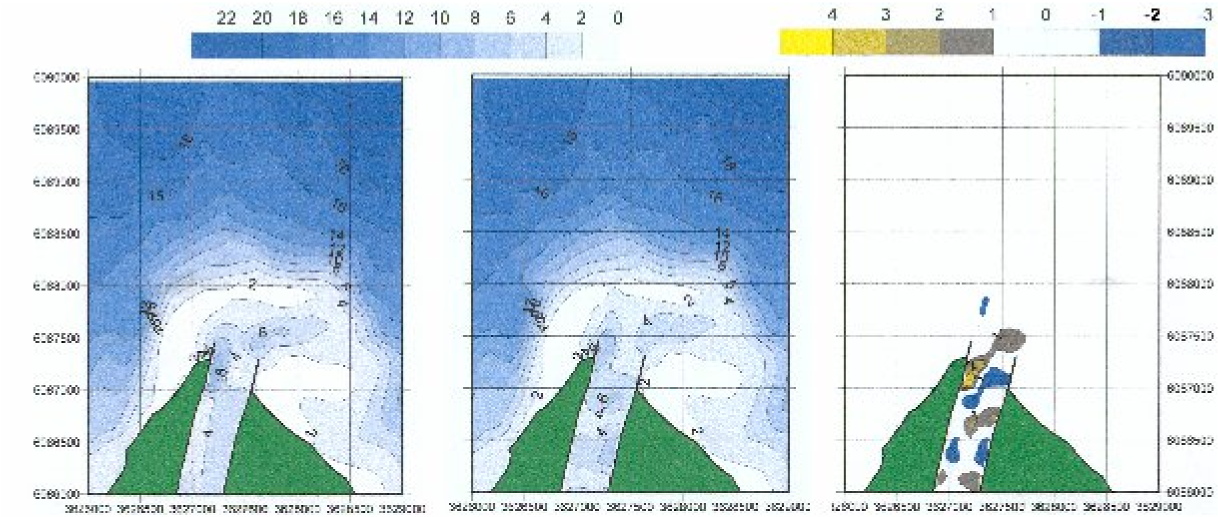
Breakwaters – present situation
Discharge of 1% probability Q =3840m^3/s
Duration 3.6 days



iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

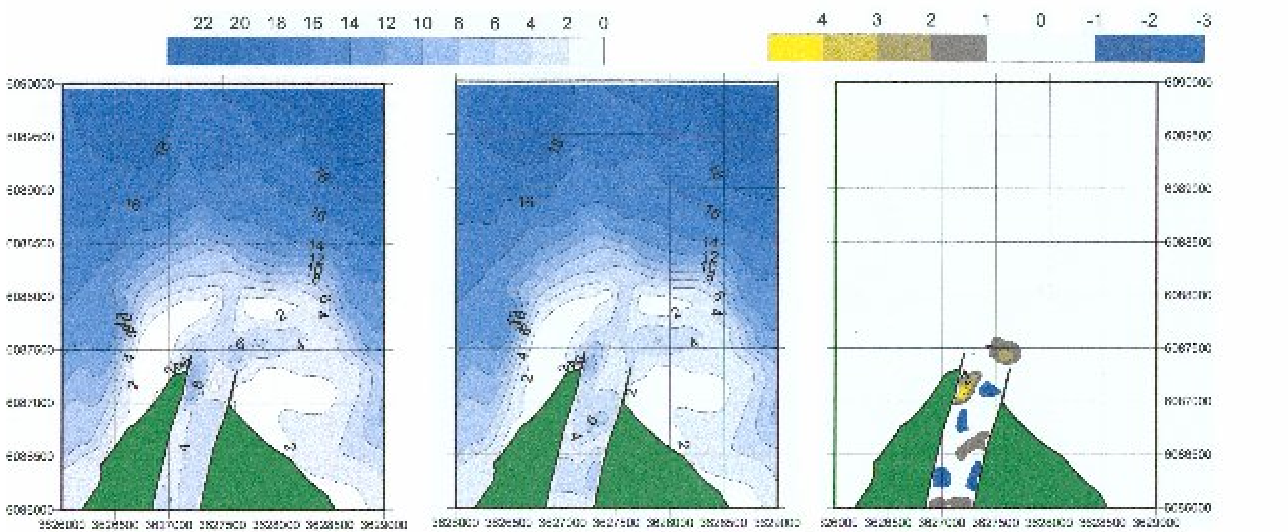
Breakwaters – present situation
Discharge of 1% probability Q =3840m^3/s and mean Q = 1000 m^3/s
Duration 3.6 days + 3 months

