platino

platform for the implementation of NAIADES

# Task 5.3.1
# Study on hydromorphological alterations on the Danube

**University of Natural Resources and Applied Life Sciences, Vienna**
Department of Water, Atmosphere and Environment
Institute of Water Management, Hydrology and Hydraulic Engineering

9 - 10th June 2009, Workshop in Zagreb

Helmut Habersack, Elisabeth Jäger, Christoph Hauer

# Content

1. Introduction
2. Problems and objectives
3. Methods
4. Results
5. Summary
6. Conclusions
7. Recommendations

# Introduction

- **Hydromorphological alterations** – one of the main ecological pressures and IWT infrastructure needs

Navigation

**+**

Flood protection, hydropower-generation…

# Introduction

## WHAT IS HYDROMORPHOLOGY ?

‘hydromorphology is the physical characteristics of the riverine structures such as river bottom, river banks, the river’s connection with the adjacent landscapes and its longitudinal as well as habitat continuity’ (ICPDR, 2007)

Hydromorphological quality elements:

- hydrological regime
- river continuity (biota AND sediments)
- morphological conditions

# Introduction

- Navigation is a traditional activity on the Danube
- Since the 15th century:
  - Change of the natural course of the rivers in the DRB, mainly for flood protection, navigation, hydropower generation

| River | First engineering measures | Systematic hydraulic engineering measures at long river reaches |
|---|---|---|
| Po | Embankments 13th–14th centuries | Mainly 18th century downstream of Piacenza |
| Rhône | 18th—early 19th | 1876–1884 (Ing. Jacquet) 1884–1920 (Ing. Girardon) |
| French Alpine large rivers | 16th–17th (embankments for protecting the towns) | Isère (1829–1845); Arve (1820–1838); Var (1844–1869) |
| Rhine | Channelisation, bank protection 18th century | Beginning 1804 (Tulla) |
| Elbe | Flood retention 14th–16th century | 1821–1905 |
| Danube | Improvement for shipway 15th century | 1830–1890 |

*Source*: Garbrecht (1985); Vischer (1986); Braga and Gervasoni (1989); Bravard and Peiry (1993); Tricart and Bravard (1991); Poinsart and Salvador (1993).

# Introduction

## NEED OF THIS STUDY

- arises by

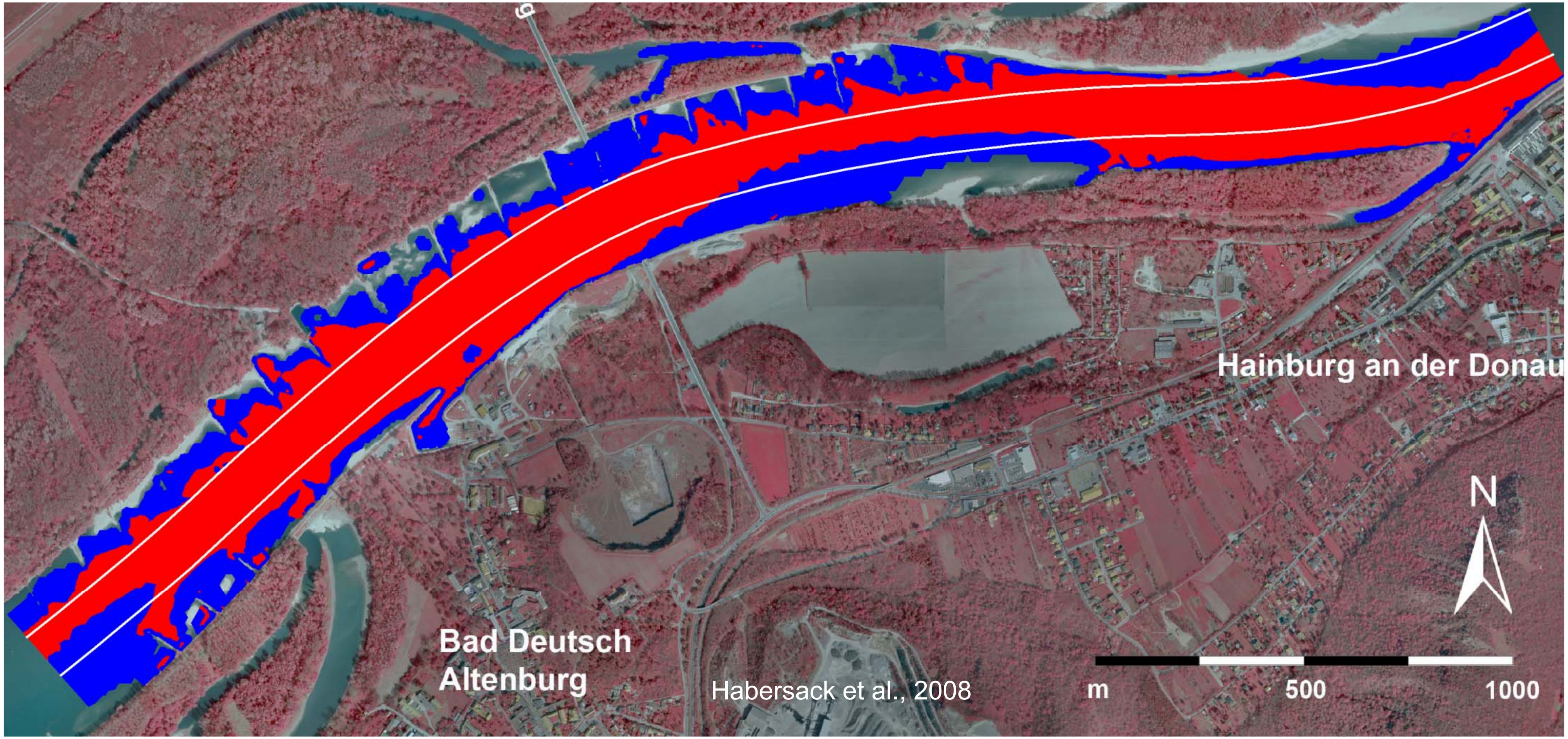
  - **Water Framework Directive (WFD)**
  - **Joint Statement 2007**
  - **NAIADES**

  as hydromorphology is an essential quality parameter for large river systems and needs to be considered when planning navigation projects.

- This study: **Basis for** the **Manual on Good Practices** in sustainable Waterway Planning

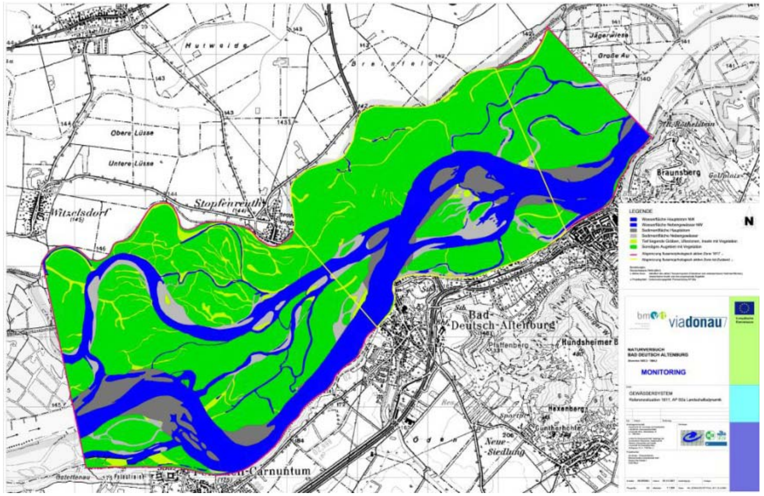
# Navigable water depth

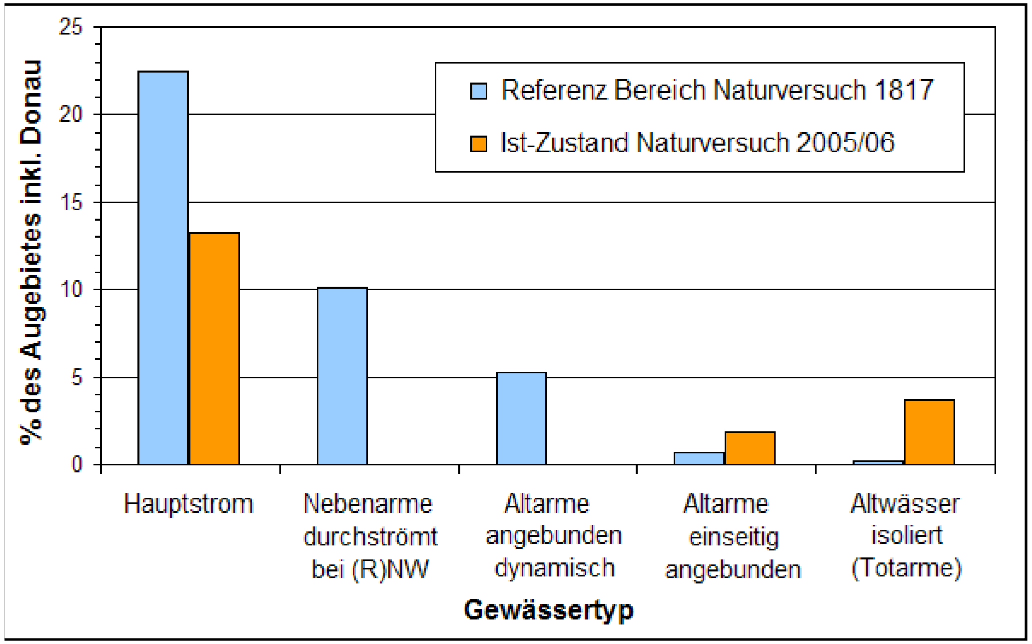
- Red: sufficient water depth at low flow conditions
- Blue: water depth < 25 dm



# Historical reference

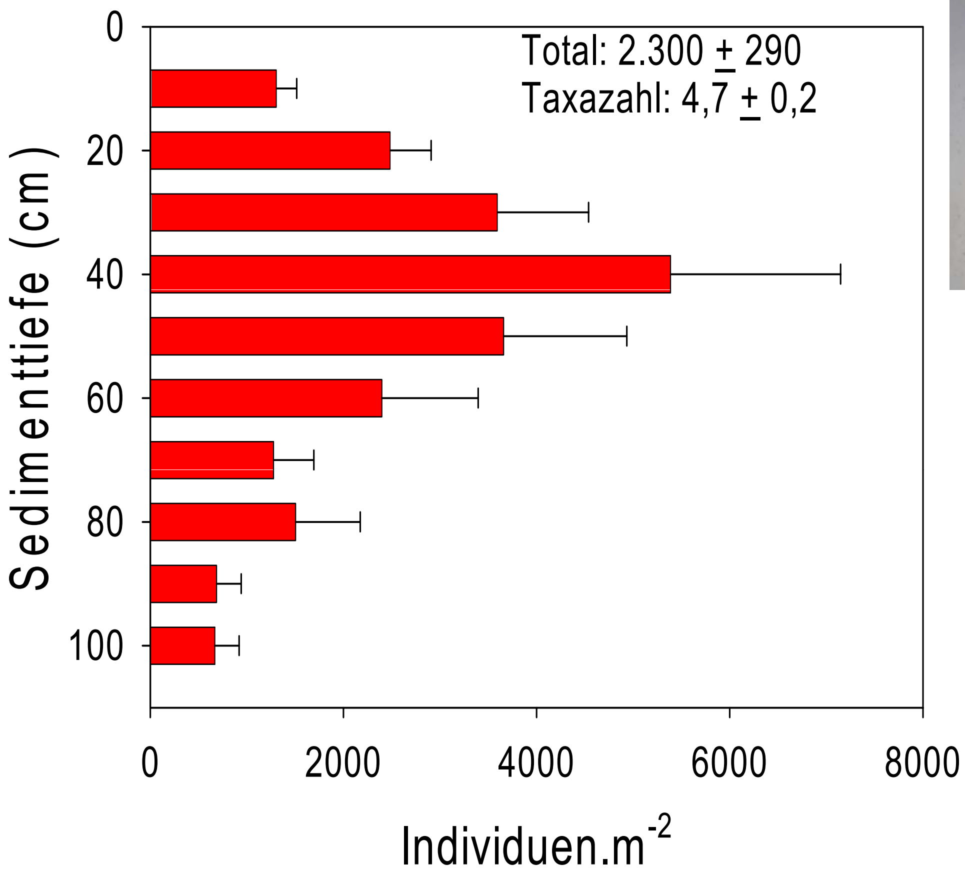
- High percentage of dynamic waters
- Almost no non connected side arm systems



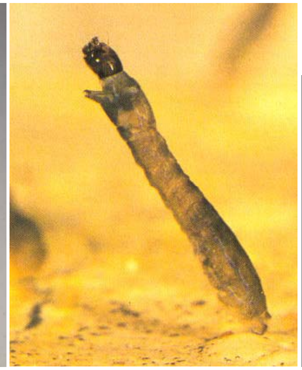
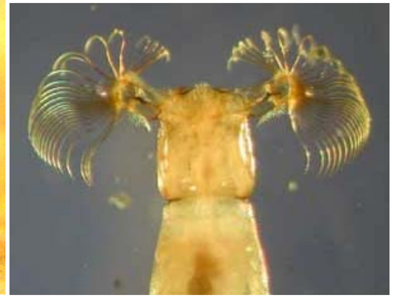




Hohensinner et al., 2008

# MZB – Danube instream




Reckendorfer et al., 2009

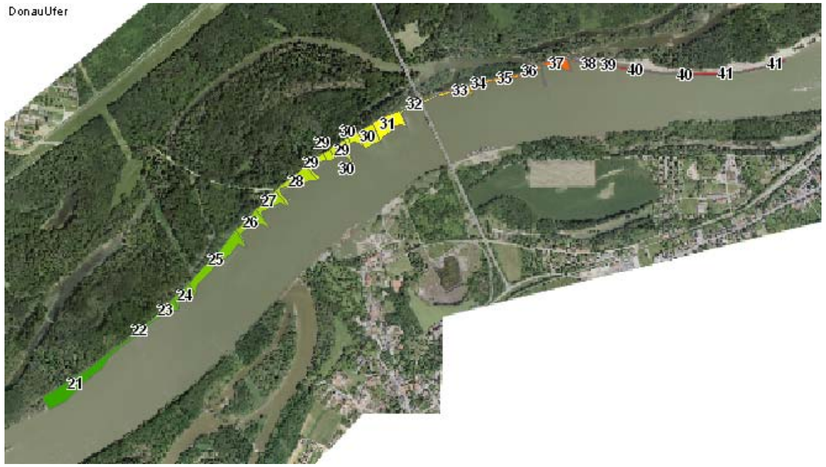
- Colonization to 1 Meter
- Max. at 40 cm

