WISA-Workshop on International Sediment Advances,
13th ISRS, Stuttgart, 20th September 2016

HYDRAULIC, MORPHOLOGICAL AND BIOLOGICAL INTERACTIONS IN SEDIMENT MANAGEMENT

PRESENTATION

by G. DI SILVIO (WASER)

PURPOSES AND SCOPES OF WISA

- **Informing on the novelties of a few major Organizations active in sediment research.**
- **Debating a particular issue of tropical interest, from the viewpoint of each Organization.**

ORGANIZATIONS REPRESENTED IN THE PRESENT WISA

WASER, ***World Association for Sedimentation and Erosion Research***

IAHR, ***International Association for Hydro-Environmental Engineering (Fluvial Hydraulics & Coastal Hydraulics Commitees)***

IAHS, ***International Association of Hydrological Sciences (International Commission on Continental Erosion)***

CONSOWA, ***World Conference on Soil and Water Conservation (ISCO, WASWAC, ESSC, IUSS, SWCS, IECA…)***

UNESCO - ISI, ***International Sedimentation Initiative (Group of experts)***

LOC-13th ISRS, ***Stuttgart, Germany (German Scientific Community)***

Other Organizations represented in the past WISA's

ICOLD, ***International Commission on Large Dams (Technical Committee on Sedimentation)***

LOC-12th ISRS, ***Kyoto, Japan (Japanese Scientific Community)***

TOPICAL ISSUES OF PAST AND POSSIBLE FUTURE WISA'S

- IMPACT OF DAMS ON RIVERS AND SEDIMENT MANAGEMENT – 12th ISRS, Kyoto, Japan, Sept 3, 2013
- HYDRAULIC, MORPHOLOGICAL AND BIOLOGICAL INTERACTION IN SEDIMENT MANAGEMENT – 13th ISRS, Stuttgart, Germany, Sept 20, 2016

……..

- HYDROLOGICAL, HYSTORICAL AND GEOLOGICAL TIME-SCALES OF SEDIMENTARY SYSTEMS
- ANTROPIZATION AND RE-NATURALIZATION OF SEDIMENTARY SYSTEMS
- REDUCTIONIST AND HOLISTIC APPROACHES IN SEDIMENTARY-SYSTEM ANALYSIS

……..

Workshop on the International Sediment Advancements (WISA)
Hydraulic, Morphological and Biological Interactions in Sediment Management

Chair: Giampaolo di Silvio

13:15 – 13:20 ***Introduction***
Giampaolo Di Silvio, *WASER*

13:20 – 13:45 ***Eco-sedimentology. A new area in sediment studies***
Zhaoyin Wang*, IAHR*

13:45 – 14:10 ***Changing perspectives on the suspended sediment load of rivers***
Desmond Walling, *IAHS*

14:10 – 14:35 ***Hydrological processes in soils of sloping lands as a basis for sediment production and sediment yield***
Ildefonso Pla Sentis, *CONSOWA*

14:35 – 15:00 ***Developments in Reservoir Sediment Management***
Rollin Hotchkiss, *UNESCO-ISI*

15:00 - 15:30 **COFFEE BREAK**

Chair: Rollin Hotchkiss

15:30 – 15:55 ***Influence of morphological changes on ecology: a cascade of scales***
Silke Wieprecht, *LOC*

15:55 – 16:20 ***A hydro-, morpho-, bio-dynamic model for long-term, basin-scale river simulations***
Giampaolo Di Silvio, *WASER*

16:20 - 17:00 **PLENARY DISCUSSION**

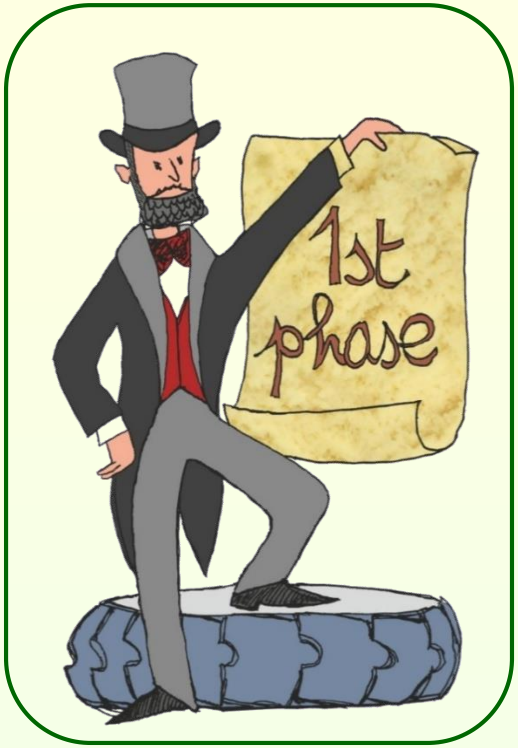
WISA-Workshop on International Sediment Advances,
20th September 2016

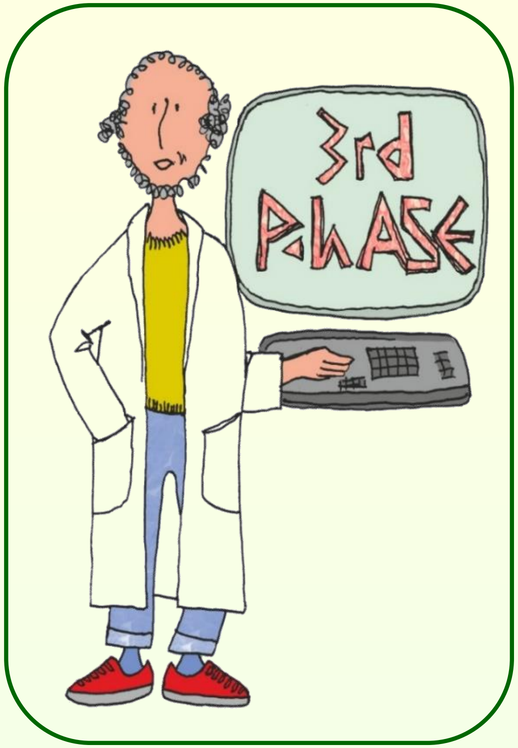
HYDRAULIC, MORPHOLOGICAL AND BIOLOGICAL INTERACTIONS IN SEDIMENT MANAGEMENT

A HYDRO-, MORPHO-, BIO-DYNAMIC MODEL FOR LONG-TERM, BASIN-SCALE RIVER SIMULATIONS

by G. DI SILVIO (WASER)

CHANGES IN RIVER ENGINEERING





RIVER CONTROL & WATER RESOURCES UTILIZATION

hydraulics and hydraulic structures

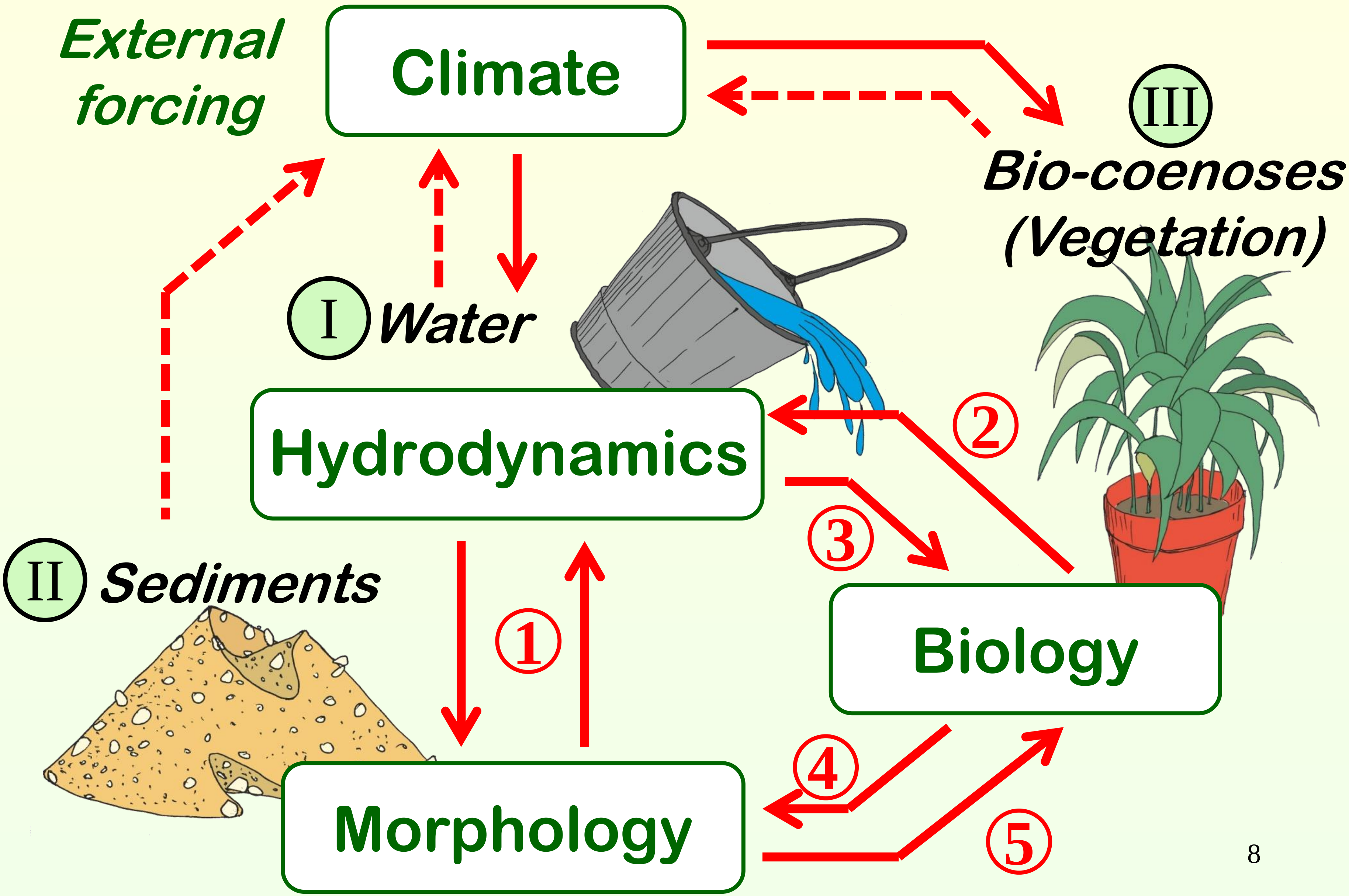
RIVER & WATERSHED MANAGEMENT

+ hydrology
+ statistics

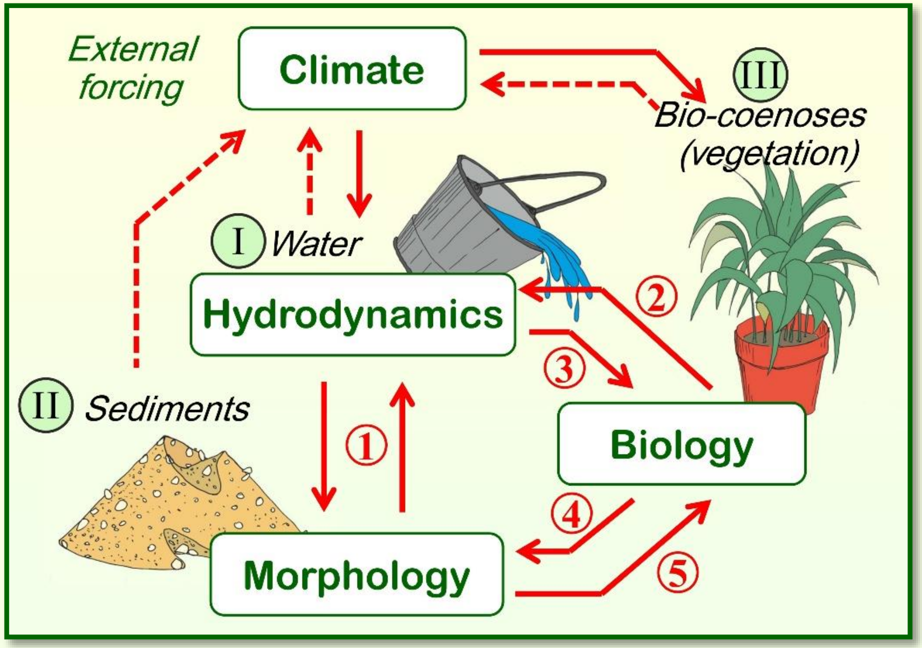
RIVER & WATERSHED RESTORATION

+ geomorphology
+ biology

WATER, SEDIMENTS & VEGETATION



HYDRO-, MORPHO-, BIO-DYNAMIC PROCESSES



EQUATIONS
(in general p.d.e.)

I Mass & Momentum conservation: (Naver-Stokes equations, more or less simplified)

II Mass & Momentum conservation: (Sediment transport eqs.)