III - execution of narrow deep channel



iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

Breakwaters – present situation
Discharge of 15% probability Q =1600m^3/s
Duration 3 months



iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

Breakwaters – present situation and execution of narrow channel
Discharge of 15% probability Q =1600m^3/s
Duration 3 months

IV – two breakwaters

A – *short* breakwataers:

eastern - extended 480 m,

western - extended 310 m

B – *medium* breakwaters:

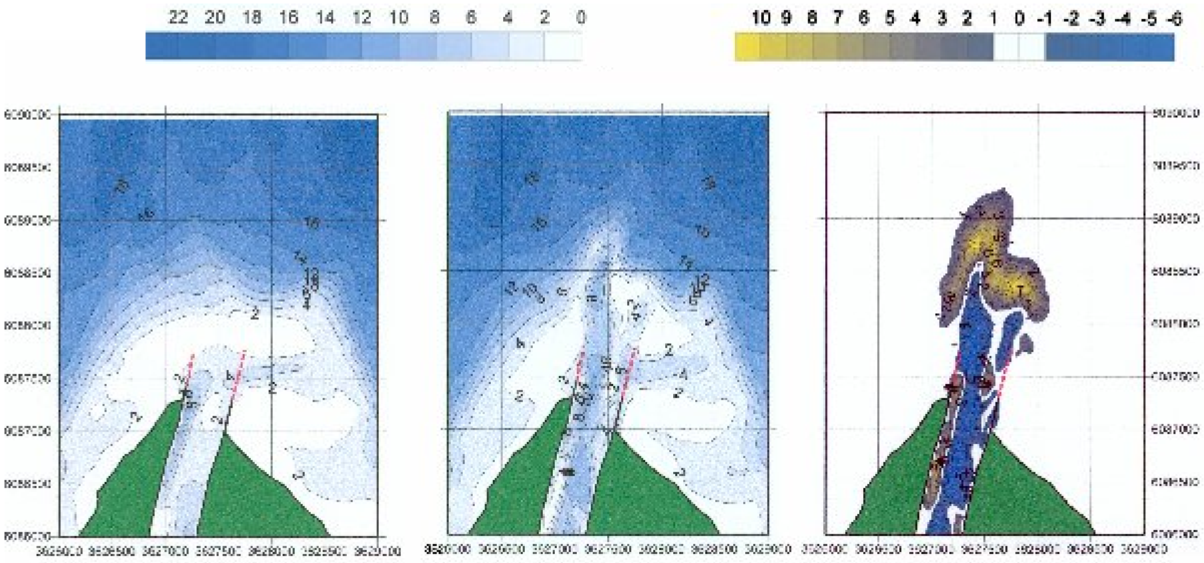
eastern - extended 760 m,

western - extended 560 m

C – *long* breakwaters:

eastern - extended 900 m,

western - extended 690 m



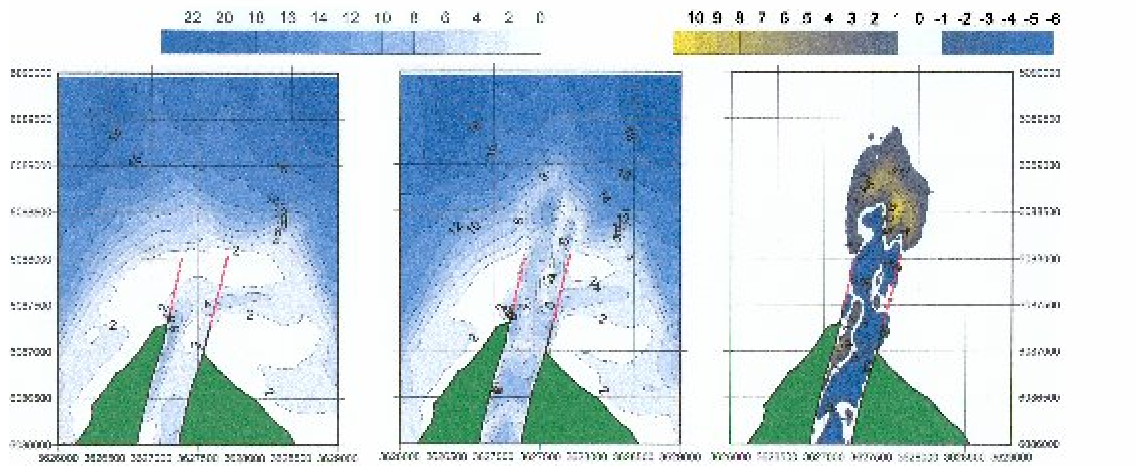
iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