Moog, 2009


FLUSSBAULICHES GESAMTPROJEKT

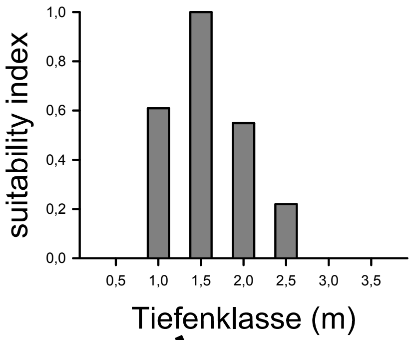
BOKU

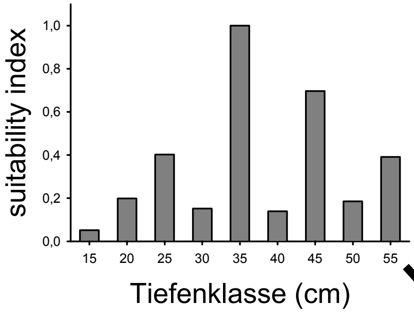
IWHW

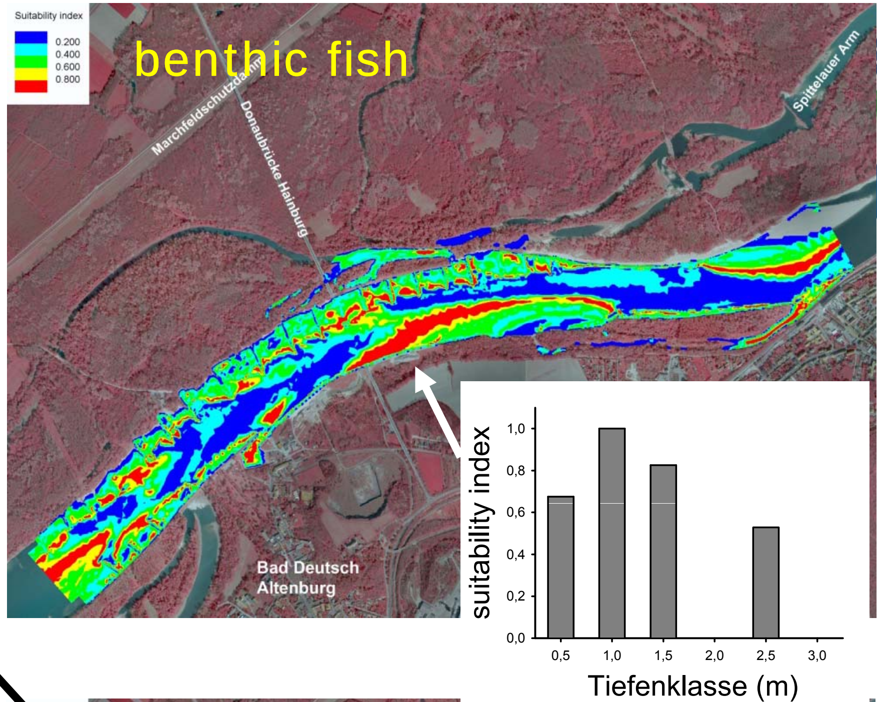


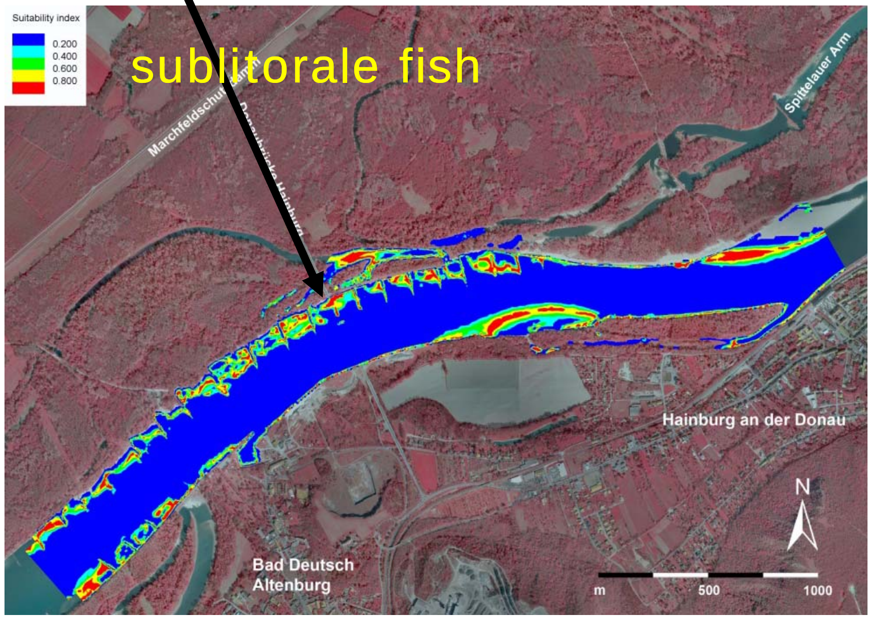

Schiemer et al., 2008

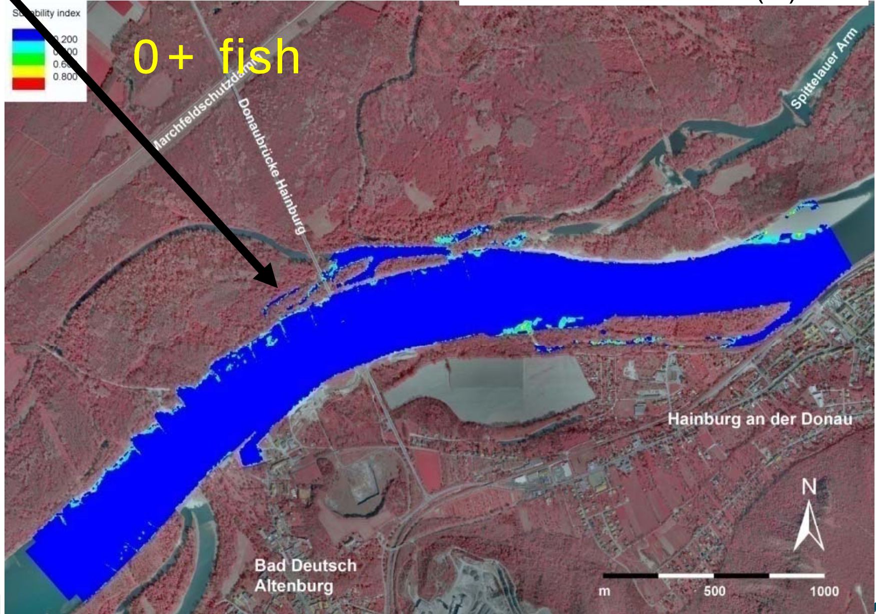
# Habitatmodelling (Microscale)




Durchfluss: Q1750

Habersack, Hauer, Tritthart, Liedermann, Keckeis et al., 2008

# Content

1. Introduction
2. Problems and objectives
3. Methods
4. Results
5. Summary
6. Conclusions
7. Recommendations

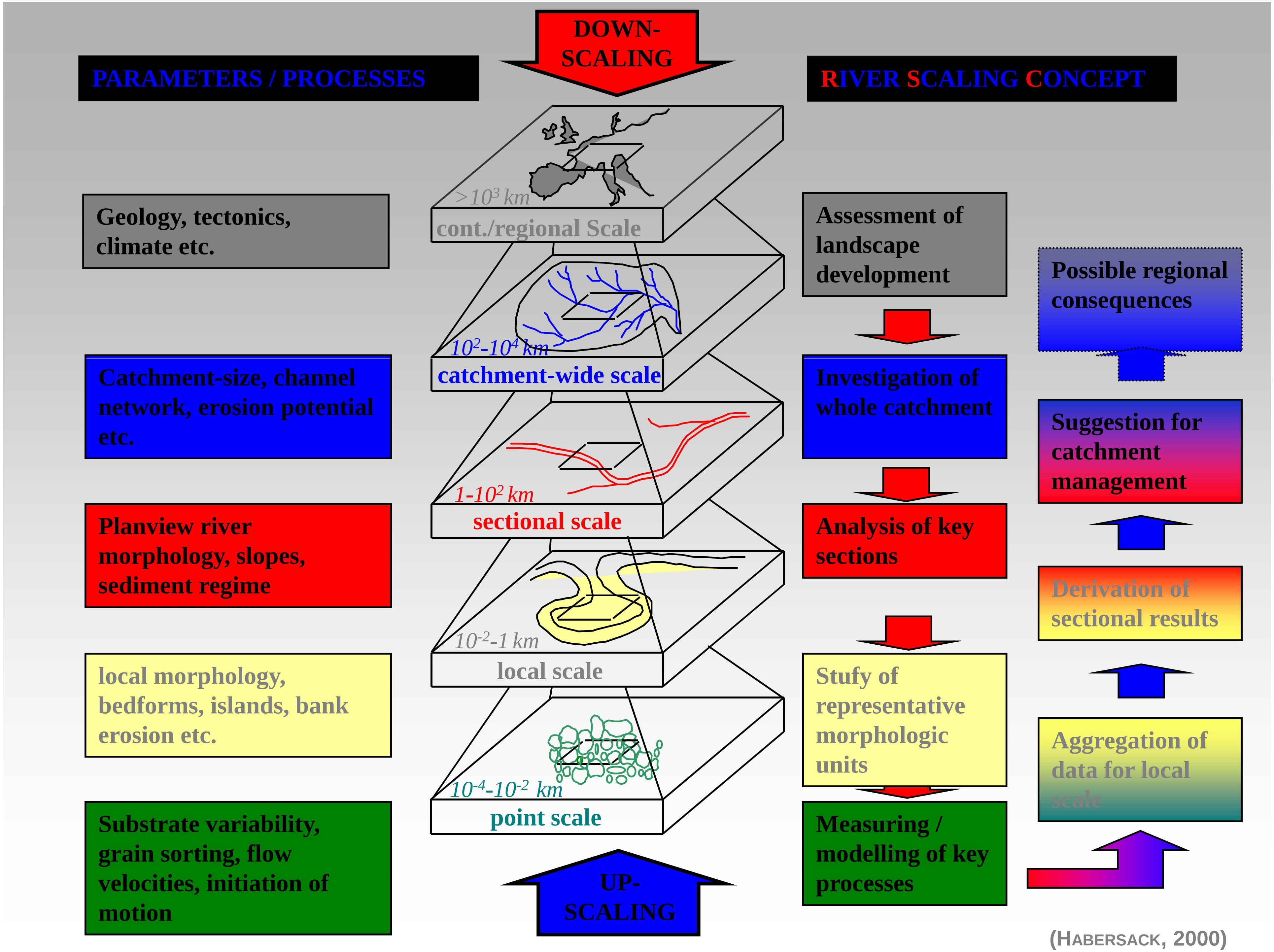
# Problems and objectives

- Problems:
  - Negative impact of navigation on hydromorphology
- Objectives:
  - Scientific assessment to survey, evaluate and discuss pressures from inland navigation in combination with other pressures (e.g. hydropower, flood protection,…) on hydromorphological alterations within three different scales

# Content

# Methods (1)

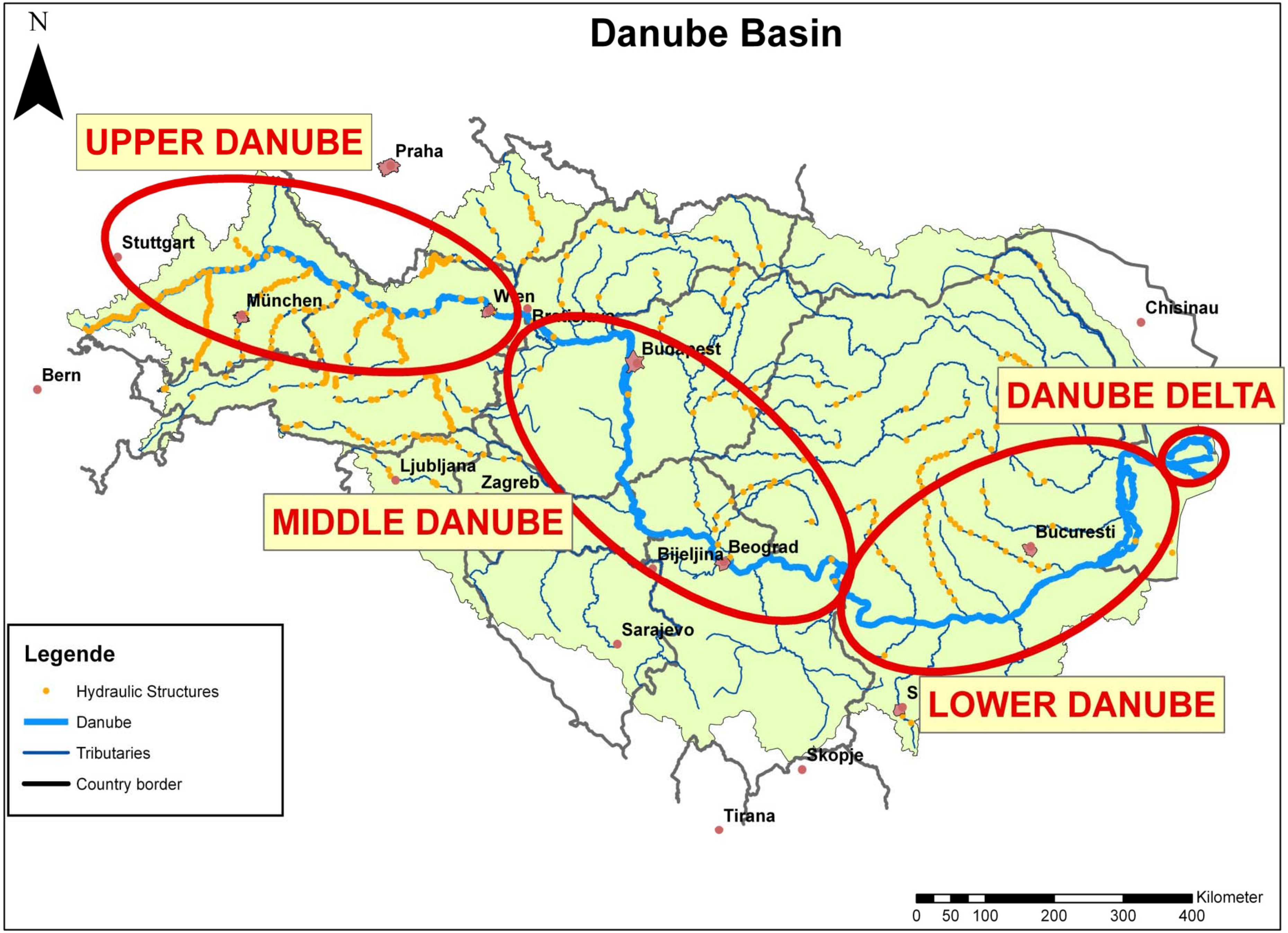
- Scaling approach according to the *River Scaling Concept* (HABERSACK, 2000):
  - Danube River Basin (catchment-wide scale)
  - Danube River Sections (sectional scale)
  - Danube River Localities (local scale)


DOWN-SCALING
PARAMETERS / PROCESSES
RIVER SCALING CONCEPT
Geology, tectonics, climate etc.
>10³ km
cont./regional Scale
Assessment of landscape development
Possible regional consequences
Catchment-size, channel network, erosion potential etc.
10²-10⁴ km
catchment-wide scale
Investigation of whole catchment
Suggestion for catchment management
Planview river morphology, slopes, sediment regime
1-10² km
sectional scale
Analysis of key sections
Derivation of sectional results
local morphology, bedforms, islands, bank erosion etc.
10⁻²-1 km
local scale
Stufy of representative morphologic units
Aggregation of data for local scale
Substrate variability, grain sorting, flow velocities, initiation of motion
10⁻⁴-10⁻² km
point scale
Measuring / modelling of key processes
UP-SCALING
(HABERSACK, 2000)

# Methods (2)

- Literature research
  - Collection of studies, reports, conference papers/proceedings, journal articles, books, etc.
- Analysis and qualitative evaluation of literature
  - Relevance of each literature for this study
  - Central topic and investigation area of each literature
- Allocation of literature to
  - selected issues (sediments, ecology…) and
  - sub-catchments of the Danube River Basin

Results of literature analysis → **DANUBE CATALOGUE**


Danube Basin
N
UPPER DANUBE
MIDDLE DANUBE
LOWER DANUBE
DANUBE DELTA
Praha
Stuttgart
München
Bern
Chisinau
Ljubljana
Zagreb
Bijeljina
Beograd
Bucuresti
Sarajevo
Skopje
Tirana
Legende
Hydraulic Structures
Danube
Tributaries
Country border
Kilometer
0 50 100 200 300 400

# Content

1. Introduction
2. Problems and objectives
3. Methods
4. Results
5. Summary
6. Conclusions
7. Recommendations

# Results

Content of the **DANUBE CATALOGUE**:

