1222·2022 800 ANNI

Università degli Studi di Padova

DIPARTIMENTO DI GEOSCIENZE

Dove vanno i sedimenti? Dalle escavazioni in alveo al monitoraggio morfologico

CIRF Centro Italiano per la Riqualificazione Fluviale

UNIVERSITÀ DEGLI STUDI DI SALERNO

dicv Dipartimento di Ingegneria Civile

ORDINE DEGLI INGEGNERI DELLA PROVINCIA DI SALERNO

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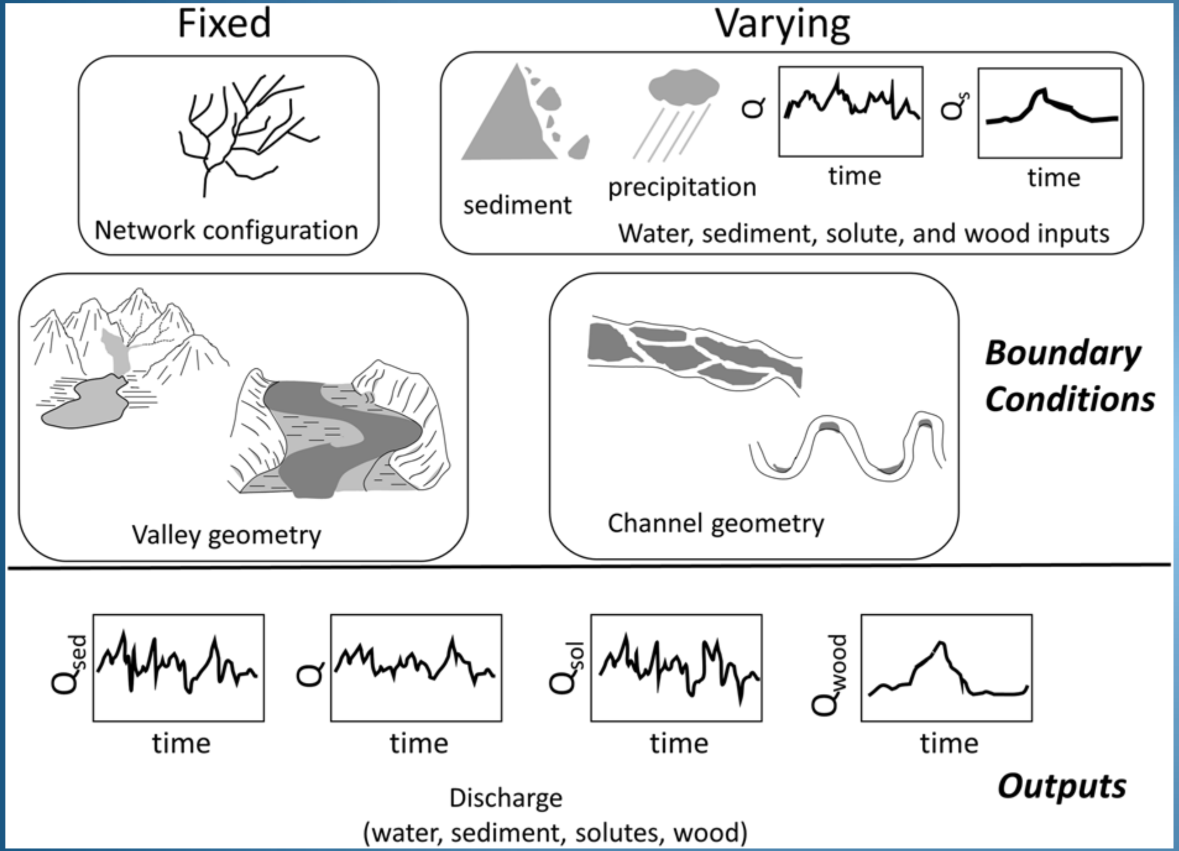
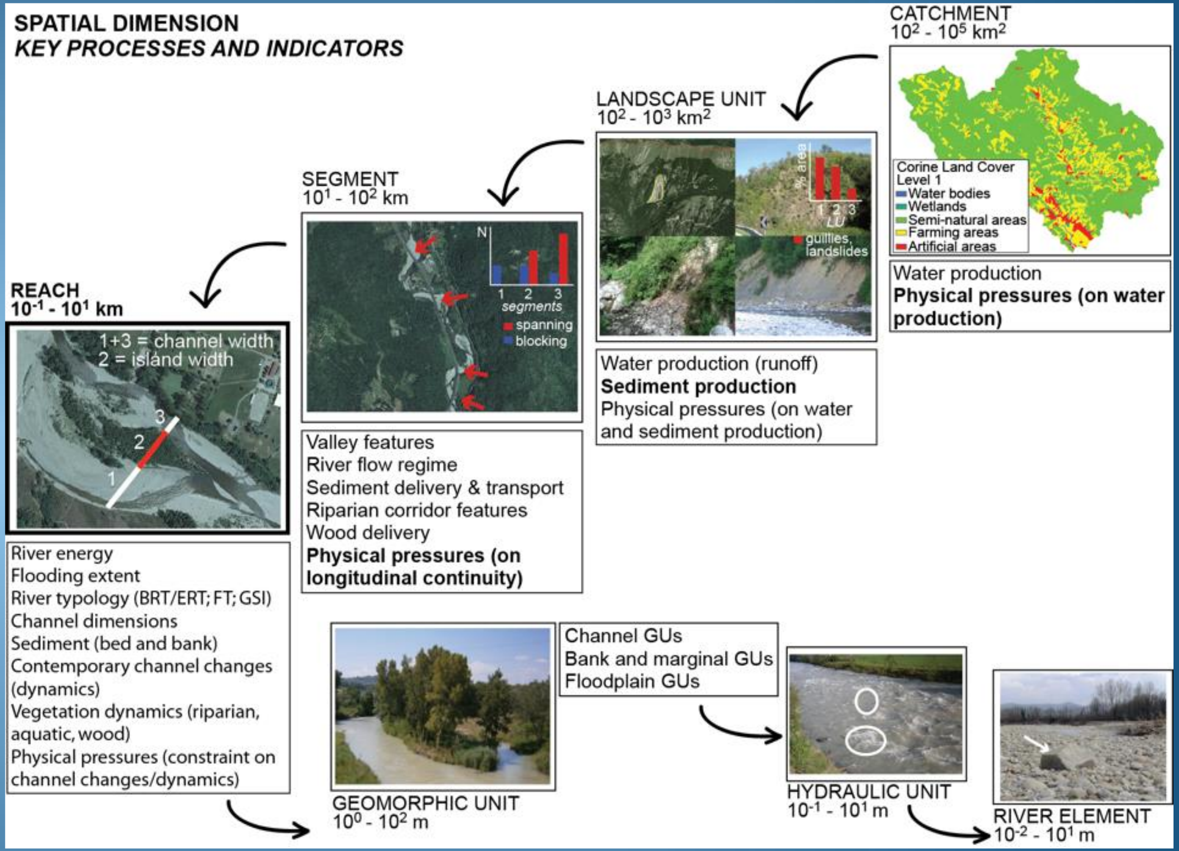
University of Padova

WEBINAR: 8 INCONTRI DI FORMAZIONE E
CONFRONTO SULLA RIQUALIFICAZIONE FLUVIALE
19/03/2021

Il Sistema fluviale


Fixed
Varying
Network configuration
sediment
precipitation
Q
time
Q_s
time
Water, sediment, solute, and wood inputs
Valley geometry
Channel geometry
Boundary Conditions
Q_{sed}
time
Q
time
Q_{sol}
time
Q_{wood}
time
Outputs
Discharge
(water, sediment, solutes, wood)

Wohl et al. (2018)



SPATIAL DIMENSION
KEY PROCESSES AND INDICATORS

CATCHMENT
10^2 - 10^5 km^2

Corine Land Cover
Level 1
Water bodies
Wetlands
Semi-natural areas
Farming areas
Artificial areas

Water production
Physical pressures (on water production)

LANDSCAPE UNIT
10^2 - 10^3 km^2

% area
1 2 3
LU
gullies, landslides

Water production (runoff)
Sediment production
Physical pressures (on water and sediment production)

SEGMENT
10^1 - 10^2 km

N
1 2 3
segments
spanning
blocking

Valley features
River flow regime
Sediment delivery & transport
Riparian corridor features
Wood delivery
Physical pressures (on longitudinal continuity)

REACH
10^{-1} - 10^1 km

1+3 = channel width
2 = island width
1
2
3

River energy
Flooding extent
River typology (BRT/ERT; FT; GSI)
Channel dimensions
Sediment (bed and bank)
Contemporary channel changes (dynamics)
Vegetation dynamics (riparian, aquatic, wood)
Physical pressures (constraint on channel changes/dynamics)

GEOMORPHIC UNIT
10^0 - 10^2 m

Channel GUs
Bank and marginal GUs
Floodplain GUs

HYDRAULIC UNIT
10^{-1} - 10^1 m

RIVER ELEMENT
10^{-2} - 10^1 m

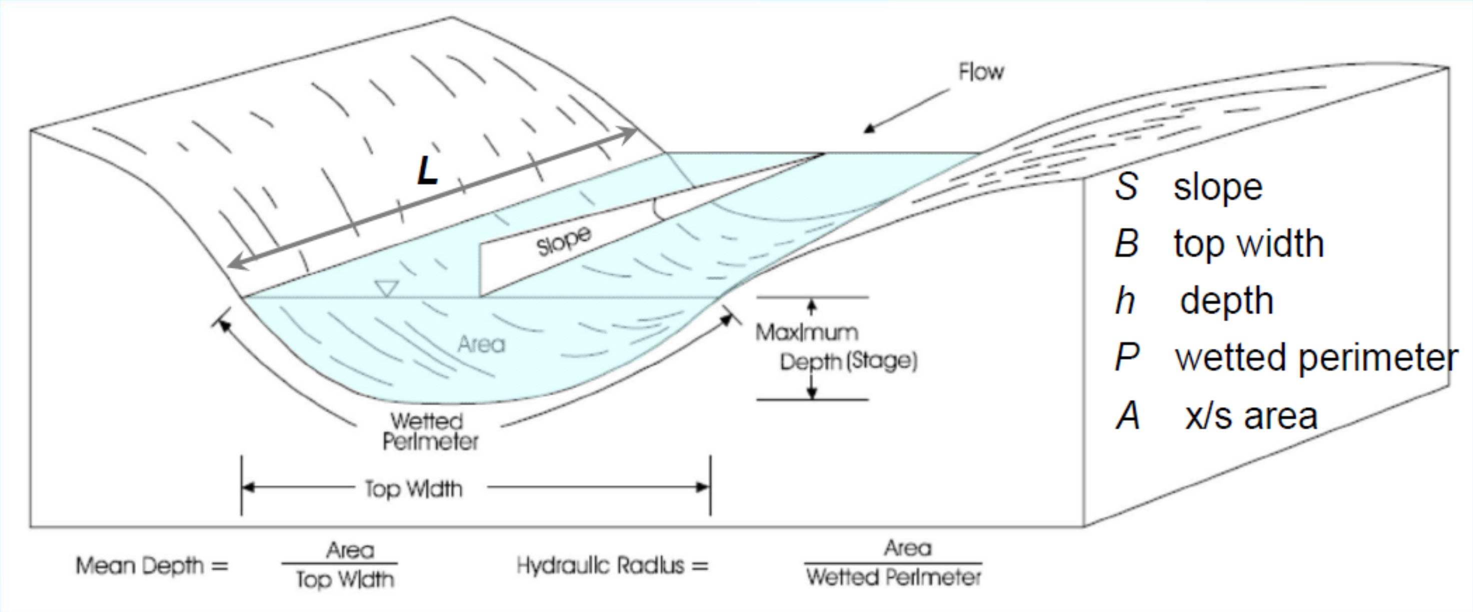
Gurnell et al. (2016)

Il trasporto solido nei fiumi

Il trasporto solido nei fiumi: la teoria

Momentum: Newton's 2nd Law, $\Sigma F = ma$

Normal flow
no accelerations, so $\Sigma F = 0$



S slope
B top width
h depth
P wetted perimeter
A x/s area

$$\text{Mean Depth} = \frac{\text{Area}}{\text{Top Width}} \qquad \text{Hydraulic Radius} = \frac{\text{Area}}{\text{Wetted Perimeter}}$$

Volume of water: AL

Weight of water: ρgAL

Boundary stress: τ_o
(stresss is force/area)

Downslope component of weight of water: $\rho gALS$ ⟷ Boundary force: $\tau_o PL$

τ_o is the boundary shear stress - the flow force per unit area - it drives the sediment transport

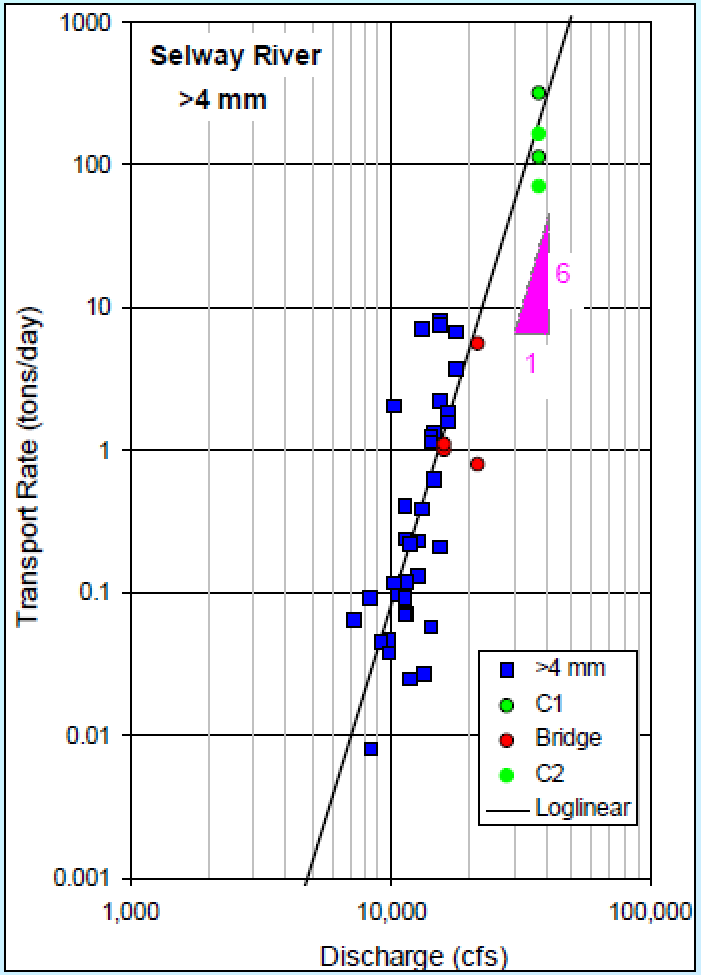
$$\tau_o PL = \rho gALS$$

$$\boxed{\tau_o = \rho gRS \quad \text{The 'depth-slope' product}}$$

$$\tau_o \simeq hS$$

h (cm)
S (%)