Breakwaters extended: eastern – 480 m, weastern – 310 m

Mean annual discharge 2002 - Q =1080m^3/s

Duration 1 year

short



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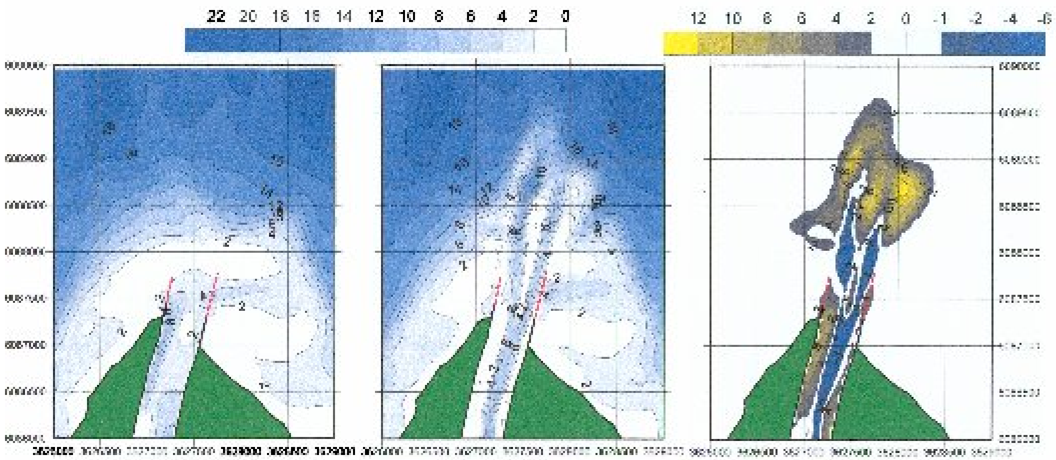
Breakwaters extended: eastern – 760 m, weastern – 560 m

Mean annual discharge 2002 - Q =1080m^3/s

Duration 1 year

medium



iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

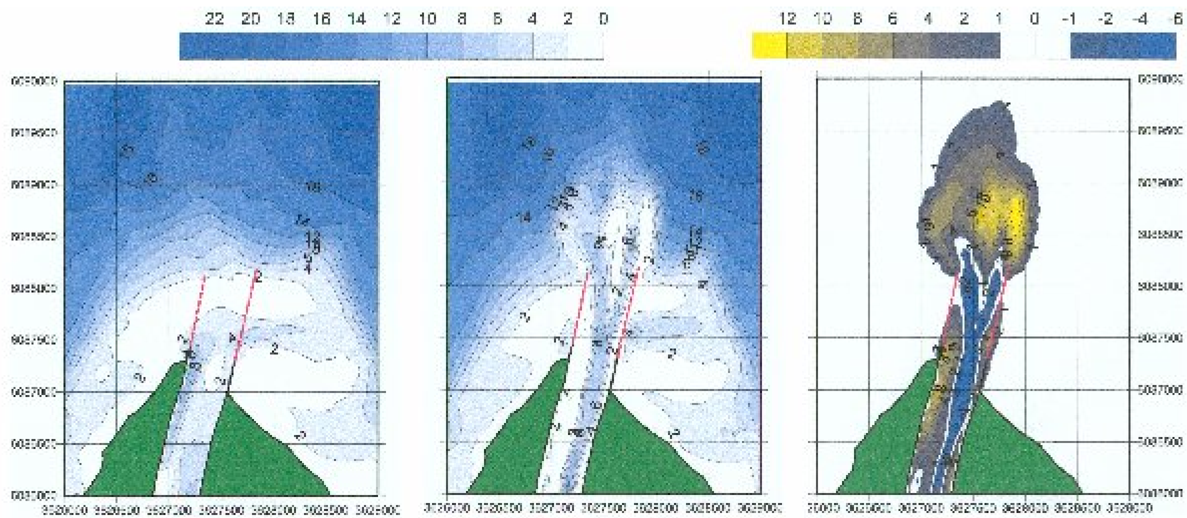
Breakwaters extended: eastern – 480 m, weastern – 310 m

Mean annual discharge 2002 - Q =1080m^3/s

Duration 10 years

short

long



iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

Breakwaters extended: eastern – 900 m, weastern – 690 m

Mean annual discharge 2002 - Q =1080m^3/s

Duration 10 years

V - extension of two breakwaters as contructing constructions

Exteded as *medium* breakwaters:

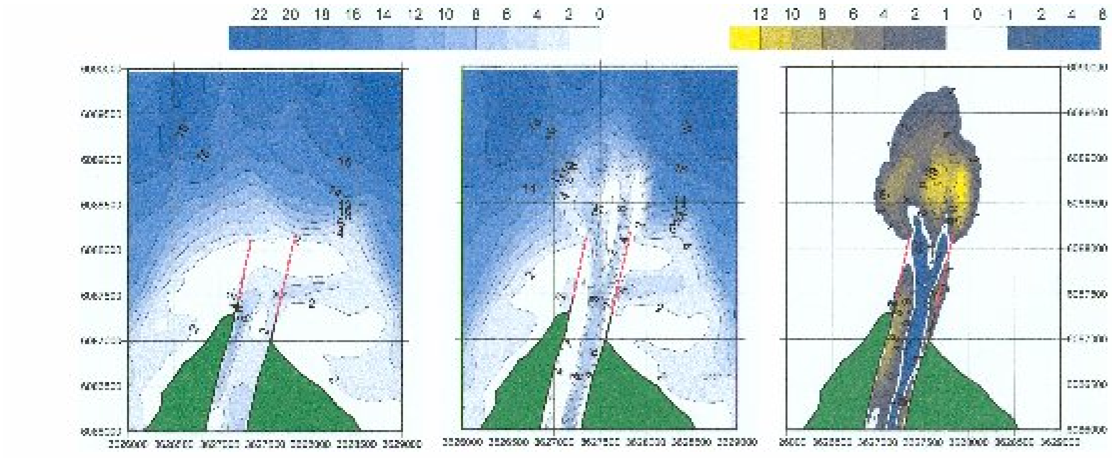
eastern - extended 720 m

western - extended 580 m

Distance between breakwaters:

at the river mouth - 450 m

at the head of breakwater - 350 m



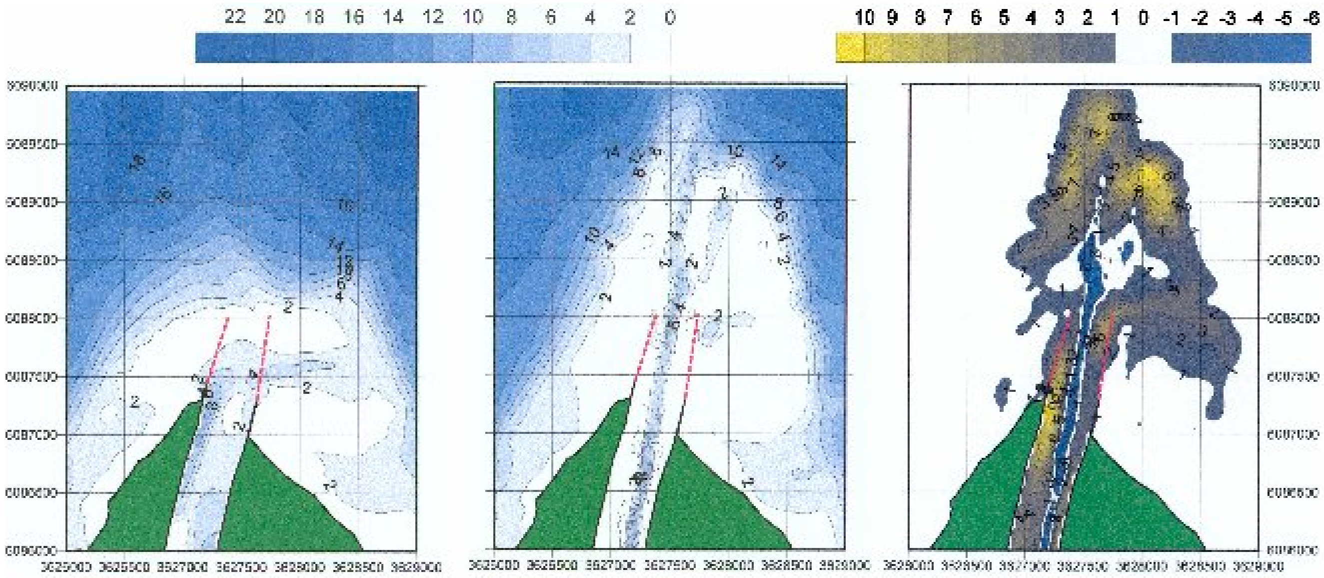
iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