- Bibliography of collected literature (as basis for a Access-database)

| ID-Number | Relevance for Platina | Countries | Part of the Danube | Study area | river kilometre [rkm] (length of the reach in km) | Year | Issue | Power plant | Title |
|---|---|---|---|---|---|---|---|---|---|
| **1** | **1** | **Austria** | **Upper Danube** | **Donaugebiet zwischen Wallsee und Dornach (östliches Machland)** | **rkm2094-2084** | | **Fish fauna** | **-** | **Studie zur Untersuchung der Fischfauna im Donaugebiet zwischen Wallsee und Dornach unter besonderer Berücksichtigung der FFH-Schutzgüter** |
| 2 | **1** | Austria | Upper Danube | Donaugebiet zwischen Wallsee und Dornach (östliches Machland) | rkm2094-2084 | 2007 | Fish fauna | - | Fischfauna der Donau im östlichen Machland unter besonderer Berücksichtigung der FFH-Schutzgüter und ihres Erhaltungszustandes; Maßnahmen und Potential für Revitalisierungen |
| 3 | **1** | Hungary | Middle Danube | Floodplain between the flood protection dikes (Szigetköz region) | - | 2002 | Power plant | Gabcíkovo | Environmental impacts of the Gabcíkovo Barrage System to the Szigetköz region |
| 4 | **2** | Rumania | Lower Danube | - | rkm942 | 1998 | Power plant | Iron Gate | Twenty-five years of safe exploitation of the hydro power plant "Iron Gate I" on the Danube River |
| **5** | **2** | Austria | Upper Danube | 50km lange freie Fließstrecke; nördlich von Wien - Regelsbrunn | rkm1945-1895 (50km) | 2004 | Fish fauna | - | The importance of inshore areas for adult fish distribution along a free-flowing section of the Danube, Austria |
| 6 | **1** | Austria | Middle Danube | Nationalpark Donauauen, 25km lange freie Fließstrecke zwischen Wien und der slowakischen Grenze | 25km | 1998 | Floodplain | - | Conservation by restoration: the management concept for a river-floodplain system on the Danube River in Austria |
| 7 | **1** | Hungary | Middle Danube | Hungarian Danube | 300km | 2008 | Fish fauna, Hydromorphology | - | Comparison of Fish Assemblage Diversity in Natural and Artificial Rip-Rap Habitats in the Littoral Zone of a Large River (River Danube, Hungary) |
| 8 | **2** | Slovakia | Middle Danube | Devin Gate, Bratislava | rkm1861-1875 (14km) | 2002 | Hydromorphology | - | Channel evolution of the pre-channelized Danube River in Bratislava, Slovakia (1712-1886) |
| **9** | **3** | Bulgaria | Lower Danube | Bulgarian Danube, Timok River to the town Silistra | 471km | 1995 | Riverine Landscape Planning | - | An experiment in greenway analysis and assessment: the Danube River |
| 10 | **2** | Romania | Lower Danube | Lower Danube and Delta | - | 1997 | Fish fauna | - | Endangered migratory sturgeons of the lower Danube River and its delta |
| 11 | **3** | Netherlands, Austria, France | Upper/Middle/Lower Danube | - | - | 2004 | Fish fauna | - | Habitat loss as the main cause of the slow recovery of fish faunas of regulated large rivers in Europe: the transversal floodplain gradient |
| 12 | **1** | Slovakia | Middle Danube | Hungarian/Slovak Danube | ~ rkm1850-1805 | 2003 | Power plant, Fish fauna | Gabcíkovo | Initial impact of the Gabcíkovo hydroelectric scheme on the species richness and composition of 0+ fish assemblages in the Slovak floodplain, River Danube |
| 13 | **2** | Slovakia | Upper/Middle/Lower Danube | Seven stations along the river | | 2006 | Hydrology | - | Long-term discharge prediction for the Turnu Severin station (the Danube) using a linear autoregressive model |
| 14 | **1** | Austria | Upper Danube | Machland | rkm2094-2084 (10.25km) | 2004 | Floodplain | - | Reconstruction of the characteristics of a natural alluvial river-floodplain system and hydromorphological changes following human modifications: the Danube River (1812-1991) |
| | | | | | Machland: rkm2094.4-2084 | | | | |

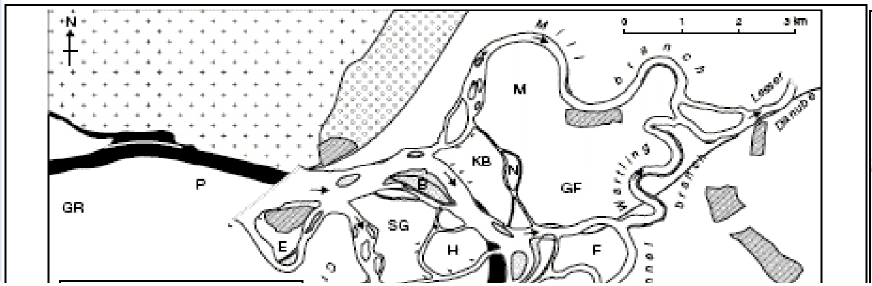
# Results

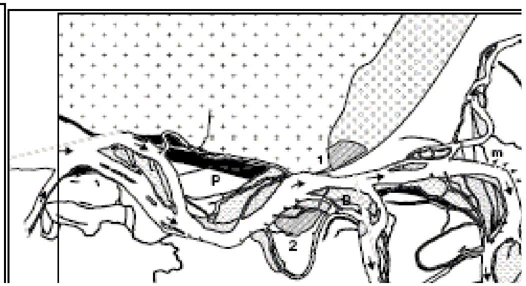
Content of the **DANUBE CATALOGUE**:

- Info sheets according to the Danube's sub-catchments and selected issues

Middle Danube — Hydromorphology

| ID | stretch | issue | facts |
|---|---|---|---|
| ID 8 | Bratislava, Devin Gate | Channel evolution of the pre-channelized Danube river in Bratislava, Slovakia (1712-1886) | Due to relatively high rates of lateral activity, the Danube reworked a high proportion of the active belt floodplain over 1712-1886, with minor central parts of major islands left untouched.<br>The key mechanism of planform change were avulsion through switching of a stream chute channels, and meander development by migration, progression and cut-offs.<br>Effectiveness of human interventions was limited by increased fluvial activity over the 18th century.<br>Geomorphic effects of frequent floods -> amplified by human works (stabilization, simplification of the river pattern, concentration and widening of the main channel)<br>Another sign of channel readjustment -> in the first half of the 19th century -> development of large meanders, producing new anastomosing-meandering parallel channels at the lower end of the study reach. |

# Results

Lower Danube — Sediments

| ID | stretch | issue | facts |
|---|---|---|---|
| ID 57 | Lower Danube | Assessment of the balance and management of sediments of the Danube waterway | suspended load dominates the overall sediment transport (100yrs ago highest values in Delta 70mio t/yr |
| | | | before Iron Gate dams (1979/84) 50mio t/yr in the Delta, afterwards transported suspended sediment decreased considerably |
| | | Morphological changes | river bed is undergoing a permanent erosion process downstream of IG dams along entire RO-BG stretch, which means more erosion, unstable banks, more shallows and more islands (93 with total length of 283km in 1934 to 135 with total length of 353km in 1992) |

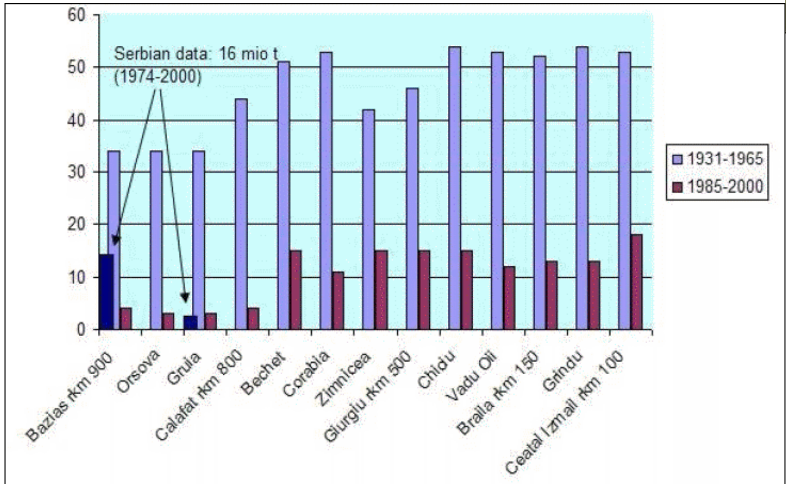
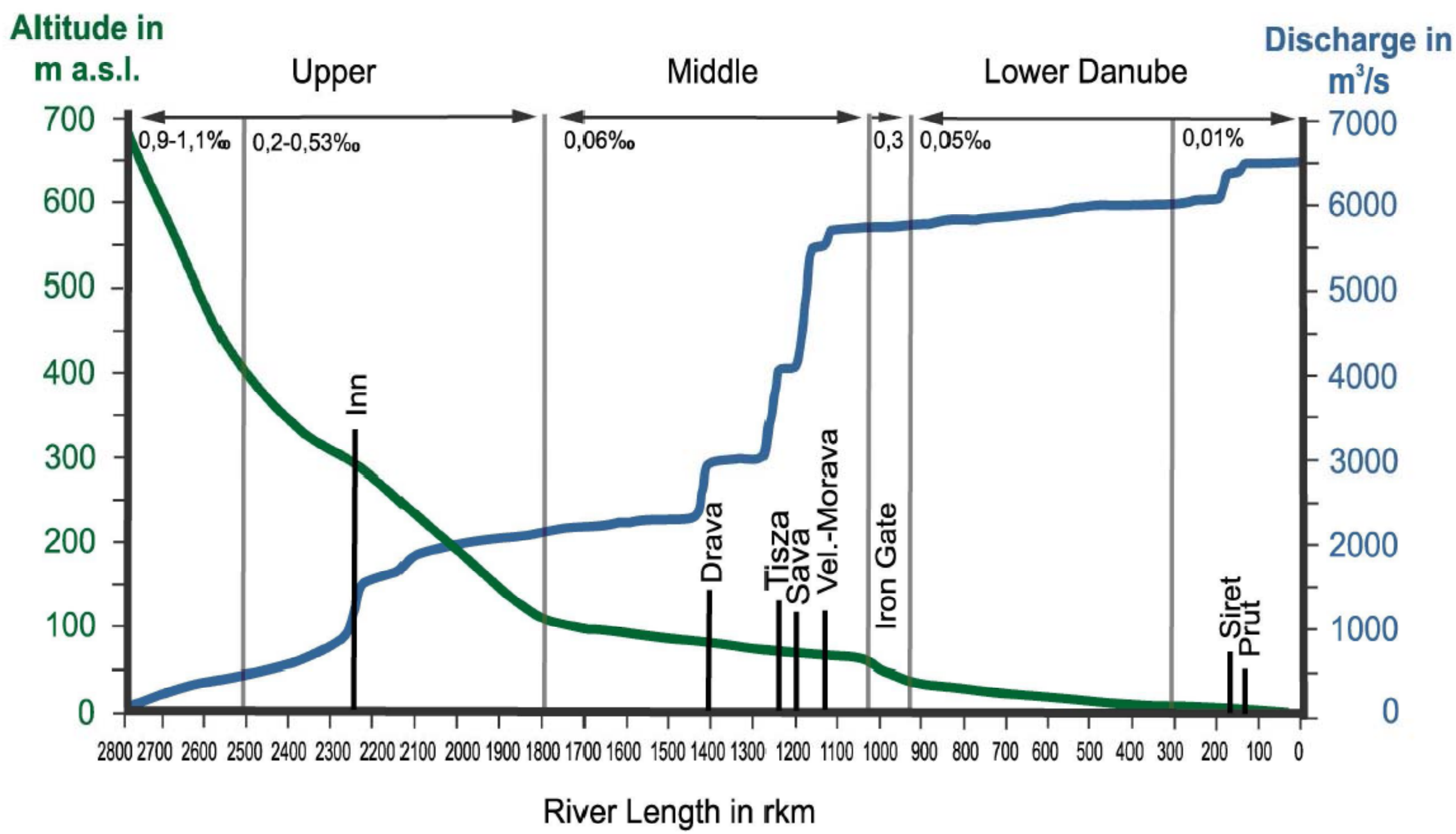



Figure 6: Sediment transport in the lower Danube in millions of tons per year since the construction of the Iron Gate dams (Batuca 2002). The Serbian measurements indicate a rather different picture for the sediment entry into the Iron Gate (station Bazias in the graph), which had a very small decrease even when compared to what the major tributaries Tisa, Sava and Velika Morava delivered to the Danube before the construction. After the dam Iron gate 1, the amount is reduced to about 2.5-3 million t/yr as indicated jointly. Furthermore the time interval from 1985-2000 represents rather low values, as the flood discharges were under the average. This figure underlines the uncertainties of transboundary measurements and hydrographical conditions for a rather short time interval (1985-2000).

# Results – Catchment scale

*Danube River Basin*



# Results – Catchment scale

## Driving forces and impacts – *Danube River Basin*

⇨ Navigation

⇨ Flood protection

⇨ Hydropower plants

⇨ Climate change

⇨ Changes in land use

⇨ Point and diffuse source pollution

# Results – Catchment scale

Driving forces and impacts – *Danube River Basin*

⇨ Navigation

- sediment regime (river bed incision, dredging…)
- Increased bed slope/flow velocity, increase/acceleration of flood waves
- Reduced river length/width, fixed river bed and shorelines, loss of morphological dynamics; loss of inshore habitats

# Results – Sectional scale

## Driving forces and impacts – ***Navigation***

⇨ Upper Danube

- Shortening of the river length
- Prevented side erosion
- Disconnection/silting of side-arm system and floodplains

⇨ Middle Danube

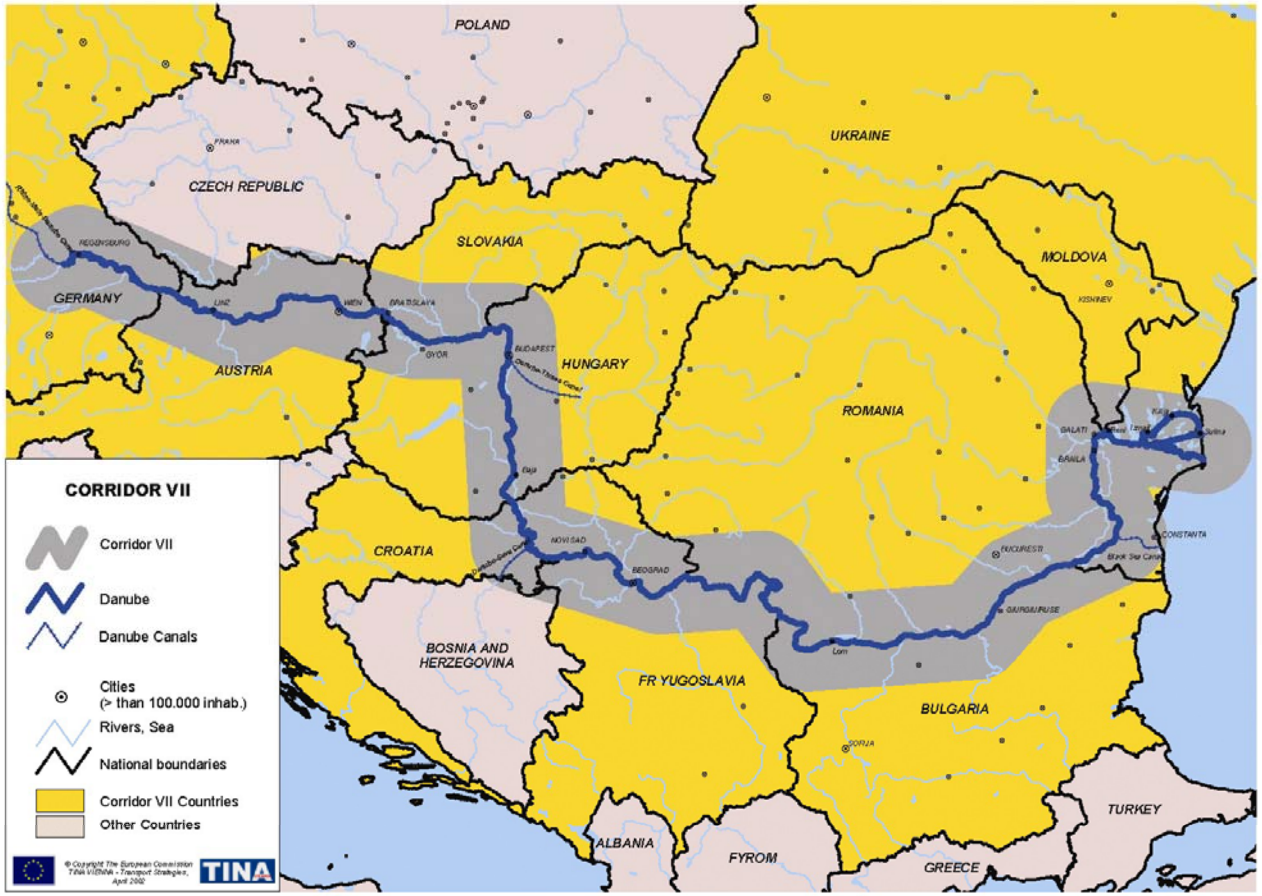
- Limited lateral dynamics of the river (e.g. at the Slovakian Danube)
- Limited hydrologic interaction
- Reduced river length, River bed degradation, Aggradation of side-arms and oxbows

⇨ Lower Danube

- Bank instabilities (in the context of hydropower plants)
- Wake and splash processes
- Local turbidity due to dredging measures

