

RESTORATION OF FLUVIAL ECOSYSTEMS

Athens Course

Tools for Evaluating Fluvial Geomorphological Integrity. Aquatic Habitat Modelling in River Restorations.

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Introduction

- 1-. Geomorphology, Fluvial classifications and River Restoration.
- 2-. Evaluation of River Restoration Projects: An Adaptive Management Approach

Evaluation of River Restoration Projects.

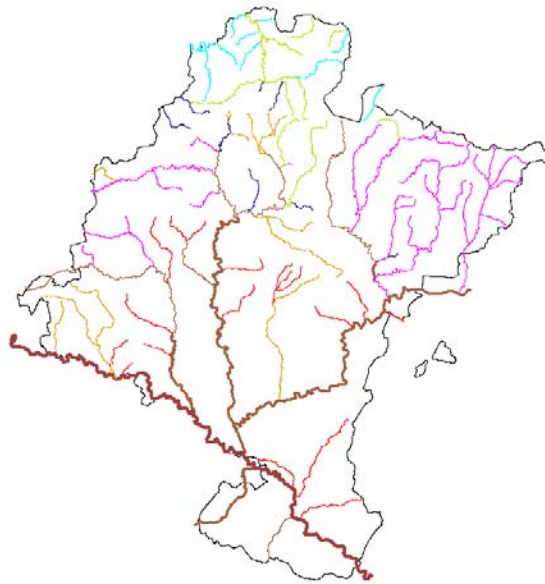
- 3-. Fluvial geomorphological integrity (IGF).
- 4-. Aquatic habitat modelling

Case study:

- 5-. River Jarama. Valdetorres Restoration Project.

Let me know any doubt or question that could arise.

1-. Geomorphology, Fluvial classifications and River Restoration.



- Tipificacion ETSIM
- Siliceo
 - Mixta
 - Calcareo
 - Arcilloso
 - Arcilloso calcareo cca pequena
 - Arcilloso calcareo cca mediana
 - Arcilloso calcareo cca grande
 - Arcilloso calcareo cca muy gra
 - Temporal
 - Ambito_estudio_navarra.shp
 - Contorno_navarra_ok.shp

0 60 Kilometers



APPROACHES TO RIVER TYPOLOGY

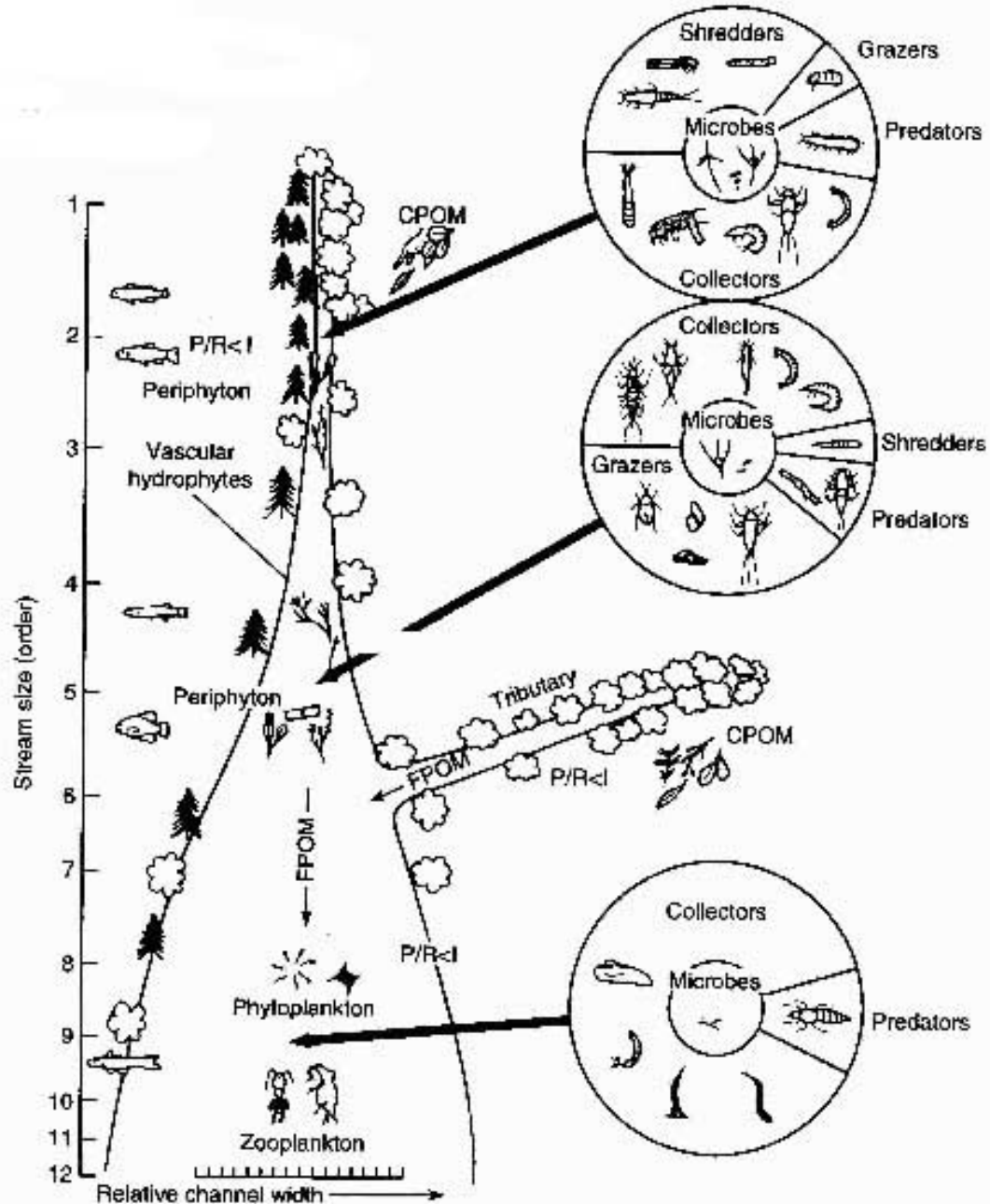
- Early classifications (morphological)
- Process-based classifications (slope-discharge relationship)
- Energy / Stream power-based classifications
- Hierarchical classifications