Figure adapted from WINXSPro manual, USFS



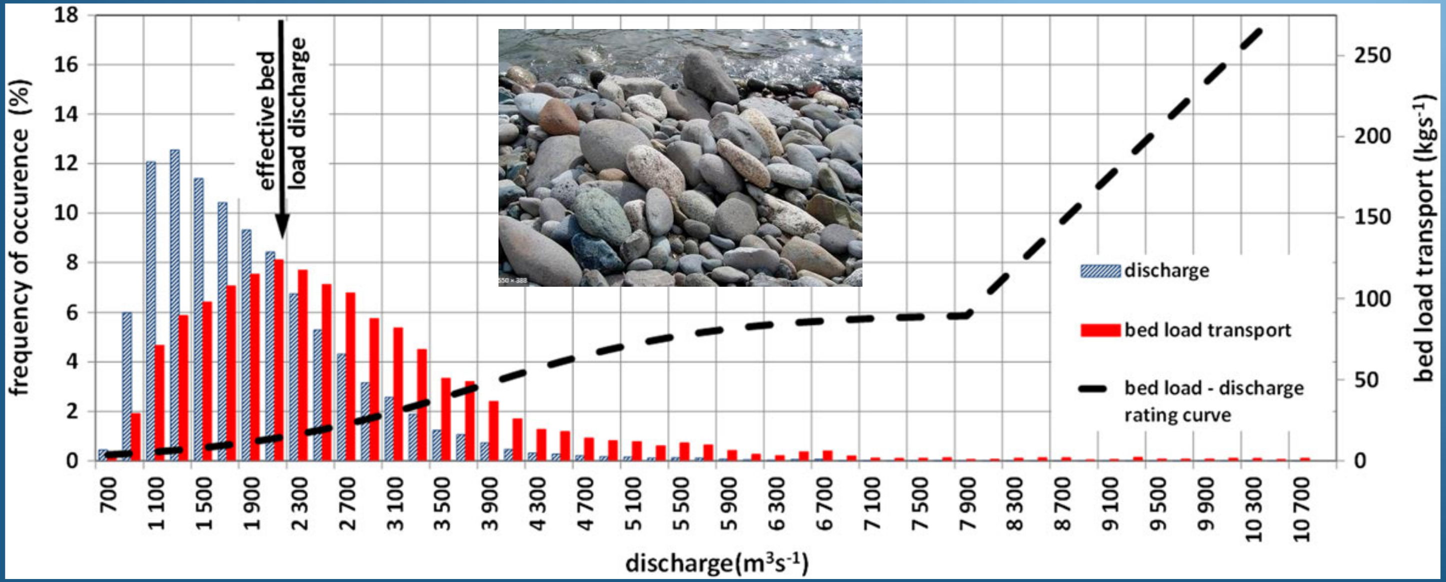
A typical transport model: $q^* = a(\tau^* - \tau_c^*)^b$

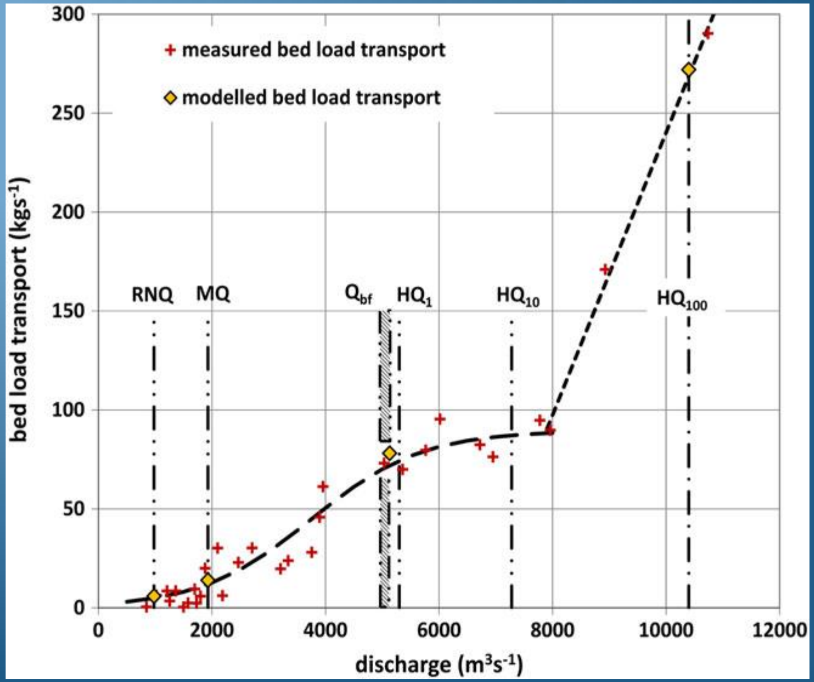
Il trasporto solido nei fiumi: la pratica

Back to the second problem
….. transport rates

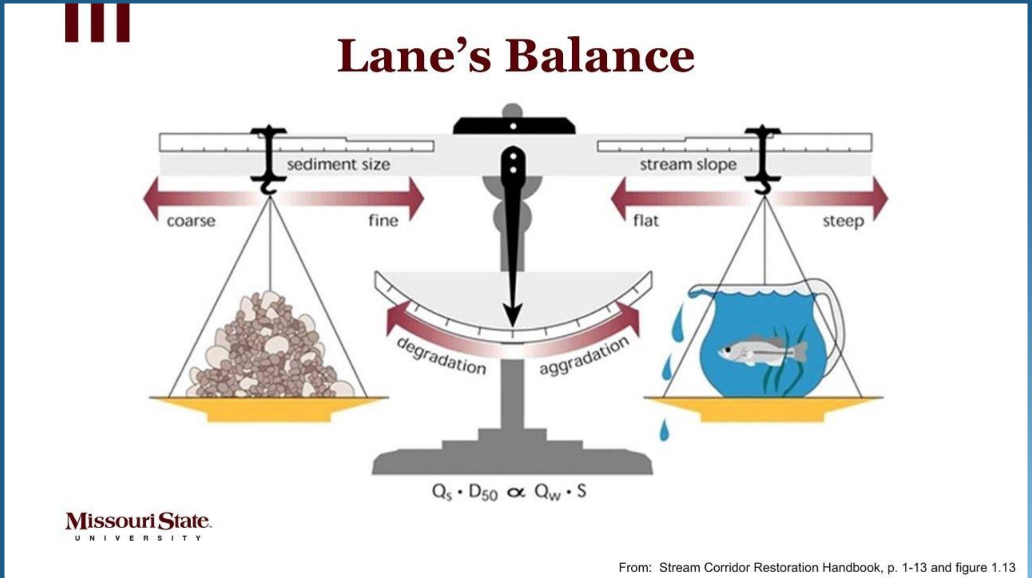
Rickenmann JHE 2017

Liedermann et al. ESPL 2017





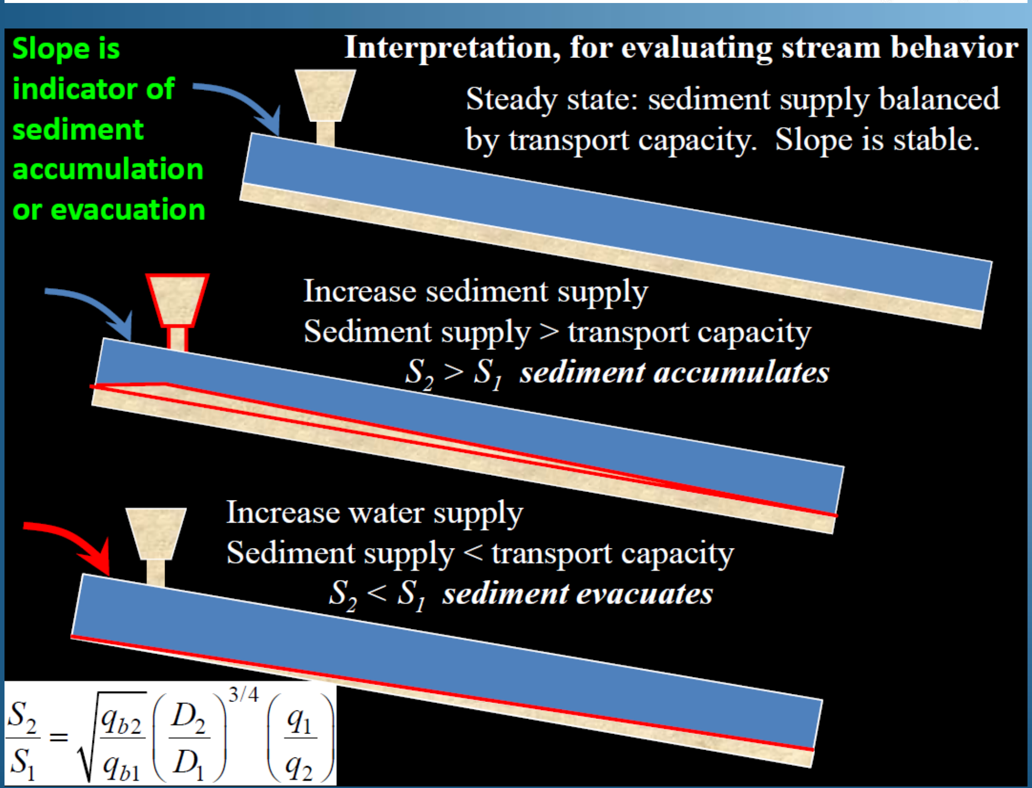
Il trasporto solido e le forme fluviali



Lane's Balance

sediment size
coarse
fine
stream slope
flat
steep
degradation
aggradation
Qs • D50 ∝ Qw • S
Missouri State University

From: Stream Corridor Restoration Handbook, p. 1-13 and figure 1.13



Slope is indicator of sediment accumulation or evacuation

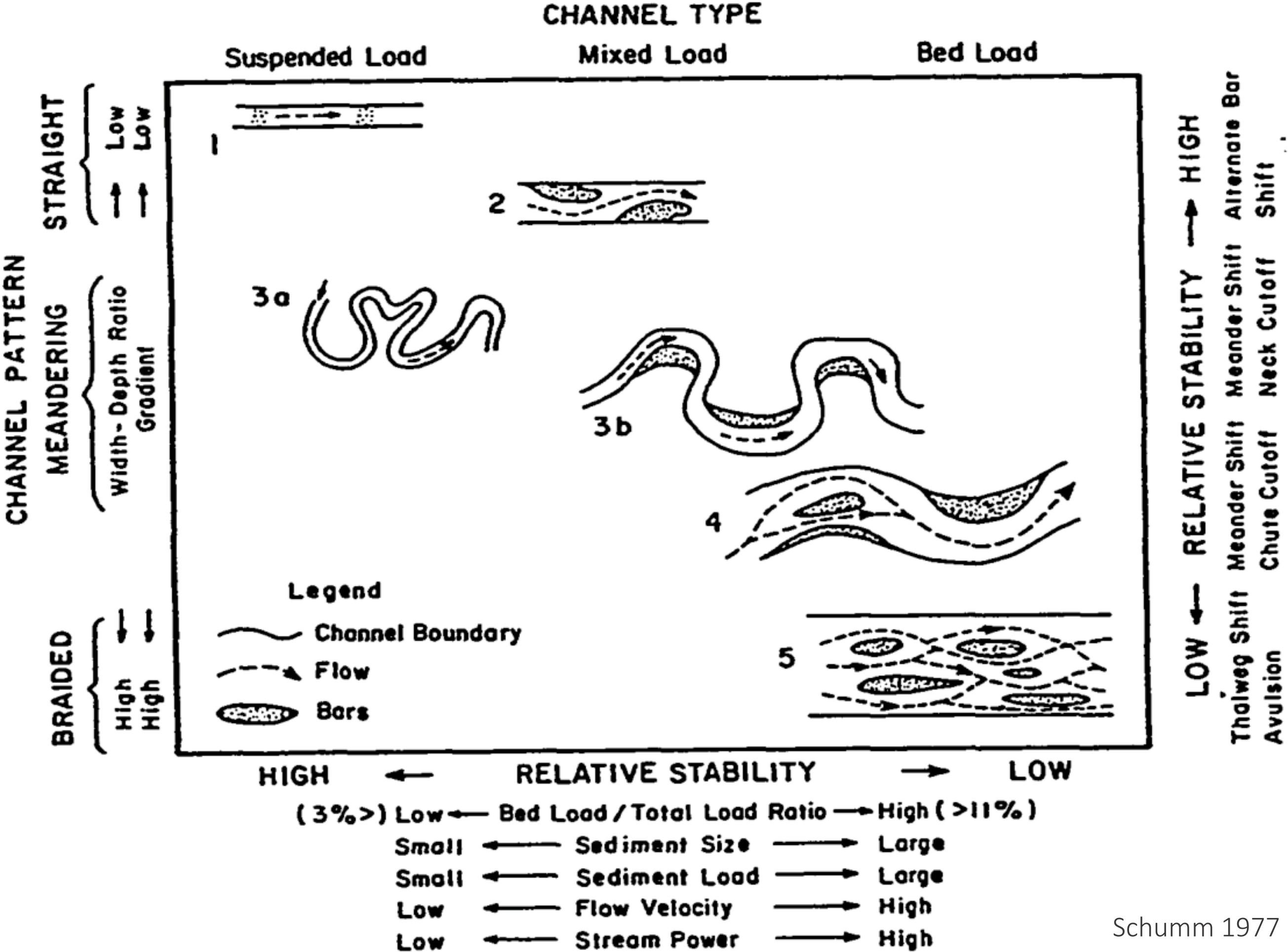
Interpretation, for evaluating stream behavior

Steady state: sediment supply balanced by transport capacity. Slope is stable.