# Results – Catchment scale

*Danube River Basin - Navigation*




via donau, 2007

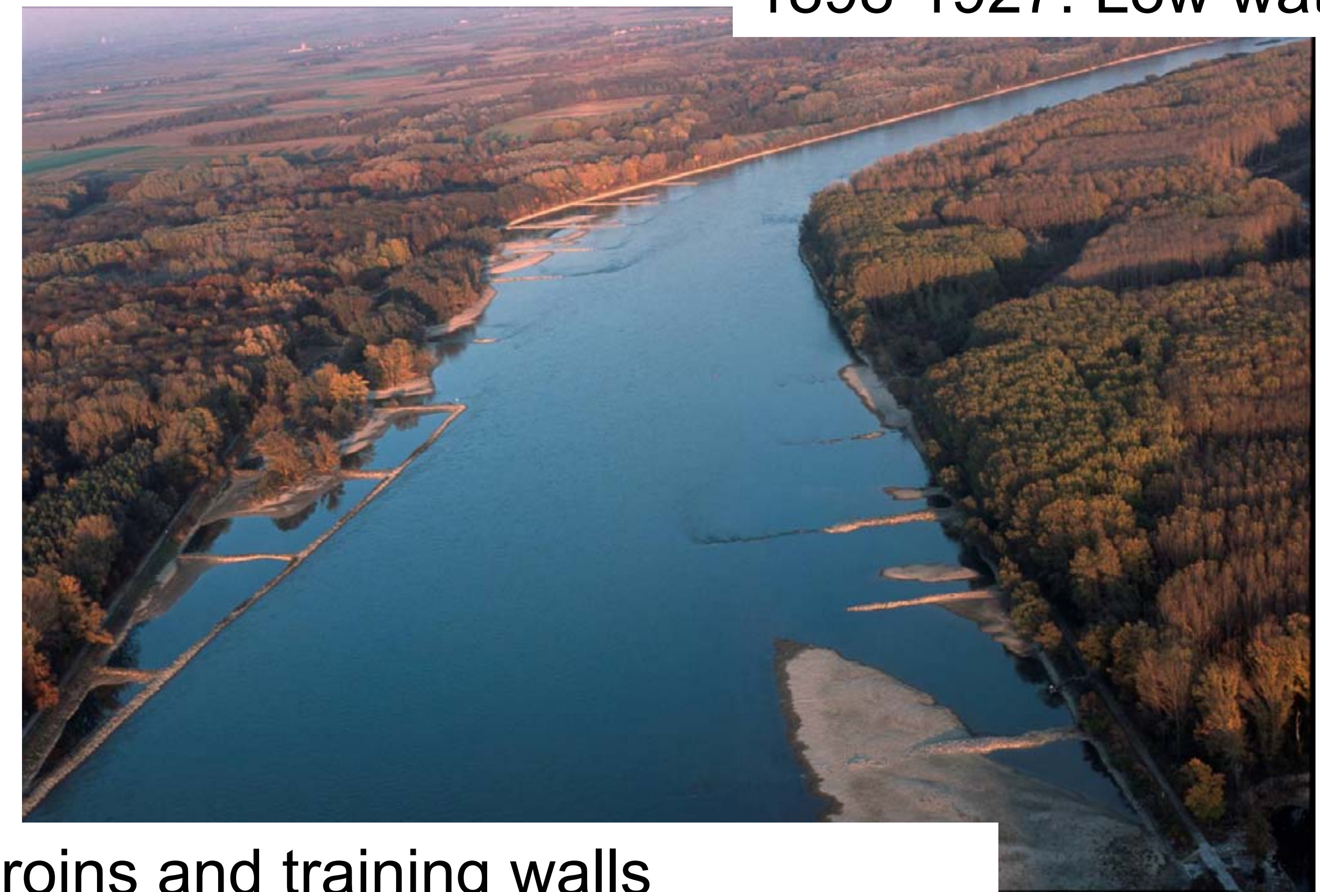
2411 km navigable (Sulina-Kelheim)

Waterway transport in the Danube Corridor increased by 85 % between 1994-2002

# Results – Sectional scale

*Upper Danube - Navigation*

1898-1927: Low water regulations



Groins and training walls

National Park
Donauauen

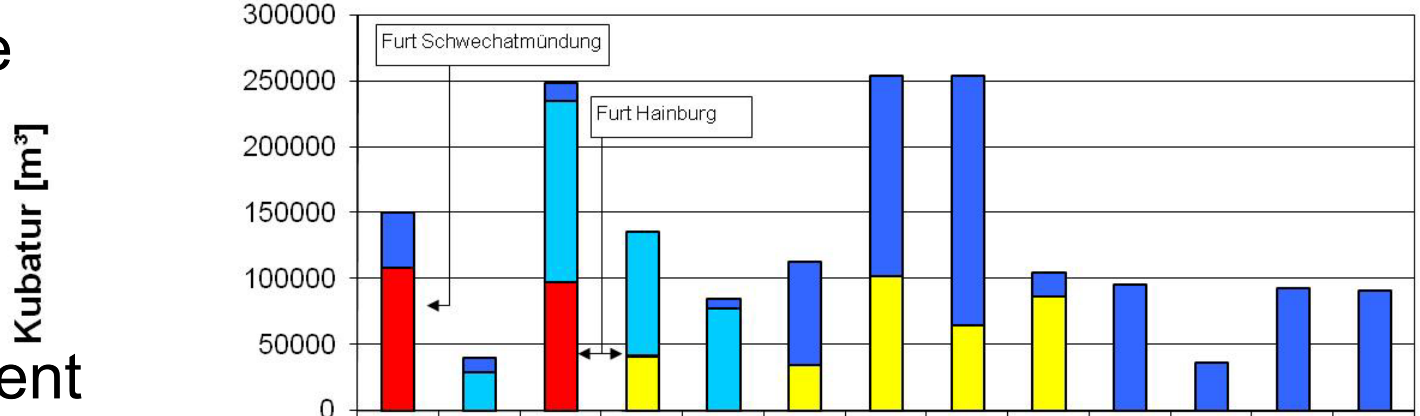
# Results – Sectional scale

## *Upper Danube – Dredging (e.g. East of Vienna)*

Low dredged volumes along the Upper Danube compared to the Lower Danube

Affecting sediment regime, but minimized by returning of the material

**Instandhaltungsbaggerungen Donau östlich von Wien**




| | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Summe der Baggerungen | 150250 | 40160 | 249280 | 136160 | 85256 | 113158 | 254507 | 254825 | 105280 | 95794 | 36025 | 92962 | 90930 |
| Verklappt im Fluss | 41300 | 10610 | 13730 | | 7406 | 78158 | 152207 | 190145 | 18880 | 95794 | 36025 | 92962 | 90930 |
| Uferstrukturierung | | 29550 | 138150 | 93800 | 77850 | | | | | | | | |
| Eleviert Ö (WSD) | 108950 | | 97400 | 1200 | | | | | | | | | |
| Eleviert SK (Theben) | | | | 41160 | | 35000 | 102300 | 64680 | 86400 | | | | |

**Jahr**

Via donau, 2009

# Results – Sectional scale

*Lower Danube – Bottleneck for navigation*


e.g. Belene Island

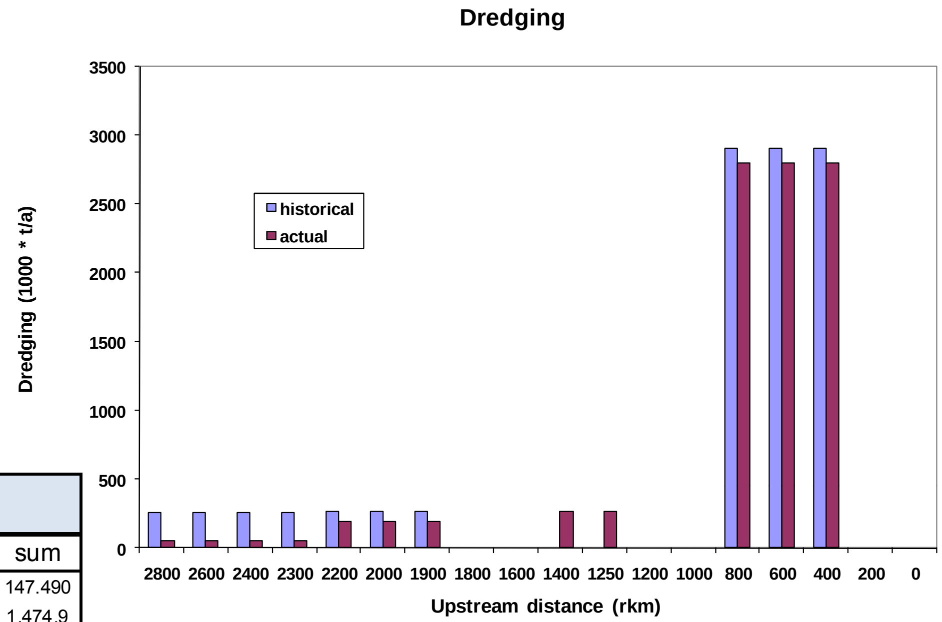
Number of islands increased from 93 (1934) to 135 (1992)

Side erosion

# Results – Sectional scale

## *Lower Danube – Dredging*

High dredging volumes compared to upper reaches




| Period | State | Romania | | | Bulgaria | | | Total | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Type * | 1 | 2 | sum | 1 | 2 | sum | 1 | 2 | sum |
| 1961-1970 | $m^3.10^3$ | 45.230 | 49.430 | 94.660 | 27.530 | 25.300 | 52.830 | 72.760 | 74.730 | 147.490 |
| Mean annual | $m^3.10^3/Y$ | 452,3 | 494,3 | 946,6 | 275,3 | 253,0 | 528,3 | 727,6 | 747,3 | 1.474,9 |
| | % | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 1971-1990 | $m^3.10^3$ | 30.608 | 23.113 | 53.721 | 9.986 | 8.639 | 18.625 | 40.594 | 31.752 | 72.346 |
| Mean annual | $m^3.10^3/Y$ | 1.530,4 | 1.156,6 | 2.686,0 | 499,3 | 431,9 | 931,2 | 2.029,7 | 1.587,6 | 3.617,3 |
| | % | 338,4 | 234 | 283,8 | 181,4 | 170,7 | 176,3 | 278,9 | 212,4 | 245,2 |
| 1961-1990 | $m^3.10^3$ | 35.131 | 28.056 | 63.187 | 12.739 | 11.169 | 23.908 | 47.870 | 39.225 | 87.095 |
| Mean annual | $m^3.10^3/Y$ | 1.171,0 | 935,2 | 2.106,2 | 424,6 | 372,3 | 796,9 | 1.595,7 | 1.307,5 | 2.903,2 |
| 1991- 2005 | $m^3.10^3$ | 2.017 | 17.043 | 19.061 | 427 | 6.785 | 7.212 | 2.444 | 23.828 | 42.889 |
| Mean annual | $m^3.10^3/Y$ | 135 | 1.136 | 1.271 | 29 | 452 | 481 | 163 | 1.589 | 1.752 |

Modev, 2008

Type 1: dredging for maintenance of the navigation
Type 2: dredging for sand and gravel production

# Results – Catchment scale

Driving forces and impacts – *Danube River Basin*

⇨ Flood protection

- Disturbed sediment regime
- Lowered water levels due to the reduction of river length and therefore higher flow velocities, reduced hydrological connectivity
- reduction of retention areas due to the loss of floodplains, reduced river length/width, increased shear stress, river bed erosion…
- Loss of riverine structures, loss of habitats…

# Results – Catchment scale

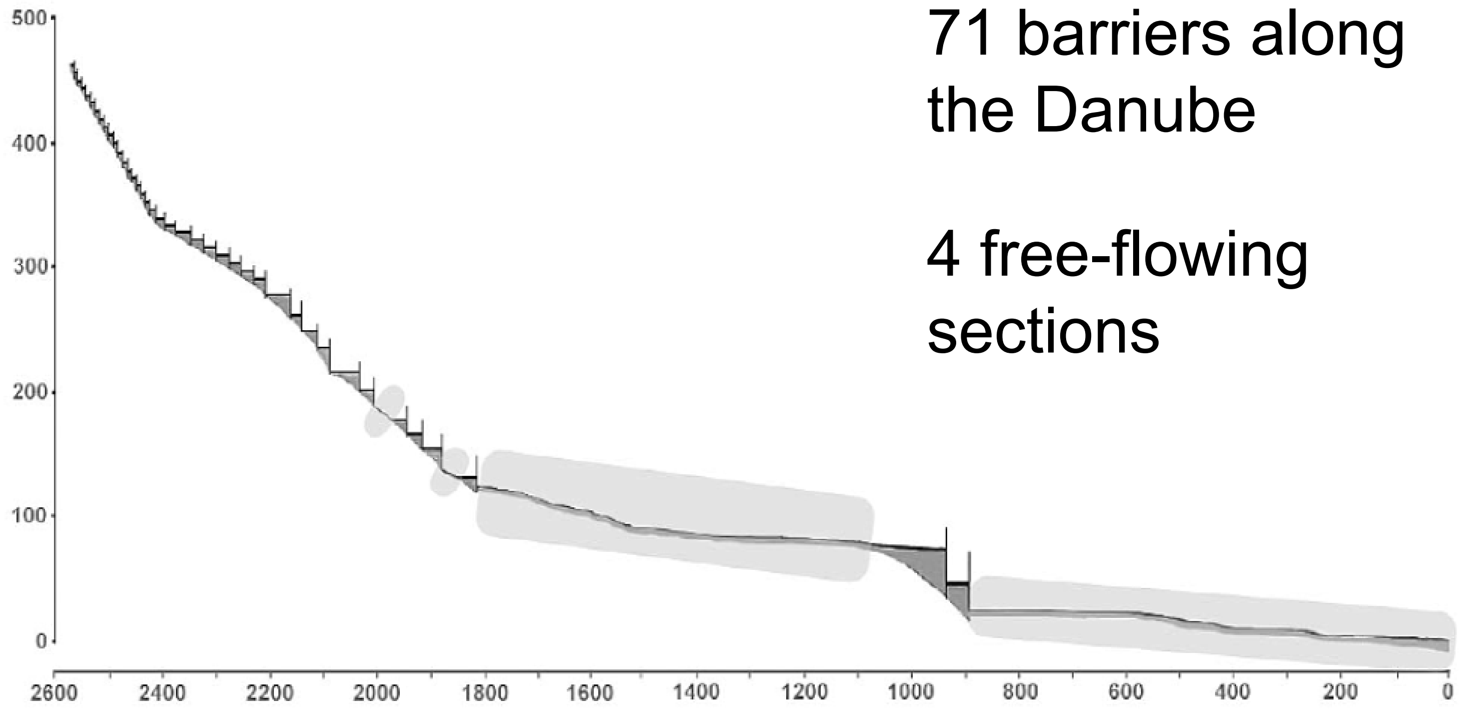
<u>Driving forces and impacts</u> – *Danube River Basin*

⇨ Hydropower

- Hydrological and hydraulic changes (reduced flow velocities at reservoirs…)
- sediment transport (surplus – deficit)
- loss of continuity (fish and sediments) and habitats
- Modification of river morphology (disruption of the longitudinal/lateral connectivity…)