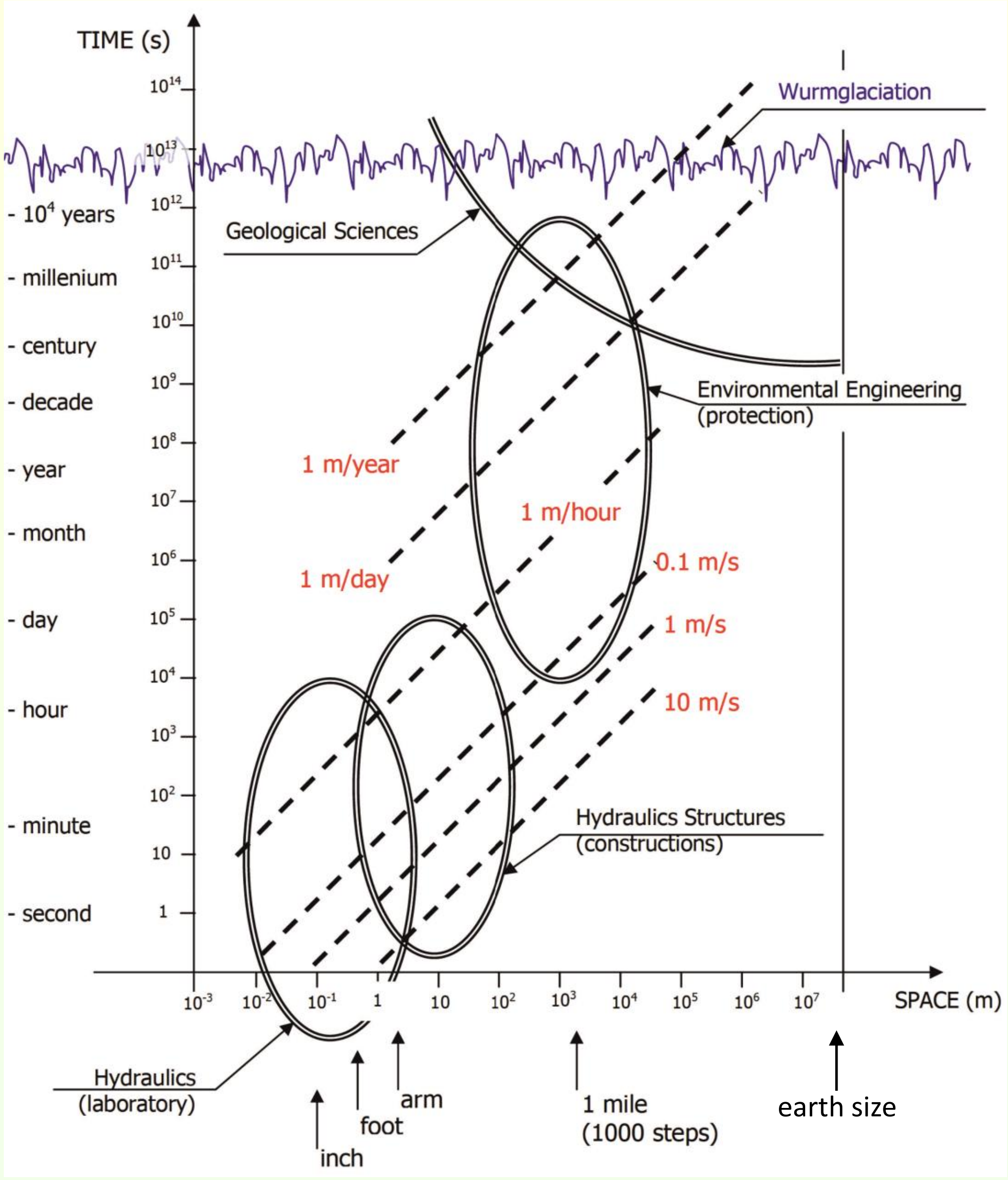
III Mass & Energy conservation: (Biodynamic eqs.)

INTERACTIONS

1. Development and evolution of micro-, meso and mega-forms (nude cross-section)
2. Increasing flow resistance, decreasing stream power
3. Fostering or hampering vegetation density
4. Reducing or facilitating sediment removal
5. Selective actions on individual species

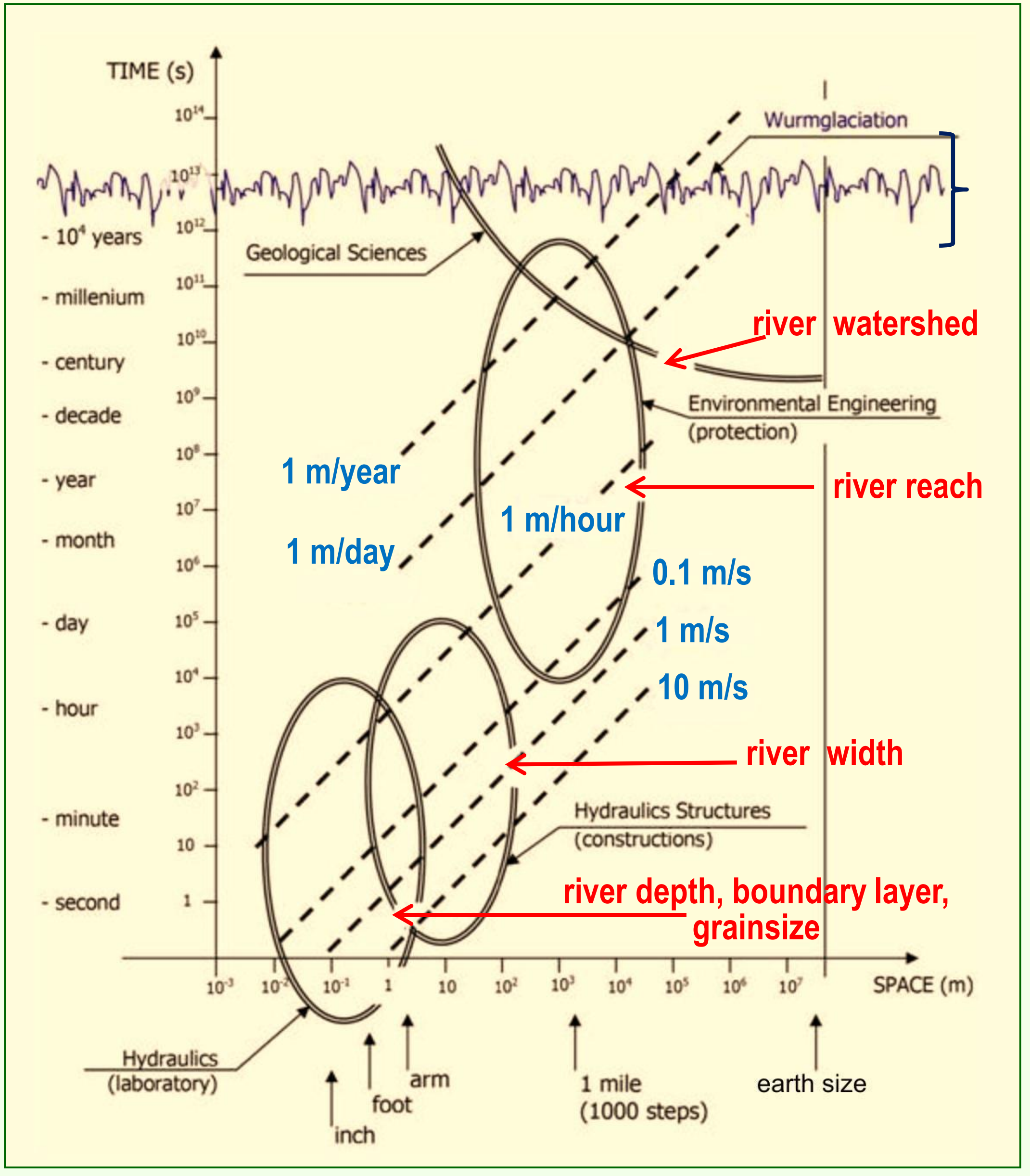
ABSOLUTE SPACE- & TIME-SCALES

River-related Sciences & Applications



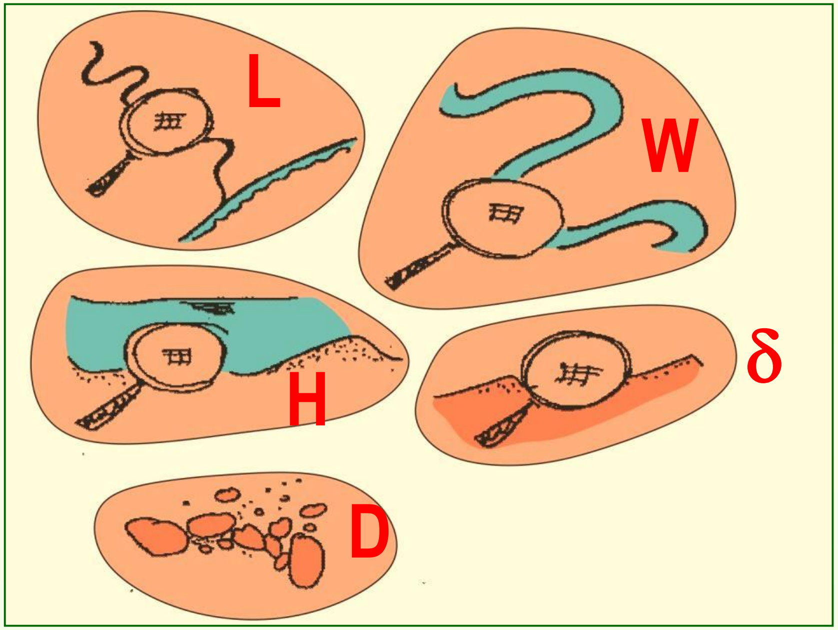
RELATIVE SPACE- & TIME-SCALES

(Sub-)System Size (space) & Response (time)



EVOLUTION OF FLUVIAL (SUB-)SYSTEMS

Dominant Process and Significant Size



- **RIVER WATERSHED ~L^2**
  Fluvial system (tributaries and hydrographic network) configuration
- **RIVER REACH ~L**
  Bottom profile and grain size distribution
- **RIVER WIDTH ~W**
  Mesoforms (bars, braiding, meanders, …)
- **RIVER DEPTH ~H, BOUNDARY LAYER ~δ, GRAIN SIZE ~D** Bed forms (ripples and dunes); flow resistance and sediment transport

The significant size of a fluvial (sub-)system, equally applies to hydraulic, morphological and biological processes.

e.g. *δ, D* *benthos, biofilm development;*
H *individual plant species*
W *animal species, riparian vegetation;*
L *eco-coenoses of the fluvial corridor.*

MODELLING HYDRO-, MORPHO-, BIO-DYNAMIC INTERACTIONS AT ALL SCALES ($10^{-2} \div 10^{7}$ m)

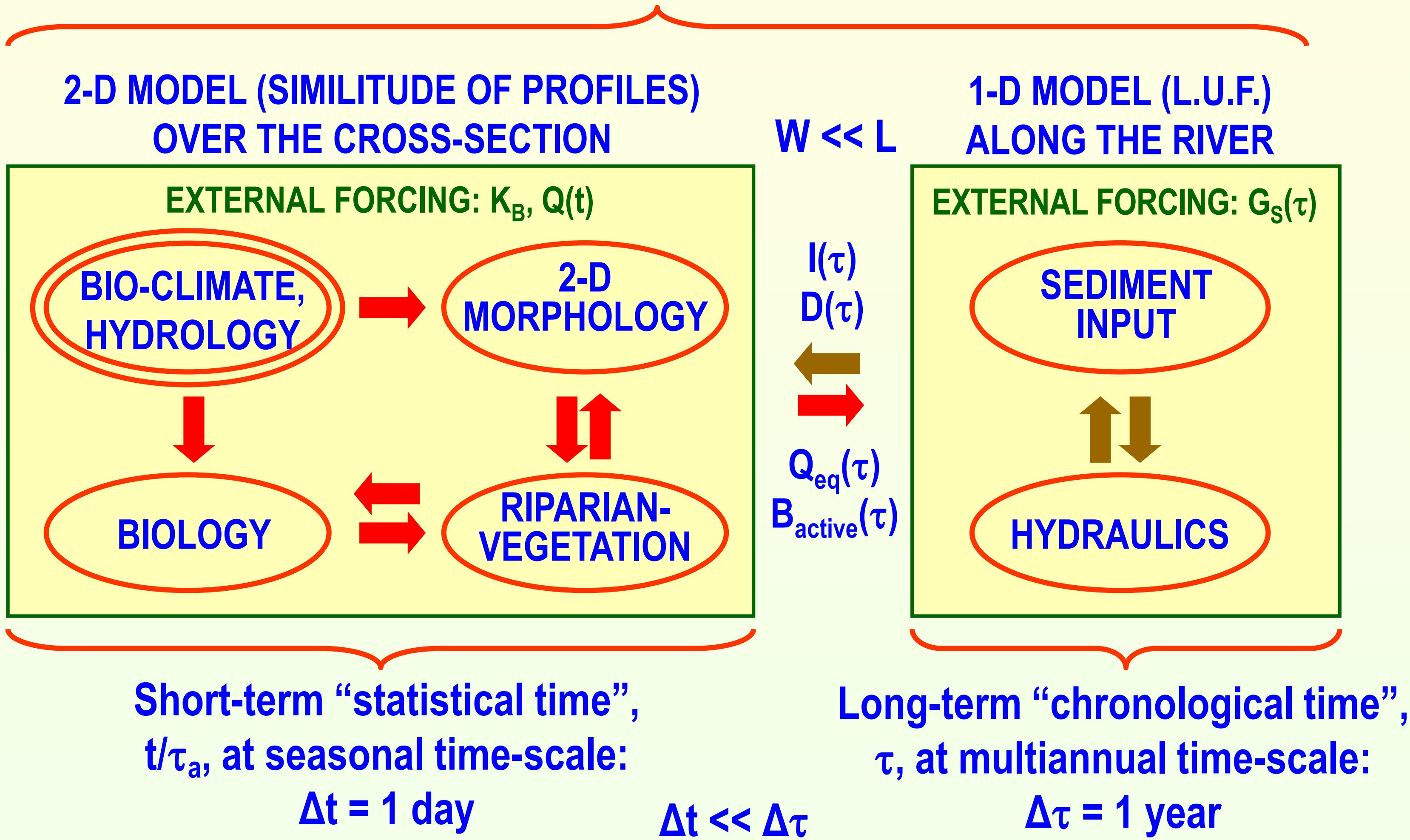
- **Impossible:** for practical (CPU) and theoretical (deterministic approach) reasons
- **Unnecessary:** only the processes having very similar space- and time scales need to be ˝mathematically coupled˝ (stricly interacting)