*“The appropriate philosophical **basis** for channel classification inherently depend on the **purpose** to which it is to be applied”*

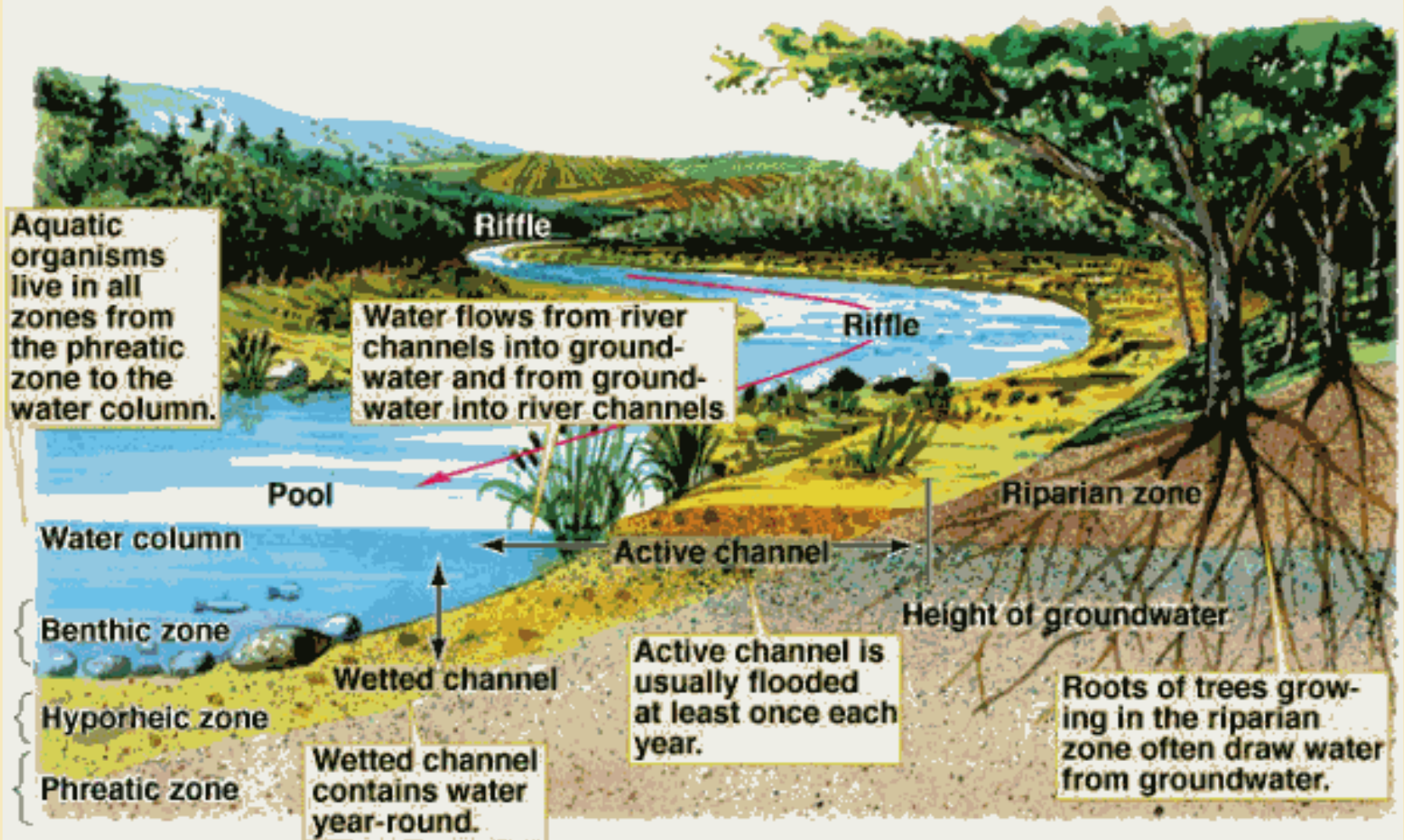
River Continuum

Vannote et al. 1980

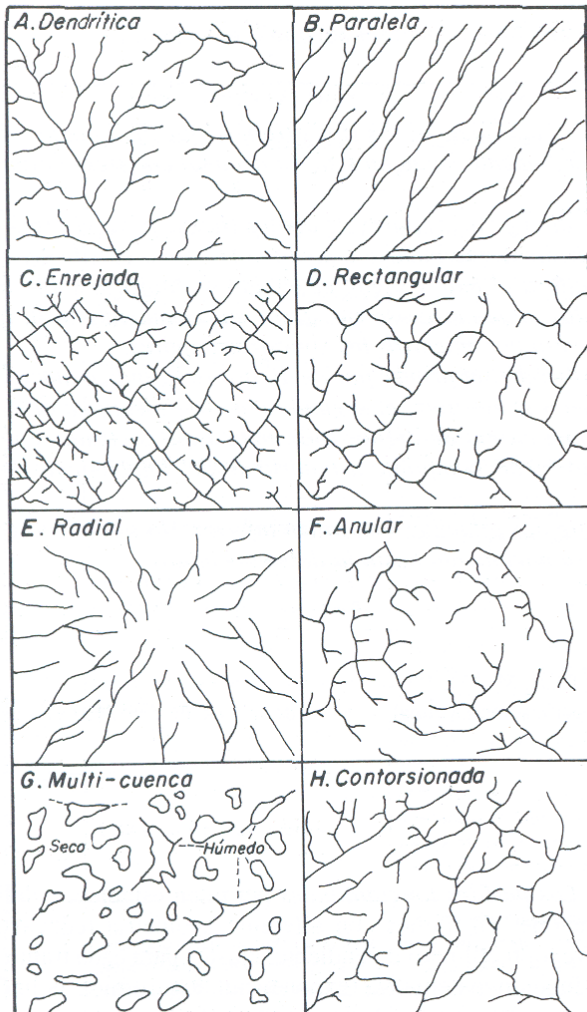
- Energy **flows and transforms** itself along the river gradient.
- Streams are best viewed as gradients or continua. Attempts to define **discrete classes** have little **ecological value** (Cushing et al., 1983)
- Boundaries between adjacent types can be abrupt or gradual



Stream Structure



Early Classifications



Adapted from De Pedraza et al. (1996) based on Zernitz (1932)

Process-based classifications

Based on Lane's relationship (1955):

$$QS \cdot D50 \propto Q \cdot S$$

Or Leopold and Wolman's (1957) quantitative relationship between slope and discharge (straight, meandering and braided)

Mode of transport	Channel sediment (M) Bedload (%)		Channel Stability		
	(%)	(%)	Stable	Depositing	Eroding
<i>Suspended load</i>	> 20	< 3	<i>Stable suspended-load channel</i>	<i>Depositing suspended-load channel</i>	<i>Eroding suspended-load channel</i>
<i>Mixed load</i>	5 to 20	3 to 11	<i>Stable mixed-load channel</i>	<i>Depositing mixed-load channel</i>	<i>Eroding mixed-load channel</i>
<i>Bed load</i>	< 5	> 11	<i>Stable bed-load channel</i>	<i>Depositing bed-load channel</i>	<i>Eroding bed-load channel</i>

Schumm, (1963, 1977)

Stream power-based classifications

Based on stream power

$$SP = \Phi \cdot s \cdot Q \cdot g / A \text{ (watt/m)}$$

Φ : specific weight (1000 kg/m³), s (slope per unit length), Q (flow), g (gravity), A (channel width)