Increase sediment supply
Sediment supply > transport capacity
$S_2 > S_1$ ***sediment accumulates***

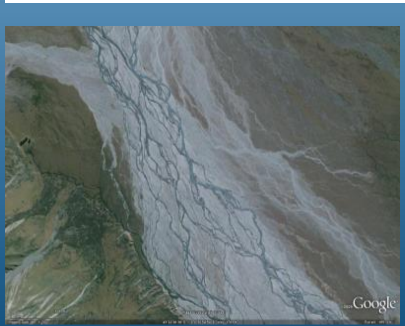
Increase water supply
Sediment supply < transport capacity
$S_2 < S_1$ ***sediment evacuates***

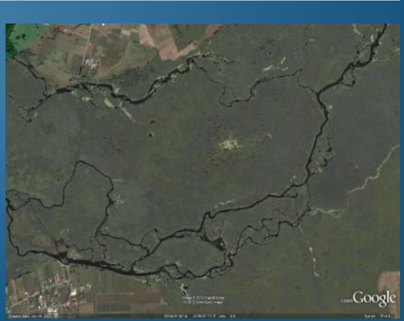
$$\frac{S_2}{S_1} = \sqrt{\frac{q_{b2}}{q_{b1}}}\left(\frac{D_2}{D_1}\right)^{3/4}\left(\frac{q_1}{q_2}\right)$$



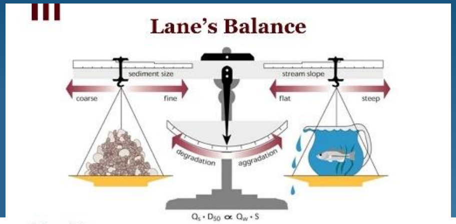
CHANNEL TYPE
Suspended Load
Mixed Load
Bed Load
CHANNEL PATTERN
STRAIGHT
MEANDERING
BRAIDED
Low
Low
High
High
Width-Depth Ratio
Gradient
1
2
3a
3b
4
5
Legend
Channel Boundary
Flow
Bars
HIGH ← RELATIVE STABILITY → LOW
(3%>) Low ← Bed Load / Total Load Ratio → High (>11%)
Small ← Sediment Size → Large
Small ← Sediment Load → Large
Low ← Flow Velocity → High
Low ← Stream Power → High
LOW ← RELATIVE STABILITY → HIGH
Thalweg Shift
Avulsion
Meander Shift
Chute Cutoff
Meander Shift
Neck Cutoff
Alternate Bar
Shift

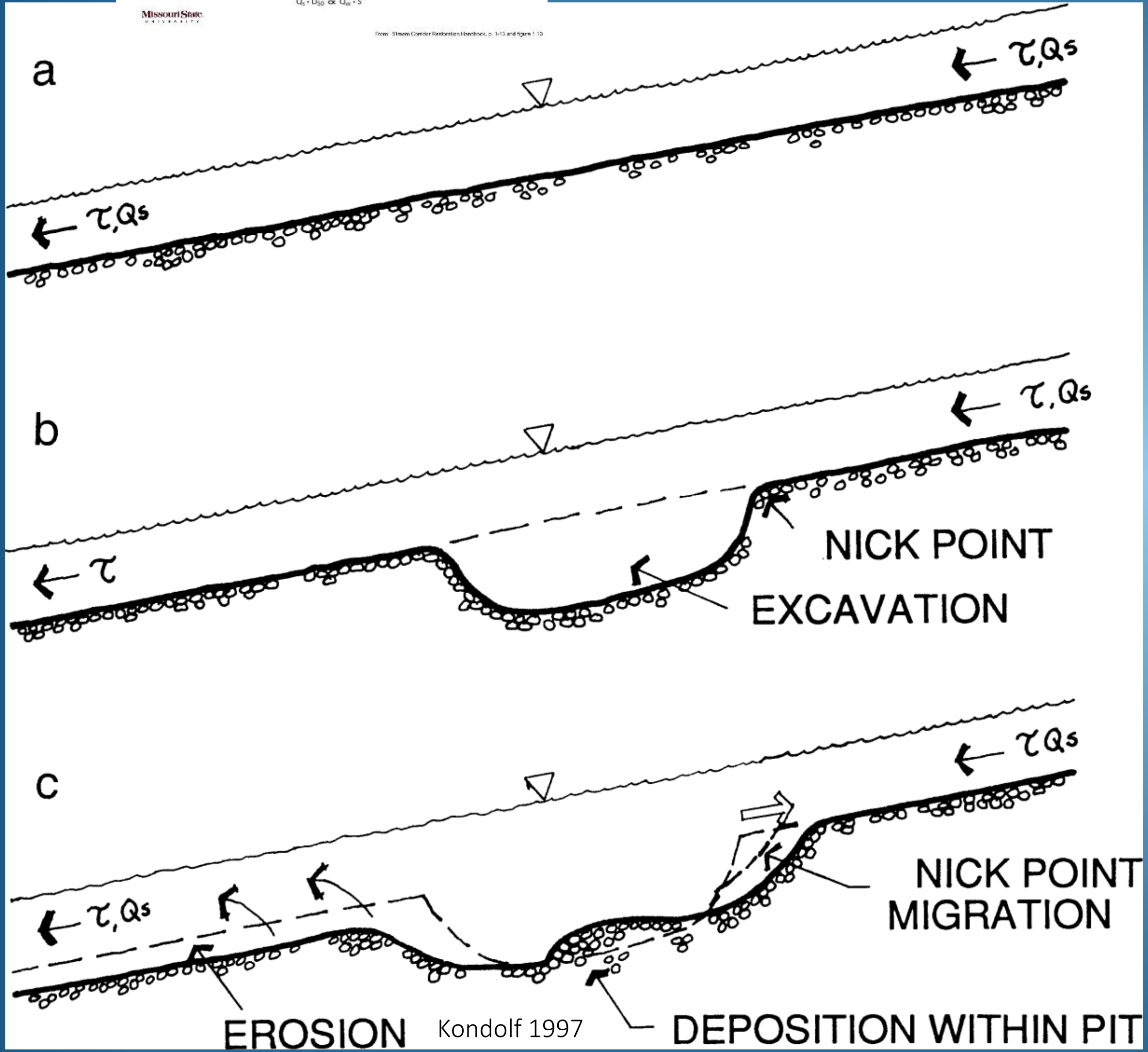
Schumm 1977



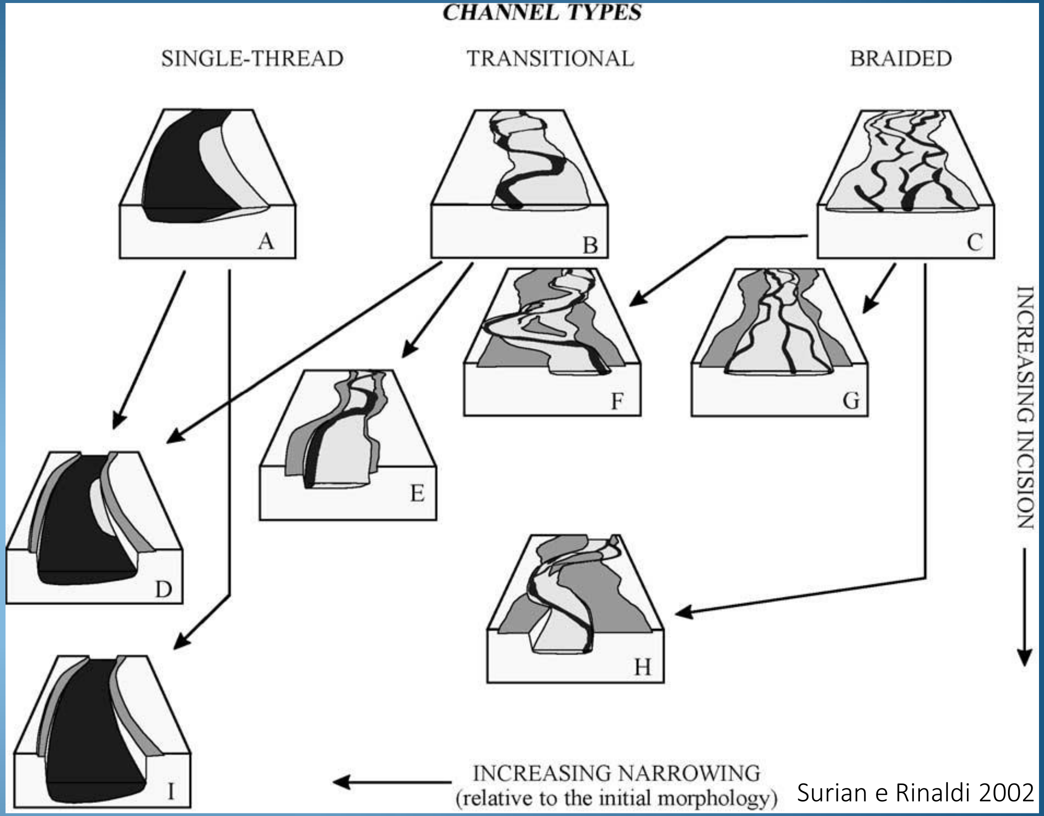


Le escavazioni cosa provocano nei fiumi?


Lane's Balance
sediment size
stream slope
coarse
fine
flat
steep
degradation
aggradation
$Q_s \cdot D_{50} \propto Q_w \cdot S$
Missouri State
From: Stream Corridor Restoration Handbook, p. 1-13 and figure 1.13


a
τ,Qs
τ,Qs
b
τ,Qs
τ
NICK POINT
EXCAVATION
c
τ,Qs
τ,Qs
NICK POINT
MIGRATION
EROSION
DEPOSITION WITHIN PIT

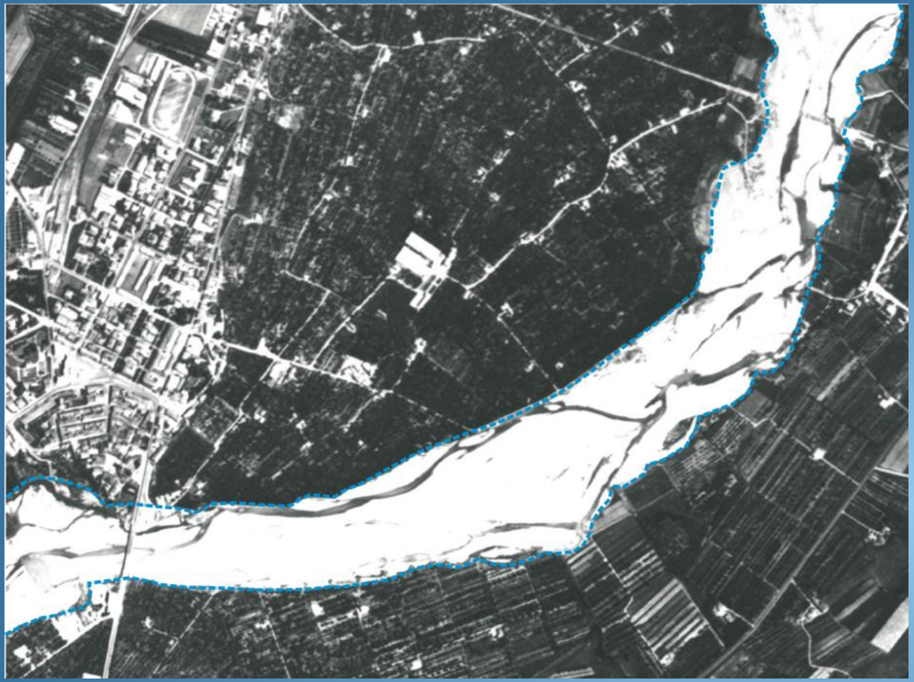
Kondolf 1997

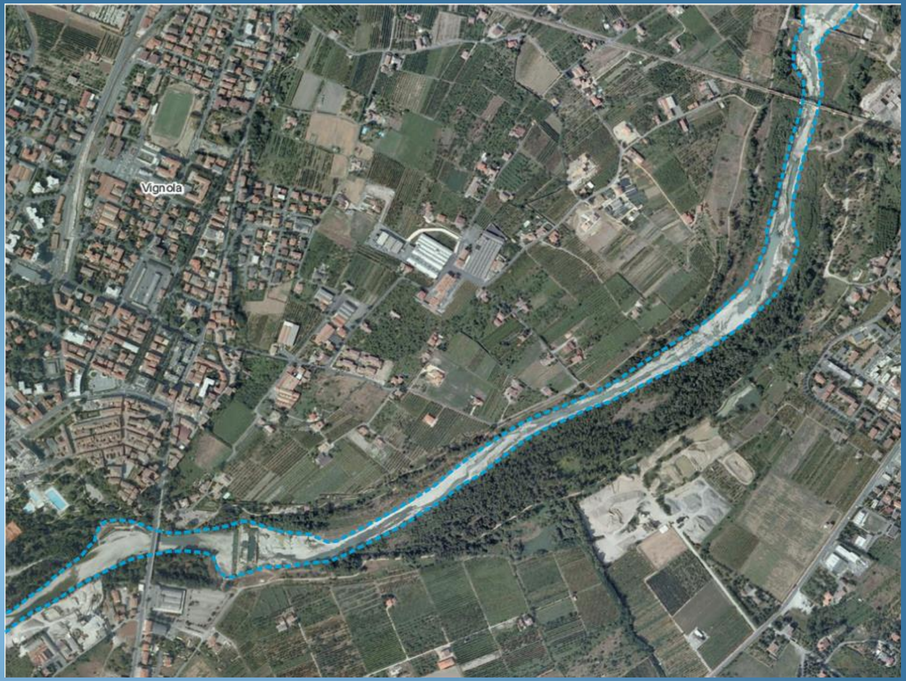

CHANNEL TYPES
SINGLE-THREAD
TRANSITIONAL
BRAIDED
A
B
C
D
E
F
G
H
I
INCREASING INCISION
INCREASING NARROWING
(relative to the initial morphology)

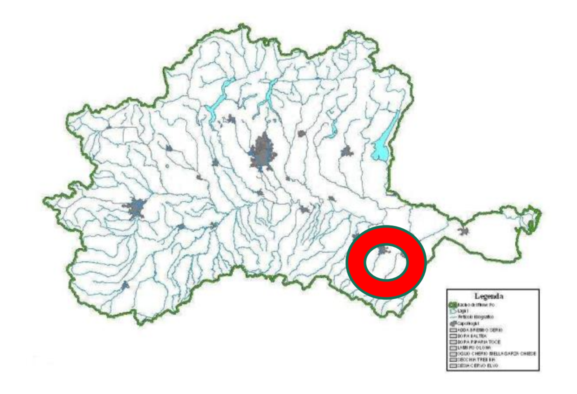
Surian e Rinaldi 2002

Channel adjustments that have occurred in Italian rivers during the past 100 years: (a) incision, which is commonly on the order of 3–4 m, but in some cases is even more than 10 m; (b) narrowing, with channel width reduction up to 50% or more.