WHAT IS TO BE DONE:

Selecting the dominant process, the relevant sub-system and the corresponding scale

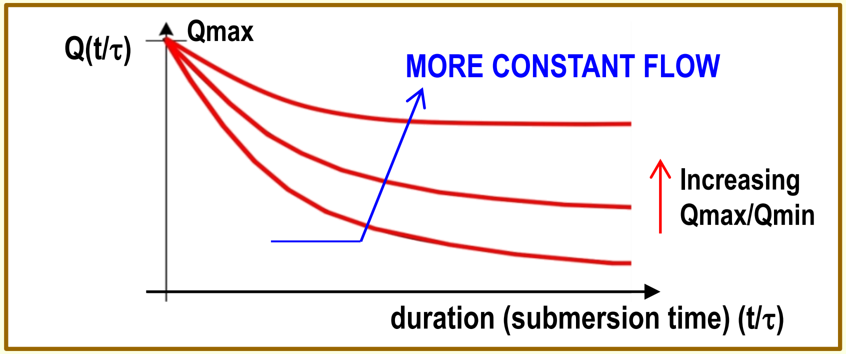
LARGER SUB-SYSTEMS:	CONSIDERED (SUB-SYSTEM):	SMALLER SUB-SYSTEMS:
stationary (equilibrium) conditions	evolving quantity	immediate adaptation
F_l=const	F(t)	$F_s = F_s[F(t)]$
(constant quantities)	(simplified differential equations)	(algebraic equations)

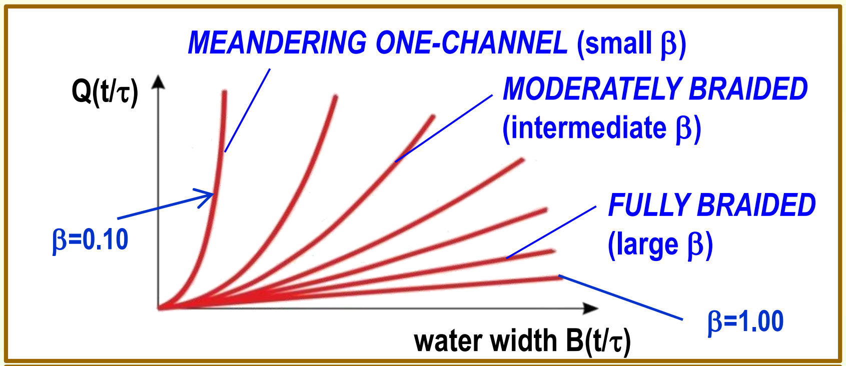
A QUASI 3-D RIVER MODEL [1][2]

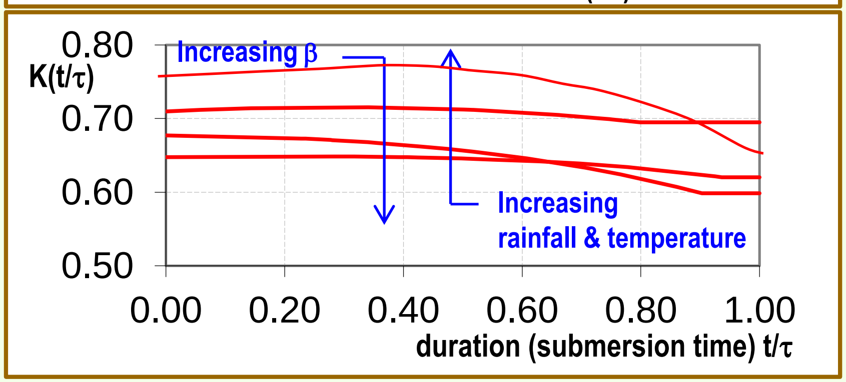


(1) Di Silvio & Nones, *ISRS 2010*, Stellenbosch
(2) Nones & Di Silvio, *JHE 2016*

COMPONENTS OF THE 2-D CROSS-SECTION MODEL







Hydrology

FLOW DURATION CURVE $Q(t/\tau)$

3 parameters (Qmax, Qave, Qmin) ← { CLIMATE

Morphology

PROFILE OF ″NUDE″ CROSS-SECTION

$B = \alpha Q(t/\tau)^{\beta}$

2 parameters $(\alpha,\beta) = f[Q_{ed}(\tau), \text{slope}]$ ← { 1-D (L.U.F.) MODEL

Biology

DISTRIBUTION OF VEGETATION DENSITY*

$K = (dBveg/dBtot) = \Pi_i K_i [Q(t/\tau)]$

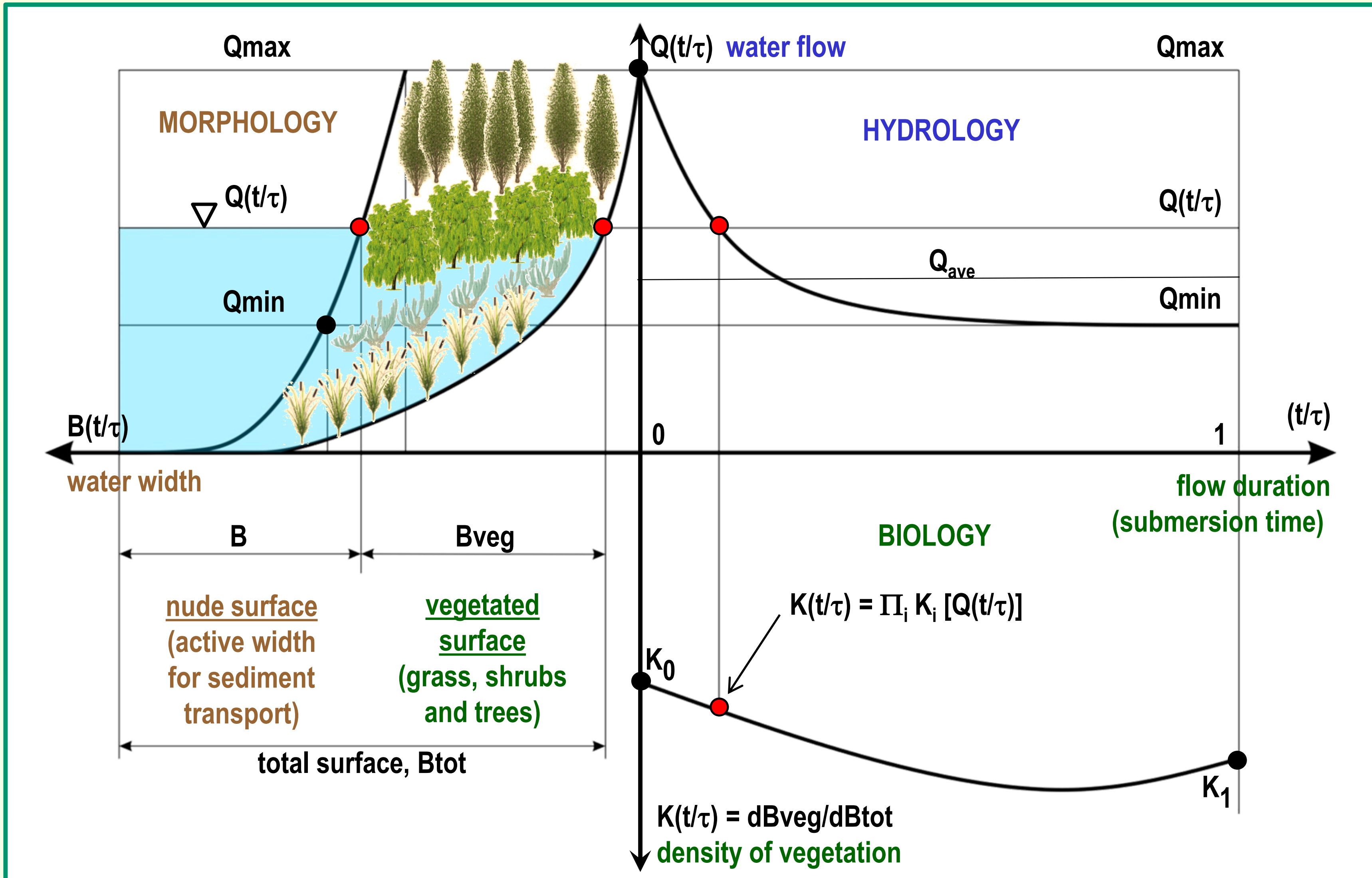
Productory of i = 1,2, … N

«limiting factors» K_i

(BIO-CLIMATE, DROWNING,

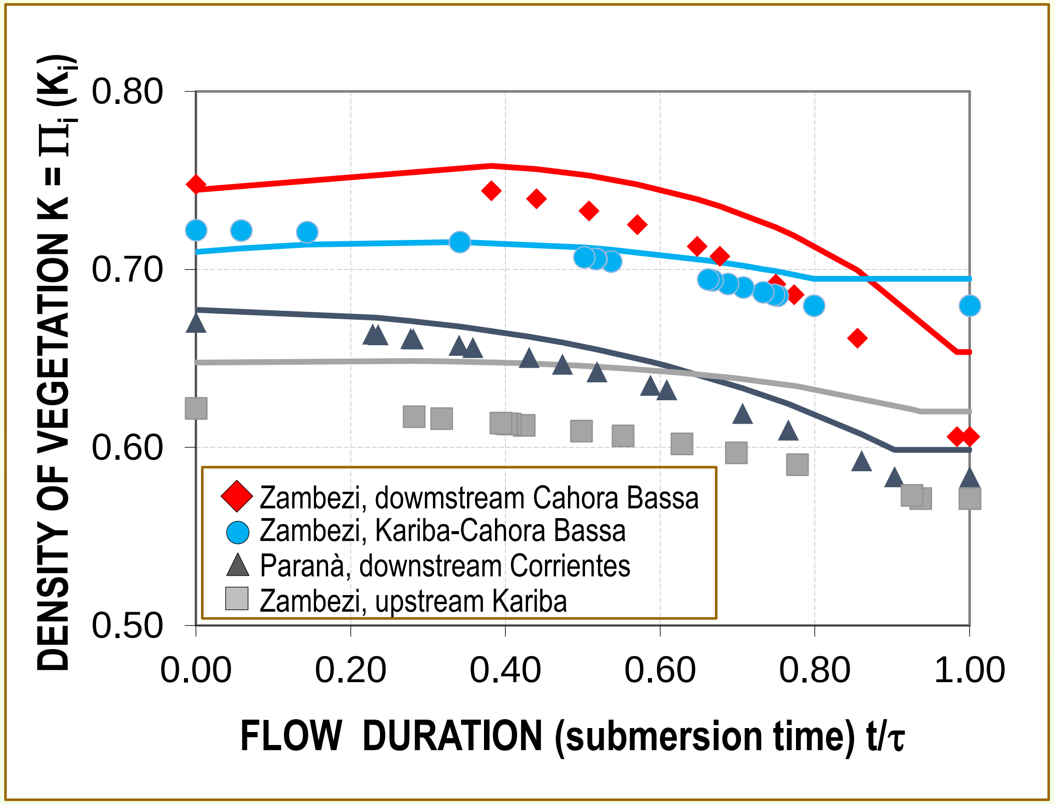
ANOXIA, EXTIRPATION, BRAIDING etc.) ← { CLIMATE, 1-D (L.U.F.) MODEL

2-D CROSS-SECTION MODEL
HYDRO-, MORPHO-, BIO-DYNAMIC INTERACTIONS



MEASURED AND COMPUTED VALUES OF VEGETATION DENSITY(1)

RESULTS IN SOME CROSS-SECTIONS OF LARGE RIVERS



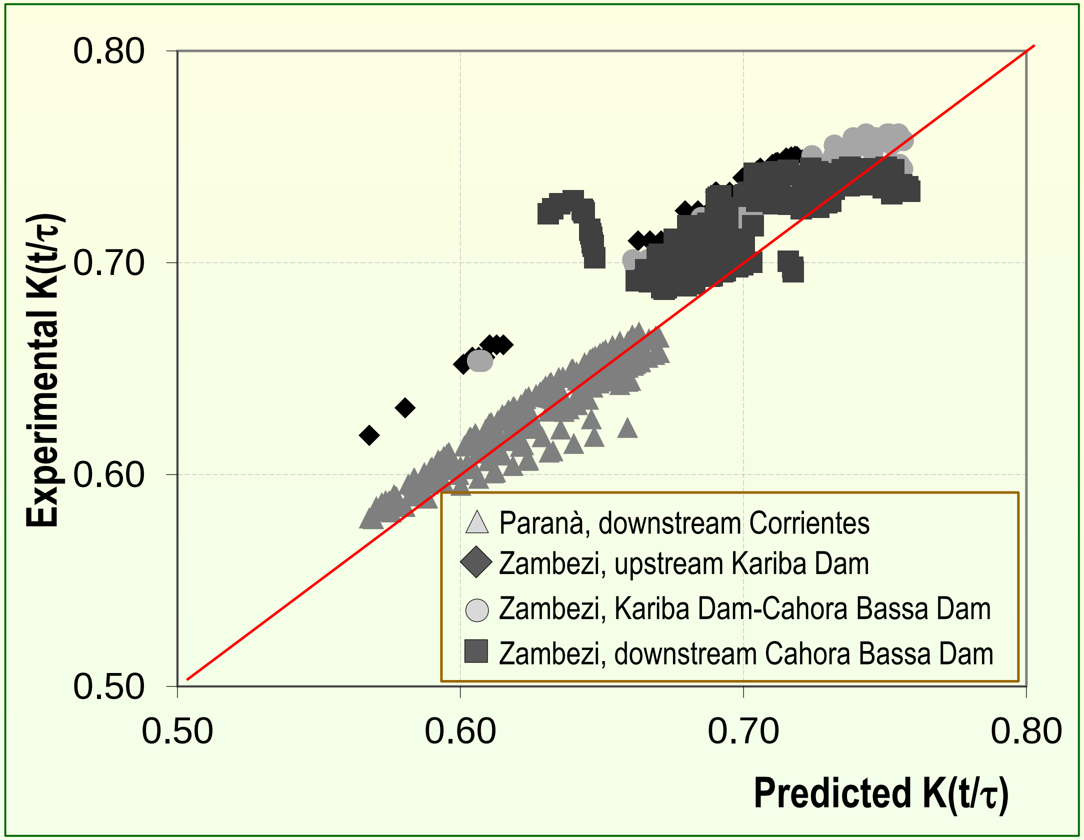
- The seasonal effects of hydrology and morphology are reflected by the curve profile f(t/τ).
- The effects of the constant climate (annual temperature and precipitation) are reflected by the curve averaged position.