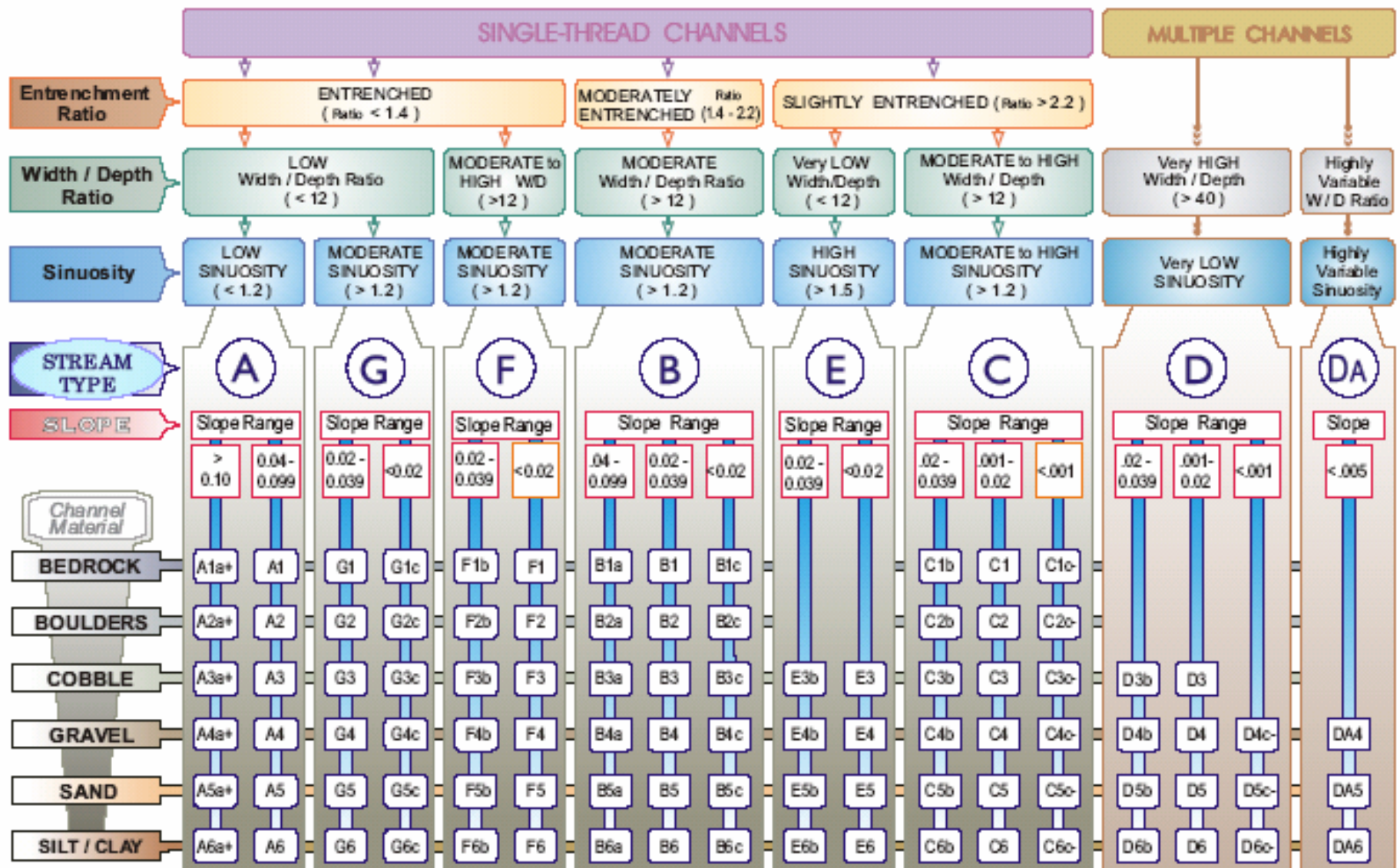
Geomorphological classifications (a priori)

STREAM TYPE	A	D	B & G	F	C	E
PLAN VIEW						
CROSS SECTION VIEW						
AVERAGE VALUES	1.5	1.1	3.7	5.3	11.4	24.2
RANGE	1 - 3	1 - 2	2 - 8	2 - 10	4 - 20	20 - 40

Sinuosity

Rosgen's types (1994): combination of hydraulic geometry concepts and field experience, with the aim to **predict river's behavior from its appearance**

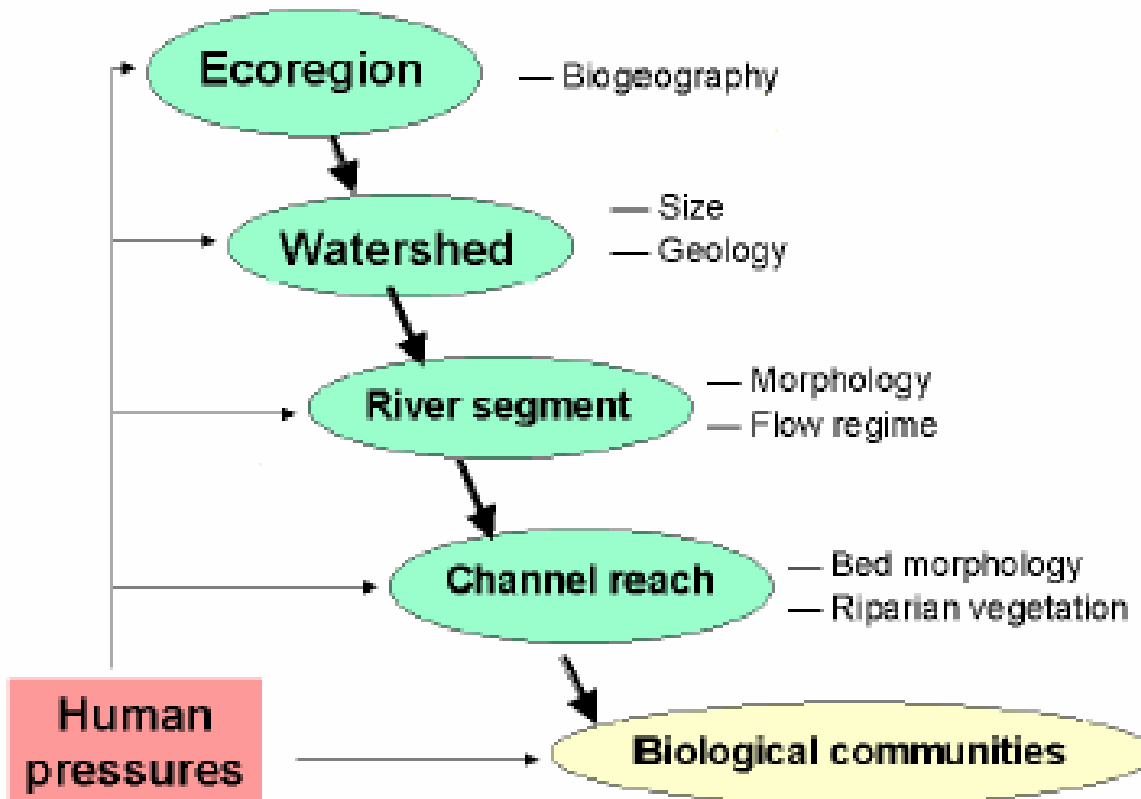
The Key to the Rosgen Classification of Natural Rivers