Restringimento dell’alveo

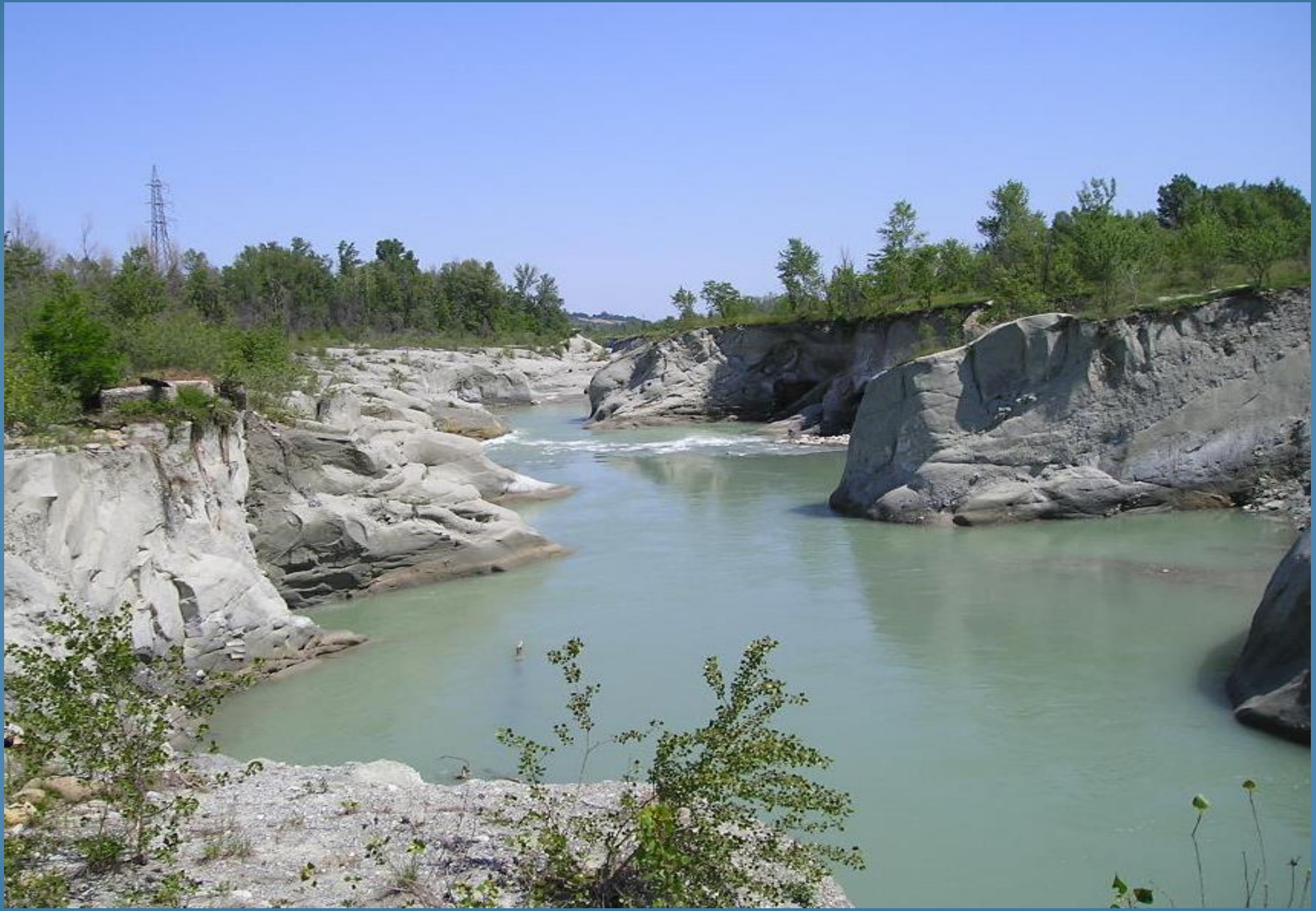





Legenda
Bacino del fiume Po
Laghi
Reticolo idrografico
Capoluoghi
ADDA BREMBO SERIO
DORA BALTEA
DORA RIPARIA TOCE
LAMBRO OLONA
OGLIO CHERIO MELLA GARZA CHIESE
SECCHIA TREBBIA
SESIA CERVO ELVO

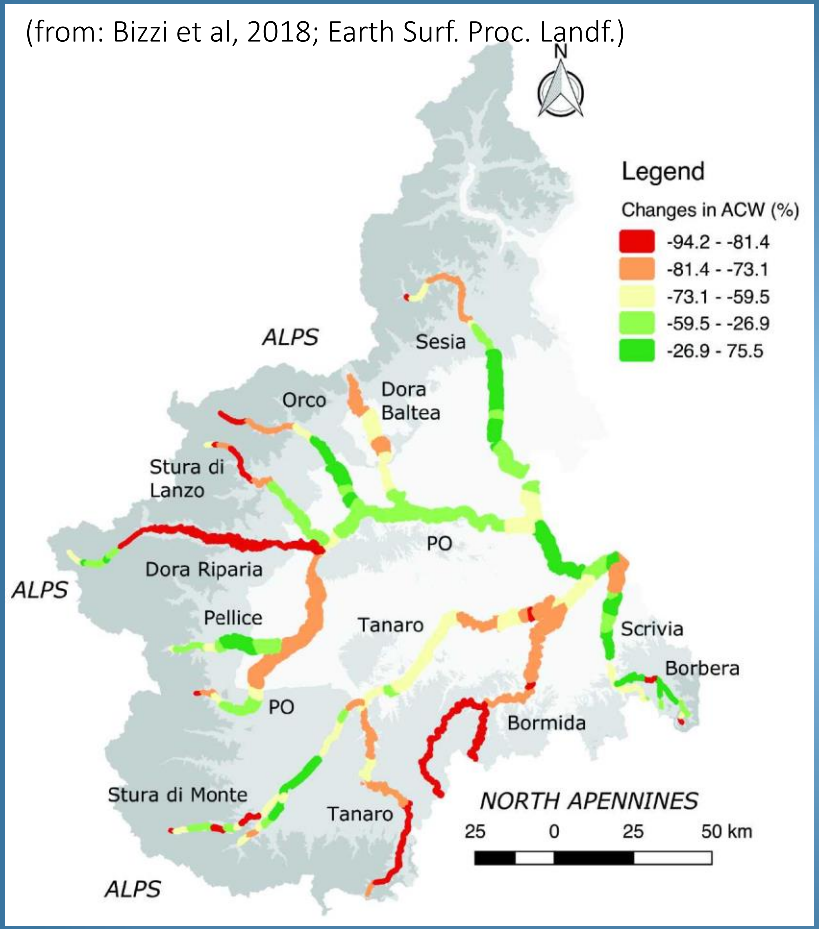
Fiume Panaro

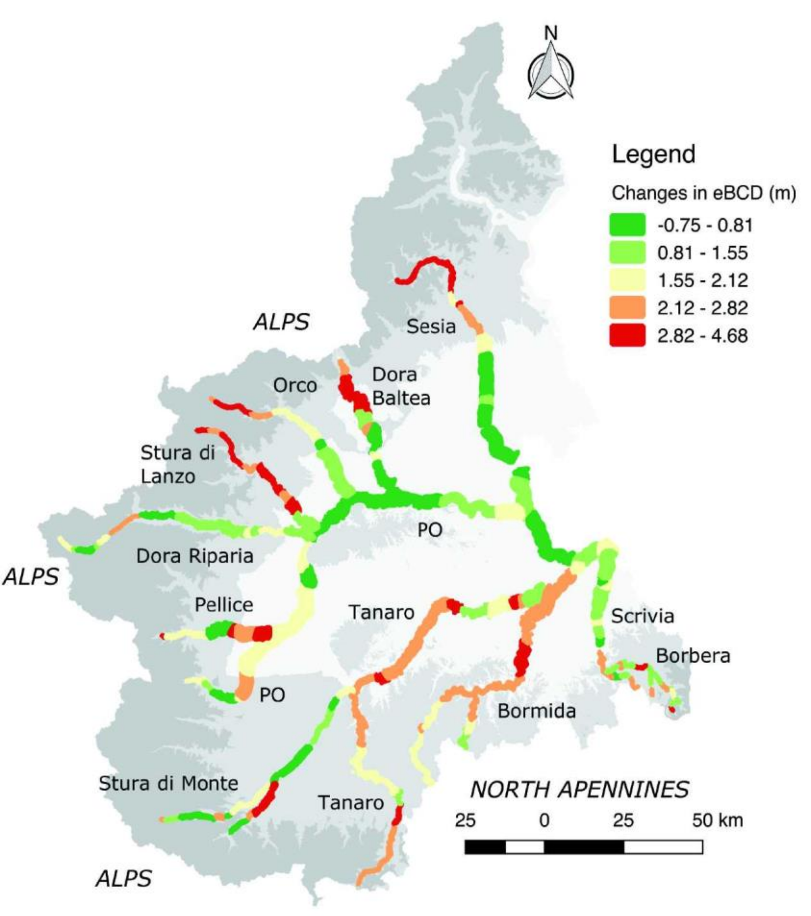
Incisione del letto e affioramento del substrato roccioso



Secchia River
Incision up to 12 m (locally)

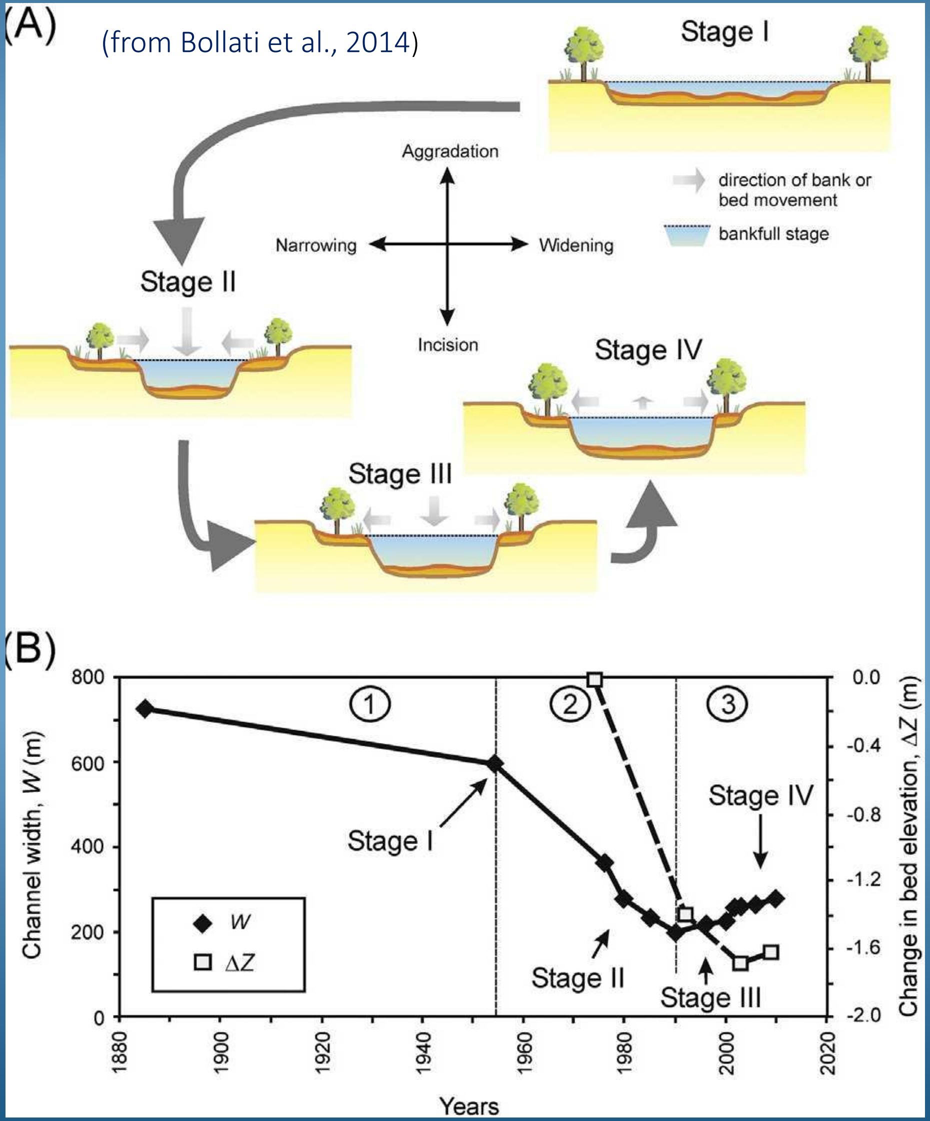
Stima impatto antropico su alterazioni fluviali a scala di bacino

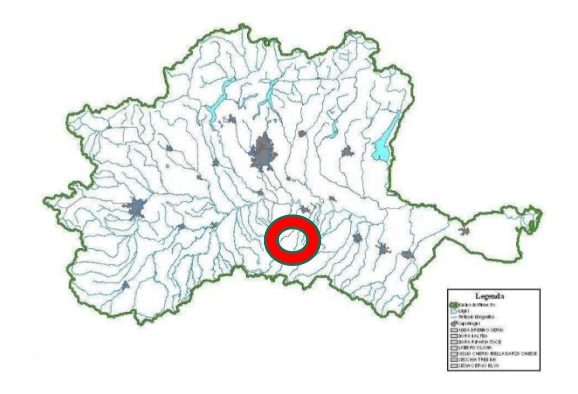

(from: Bizzi et al, 2018; Earth Surf. Proc. Landf.)
N
Legend
Changes in ACW (%)
🟥 -94.2 - -81.4
🟧 -81.4 - -73.1
🟨 -73.1 - -59.5
🟩 -59.5 - -26.9
🟩 -26.9 - 75.5
ALPS
Sesia
Orco
Dora Baltea
Stura di Lanzo
PO
Dora Riparia
ALPS
Pellice
Tanaro
Scrivia
Borbera
PO
Bormida
Stura di Monte
Tanaro
NORTH APENNINES
25 0 25 50 km
ALPS