N.B. The tendency to compensation of the various K_i (t/τ), is probably due to the different adaptation of individual species.

(1) Nones & Di Silvio, JHE 2016

VEGETATION MODEL VERIFICATION[1]

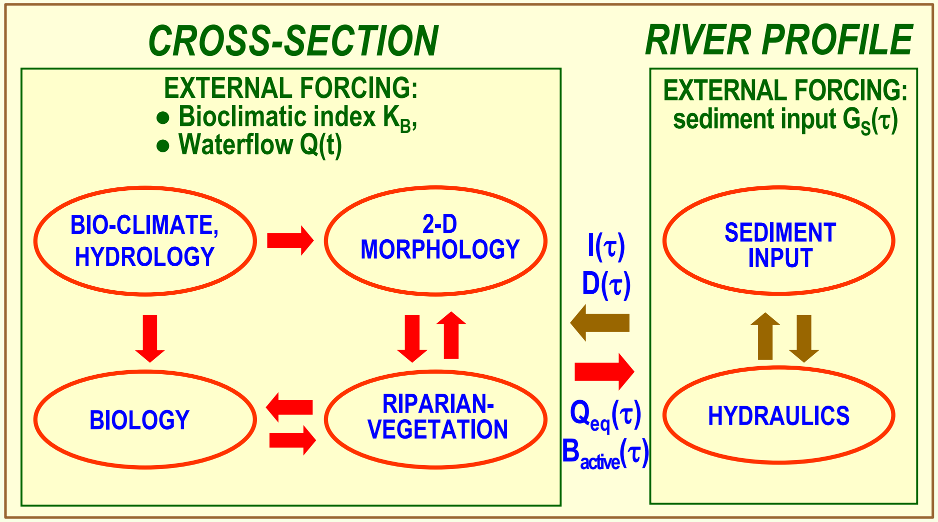
OVERALL RESULTS



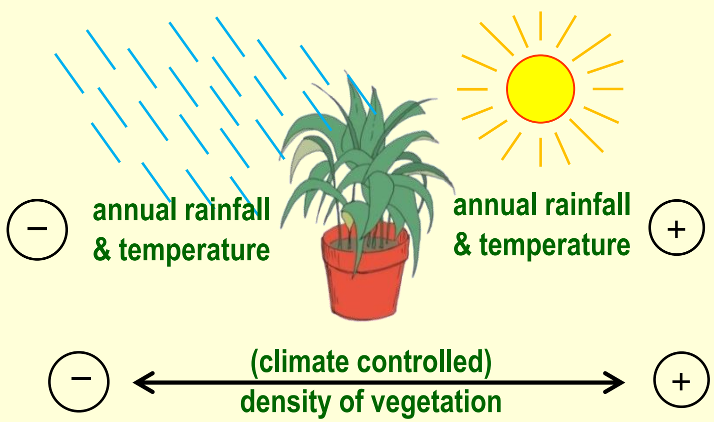
- **The graph does not distinguish between the <u>seasonal effects</u> f(t/τ) of hydrology and morphology, and the <u>annually averaged effects</u> of the constant climate.**

(1) Nones & Di Silvio, JHE 2016

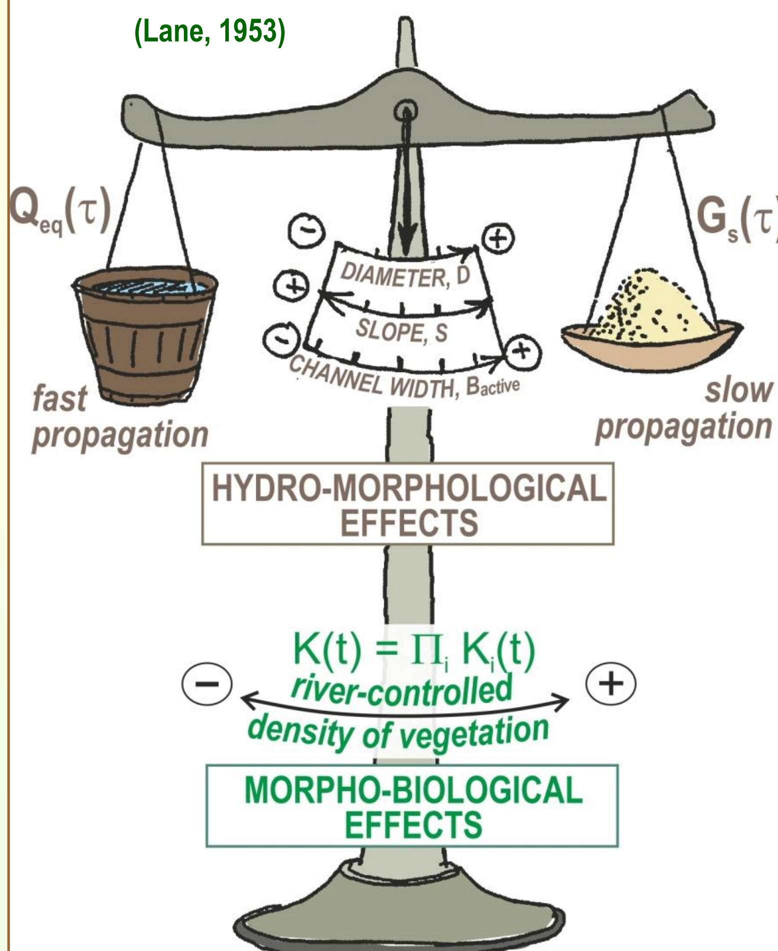
EFFECTS OF EXTERNAL FORCING PERTURBATIONS



GEOGRAPHIC BIO-CLIMATIC INDEX, K_B



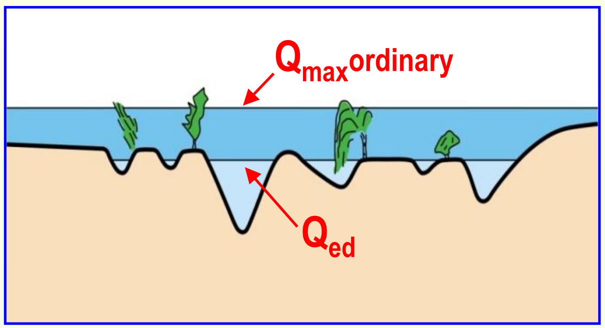
WATER & SEDIMENT INPUT



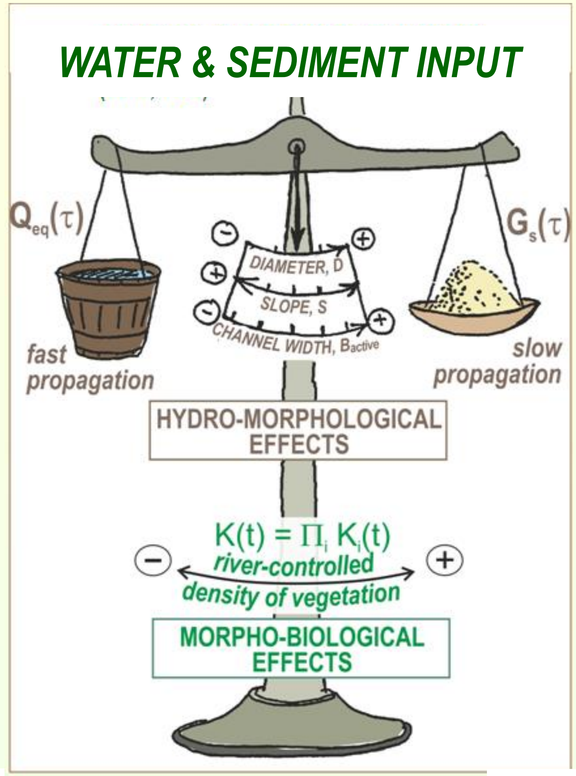
EXPECTED CHANGES OF RIVER LANDSCAPE

– BIO-CLIMATIC INDEX K_B +

- ***Lower annual rainfall and/or temperature***
- ***Larger equivalent discharge and/or lesser sediment input***

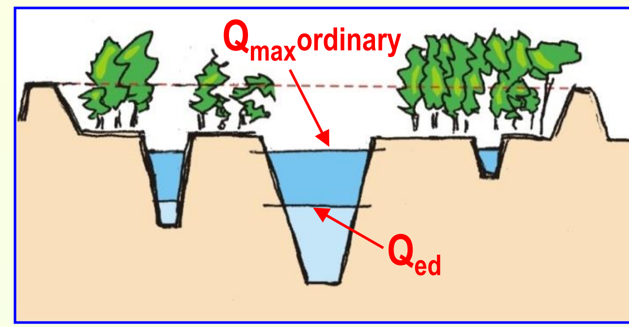


Braiding configuration; large total water width; shallow and wide wandering channels; sparse and temporary riparian vegetation; no permanent planitial vegetation; humid zones; transversal gradients



Water withdrawal ►
Flood-peak abatment ►
Navigation canals ►
◄ ***Sediment interception***

- ***Higher annual rainfall and/or temperature***
- ***Small equivalent discharge and/or larger sediment input***



Meandering or straight one-channel configuration; deep and narrow stable channel; smaller total water width; no active secondary channels; no riparian and planitial vegetation; persistent humid zones; no transversal fluxes; «plastered» river

BUT WHEN AND WHERE?

APPLICATIONS OF THE QUASI 3-D MODEL

Long-term prediction of the longitudinal and trasversal evolution of large rivers in time and space, consequent to complex anthropogenic impact and/or climatic changes, requires the application of the ***complete hydro-, morpho-, bio-dynamic model****.*
A few examples:

A **ZAMBEZI RIVER** (Africa): MORPHODYNAMIC IMPACT OF LARGE IMPOUNDMENTS; Nones and Di Silvio, Int. J. of River Basin Management, 2013.

B **ADIGE RIVER** (Italy): MULTIPLE ANTHROPOGENIC IMPACT AND MORPHOLOGICAL RECOVERY; Assessment of a re-naturalization project, Internal report, 2009.

C **PARANA' RIVER** (South America): MORPHODYNAMIC IMPACT OF CLIMATE CHANGE; Guerrero et al., IJRE 2013.

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HYDRAULIC, MORPHOLOGICAL AND BIOLOGICAL INTERACTIONS IN SEDIMENT MANAGEMENT

EXAMPLES OF APPLICATION OF THE HYDRO-, MORPHO-, BIO-DYNAMIC MODEL

by G. DI SILVIO (WASER)

APPLICATIONS OF THE QUASI 3-D MODEL

Long-term prediction of the longitudinal and trasversal evolution of large rivers in time and space, consequent to complex anthropogenic impact and/or climatic changes, requires the application of the complete hydro-, morpho-, bio-dynamic model.