Breakwaters extended: eastern – 900 m, weastern – 690 m

Mean annual discharge 2002 - Q =1080m^3/s

Duration 10 years

narrowing



iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

Contructing breakwaters

Breakwaters extended: eastern – 720 m, weastern – 580 m

Mean annual discharge 2002 - Q =1080m^3/s

Duration 10 years

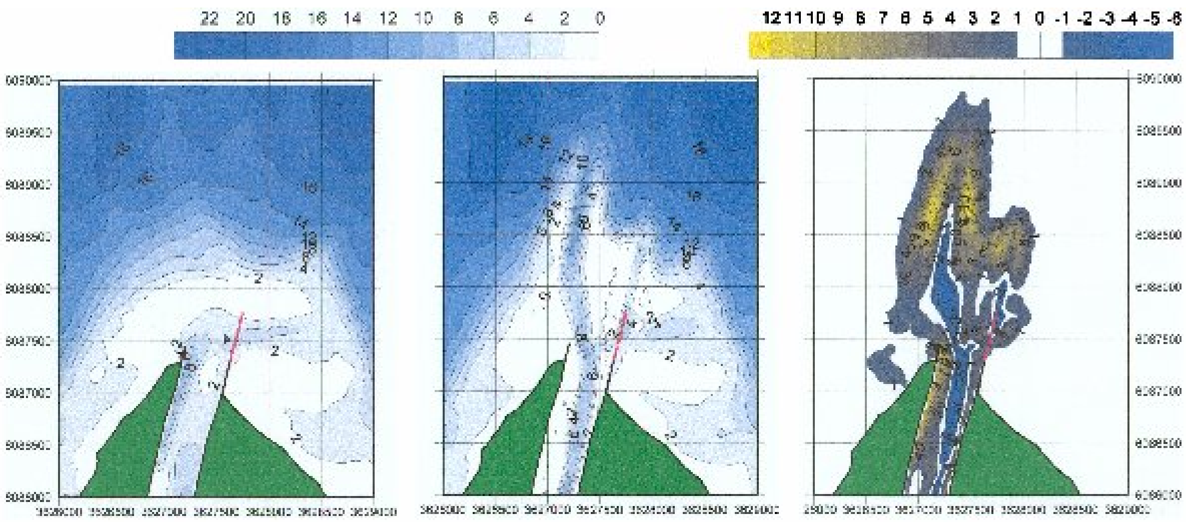
VI – estern breakwater extended

A - *short*

exteded - 480 m

C - *long*

exteded - 900 m



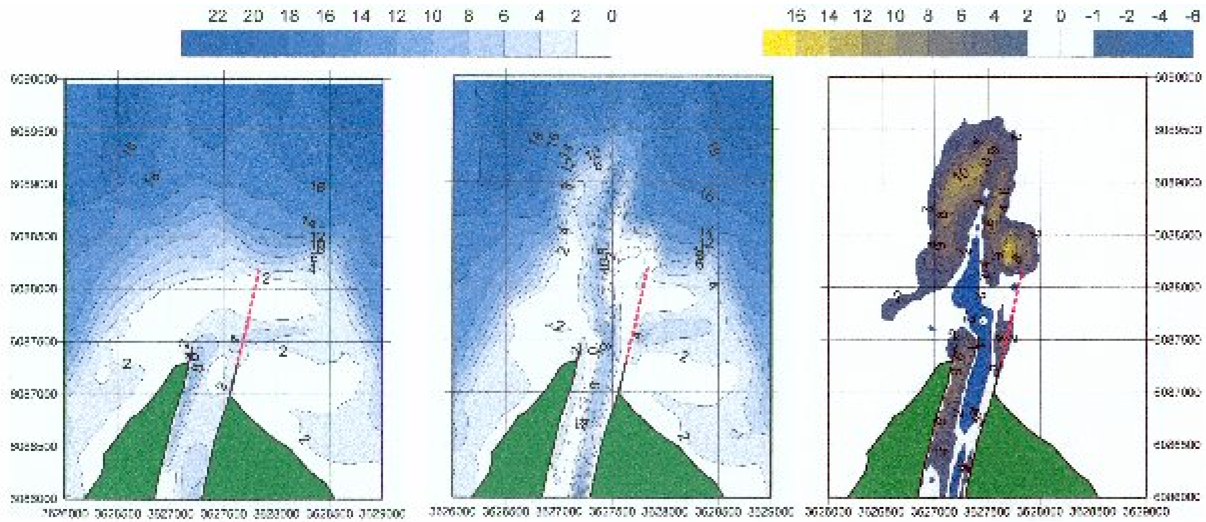
short

iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

Breakwater extended: eastern – 480 m

Mean annual discharge 2002 - Q =1080m^3/s

Duration 10 years



long

iniatial bathymetry 2002/2003 *calculated bathymetry* *difference*

Breakwater extended: eastern – 900 m

Mean annual discharge 2002 - Q =1080m^3/s

Duration 10 years


Thank you for your attention