KEY to the ROSGEN CLASSIFICATION of NATURAL RIVERS.

As a function of the "continuum of physical variables" within stream reaches, values of *Entrenchment* and *Sinuosity* ratios can vary by +/- 0.2 units; while values for *Width / Depth* ratios can vary by +/- 2.0 units.

Hierarchical classifications

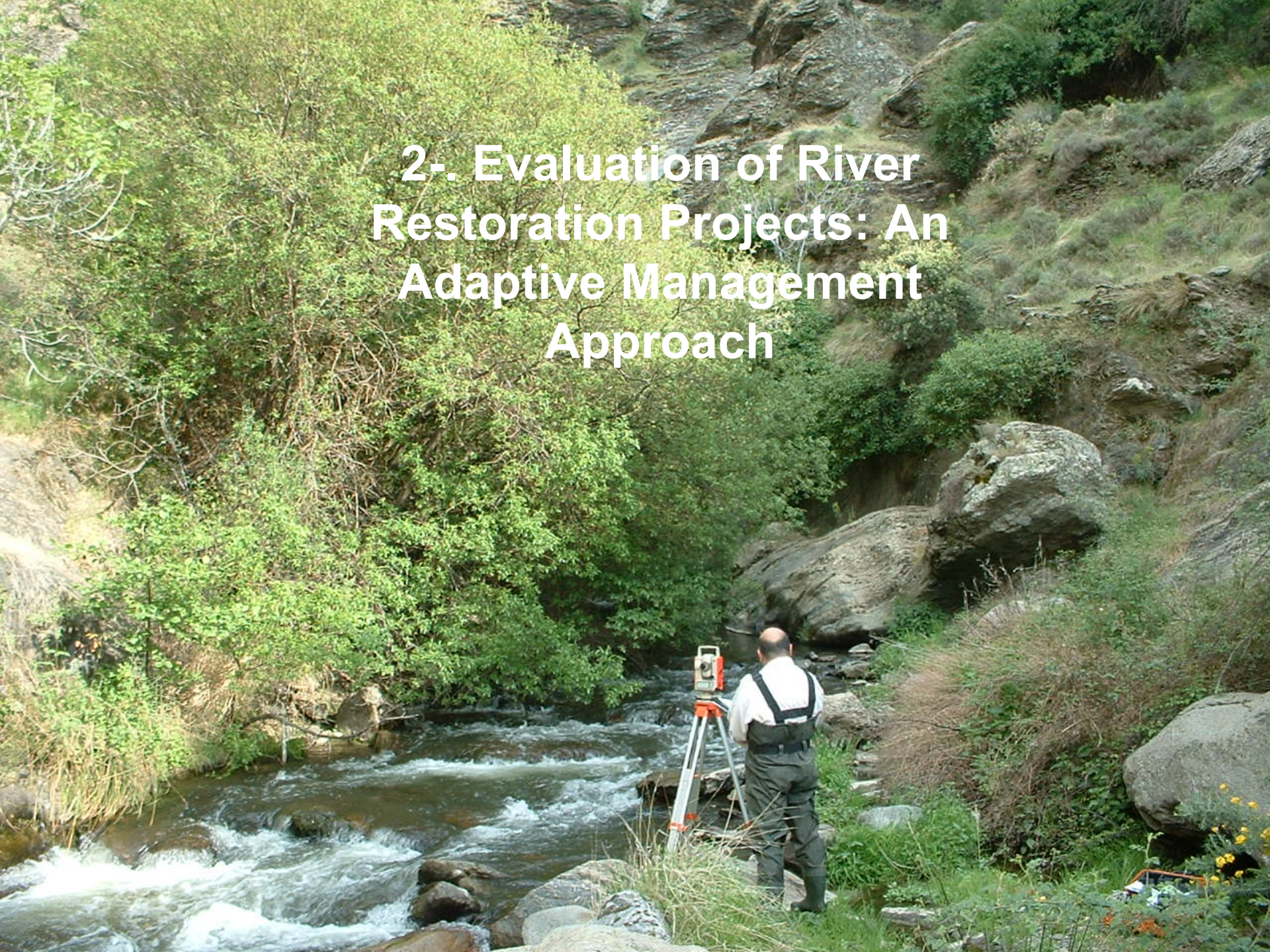


Multiple-scale river classification systems following a hierarchical scheme from ecoregion, watershed, river segment to reach. (González del Tánago & García de Jalón, 2005)

Classification and Restoration

- Channel classifications are **evolving** from a priori classifications to large geomorphological databases which can be used flexibly integrating GIS software.
- There is a **high degree of uncertainty** implicit in the prediction of a stream response to a given perturbation from existing formulae.
- Streams are **continua ruled by hierarchical forces**.
- When using a classification system is important to **avoid over-emphasizing the categories**.
- Universal classification schemes have only limited usefulness and **cannot replace understanding the fluvial system**.
- **Pragmatic applications of channel classification** can provide useful tools for understanding smaller geographic units within regional frameworks and broader hierarchical levels.

2-. Evaluation of River Restoration Projects: An Adaptive Management Approach



ADAPTIVE MANAGEMENT

- Each restoration project can be considered as an **EXPERIMENT** due to the **complexity of hydro systems** which implies high **UNCERTAINTY**.
- Each restoration project is an **OPPORTUNITY** to enlighten future actions.
- We need: 1) Effective Project Evaluations + 2) Adaptive Management Schemes.
- **Post-project appraisals (PPAs)** are evaluations of the effectiveness of river restoration projects based on **systematic data collection** (Downs and Kondolf, 2002)
- **Adaptive management** is the process whereby management is initiated, evaluated and refined (Hooling, 1978; Walters, 1986). Adaptive Management is typical incremental and uses information from monitoring to **continually evaluate and modify management practices** (Kreshner, 1997)

Geomorphologic approach