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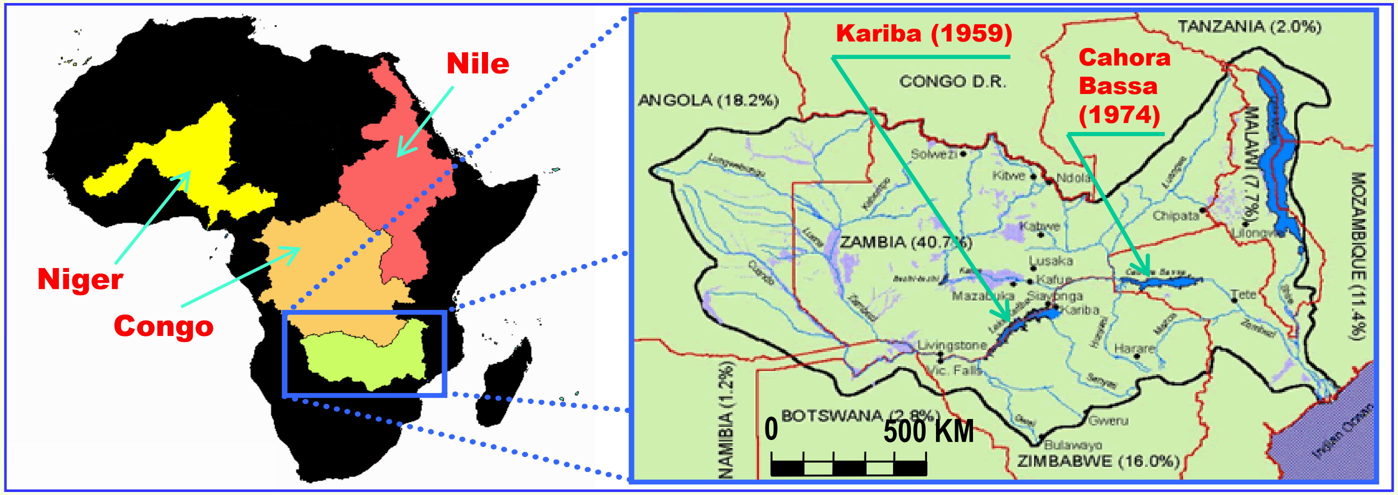
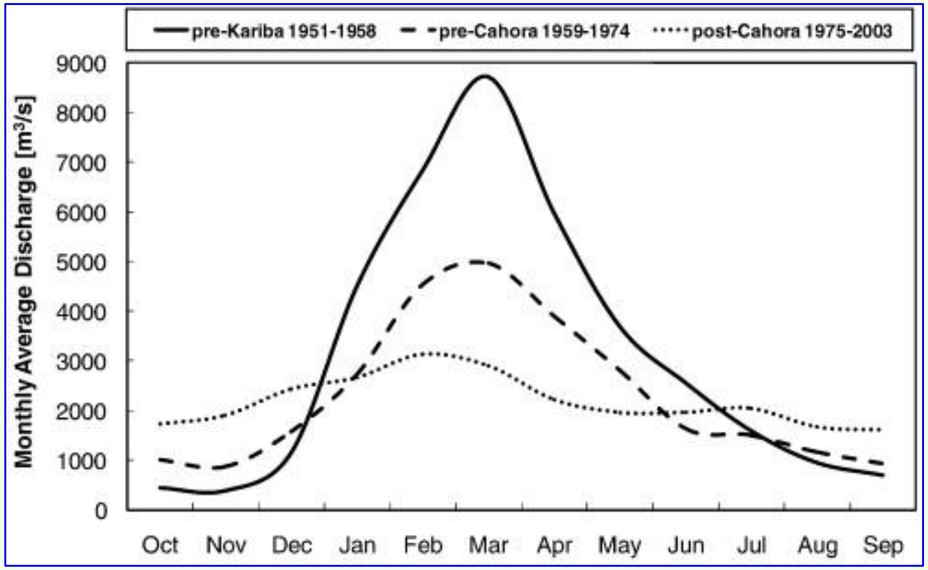
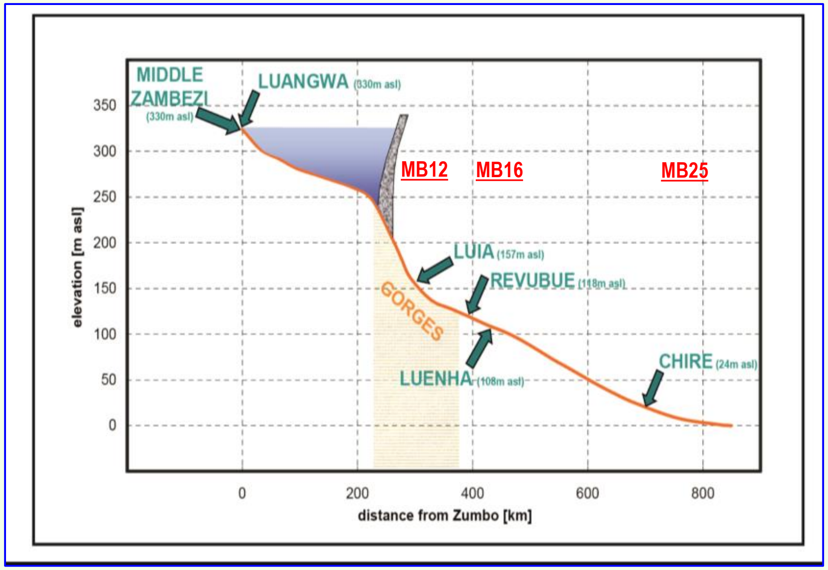
A

LOWER ZAMBEZI RIVER[1,2]



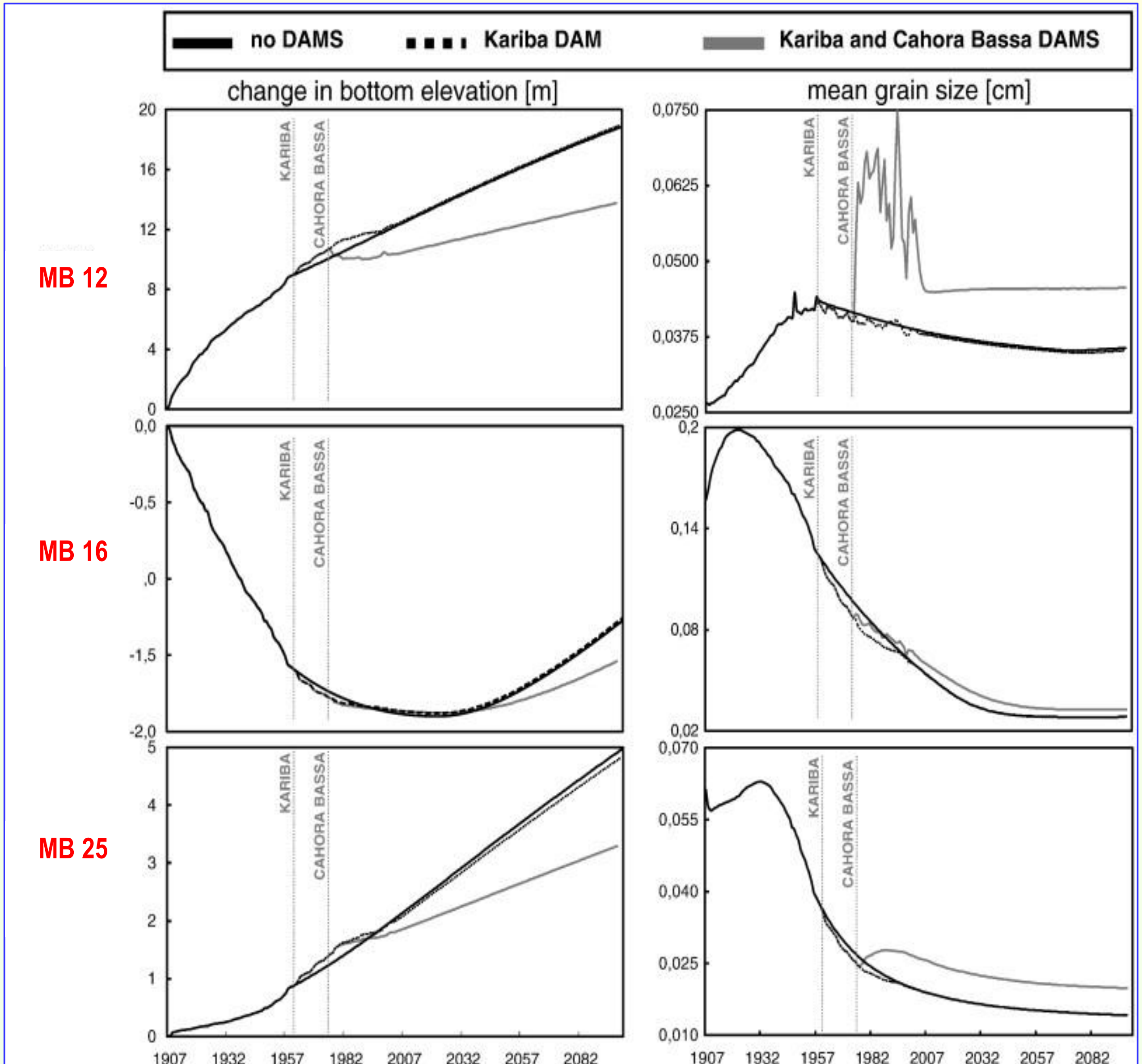




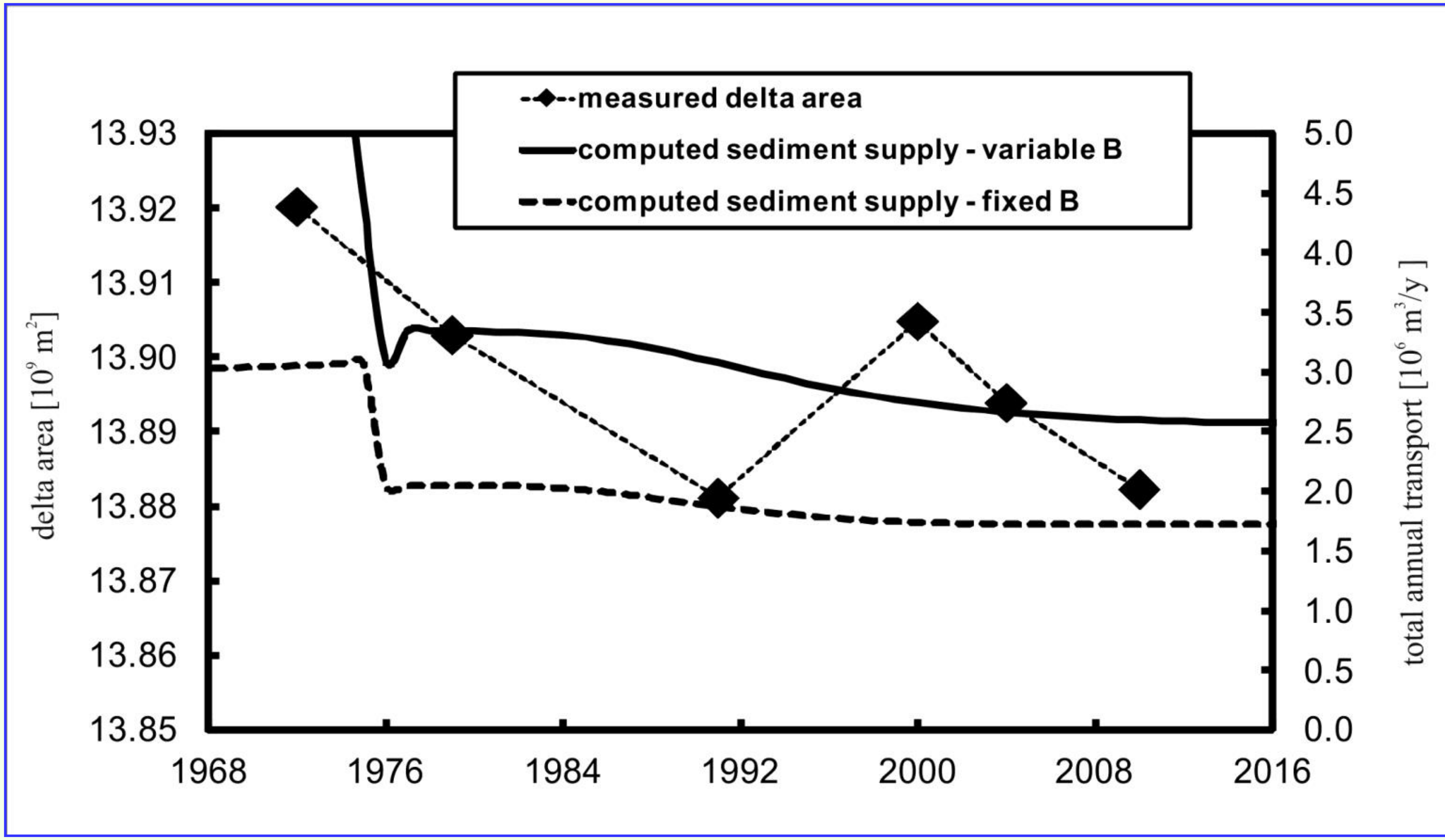
(1) Ronco et al, "Morphological effects of damming on Lower Zambezi River», Geomorphology 2010

(2) Nones et al, "Modelling the impact of large impoudments on the Lower Zambezi", JRBM 2012