# Results – Catchment scale

*Danube River Basin – Hydropower*



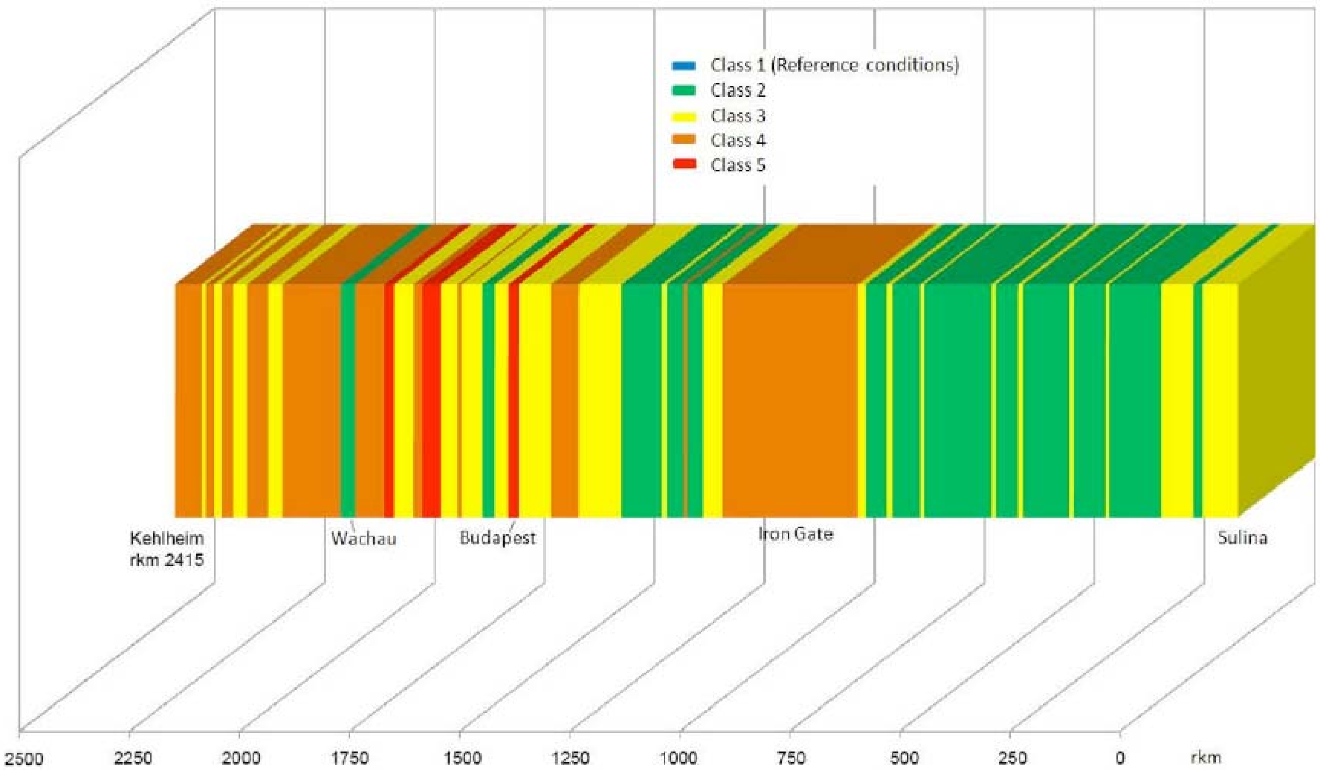

71 barriers along the Danube

4 free-flowing sections

# Results – Catchment scale

*Danube River Basin - Consequences*

Overall total hydromorphological assessment in five classes – longitudinal visualisation




1/3 good hydromorphological conditions

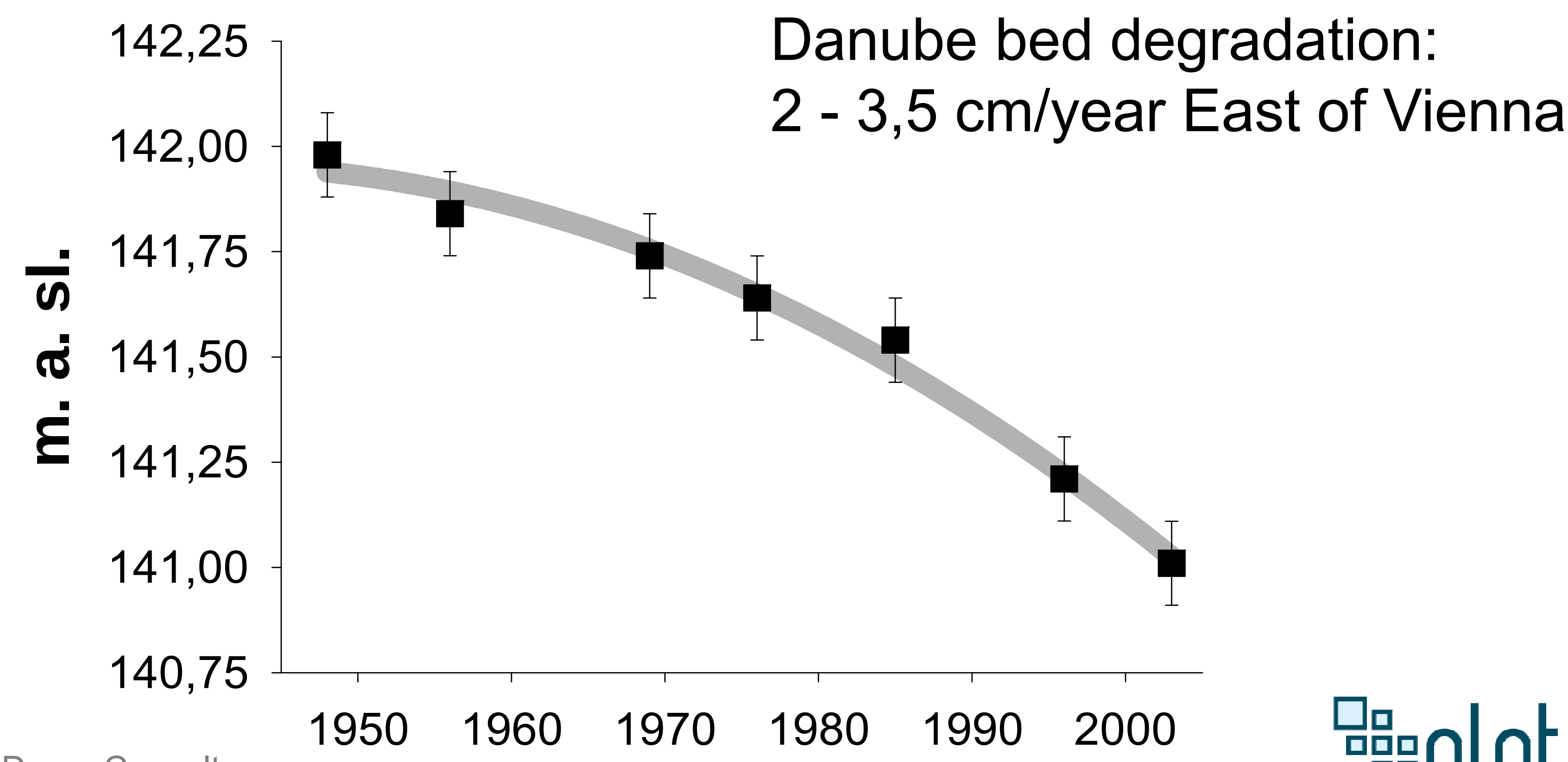
1/3 strongly altered

Upper Danube - most affected by significant hydromorphological changes

ICPDR, 2008

# Results – Sectional scale

*Upper Danube - Consequences*

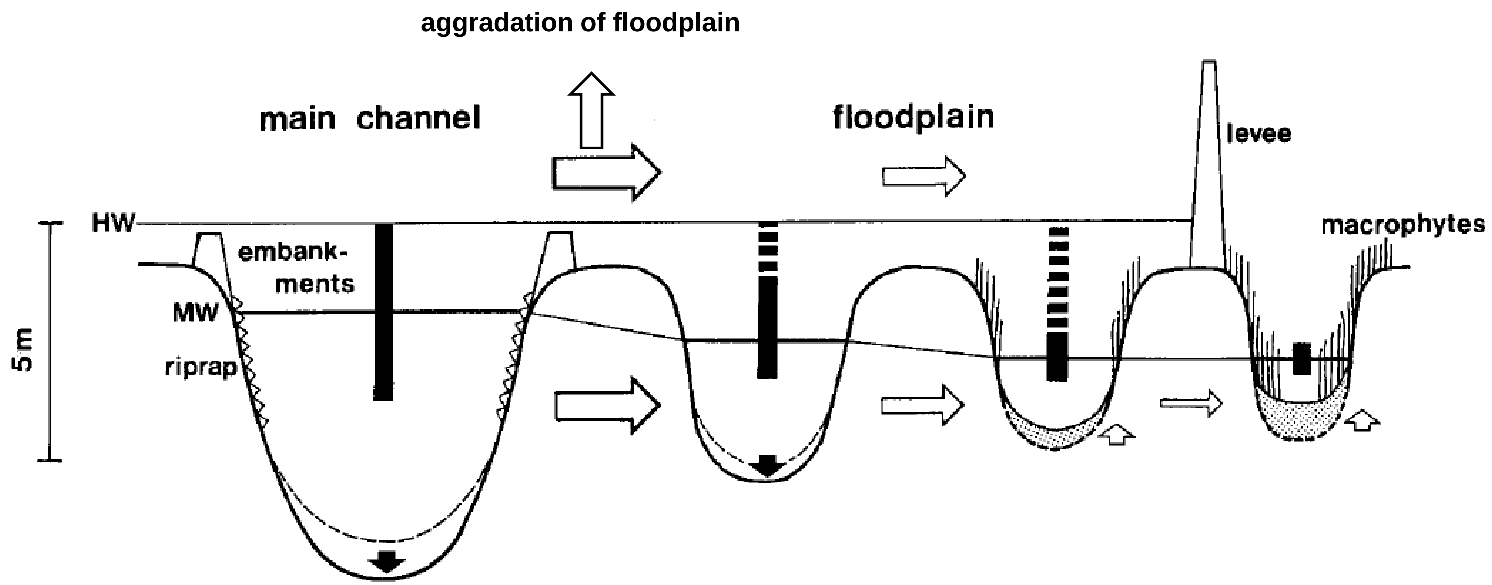



DonauConsult

# Results – Sectional scale

## *Upper Danube - Consequences*

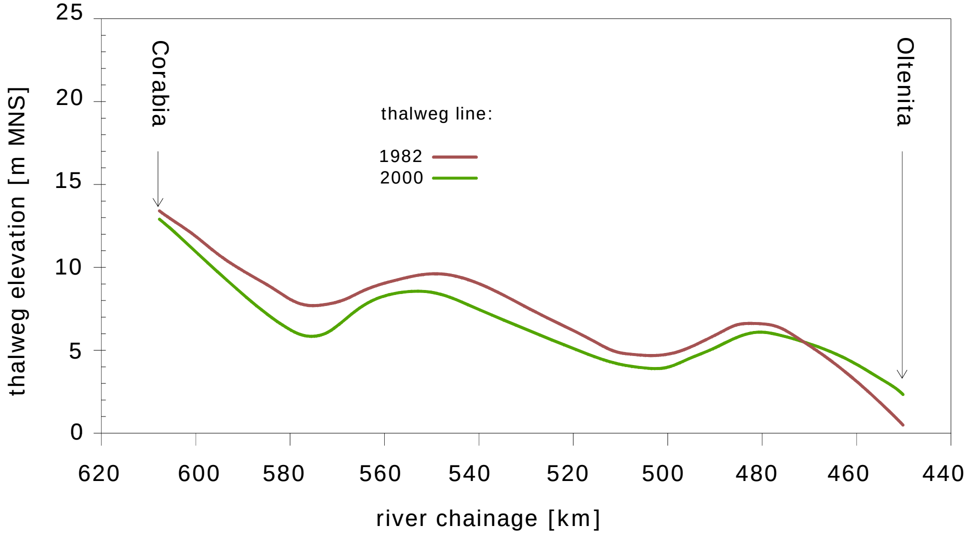
Regulation scheme




modified after Schiemer et al., 1999

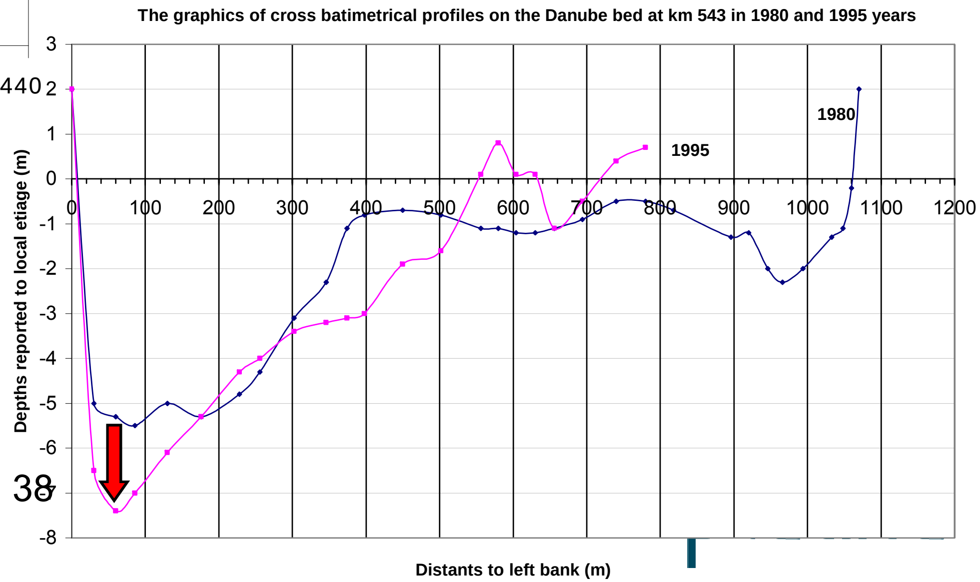
# Results – Sectional scale

## *Lower Danube - Consequences*




River bed degradation along the entire Lower Danube

Cross-sectional profile at rkm 543 (1980/1995)




modified after Batuca et al., 2002; Bondar and Teodor, 2008

# Results – Sectional scale

## Impacts – *Danube Delta*

- Water level at the Black Sea rises about 3 mm/year
- Increased suspended sediment input in the Delta lake complex
- Meander cut-offs: Sulina branch (23 km), Sfantu Gheorge (50 km)
- Side erosion along all Delta River branches due to dredging and accelerated by navigation (waves)
- Increased coastal erosion by 17 m/year
- Widening of branches: Chilia branch (about 2 m/year), Sfantu Gheorghe (about 1,2 m/year)
- River bed erosion: Sulina branch (6 cm/year)
- Dredging of navigation route at Sulina branch
- Disconnection of floodplains – decreased retention capabilities by 25 %
- Silting up and separation of lakes
- Alterations from former dredging activities
- Eutrophication
- Loss of species, aquatic plants, natural spawning habitats, changes in fish community

# Content

# Summary - Navigation

- Impacts of navigation at the **Upper Danube** are significant
  - straight single channel
  - fixed river bed
  - embankments for nearly the entire reach,….

**but**

planning approach for the future development shows tendencies to environmental objectives, e.g. ***'INTEGRATED RIVER ENGINEERING PROJECT ON THE DANUBE EAST OF VIENNA'***

# Summary - Navigation

- Impacts of navigation at the **Middle Danube** are quite moderate to considerable
- Projects are under development and should regard the JOINT STATEMENT 2007

# Summary - Navigation

- Impacts of navigation at the **Lower Danube** are marginal

**but**

this situation might change within several years depending on the selected measures to improve navigation

# Content

1. Introduction
2. Problems and objectives
3. Methods
4. Results
5. Summary
6. Conclusions
7. Recommendations

# Conclusions

- The Danube partially features a totally disturbed system (e.g. sediment continuum).
- Hydromorphology is not only an ecological issue but also an essential aspect for navigation, flood protection etc.
- Cumulative effects on hydromorphology arise not only from upstream to downstream but also backwards.
- It has to be considered that hydromorphological processes differ between each river section (Upper ⟺ Middle ⟺ Lower Danube).