PPAs should cover **all aspects of project performance** such as geomorphological, biological and social (Kondolf and Micheli, 1995) However, as geomorphology provides the framework for other elements (biological and social), a **geomorphological approach is widely used in evaluation** (Downs, 2001), based on the following facts:

- Interactions between the stream channel, floodplain and stream flows provide the **framework supporting** aquatic and riparian structures and functions.
- Geomorphologic factors are primary **determinants of the spatial and successional patterns** of biological communities (Gregory et al. 1991, Statzner et al. 1988).
- The measurement of geomorphic channel characteristics may provide a **cost-effective indicator** of overall watershed condition.

Design of monitoring schemes

Monitoring is the measure of success of a restoration project.
Well designed monitoring should indicate (Kreshner, 1997):

- 1) Whether the restoration measures were designed and implemented properly (*Implementation monitoring*)
- 2) If the restoration met the objectives (*Effectiveness monitoring*)
- 3) New insights into ecosystem structure and function (*Validation monitoring*).

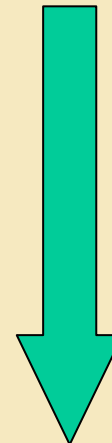
MONITORING TIME SCALE:

One-shot (single survey)

Short-term (less than 5 years)

Medium-term (5-10 years)

Long term (more than 10 years)



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OPPORTUNITY
OF LEARNING

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Indexes of fluvial habitat

A lot of indexes have been developed based on the **capacity of physical habitat to host certain fauna** (Pardo *et al.*, 2002), among them:

- **“Rapid Bioassessment Protocols”** (Barbour *et al.*, 1999) EPA
- **River Habitat Survey (RHS)** UK (Raven *et al.*, 1998).
- Based on previously cited works **IHF (Indice de Hábitat Fluvial para ríos mediterráneos)** (Pardo *et al.*, 2002) was developed for mediterranean streams.

Some of them are biased to specific habitats (i.e. mountain, high gradient, oxygenated, gravel or cobble bed reaches, and underscore other natural environments as low gradient, depositional, sandy reaches)

Evaluation of River Restoration Projects.

3-. Fluvial geomorphological integrity (IGF).