LOWER ZAMBEZI: LONGITUDINAL EVOLUTION



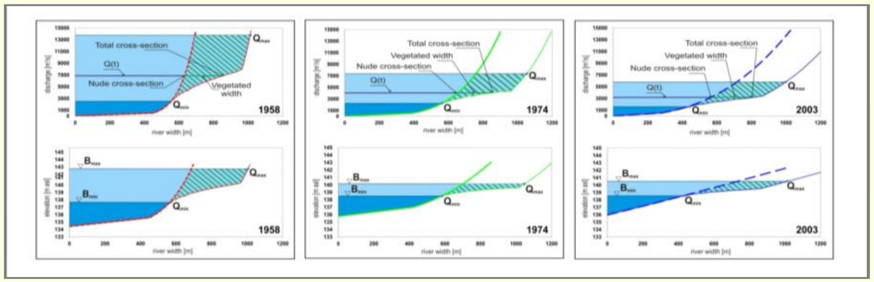
LOWER ZAMBEZI: DELTA EVOLUTION

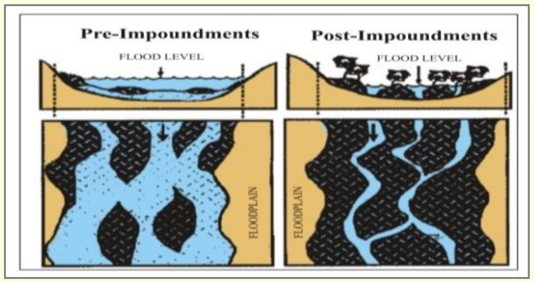


LOWER ZAMBEZI: PLANIMETRIC EVOLUTION

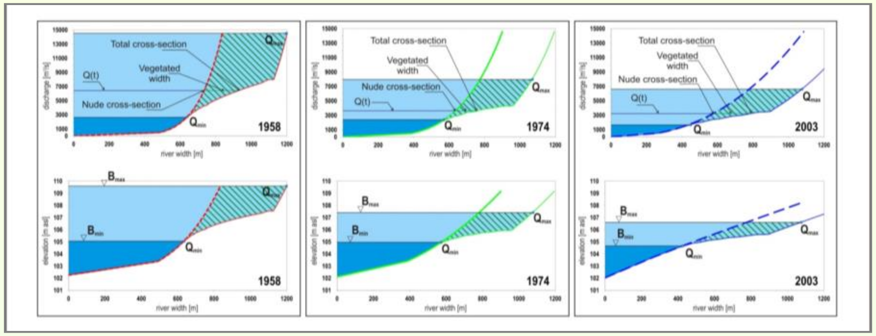
COMPUTED *(Nones and Di Silvio, 2013)*

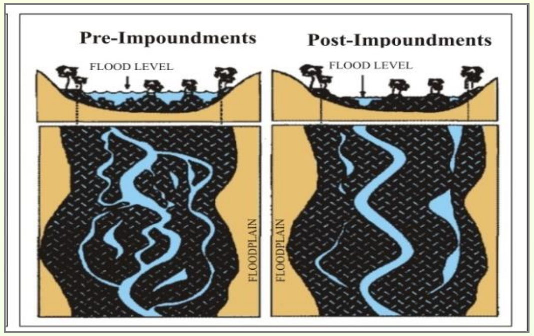
OBSERVED *(Davies et al., 2000)*



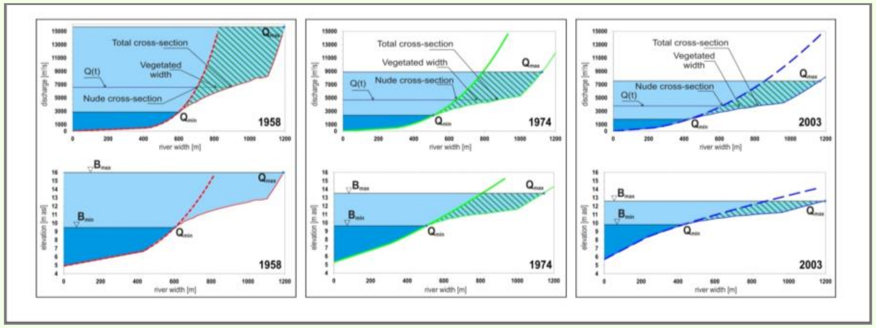


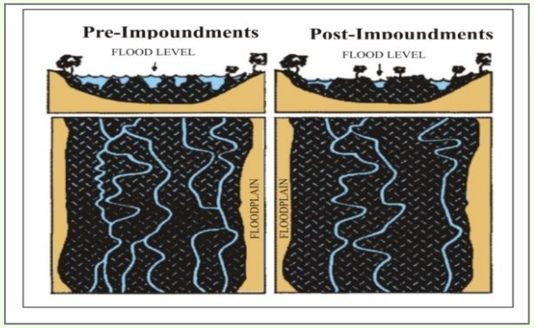
MB 12





MB 16



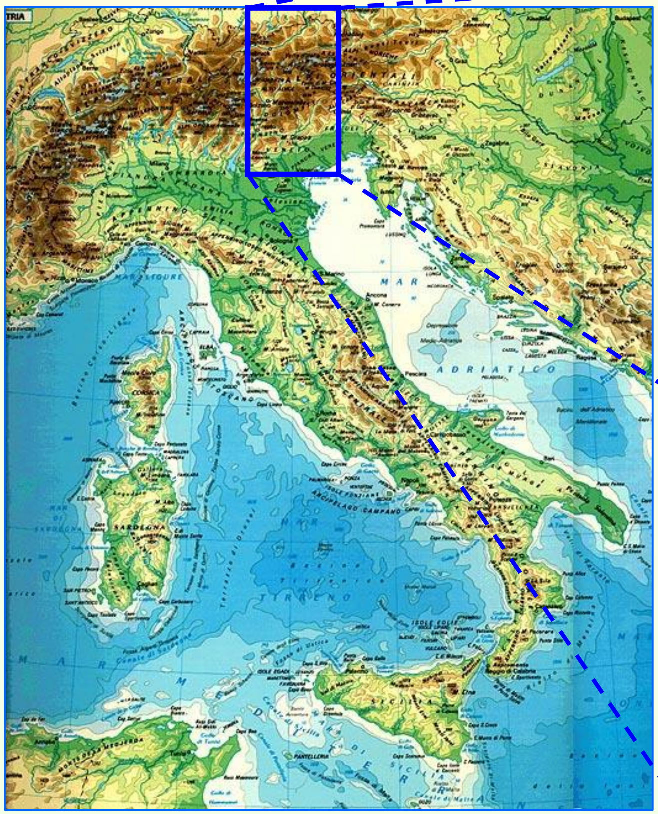


MB 25

→ less braiding less depht; thicker vegetation, → plastering

B

THE ADIGE RIVER(1,2)

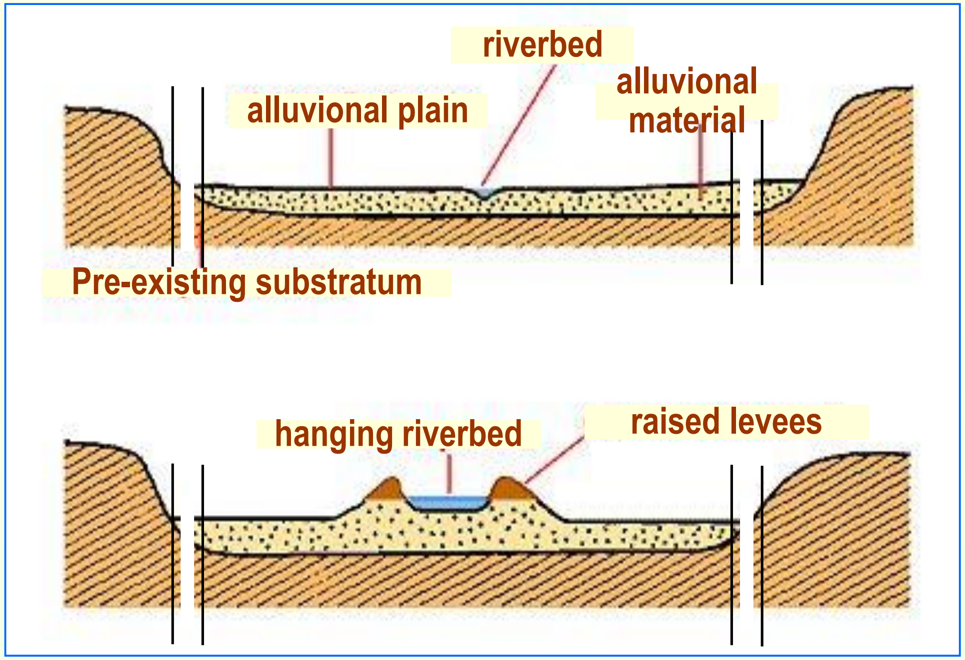


(1) Di Silvio et al, 2009 ''Fiume Adige, bilancio di sedimenti a scala di bacino'', Adige/Etsch,n. 1-2, 2009

(2) Nones, M. ''Fiume Adige, bilancio di sedimenti a scala di bacino'', Adige/Etsch,n. 1-2, Allegato tecnico, 2009

ADIGE RIVER: LONG-TERM EVOLUTION UP TO THE '50s

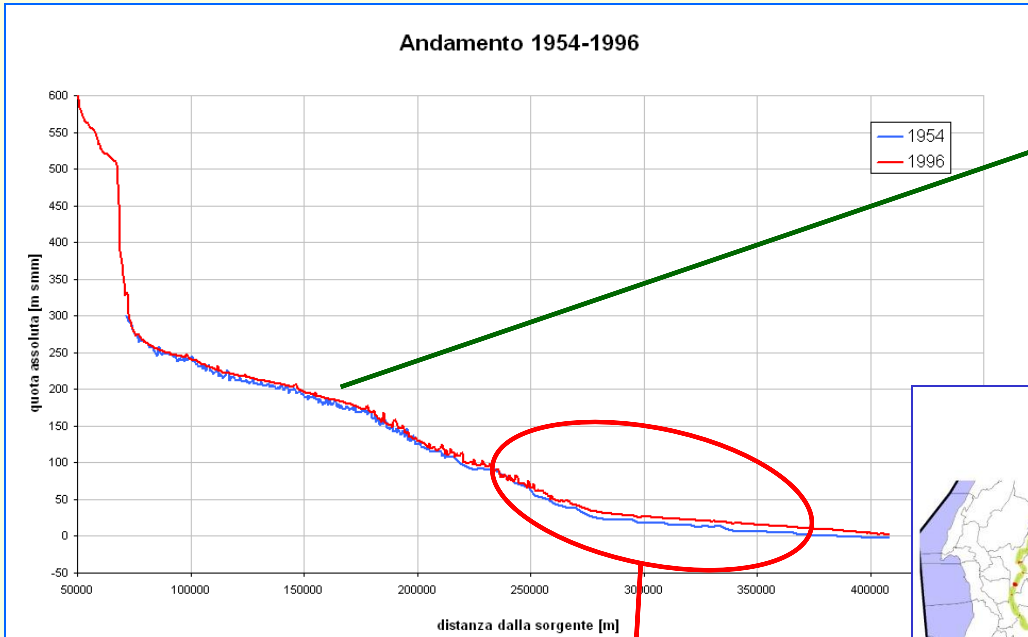
Over-aggraded river bed downstream Verona



Albaredo d'Adige (Vr)

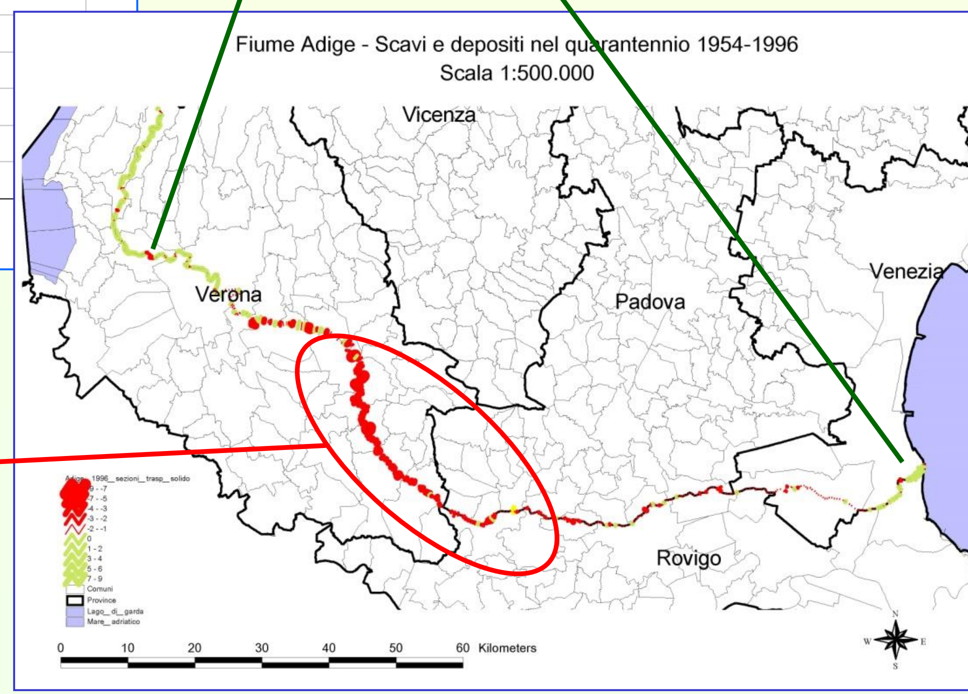
ADIGE RIVER: RECENT EVOLUTION AFTER THE '50s

PROFILE EVOLUTION



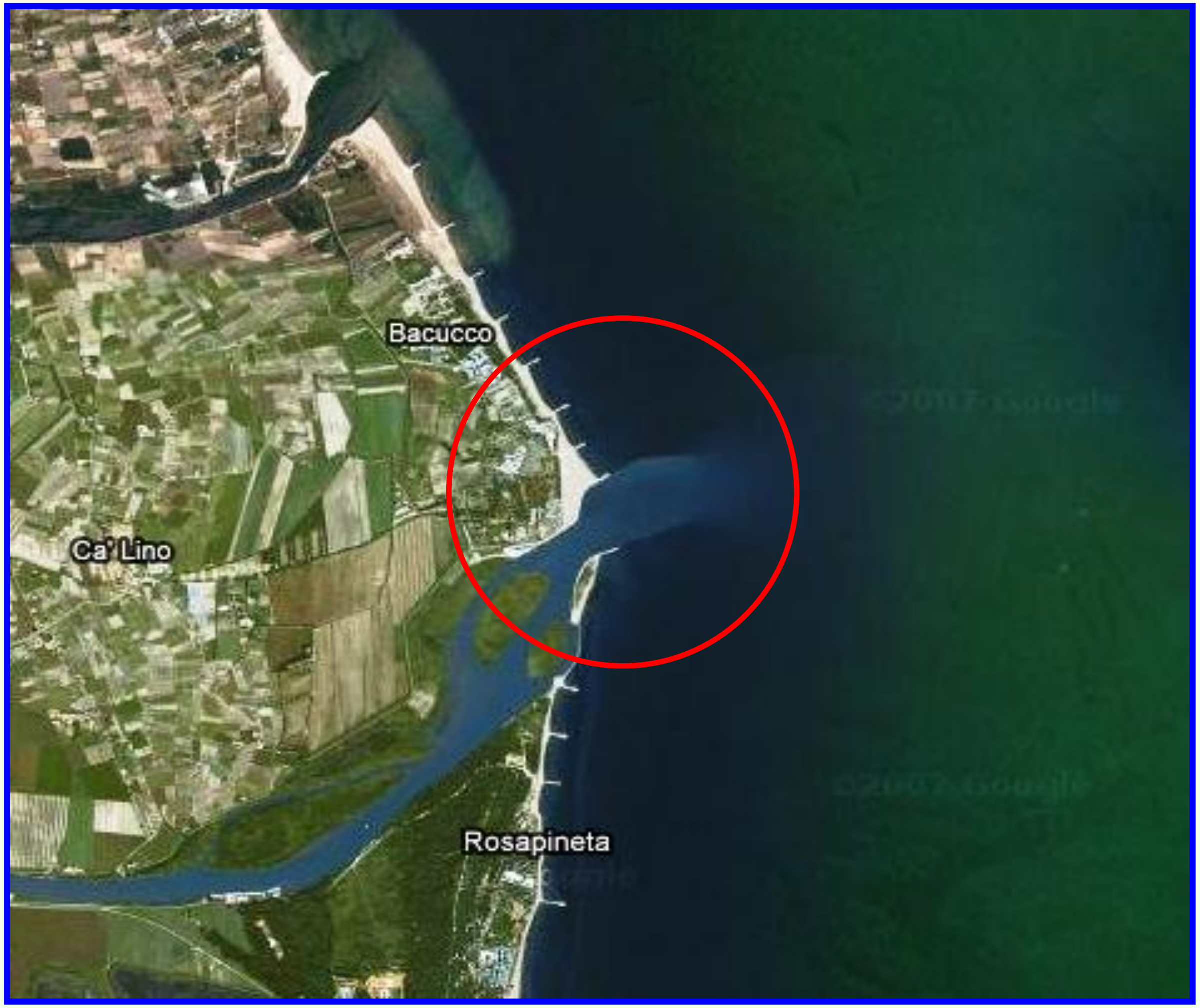
Talweg deposition, more braiding, sparser vegetation.