# Content

# Recommendations (1)

## Basin-wide scale – Danube River Basin

- In upper and middle reaches river restoration and the improvement of navigation should be aimed
- At the Lower Danube preservation of morphodynamics in combination with the improvement of navigation
- Preservation and/or establishment/improvement of the sediment continuum along the Danube tributaries in the course of hydropower plants and torrent control (re-) structures
- Development of a catchment-wide sediment management concept (e.g. against river bed degradation, aggradation of reservoirs and of the inundation areas) considering the improvement of the ecological status
- Adapted land use (e.g. at lower reaches of the Danube)
- Conservation/restoration of floodplains
- Allowing of self-forming processes (morphodynamics)

# Recommendations (2)

## Upper and Middle Danube

- Improvement of the sediment continuum
- Stop of further riverbed degradation
- Develop ecologically compatible measures , being adapted to its location to improve navigation (modification of existing groins,…)
- Implementation of restoration measures according to given river morphological processes (side erosion, bed and side-arm development, heterogeneity in river morphology and habitat diversity)
- Shift ship pathway to deeper sections in order to reduce navigation problems

## Lower Danube

- Integrated design of IWT infrastructure measures(hydraulic, morphological, ecological criteria)
- Stop of further riverbed degradation
- Defined refilling of the dredged material downstream

# Recommendations (3)

Integrated planning approach and principles (compare **JOINT STATEMENT 2007**)

- Actions to improve the current situation should be seen from both perspectives IWT (Inland Waterway Transport) and ecological integrity
- Establishment of interdisciplinary planning teams involving key stakeholders
- Definition of joint planning objectives
- Set-up of transparent planning processes
- Implement the DANUBE RIVER BASIN DISTRICT MANAGEMENT PLAN 2009, regarding the sediment continuum and morphodynamics
- Information/consultation of the International Commission for the Protection of the Danube River (ICPDR) in the DRB
- Avoidance/minimization of the impacts resulting from structural/hydraulic engineering interventions
- Use good practice measures to improve navigation (-> GOOD PRACTICE MANUAL ON WATERWAY PLANNING)
- Monitoring of the effects of implemented measures

# Thank you for your attention !

Univ. Prof. DI Dr. Helmut Habersack
University of Natural Resources and Applied Life Sciences
Muthgasse 107, 1190 Vienna, Austria
helmut.habersack@boku.ac.at

# Appendix for discussion

# Results – Sectional scale

## Driving forces and impacts – ***Flood protection***

### ⇨ Upper Danube

- Reduction of river length (Baden Württemberg 73%, Bavaria 15%, Austria 15 %)
- Disconnection of side-arms e.g. at the Austrian Danube
- River bed degradation
- Loss of riverine inshore habitats, Reduction of geomorphic processes

### ⇨ Middle Danube

- Reduction of river length (Hungary 18 % , Serbia 10 %)
- River bed erosion along the Slovakian Danube
- Disconnection of floodplains by narrow flood dikes (in Hungary)
- Increase and/or acceleration of flood waves

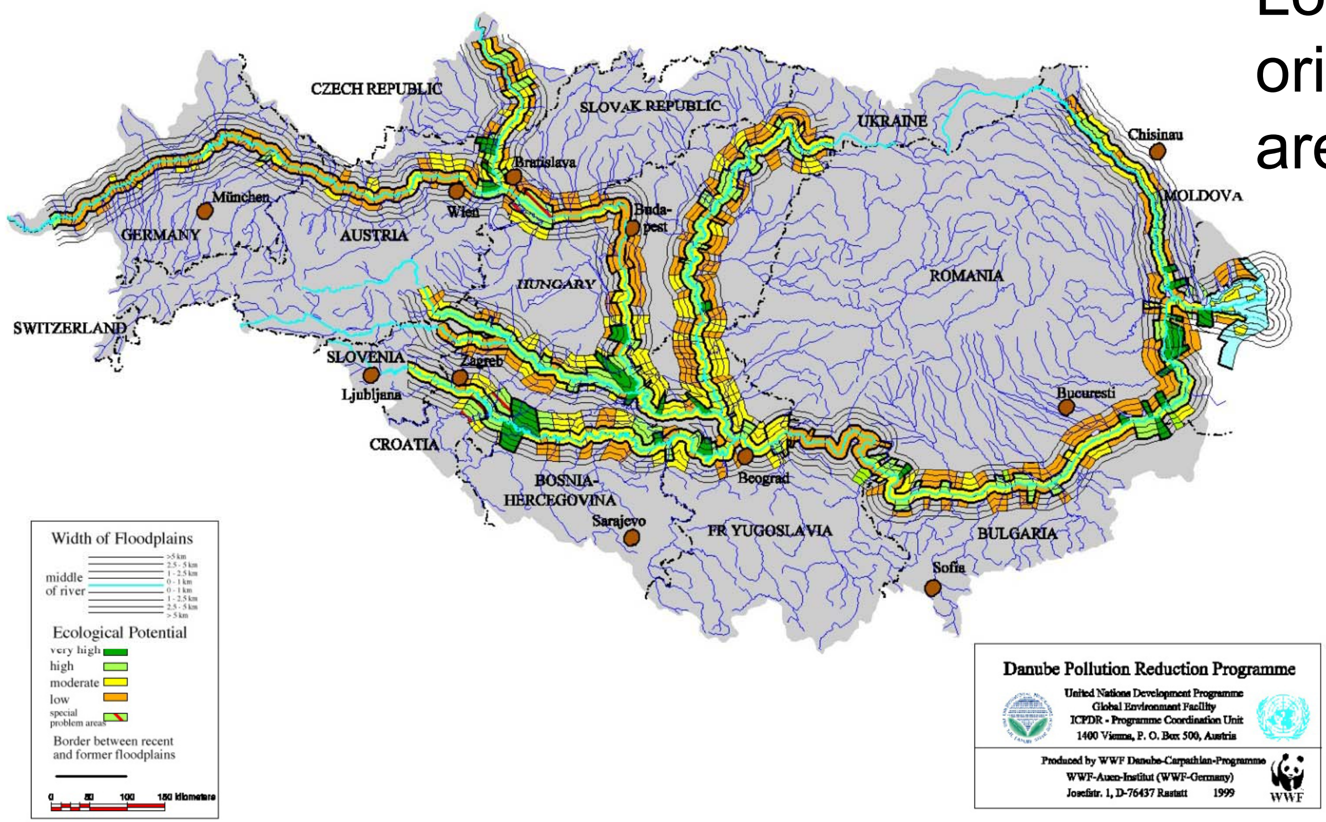
### ⇨ Lower Danube

- Reduction of lateral sediment input
- River bed erosion
- Loss of floodplains (72.600ha in BG; 426.000 ha in RO)
- retention capacity at floods reduced from 15,6 x $10^9$ $m^3$ to 4,0 x $10^9$ $m^3$

# Results – Catchment scale

*Danube River Basin – Flood protection*

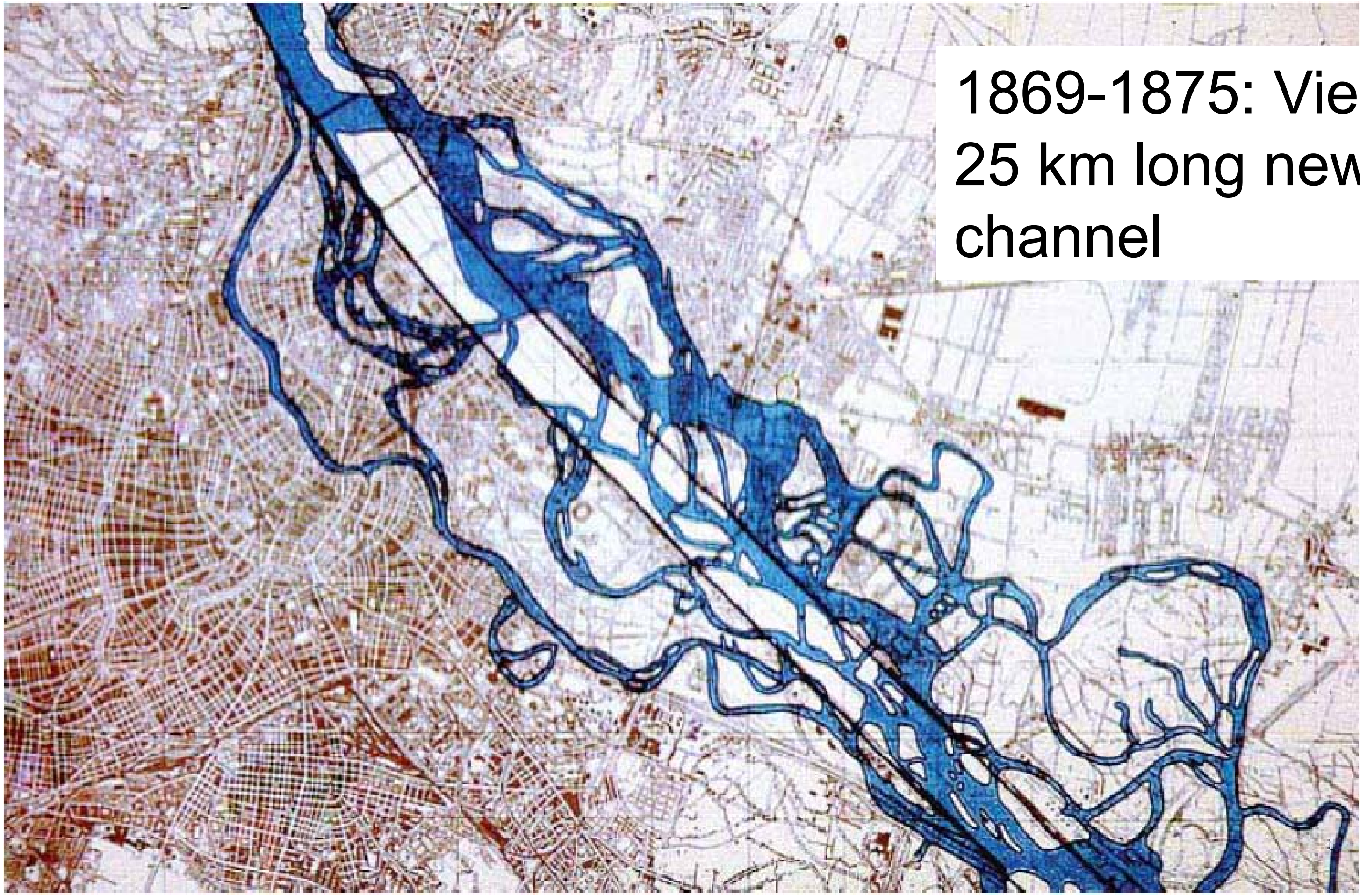
Ecological potential of floodplains in the Danube River Basin




Loss of 80 % of the original floodplain area

# Results – Sectional scale

*Upper Danube – Flood protection (e.g. Vienna)*



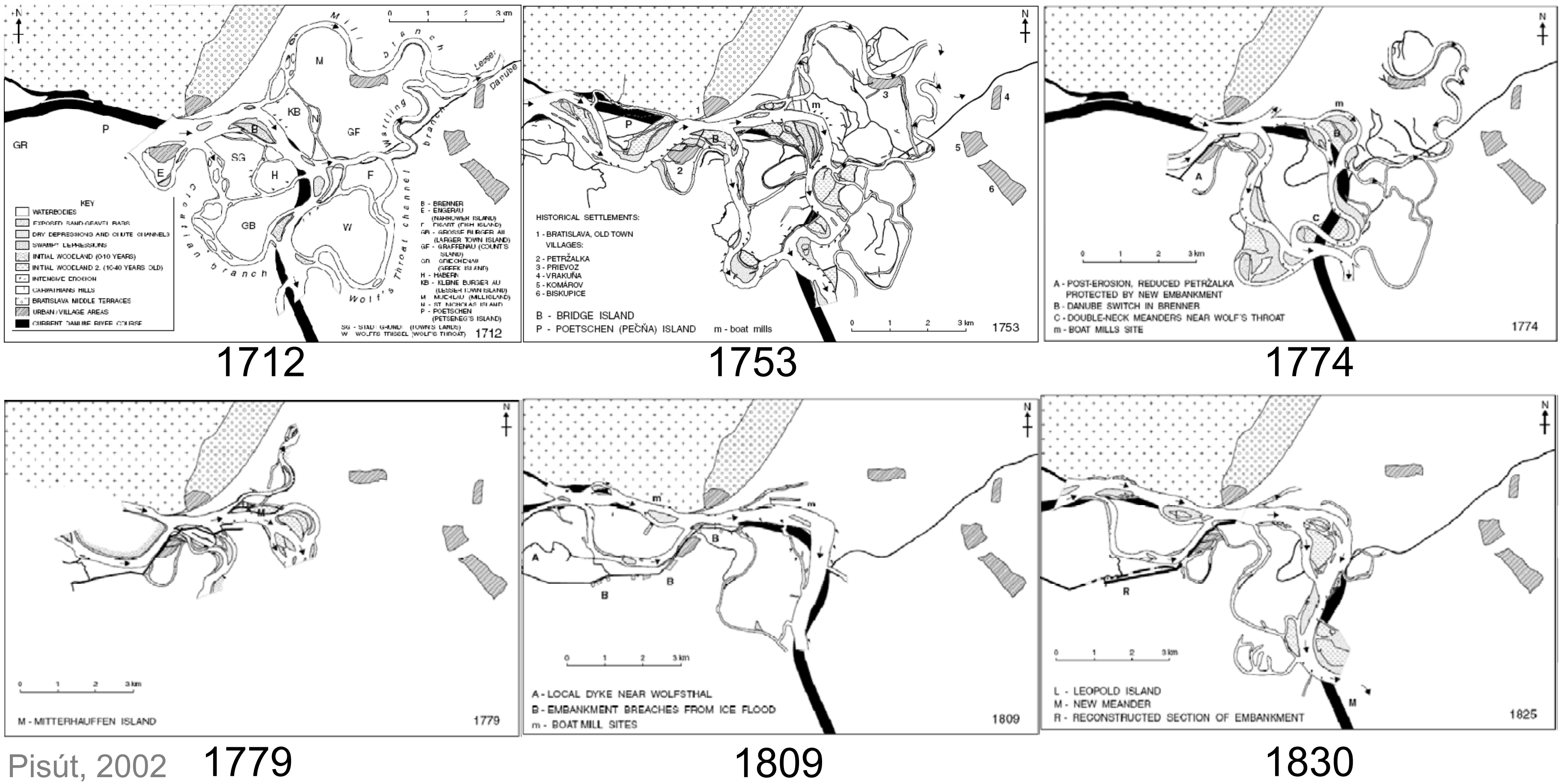
1869-1875: Vienna cut – 25 km long new straight channel

Schiemer et al., 2004

platina

# Results – Sectional scale

*Middle Danube – Flood protection (e.g. Bratislava)*




Pisút, 2002

# Results – Sectional scale

## Driving forces and impacts – ***Hydropower***

⇨ Upper Danube

- Sediment surplus in impounded river sections – reservoirs trapping efficiency of 17 %
- Sediment deficit in free-flowing sections
- Reduction of bed load input from tributaries (minus 90-95 %)
- River bed erosion downstream of HPP
- Disconnection of floodplains, Loss of continuity for fish migration/sediments

⇨ Middle Danube

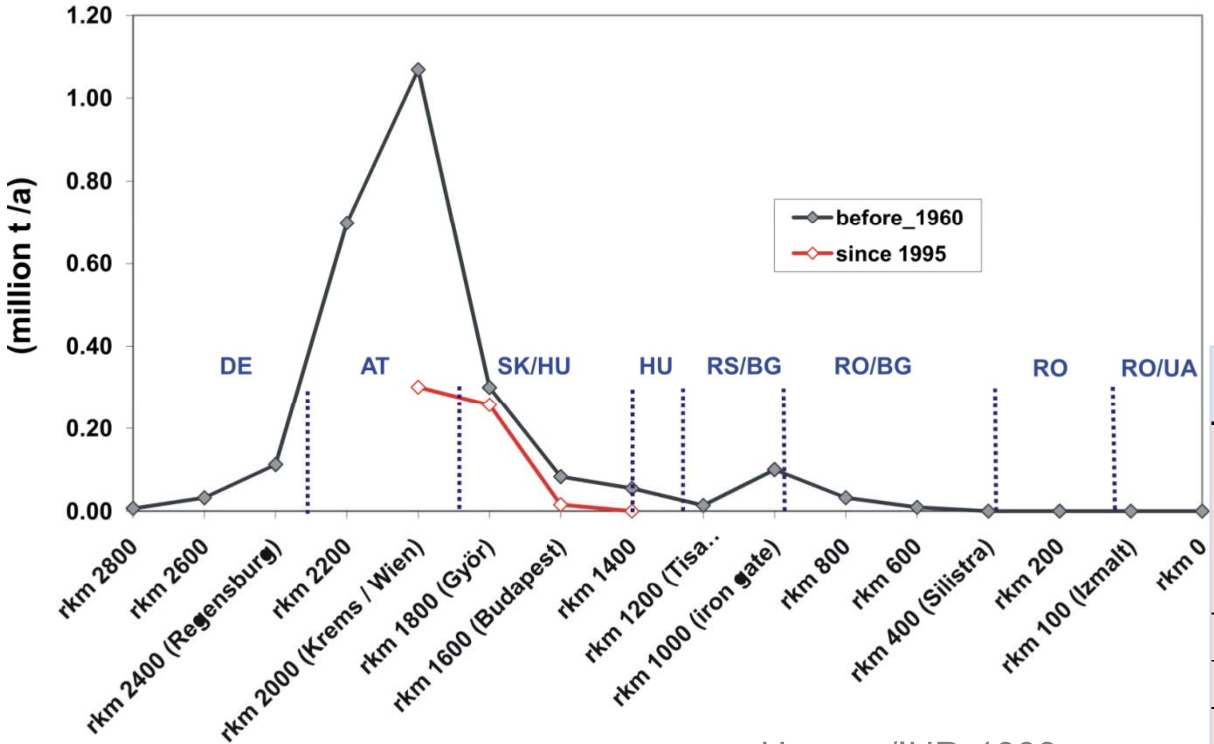
- Separated floodplains of each 4.000 ha in SK and HU
- Negative sediment balance downstream of Gabčíkovo and IG (river bed erosion)
- Deposition of suspended sediments – IG I : 50 % (20-30 mio t/year)