IGF evaluation approach

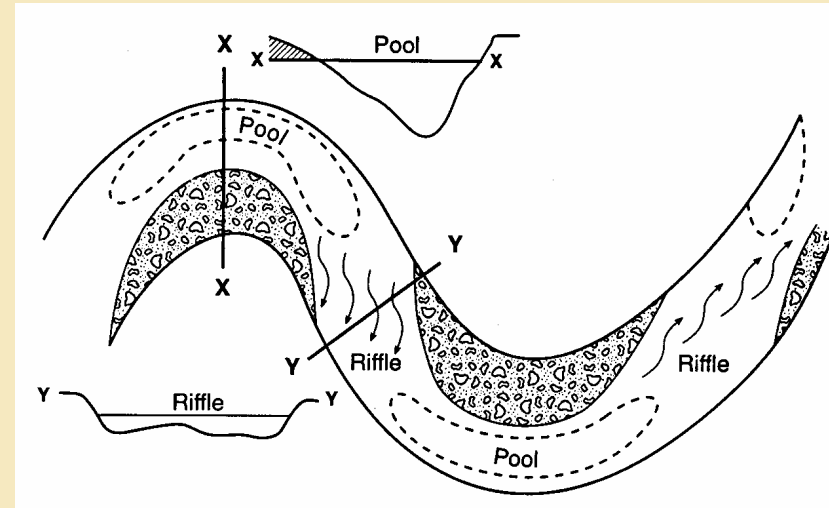
- It is NOT conceived as a fluvial habitat index.
- It is an APPROACH, a METHODOLOGY to **evaluate geomorphological condition and impacts on fluvial systems**, adaptable to different fluvial ecotypes.
- GOOD geomorphological condition DOES NOT imply necessarily habitat stability.
- GOOD geomorphological condition IS NOT a paralyzed photo of an ideal system, IT IMPLIES DYNAMIC.

Natural aquatic communities are adapted to environmental conditions than can be shifting.

Natural morphology

– **Long term stable morphology** does not mean and undeformable channel designed for a given discharge (traditional hydraulics).

– **Long term stable morphology** refers to a **hydraulic geometry adaptable to natural flow regime**, concentrating ordinary flows within the bankfull section and dissipating energy in extraordinary events through floodplain.



Basis for IGF evaluation (I)

SUBJECTS

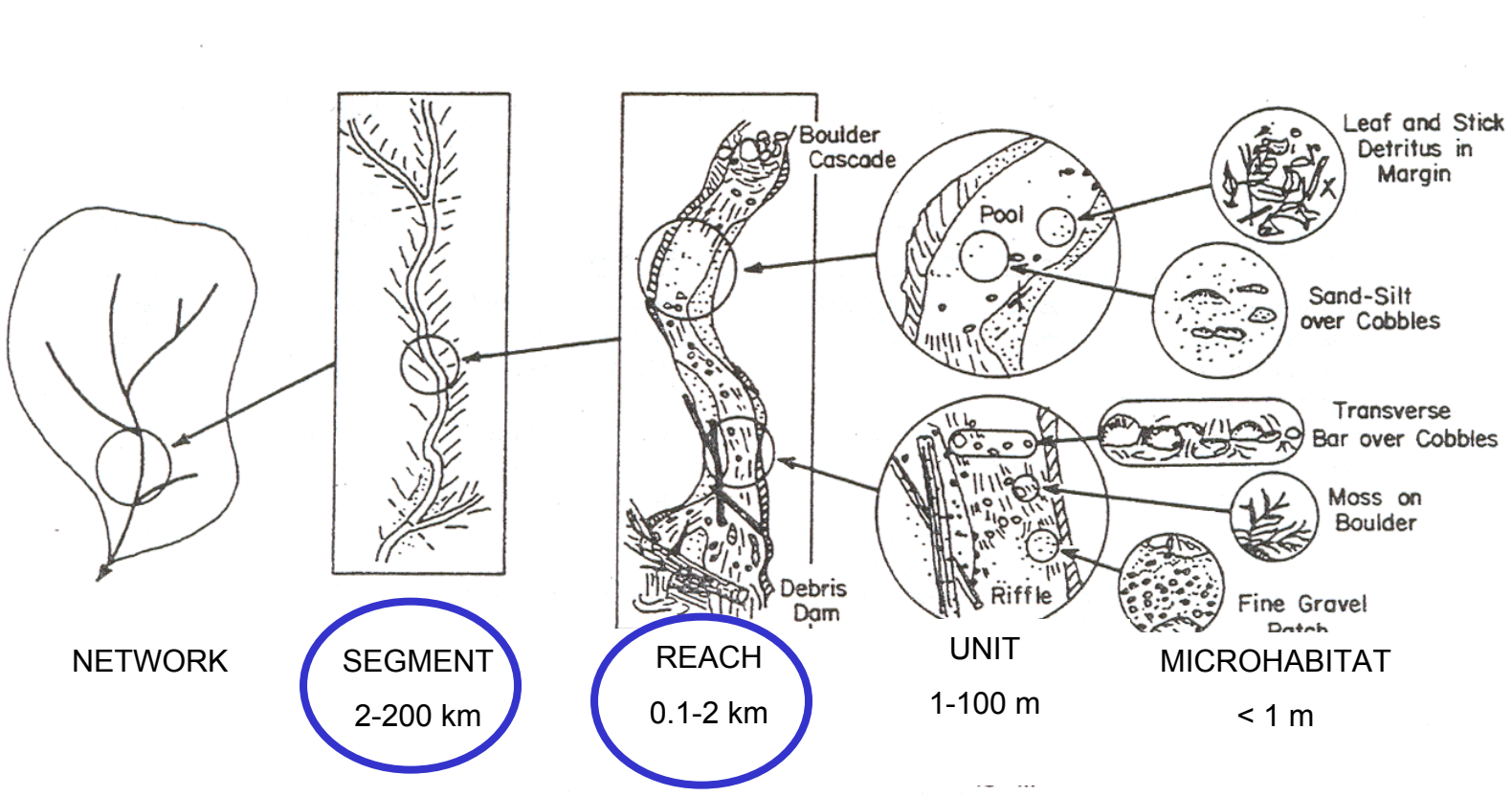
- Fluvial morphology (river channel & floodplain analysis)
- Fluvial dynamics (river processes analysis)