BOTTOM AGGRADATION-DEGRADATION

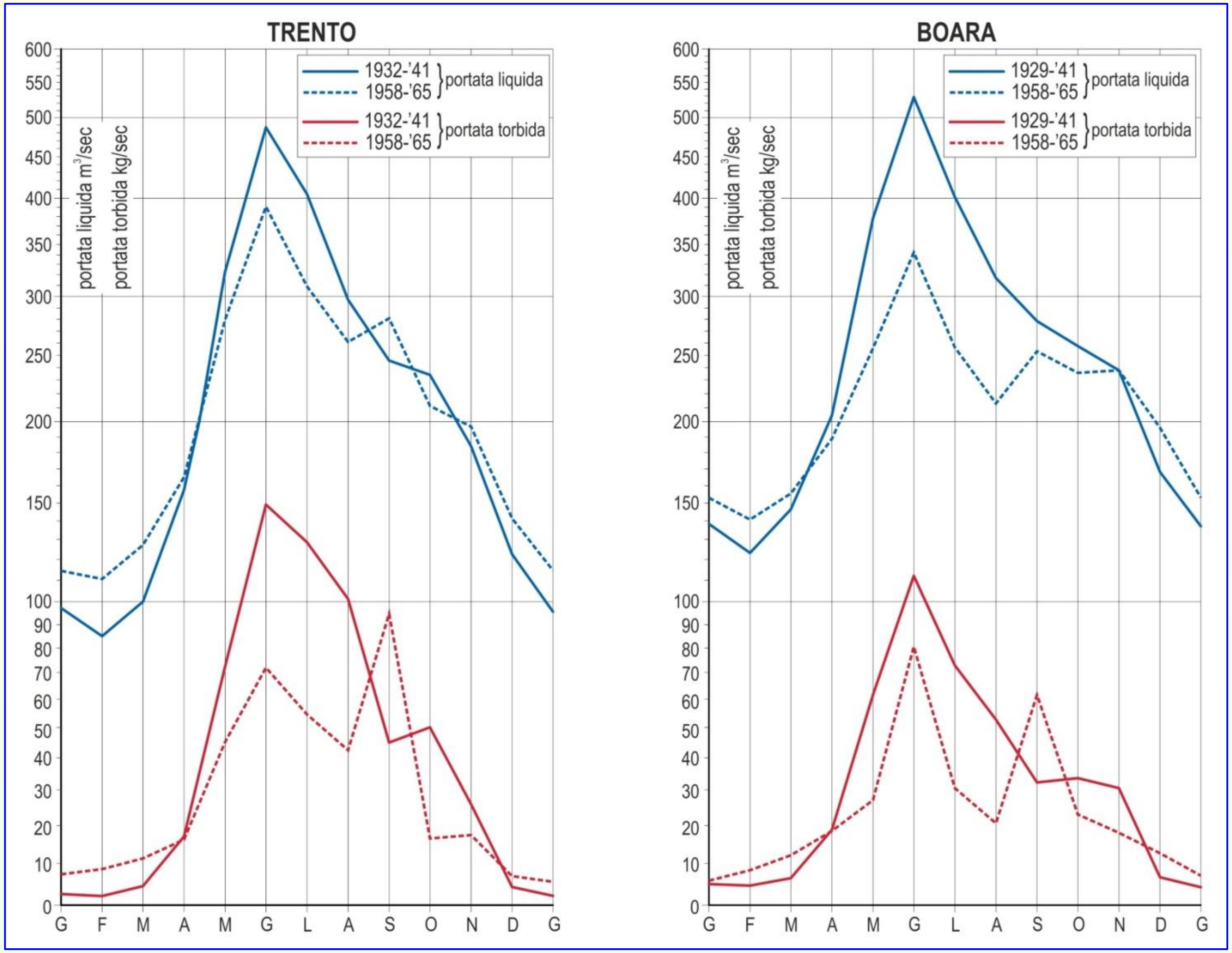


Talweg erosion, less braiding thicker vegetation.

ADIGE RIVER: DELTA SURFACE DECREASE AFTER THE '50s



ADIGE RIVER: RECENT CHANGES OF WATERFLOW & SEDIMENT TRANSPORT



Reduction of Q_{max}
Reduction of Q_{eq}
Different reduction of G_S

ADIGE RIVER: PLAUSIBLE CAUSES OF CHANGES

1) **Reduction of "equivalent" discharge, after the 1930s**
   (hydropower regulation)

2) **Water withdrawal, after the 1940s**
   (irrigation)

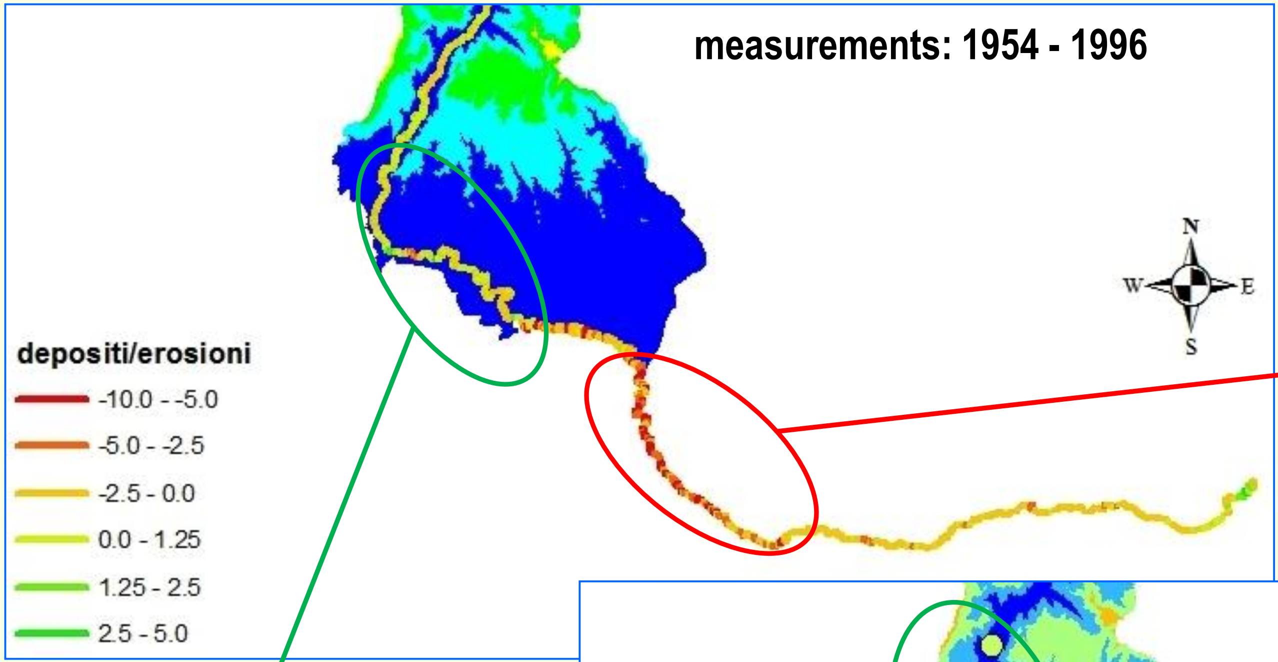
3) **Sediment interception by reservoirs, after the 1930s, mainly upland**
   (31 reservoirs, $570 \cdot 10^6$ m^3)

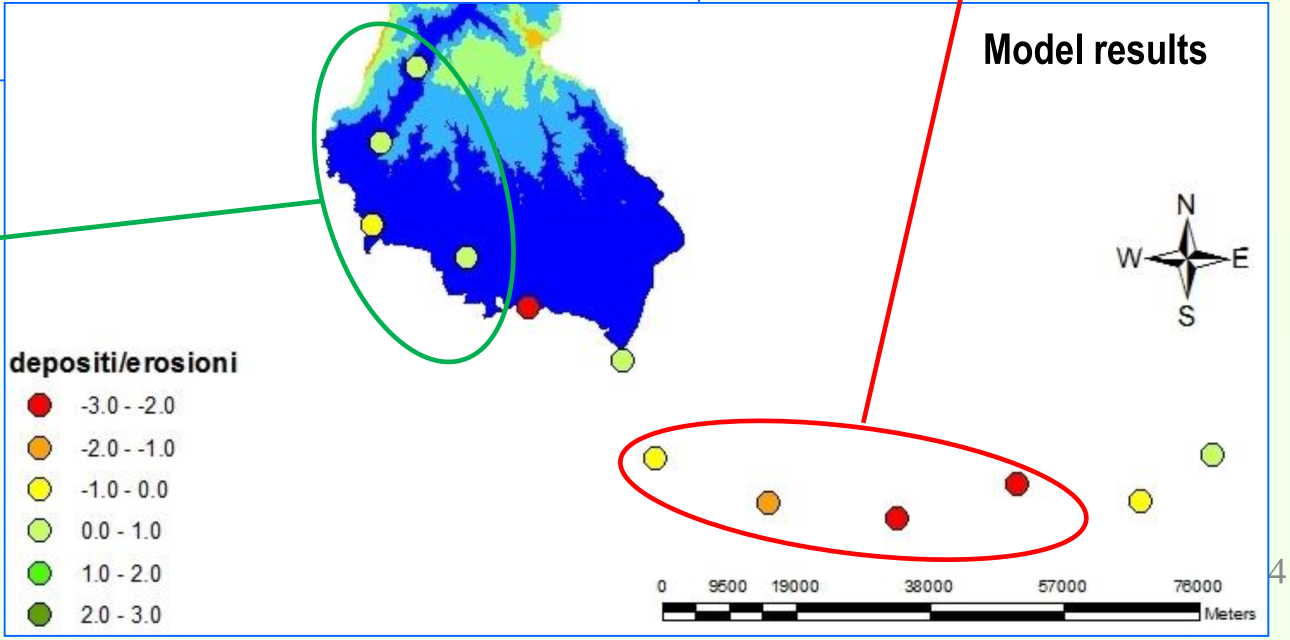
4) **Less sediment production from watershed slope, after the 1950s**
   (erosion-control works)

5) **Quarrying of gravel and sand, from the 1950s to the 1970s**

RIVER EVOLUTION 1954-1966

COMPARISON OF RESULTS AND SENSITIVITY ANALYSIS

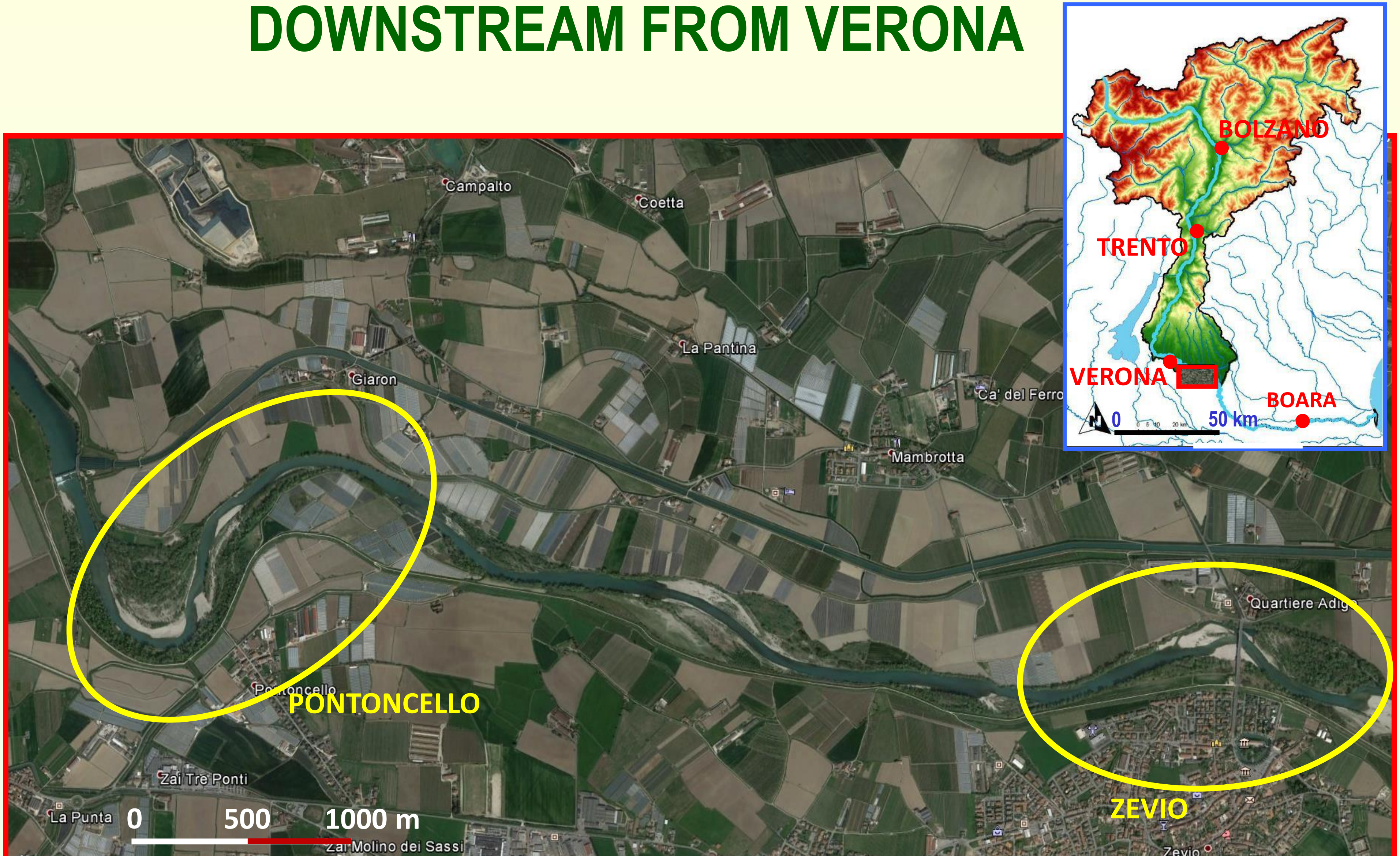




EROSION (mainly by sand quarries)