⇨ Lower Danube

- Sediment deficit (deposition of sediments in reservoirs upstream)
- River bed erosion, Side erosion

# Results – Catchment scale

*Danube River Basin – Hydropower*



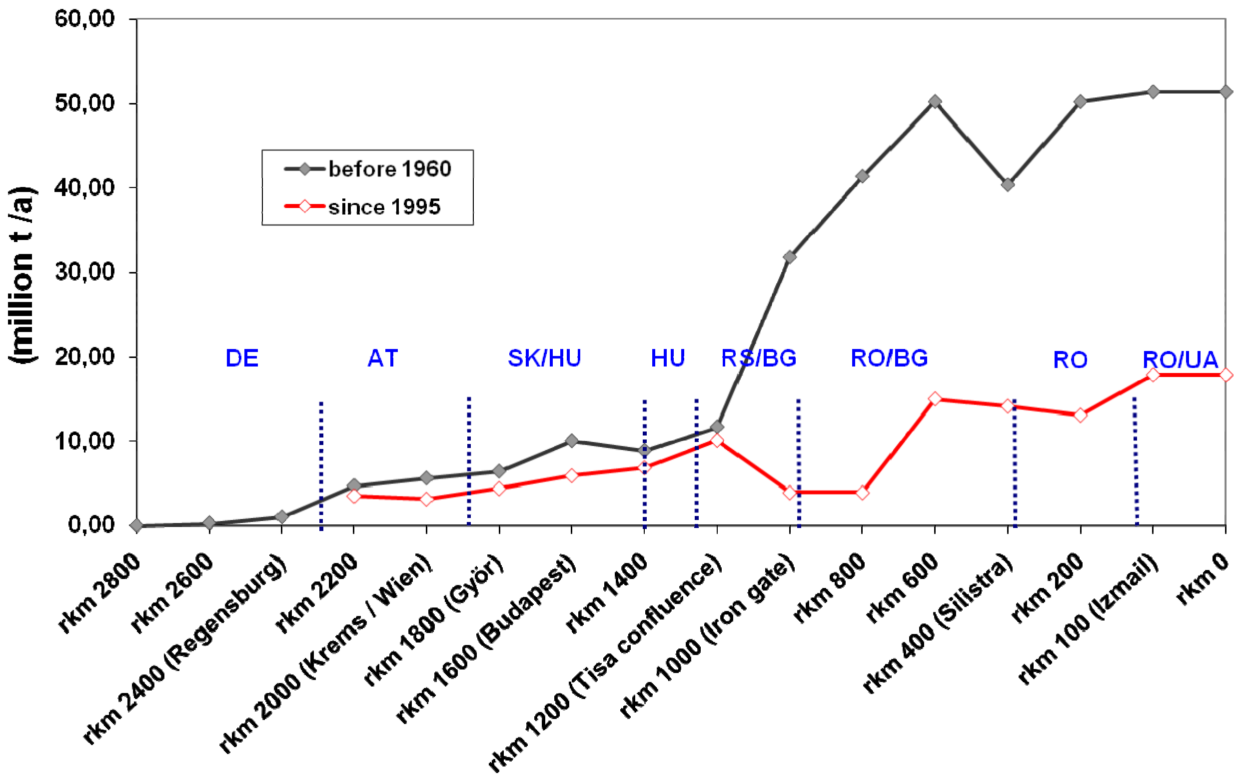

Unesco/IHP, 1993

Bed load supply practically stopped from upper reaches

| River | Location | Bed load [t/year] before 1960 |
|---|---|---|
| Danube | Donauwörth | 13,000 |
| | Ingolstadt | 94,000 |
| | Kelheim | 111,000 |
| | Straubing | 81,000 |
| Iller | close to confluence | 12,000 |
| Lech | close to confluence | 180,000 |
| Isar | close to confluence | 170,000 |
| Inn | close to confluence | 540,000 |
| Traun | close to confluence | 25,000 |
| Enns | close to confluence | 270,000 |
| Ybbs | close to confluence | 18,000 |

# Results – Catchment scale

*Danube River Basin – Hydropower*



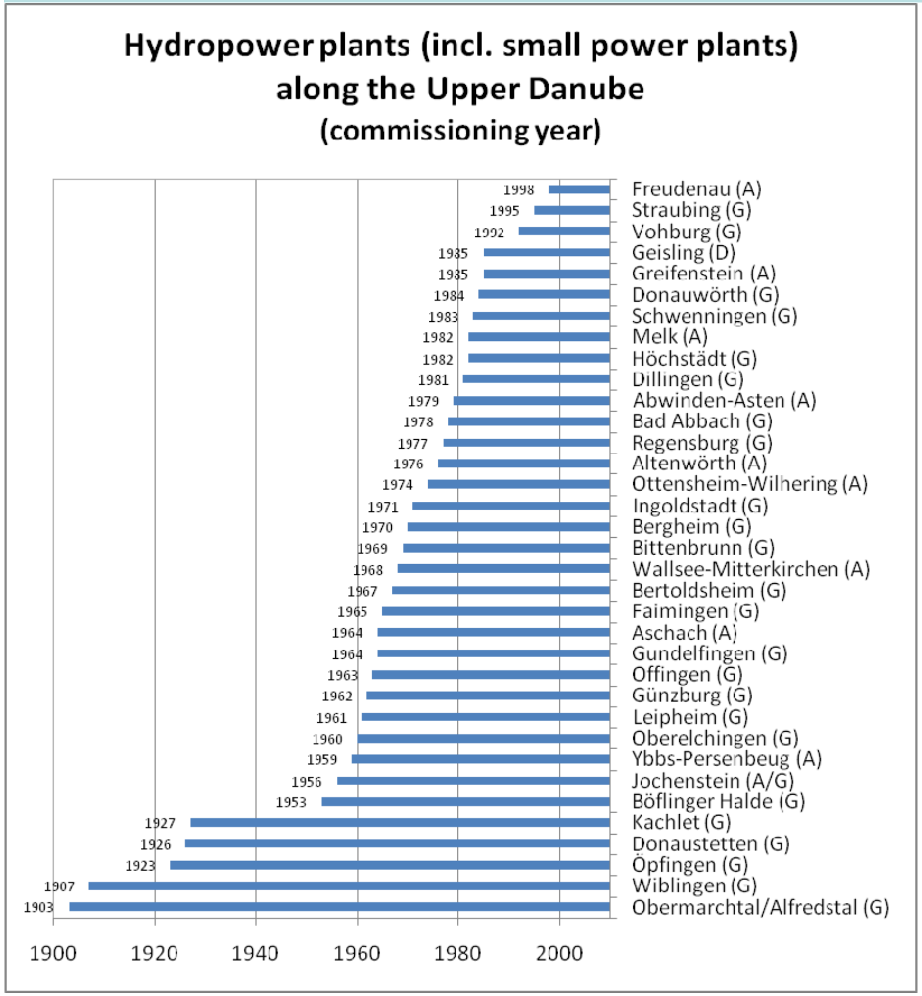

Surplus <-> Deficit

Deposition of suspended load in the reservoirs and impounded reaches

Danube Monography, 1993; Bruk et al., 2002; Bondar et al., 2000)

# Results – Sectional scale

## *Upper Danube – Hydropower*

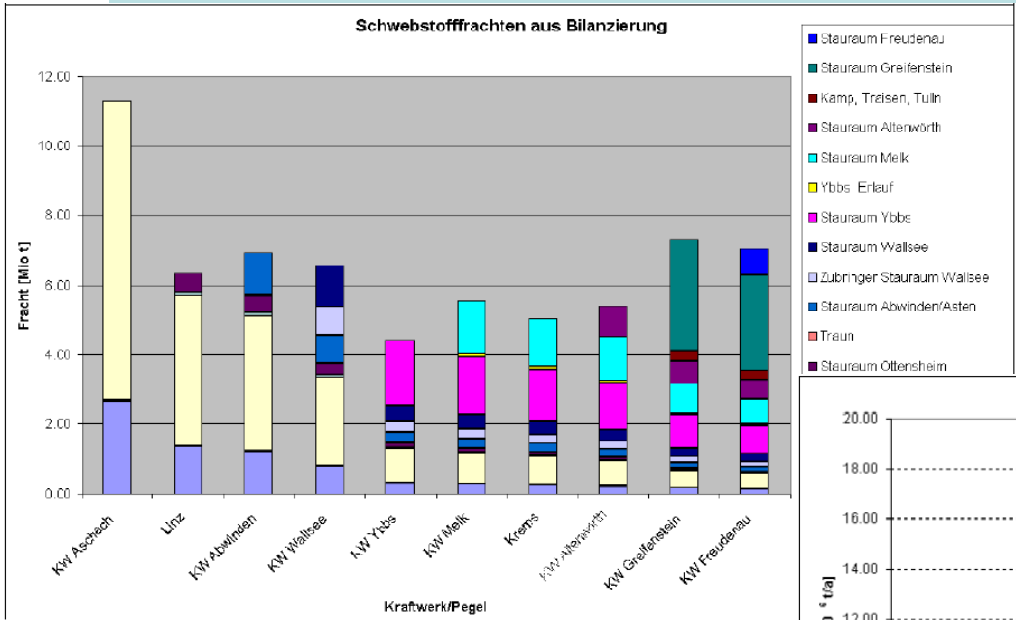



In total 68 barriers

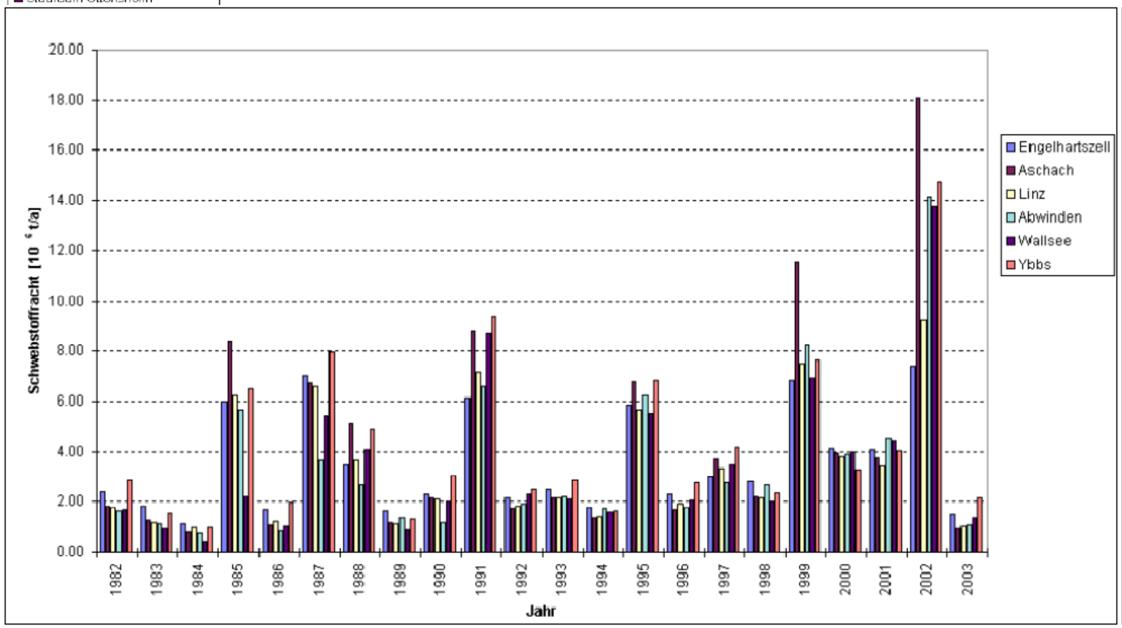
One dam every 17 km at the first 1000 km from the source

# Results – Sectional scale

## *Upper Danube – Hydropower*




Annual amount of suspended load is more or less the same but most of the load is transported during shorter time periods (few large flood events)

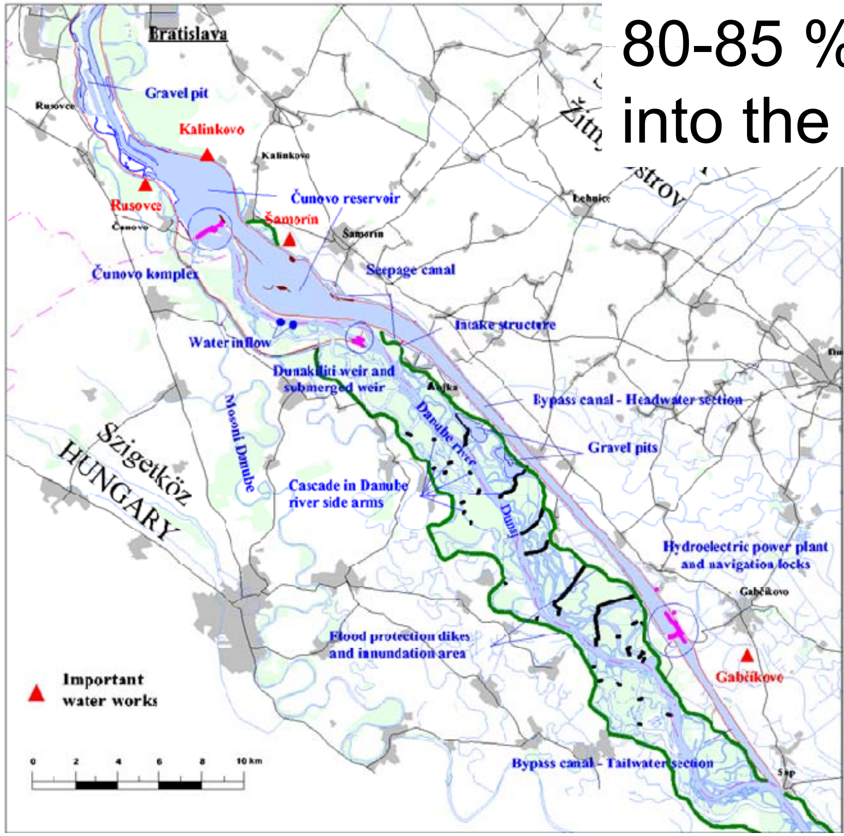



Temporal distribution of suspended load varies considerably due to dams

Nachtnebel et al., 2004

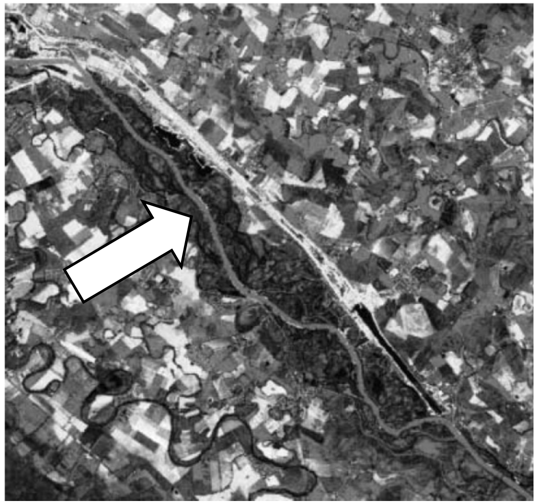
# Results – Sectional scale

## *Middle Danube – Hydropower (e.g. Gabčíkovo)*

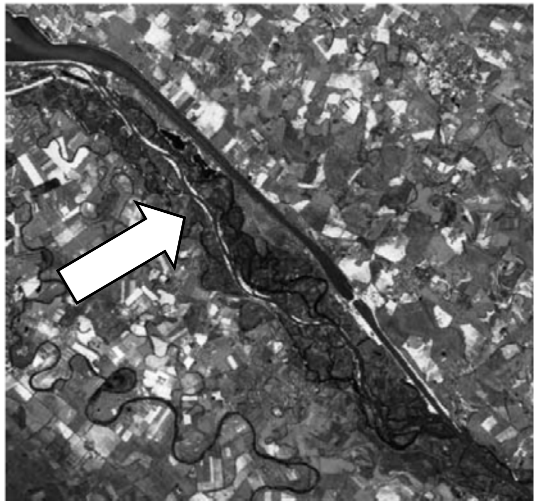



80-85 % of the river's discharge is diverted into the concrete-lined power channel