N
Legend
Changes in eBCD (m)
🟩 -0.75 - 0.81
🟩 0.81 - 1.55
🟨 1.55 - 2.12
🟧 2.12 - 2.82
🟥 2.82 - 4.68
ALPS
Sesia
Orco
Dora Baltea
Stura di Lanzo
PO
Dora Riparia
ALPS
Pellice
Tanaro
Scrivia
Borbera
PO
Bormida
Stura di Monte
Tanaro
NORTH APENNINES
25 0 25 50 km
ALPS

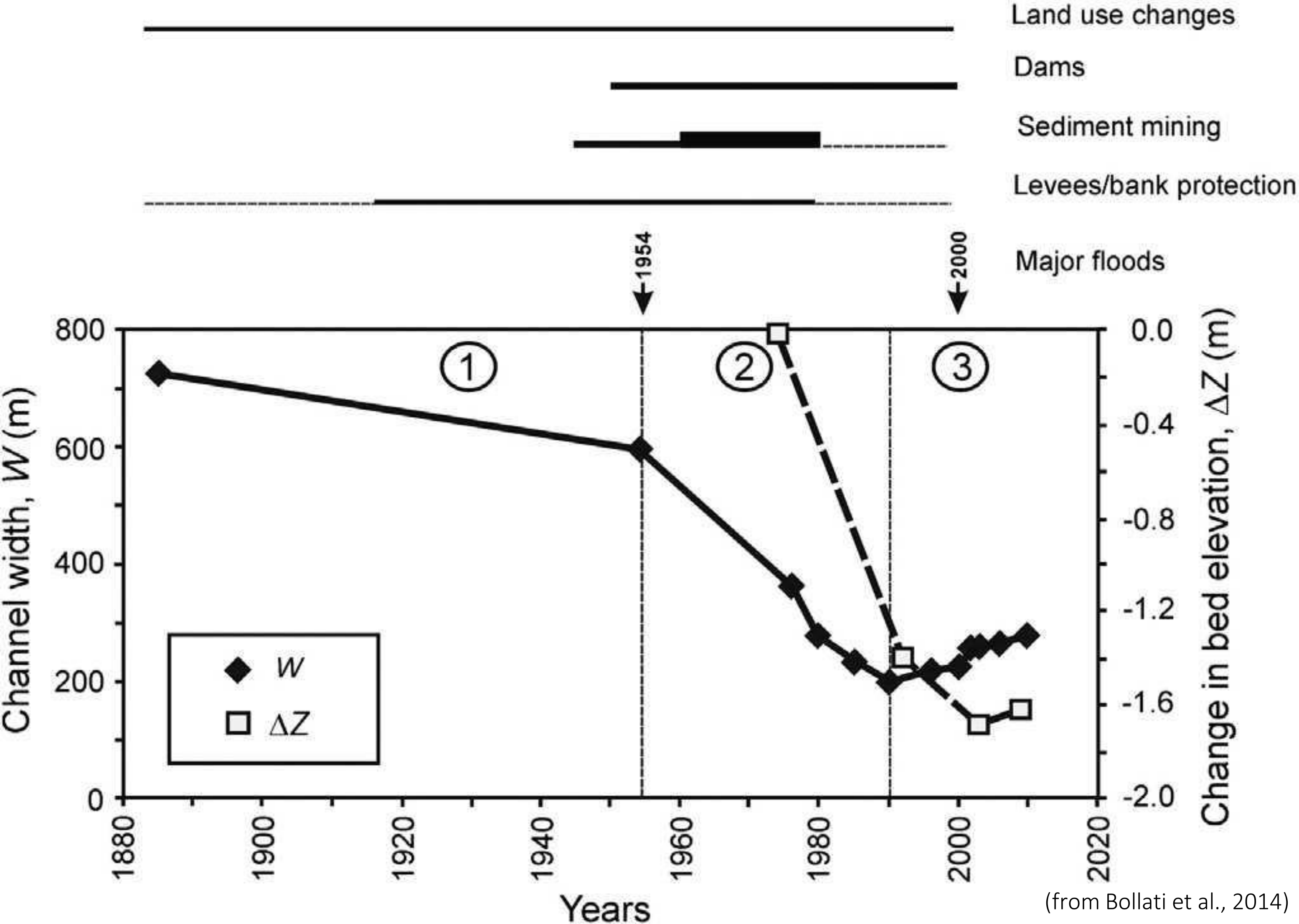
- 74% del reticolo ha sofferto un incisione dell’alveo maggiore di 1 m
- 66% degli alvei ha più che dimezzato la loro larghezza
- In totale 617 ha di alveo fluviale sono stati sottratti alla dinamica fluviale.

Il fiume Trebbia: traiettorie evolutive e fasi di riabilitazione


(from Bollati et al., 2014)

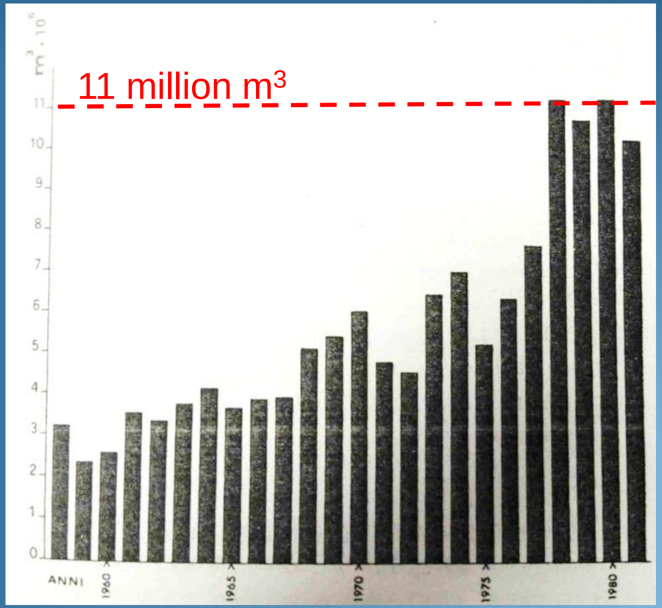

Legenda
Bacino del fiume Po
Laghi
Reticolo idrografico
Capoluoghi
ADDA BREMBO SERIO
DORA BALTEA
DORA RIPARIA TOCE
LAMBRO OLONA
OGLIO CHERIO MELLA GARZA CHIESE
SECCHIA TREBBIA
SESIA CERVO ELVO

Esploriamo le cause delle traittorie fluviali



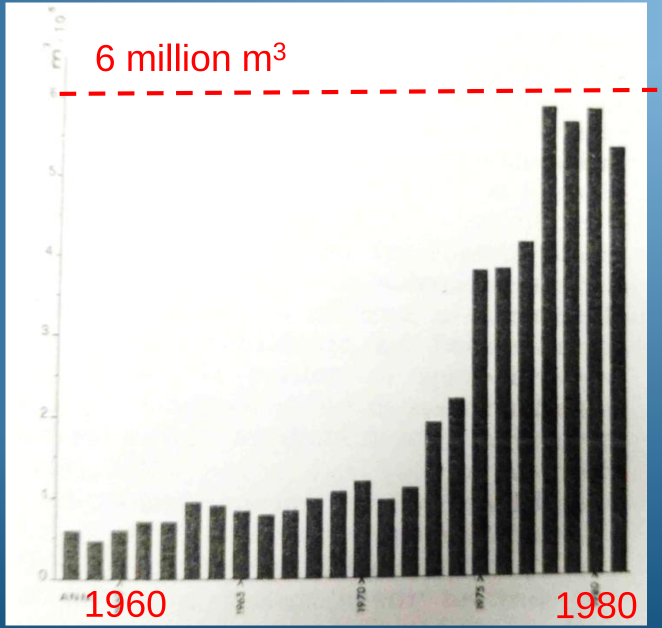
(from Bollati et al., 2014)

Le escavazioni di sediment nel Po



Tributaries

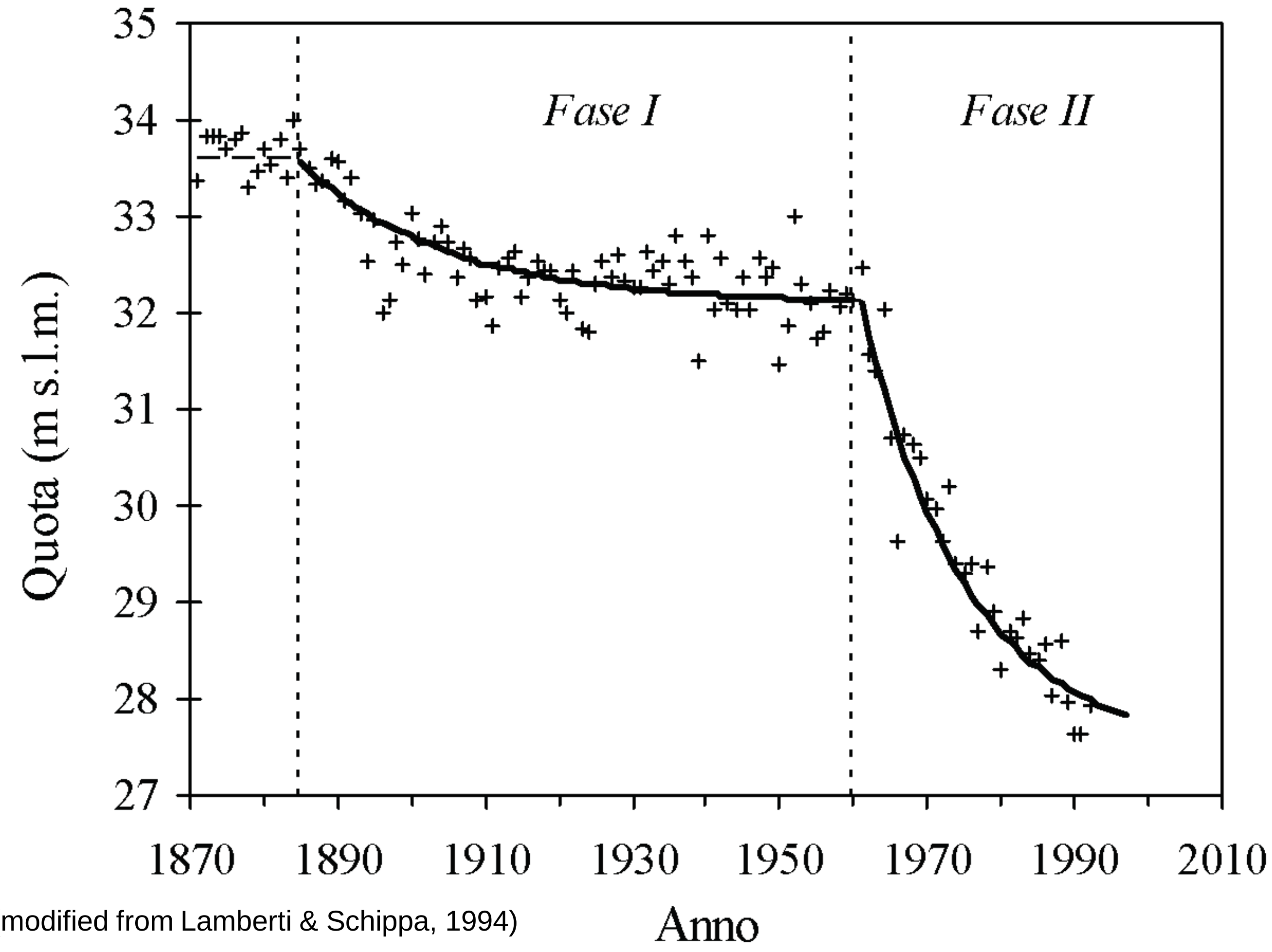
1950s – inizi 1980s: 12 milioni m^3/yr
1982 – 2005: 0.7 milioni m^3/yr
(source: Basin Authority)



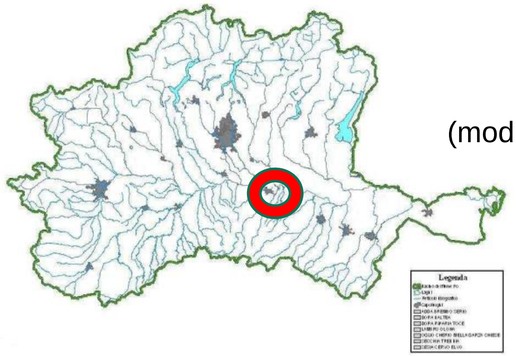
Po River

(from: Dal Cin, 1983)