DEPOSITION (mainly by lesser Q_{eq})

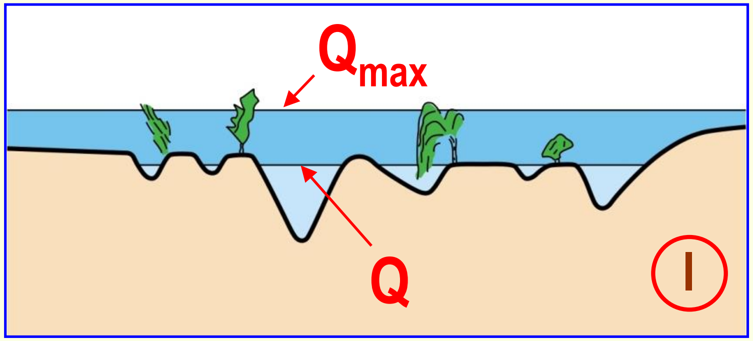
ADIGE RIVER: TWO RESTORATION PROJECTS DOWNSTREAM FROM VERONA



ANTHROPOGENIC EVOLUTION OF A PIEDMONT RIVER AND RESTORATION PROJECTS

1 PRISTINE CONDITIONS

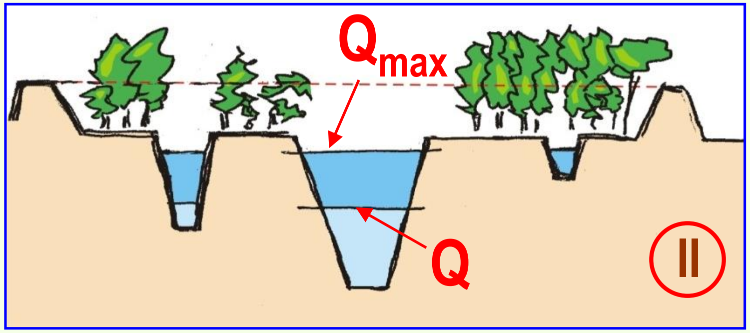
Braiding configuration; large total width; shallow and wide wandering channels; sparse riparian vegetation



Reduction of Q_{eq}

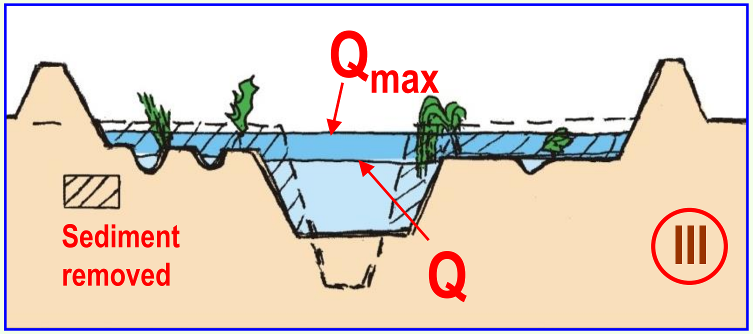
2 PRESENT CONDITIONS

Deeper and narrower main channel; obliterated secondary channels; sedimentation of islands and food-plains; permanent (riparian and plantial) vegetation; no humid zones



3 RESTORED CONDITIONS

Widening of channels; lowering of island elevation; restoration of humid zones; reopening of secondary channels
CAVEAT: Tendency to reverting to the previous conditions



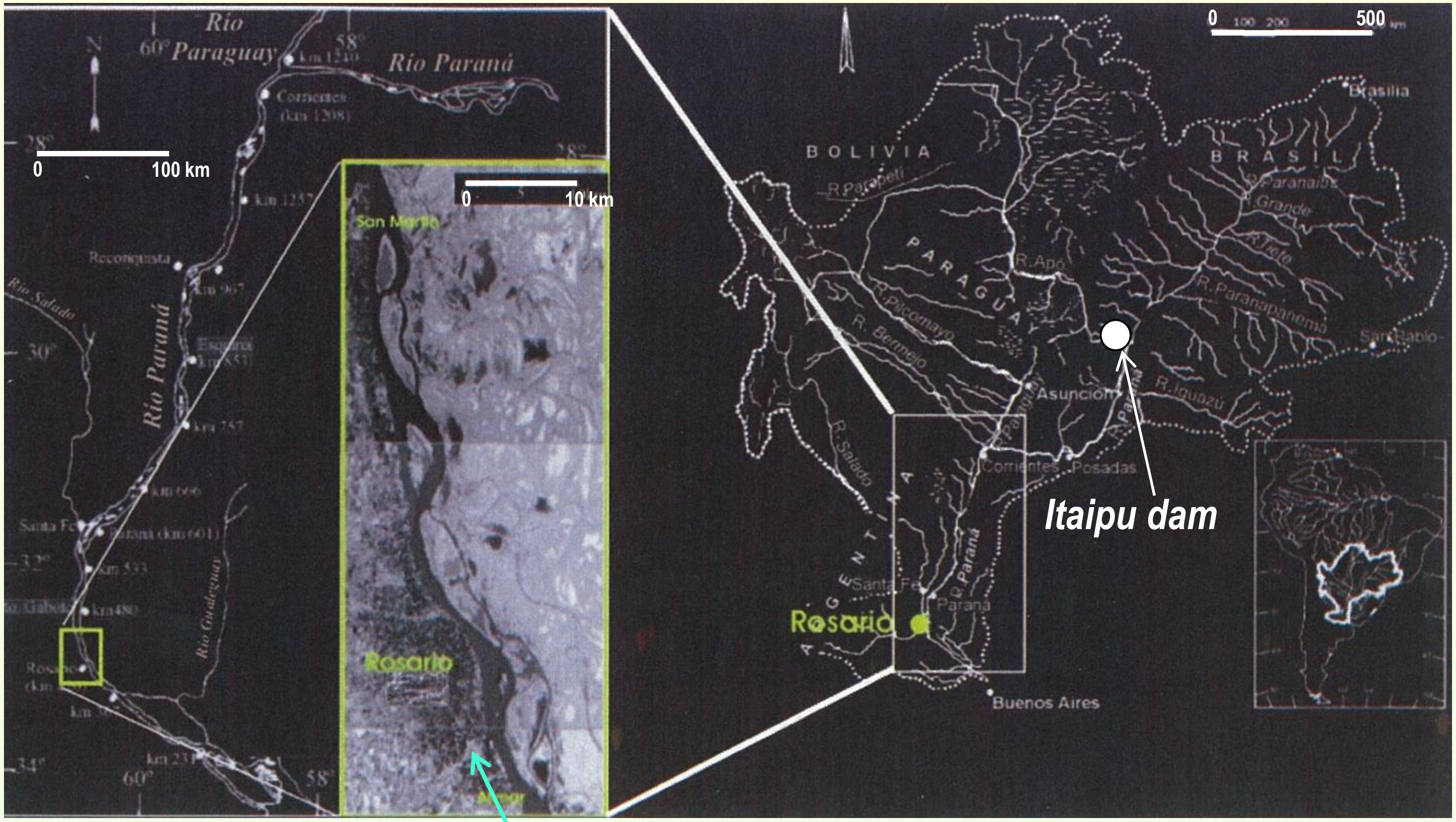
QUASI 3-D MODEL APPLIED FOR DESIGN AND MAINTENANCE

C

PARANÁ RIVER

MIDDLE AND LOW PARANÁ (QUASI 3-D MODEL[1])

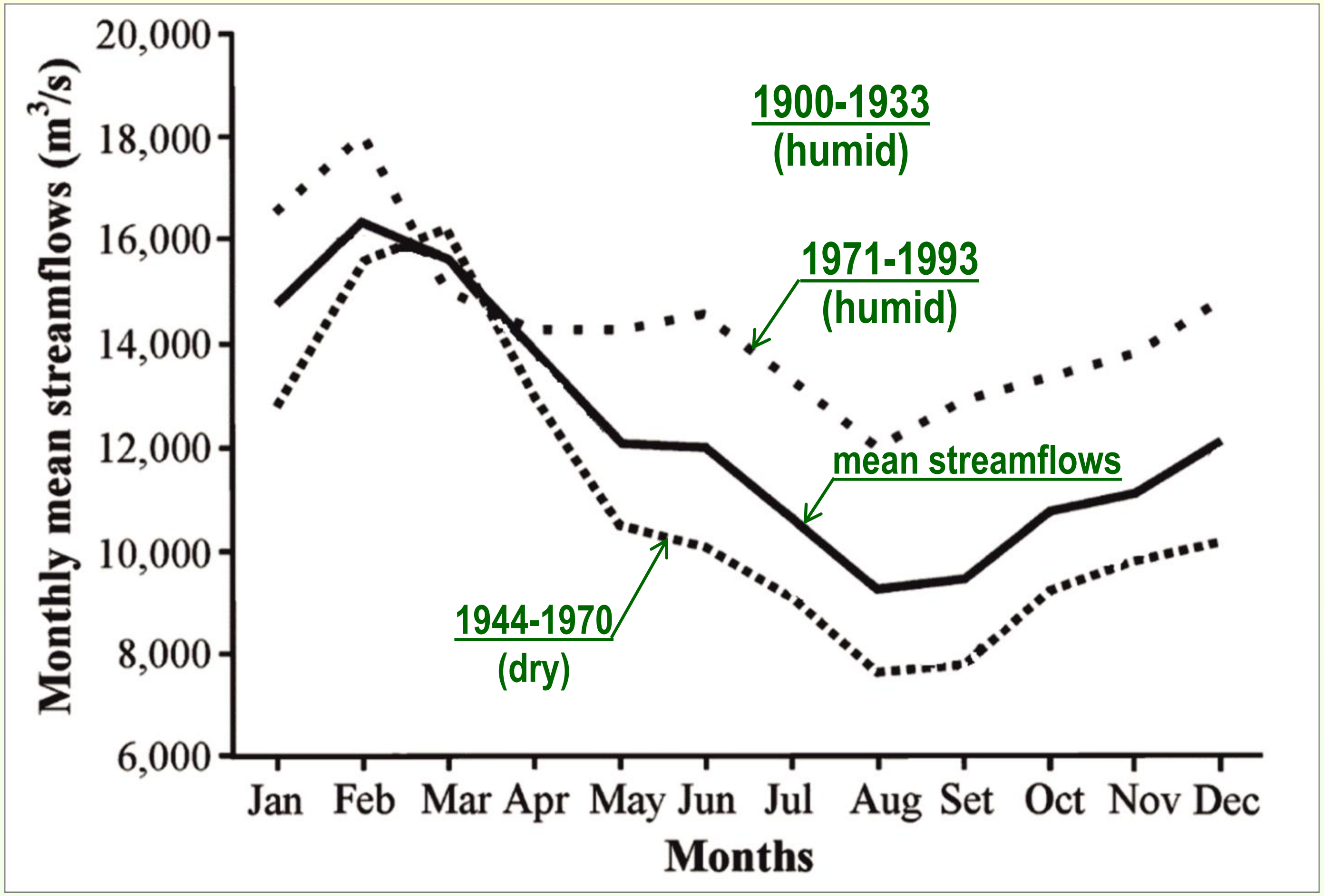
PARANÁ WATERSHED



DETAILED INVESTIGATED REACH (2-D MODEL[2])

[1], [2] **Guerrero et al. JRBM 2013**

PARANÁ RIVER: RECENT CLIMATIC CYCLES



PARANÁ RIVER: HYDRO-MORPHOLOGICAL RESPONSE TO CLIMATIC CYCLES

Period	1900-1930		1930-1970		1970-2005	
	HUMID		DRY		HUMID	
Reach	MIDDLE	LOW	MIDDLE	LOW	MIDDLE	LOW
Volume	+	+	-	-	+	+
Width	+	+	-	-	+	(-)
Depth	-	-	+	(-)	(+)	(+)

+, - balance of Lane (change of Q_{eq})

(+), (-) quasi 3-D model (plus delay, delta, dam etc.)