Before the division



After the division

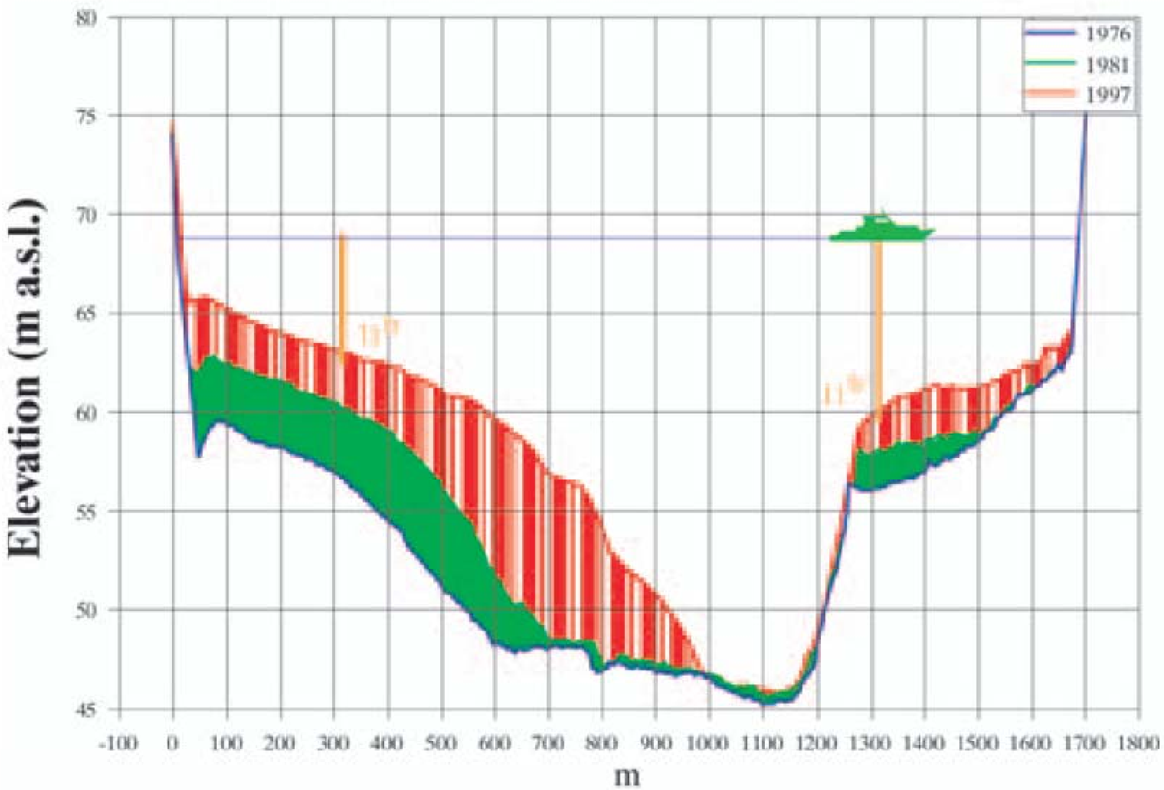


White arrow marks the old Danube

Ground Water Consulting, 2001; Smith et al., 2002

# Results – Sectional scale

*Middle Danube – Hydropower (e.g. Iron Gates)*

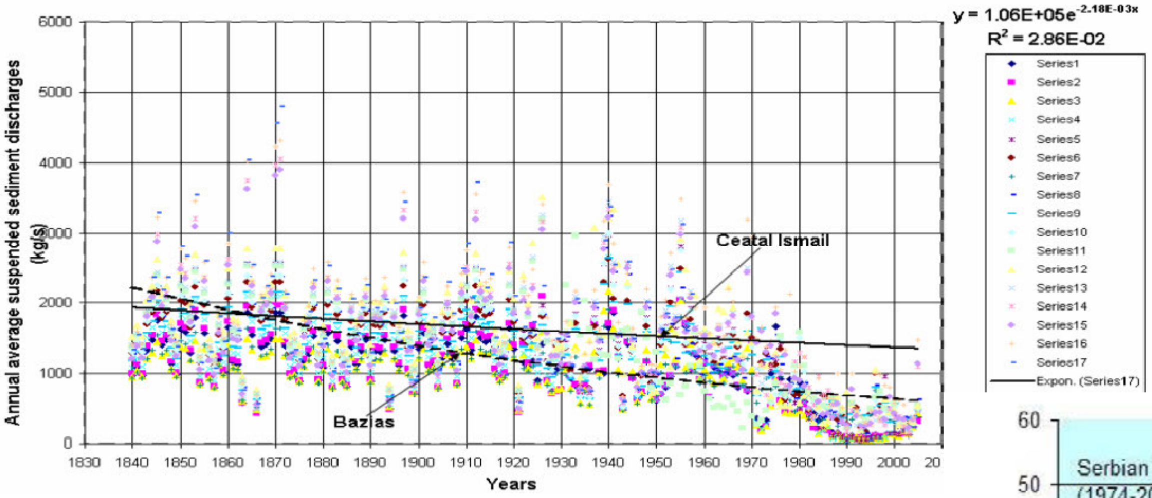


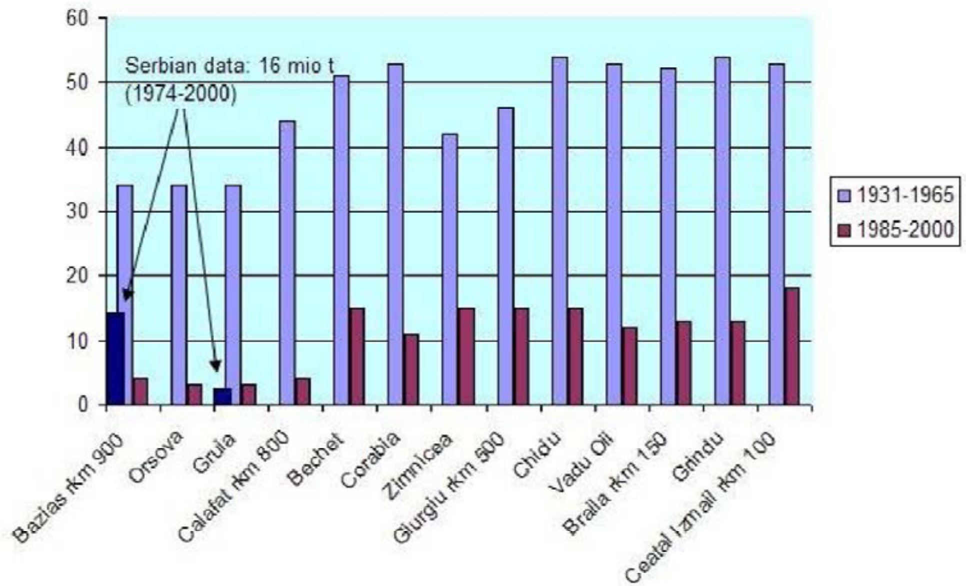

Sediment deposition at Donji Milanovac (Serbia) – upstream of the Iron Gates

IHP, 2004

# Results – Sectional scale

## *Lower Danube – Hydropower*



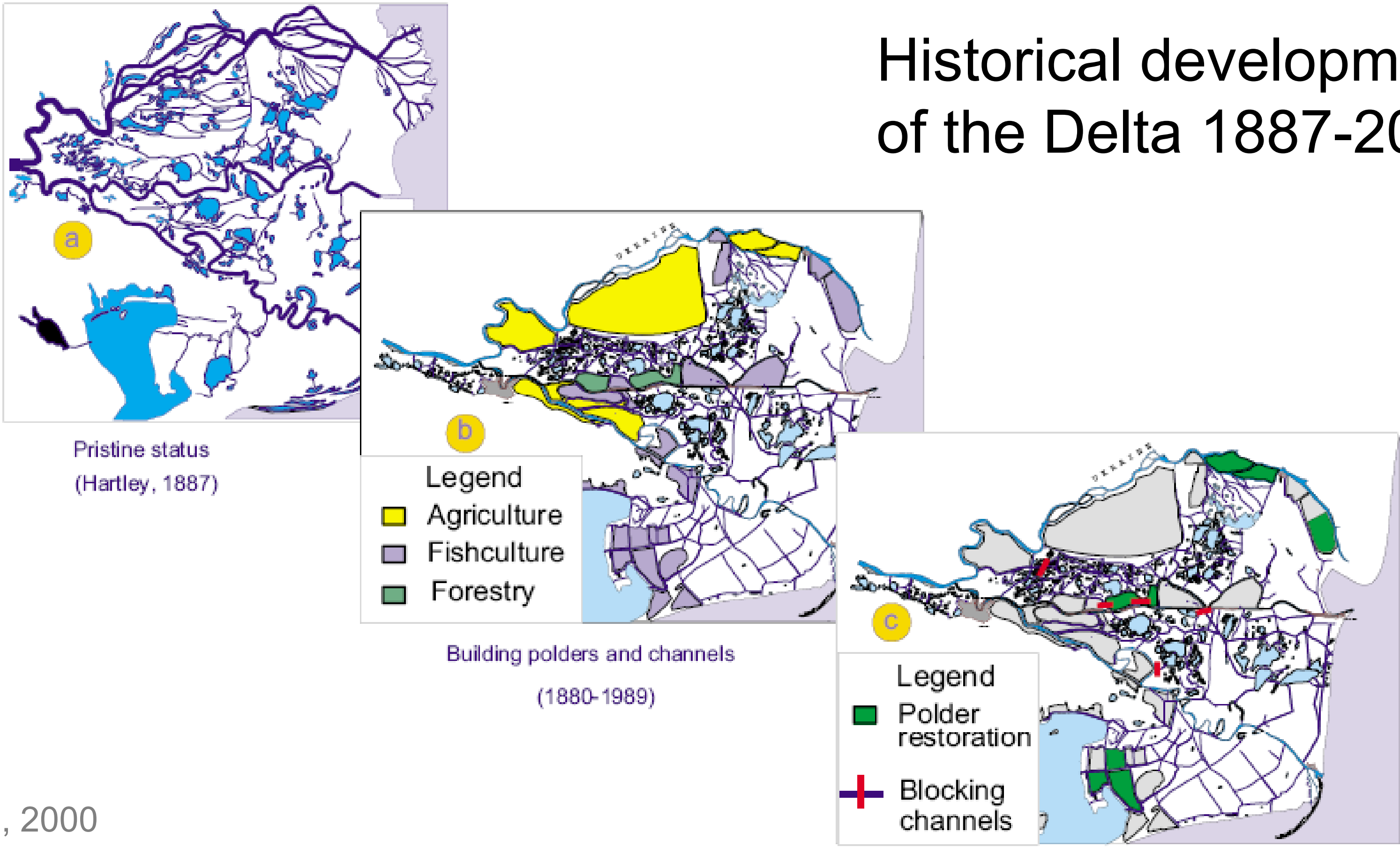

Decreasing trend of the annual suspended load

Batuca et al., 2002; Bondar, 2008

# Results – Sectional scale

## *Danube Delta*

Historical development of the Delta 1887-2000




Pristine status (Hartley, 1887)

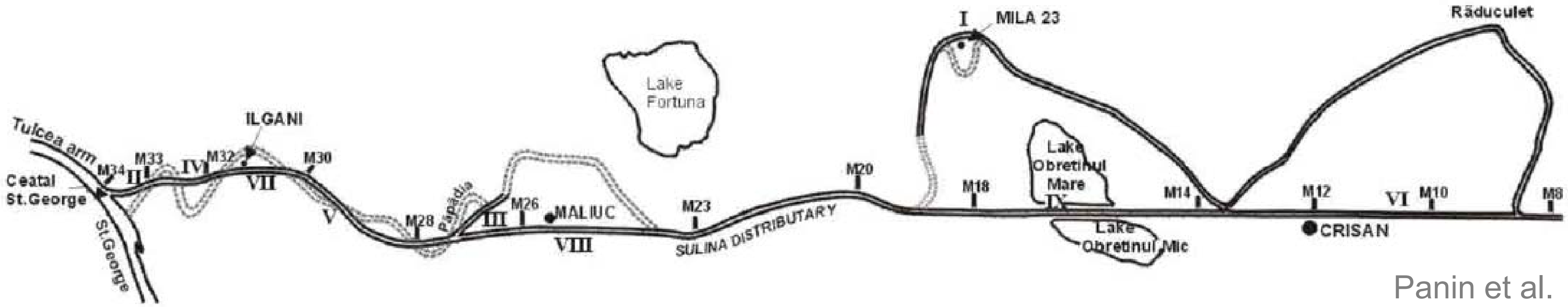
Building polders and channels (1880-1989)

Restoration works (1994-2000)

Staras, 2000

# Results – Sectional scale

*Danube Delta – e.g. Sulina branch*



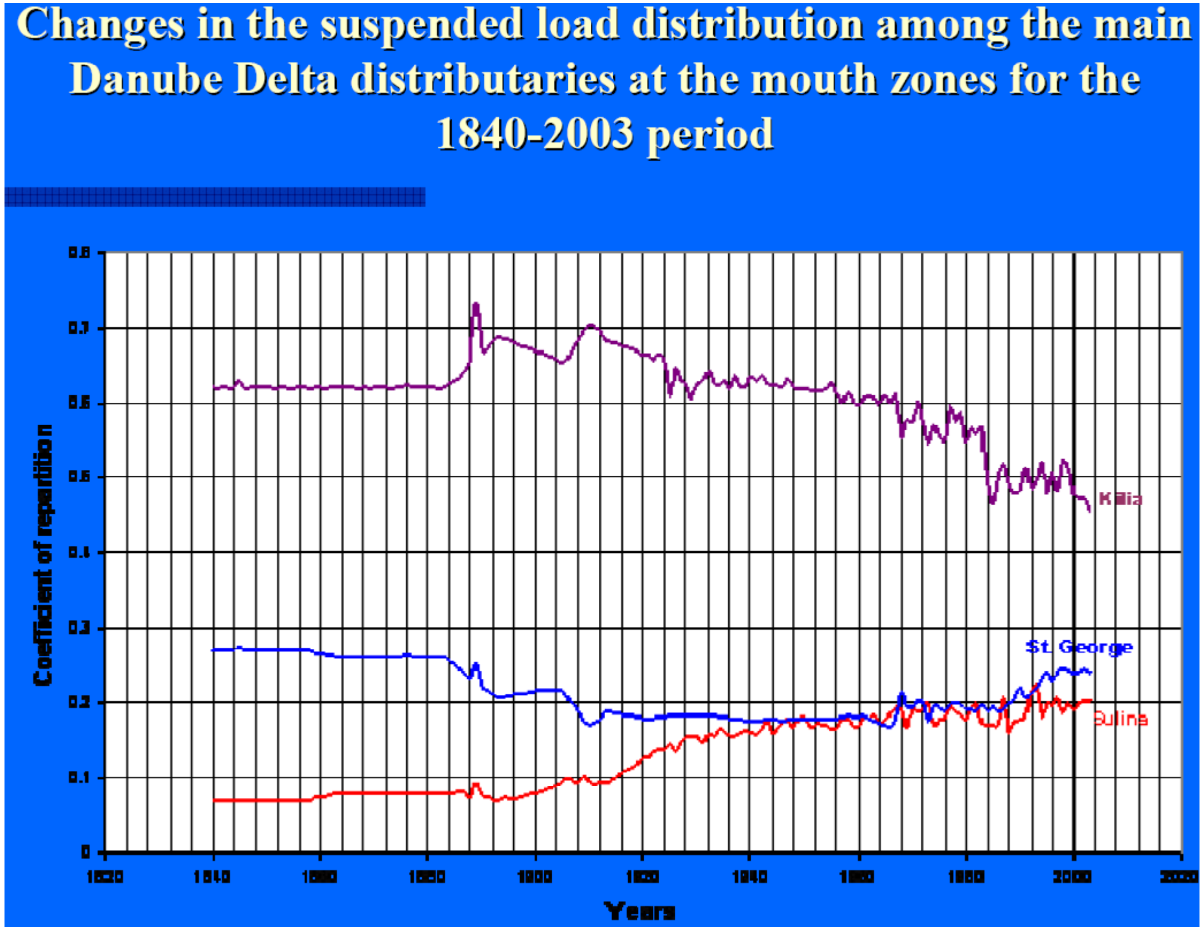

Panin et al.

Meander cut-off along the Sulina branch (1868-1902)

Reduced in length by 23 km

# Results – Sectional scale

## *Danube Delta*




Panin et al.