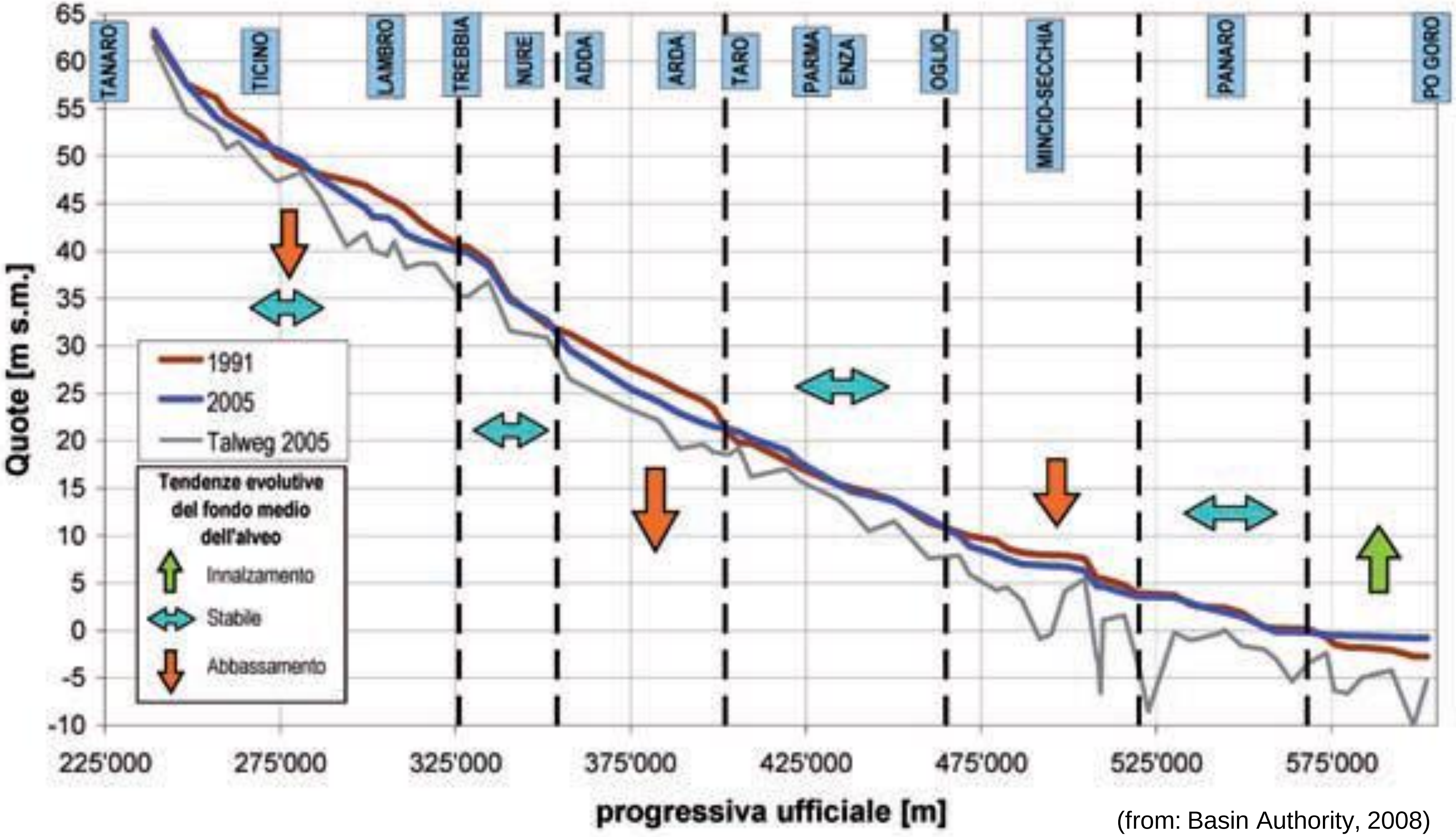
Quota del minima annual del fiume Po a Cremona (Isola Serafini)



(modified from Lamberti & Schippa, 1994)

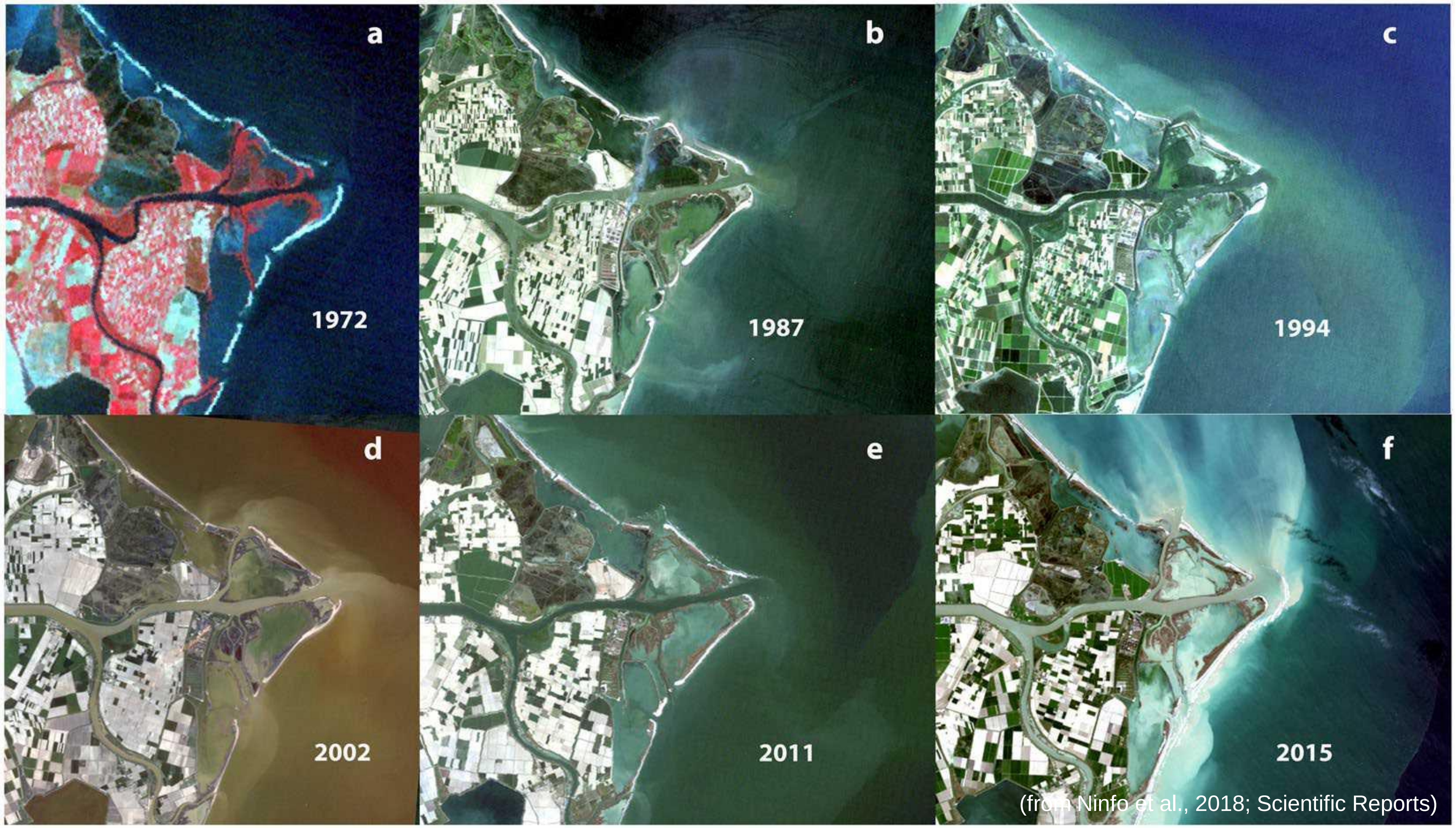


Variazioni quota letto del fiume Po tra 1991 e 2005



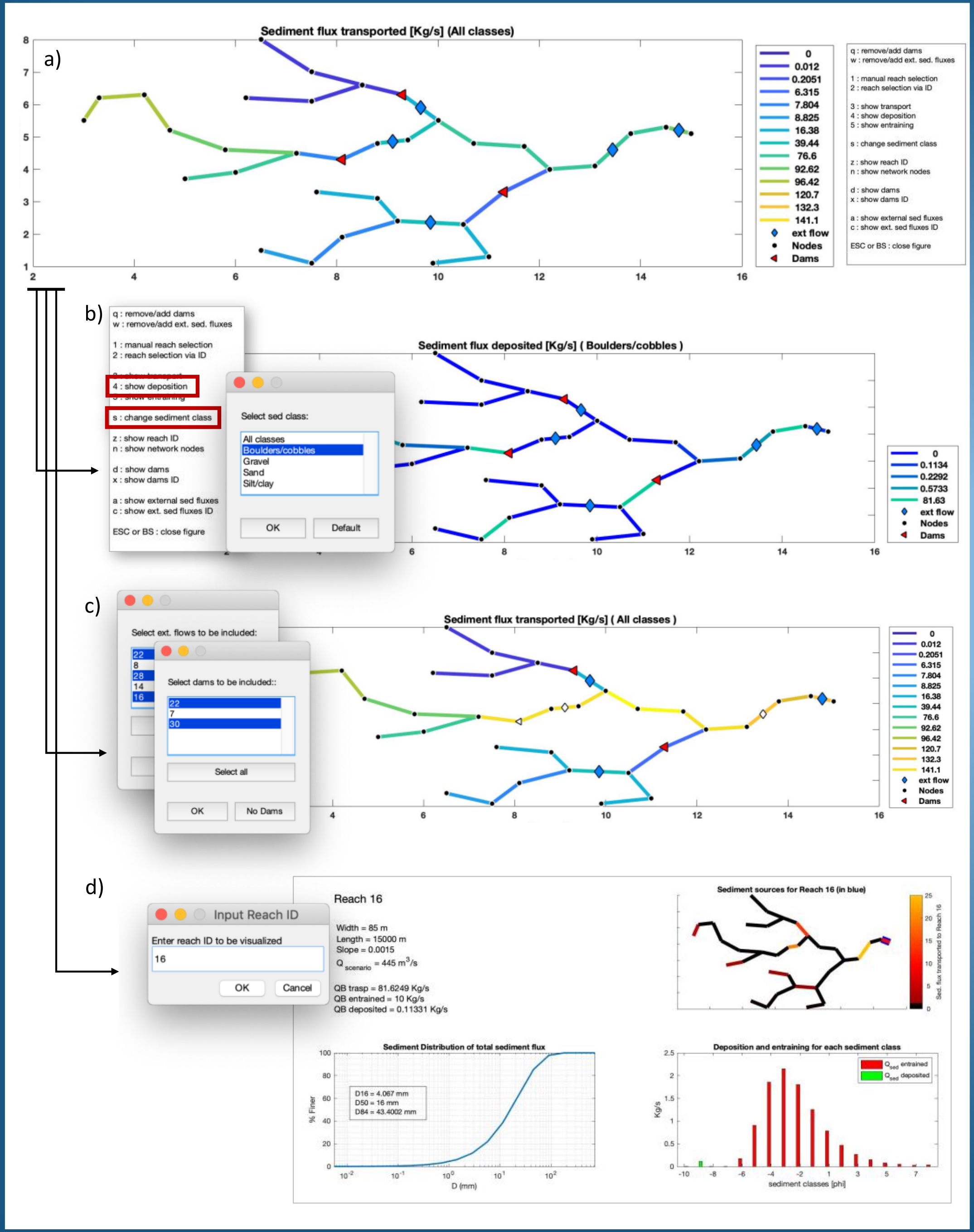
(from: Basin Authority, 2008)

Il Delta del PO


a
1972
b
1987
c
1994
d
2002
e
2011
f
2015

(from Ninfo et al., 2018; Scientific Reports)

CASCADE toolbox:
www.cascademodel.org


a)
Sediment flux transported [Kg/s] (All classes)
0
0.012
0.2051
6.315
7.804
8.825
16.38
39.44
76.6
92.62
96.42
120.7
132.3
141.1
ext flow
Nodes
Dams
b)
Sediment flux deposited [Kg/s] (Boulders/cobbles)
0
0.1134
0.2292
0.5733
81.63
ext flow
Nodes
Dams
c)
Sediment flux transported [Kg/s] (All classes)
d)
Sediment sources for Reach 16 (in blue)
Sed. flux transported to Reach 16
Sediment Distribution of total sediment flux
% Finer
D (mm)
Deposition and entraining for each sediment class
Kg/s
sediment classes [phi]
Q_{sed} entrained
Q_{sed} deposited

q : remove/add dams
w : remove/add ext. sed. fluxes

1 : manual reach selection
2 : reach selection via ID

3 : show transport
4 : show deposition
5 : show entraining

s : change sediment class

z : show reach ID
n : show network nodes

d : show dams
x : show dams ID

a : show external sed fluxes
c : show ext. sed fluxes ID

ESC or BS : close figure

Select sed class:

- All classes
- Boulders/cobbles
- Gravel
- Sand
- Silt/clay

OK | Default

Select ext. flows to be included:

- 22
- 8
- 28
- 14
- 16

Select dams to be included::

- 22
- 7
- 30

Select all

OK | No Dams

Input Reach ID

Enter reach ID to be visualized: 16

OK | Cancel

Reach 16

Width = 85 m
Length = 15000 m
Slope = 0.0015
$Q_{scenario}$ = 445 m^3/s

QB trasp = 81.6249 Kg/s
QB entrained = 10 Kg/s
QB deposited = 0.11331 Kg/s

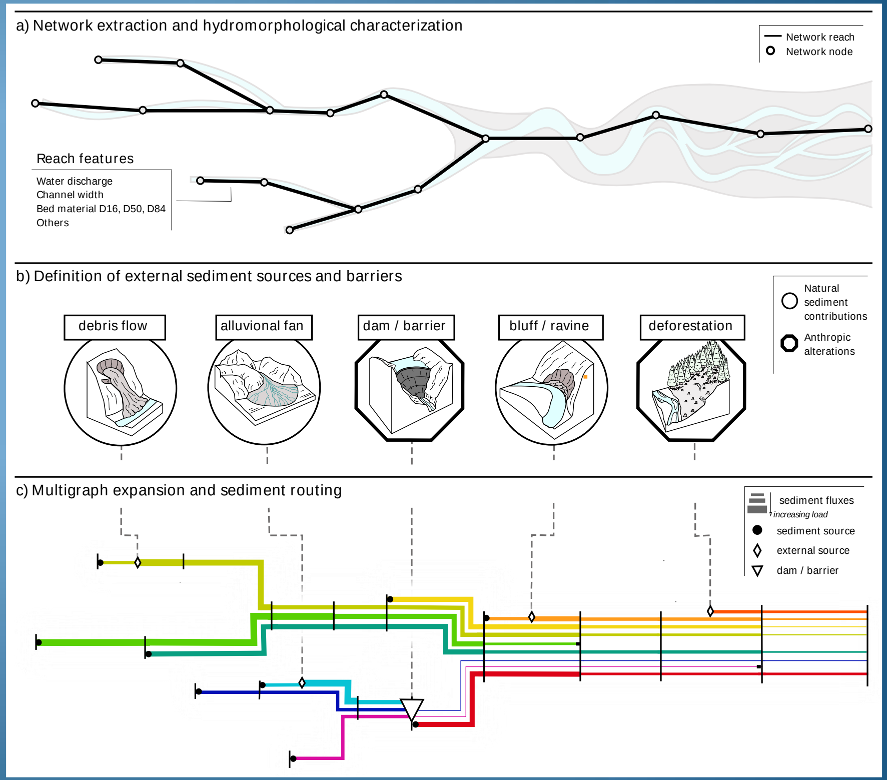
D16 = 4.067 mm
D50 = 16 mm
D84 = 43.4002 mm

Sediment Fluxes

Sediment Eroded/Deposited

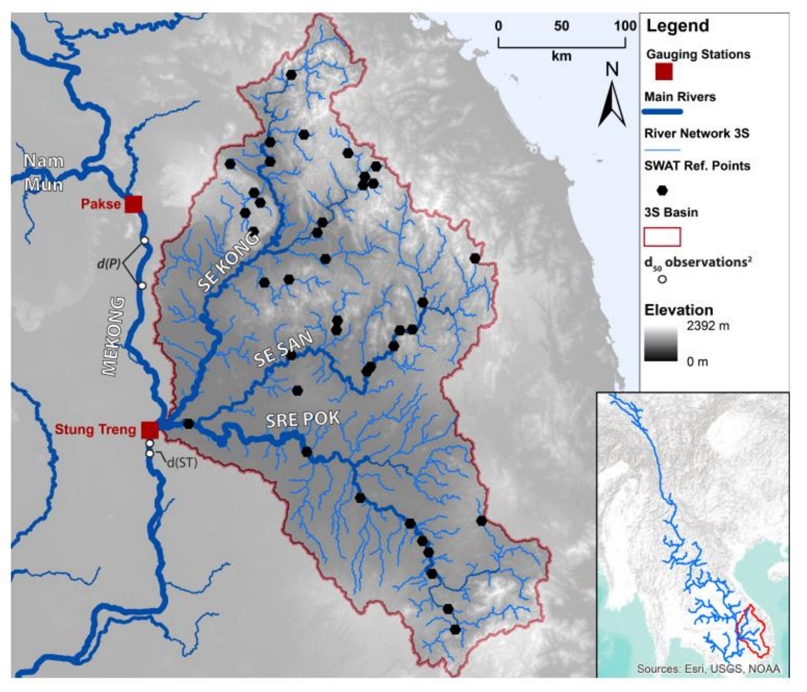
Sediment Fluxes for alternative management options

Sediment sizes and sources for a specific reach

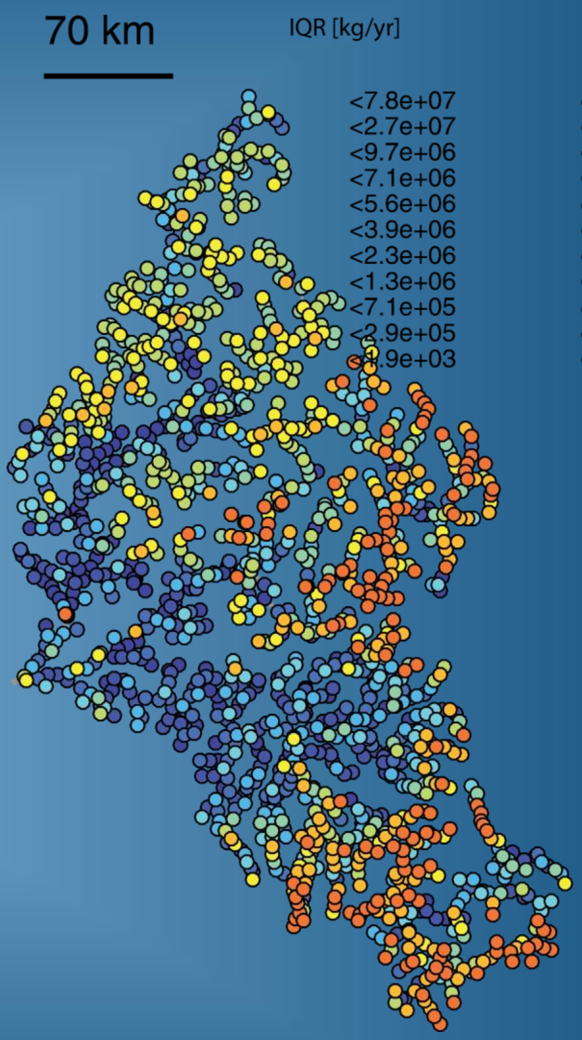

a) Network extraction and hydromorphological characterization
Network reach
Network node
Reach features
Water discharge
Channel width
Bed material D16, D50, D84
Others
b) Definition of external sediment sources and barriers
debris flow
alluvional fan
dam / barrier
bluff / ravine
deforestation
Natural sediment contributions
Anthropic alterations
c) Multigraph expansion and sediment routing
sediment fluxes
increasing load
sediment source
external source
dam / barrier

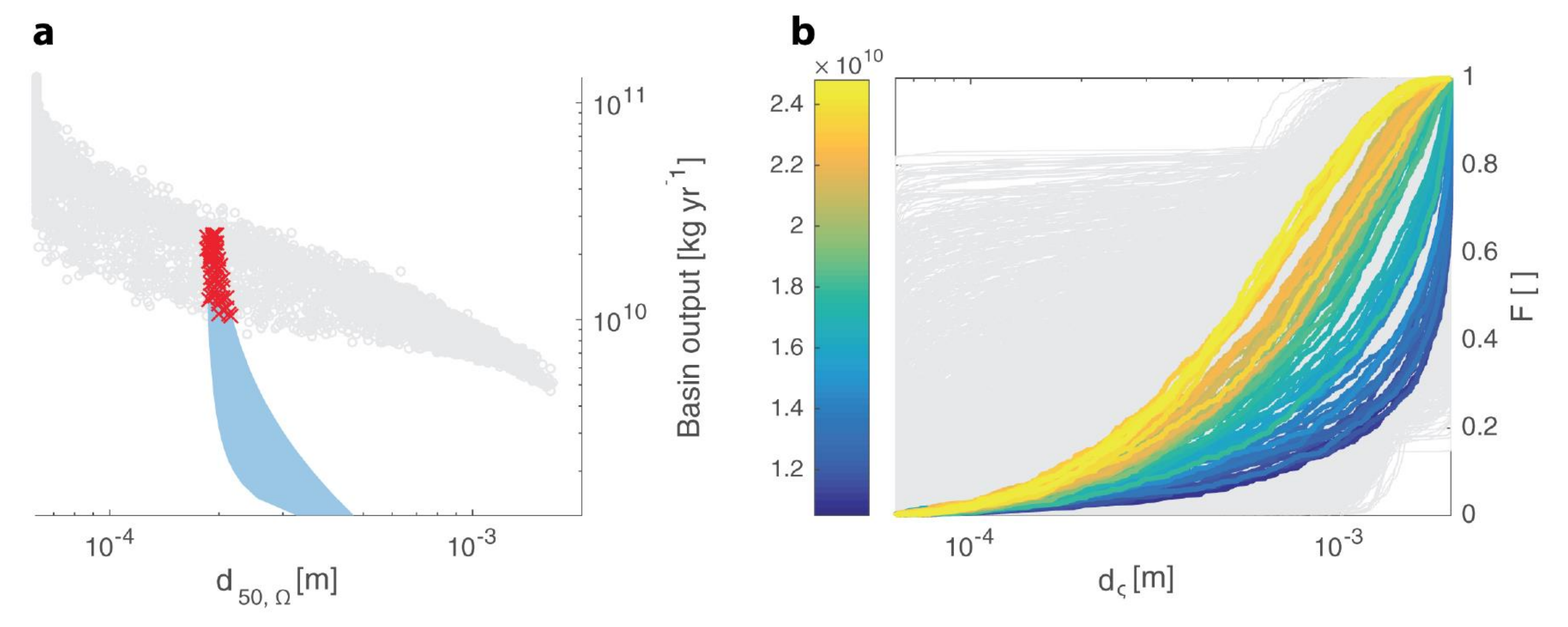
Tangi, M, Schmitt, R, Bizzi, S, Castelletti, A, (2019)
Environmental Modelling & Software, Vol. 119, p. 400-406,
https://doi.org/10.1016/j.envsoft.2019.07.008 [online]

Il caso studio del Mekong


0
50
100
km
N
Legend
Gauging Stations
Main Rivers
River Network 3S
SWAT Ref. Points
3S Basin
d_{50} observations²
Elevation
2392 m
0 m
Nam Mun
Pakse
d(P)
MEKONG
SE KONG
SE SAN
SRE POK
Stung Treng
d(ST)
Sources: Esri, USGS, NOAA

Stochastic Modeling of Sediment Connectivity for Reconstructing Sand Fluxes and Origins in the Unmonitored 3S Basin

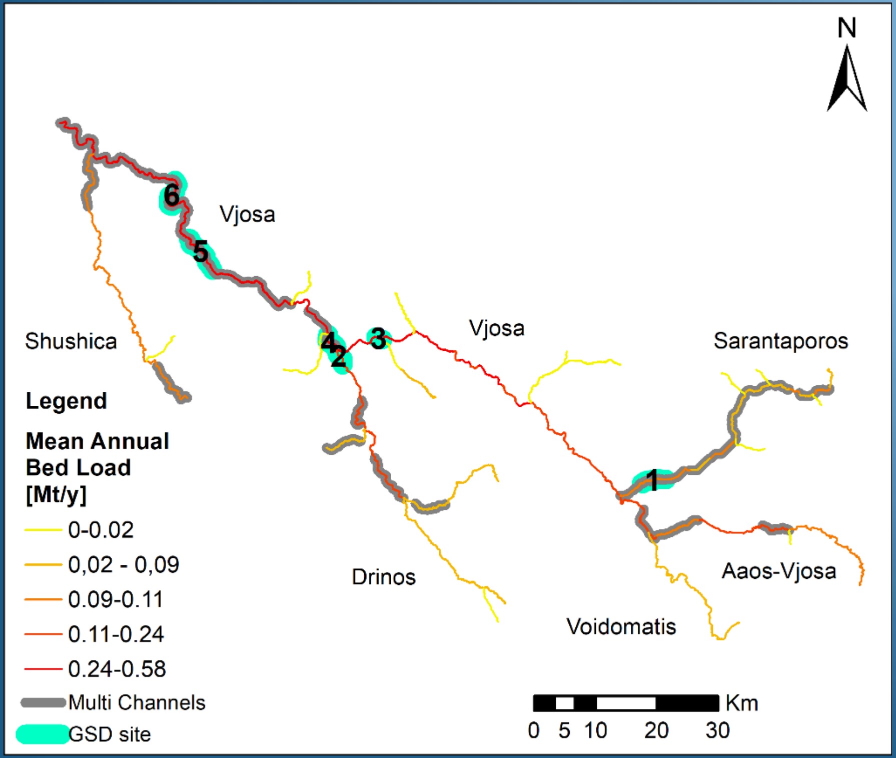

70 km
IQR [kg/yr]
<7.8e+07
<2.7e+07
<9.7e+06
<7.1e+06
<5.6e+06
<3.9e+06
<2.3e+06
<1.3e+06
<7.1e+05
<2.9e+05
<2.9e+03

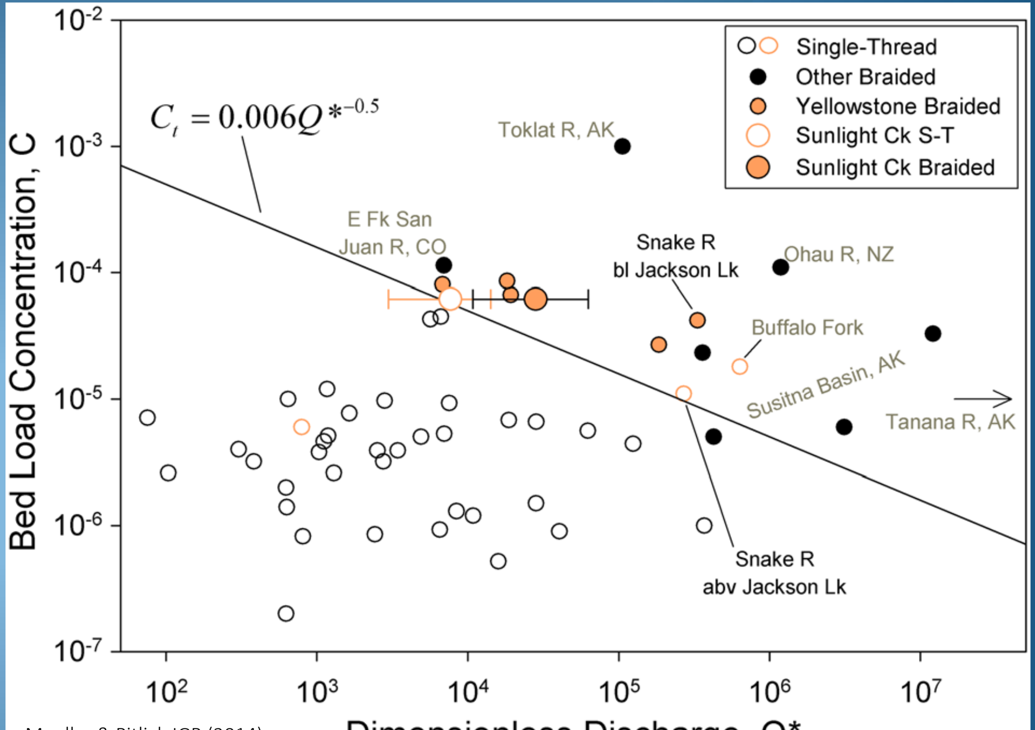


Schmitt, Bizzi et al., 2017, JGR, DOI 10.1002/2016JF004105

Il caso del Vjosa nei Balcani

From balkanrivers.net

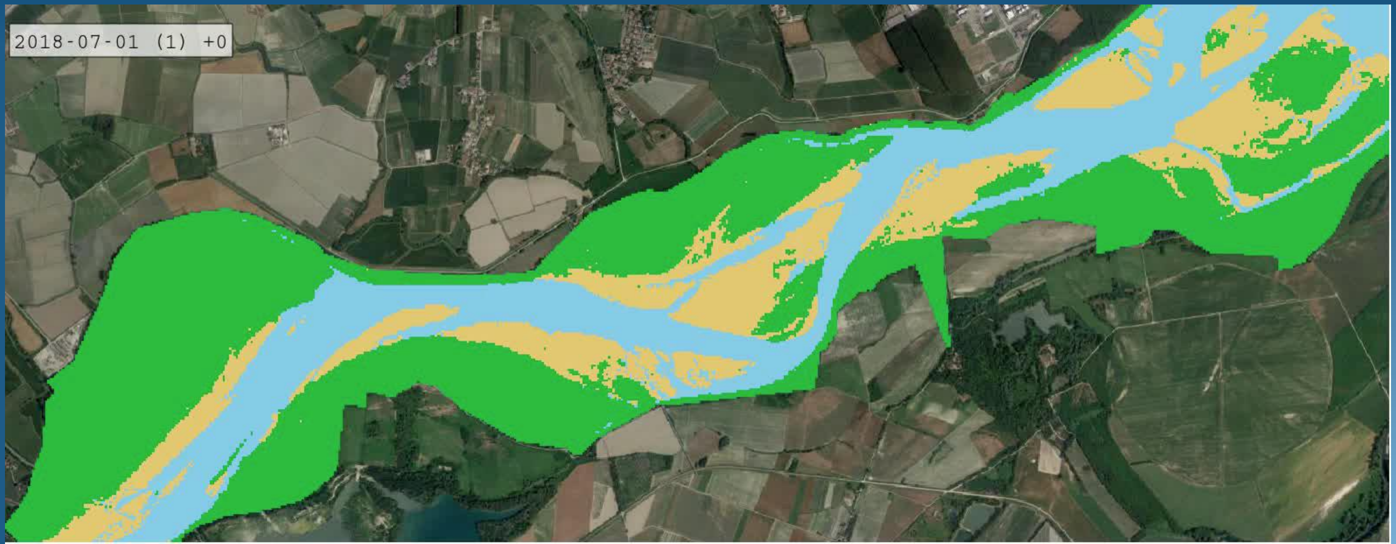

N
Vjosa
6
5
Shushica
4
2
3
Vjosa
Sarantaporos
1
Drinos
Aaos-Vjosa
Voidomatis
Legend
Mean Annual Bed Load [Mt/y]
0-0.02
0,02 - 0,09
0.09-0.11
0.11-0.24
0.24-0.58
Multi Channels
GSD site
Km
0 5 10 20 30



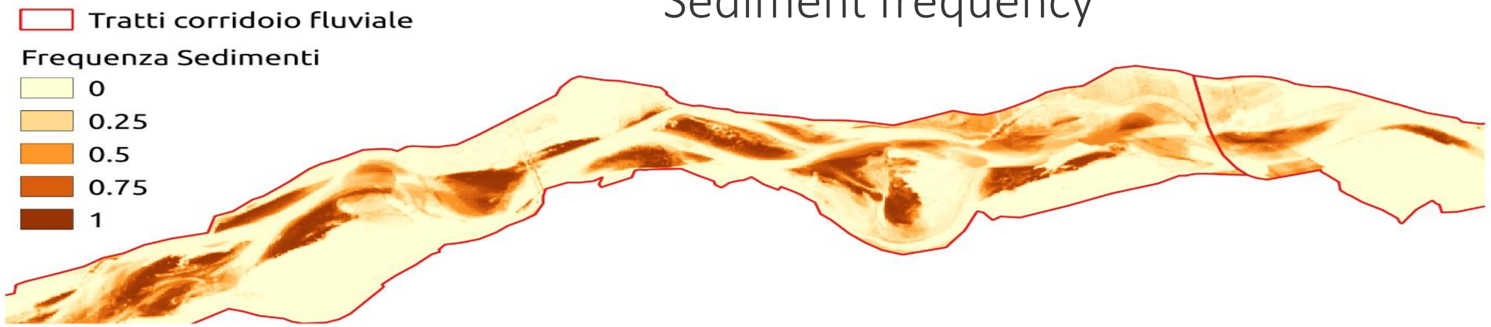
Mueller & Pitlick JGR (2014)

Uso dei Sentinel per il monitoraggi dei fiumi

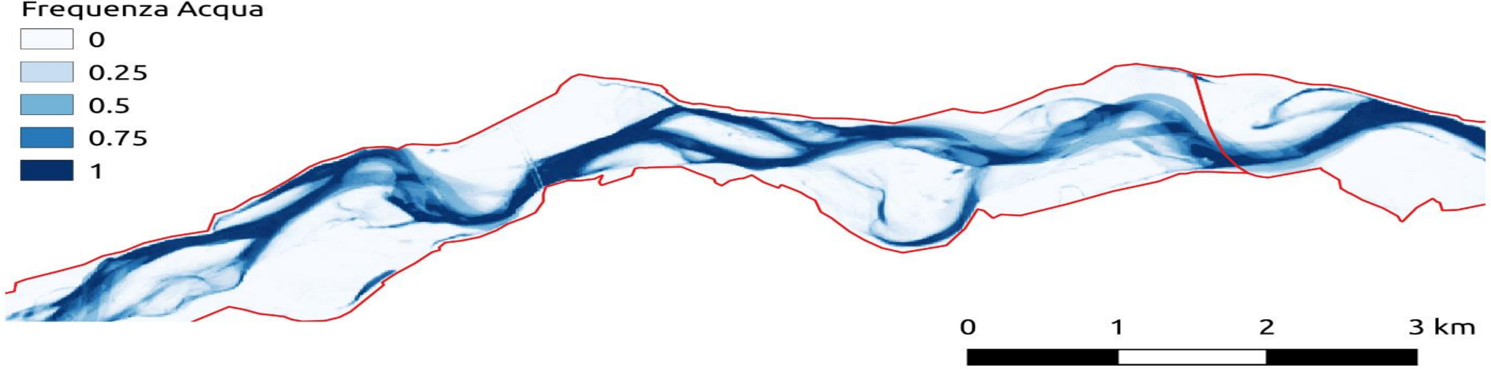
Abbiamo classificato le immagini dal Nov 2015 ad Oct 2019 e generato mappe di frequenza delle macro-unità morfologiche (Carbonneau et al. 2020 ESPL)


2018-07-01 (1) +0

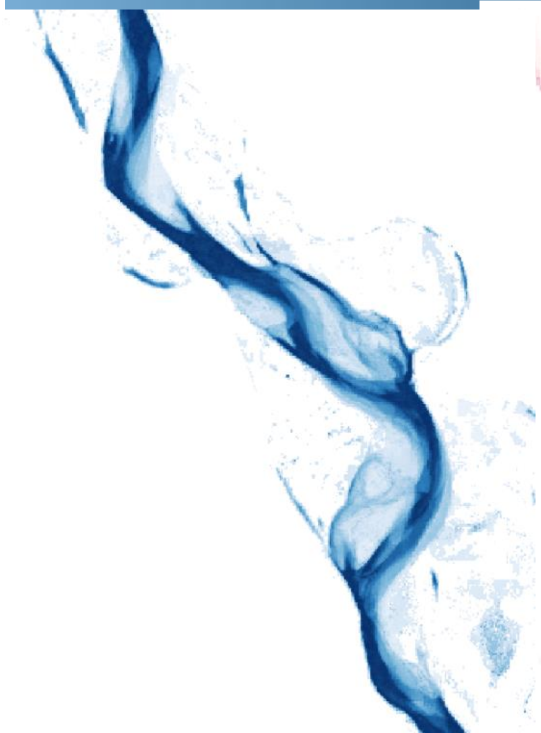
Sediment frequency


Tratti corridoio fluviale
Frequenza Sedimenti
0
0.25
0.5
0.75
1

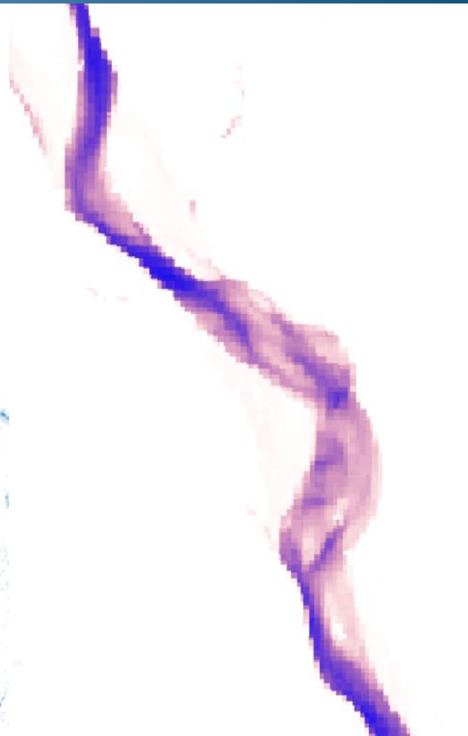
Water frequency


Frequenza Acqua
0
0.25
0.5
0.75
1
0
1
2
3 km

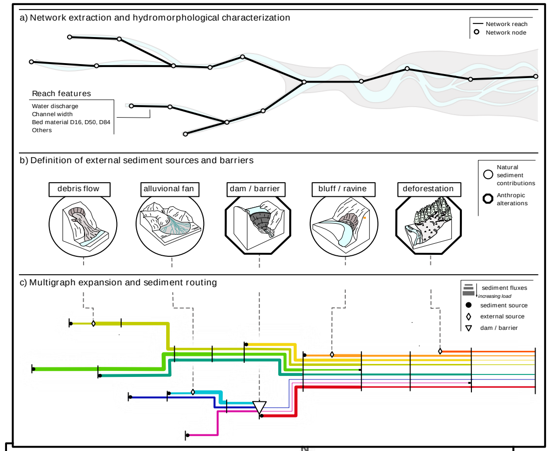
IRIS Project,
Four years , 10m Resolution

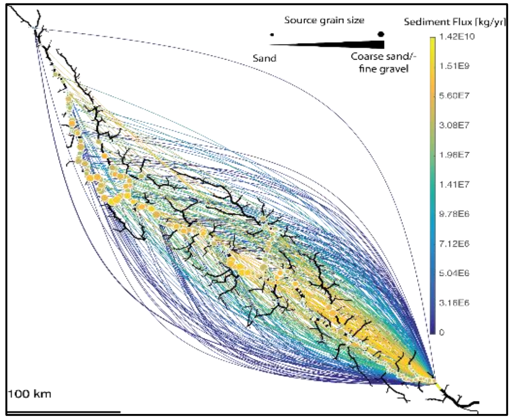


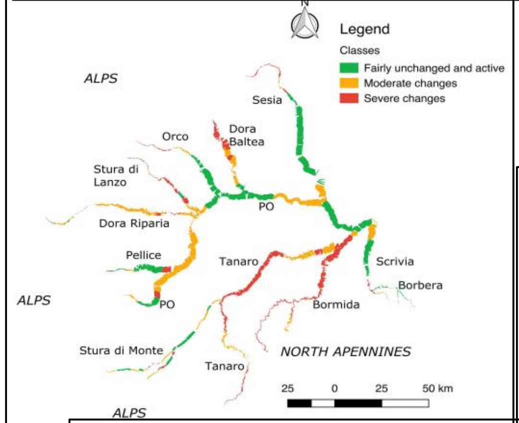
https://global-surface-water.appspot.com/
global surface water over the past 32 years at 30-metre resolution (Landsat)
Peker et al., Nature, 2016

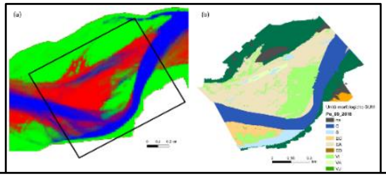


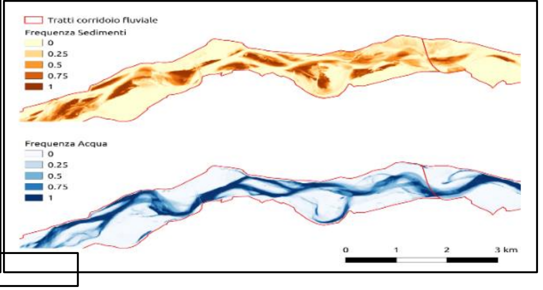
Il monitoraggio fluviale nei prossimi anni


a) Network extraction and hydromorphological characterization
Network reach
Network node
Reach features
Water discharge
Channel width
Bed material D16, D50, D84
Others
b) Definition of external sediment sources and barriers
debris flow
alluvional fan
dam / barrier
bluff / ravine
deforestation
Natural sediment contributions
Anthropic alterations
c) Multigraph expansion and sediment routing
sediment fluxes
increasing load
sediment source
external source
dam / barrier

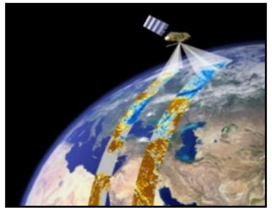

Source grain size
Sand
Coarse sand/-fine gravel
Sediment Flux [kg/yr]
1.42E10
1.51E9
5.60E7
3.08E7
1.98E7
1.41E7
9.78E6
7.12E6
5.04E6
3.18E6
0
100 km


Legend
Classes
Fairly unchanged and active
Moderate changes
Severe changes
ALPS
Sesia
Dora Baltea
Orco
Stura di Lanzo
PO
Dora Riparia
Pellice
Tanaro
Scrivia
Borbera
ALPS
PO
Bormida
Stura di Monte
Tanaro
NORTH APENNINES
25
0
25
50 km
ALPS




Tratti corridoio fluviale
Frequenza Sedimenti
0
0.25
0.5
0.75
1
Frequenza Acqua
0
0.25
0.5
0.75
1
0
1
2
3 km

Bizzi, Piegay et al. 2018 ESPL



Regional Modeling

Generation of new information/knowledge at regional/network scale

Data Acquisition

- Dati di campo di trasporto solido al fondo e in sospensione sono necessari per comprendere i processi fluviali e quindi per supportare una gestione consapevole ed efficiente.
- Esistono metodologie mergenti basate su DoD che possono supportare la stima del trasporto solido anche su fiumi medio grandi.
- I modelli a scala di reticolo/bacino possono essere validati anche con pochi e puntuali dati di trasporto solido generando le prime stime di trasporto solido e connettività dei sedimenti a scala di bacino. Una conoscenza imprescindibile per la gestione e predizione degli impatti cumulati.
- I dati Sentinel integrati con acquisizioni drone sono una soluzione efficace e poco costosa per un monitoraggio multi scala delle forme e dei processi morfologici per i fiumi medio grandi: sviluppare bacini pilota dove esplorare il legame funzionale tra forme e stime del trasporto solido nei prossimi anni è un’opportunità!