ELEMENTS

- Active forces: flows (liquids y solids)
- Passive elements: sediments, channel, valley, slope and vegetation (González del Tánago y García de Jalón, 1995).

Scale of evaluation

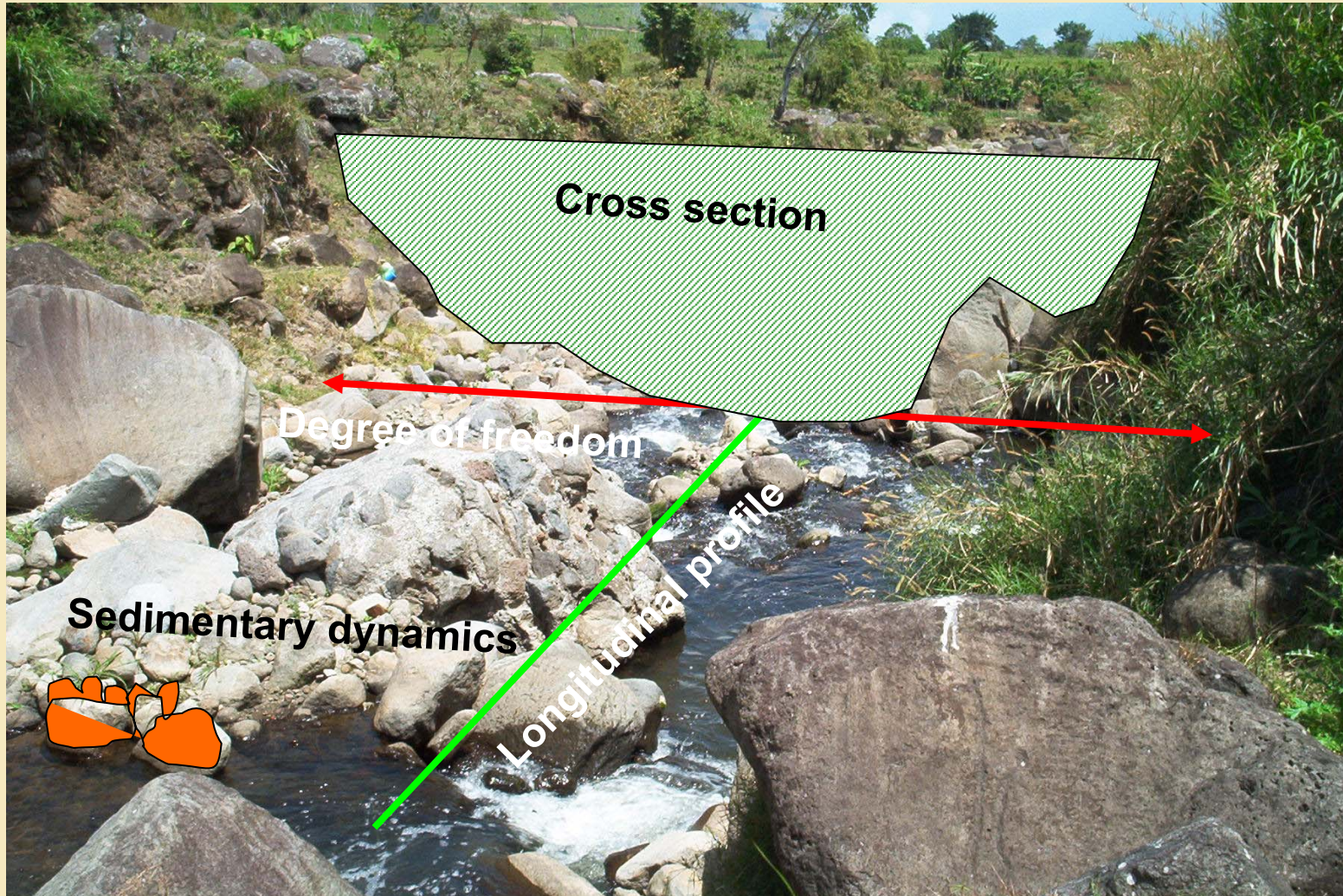
HIERARCHICAL



HIERARCHICAL EVALUATION

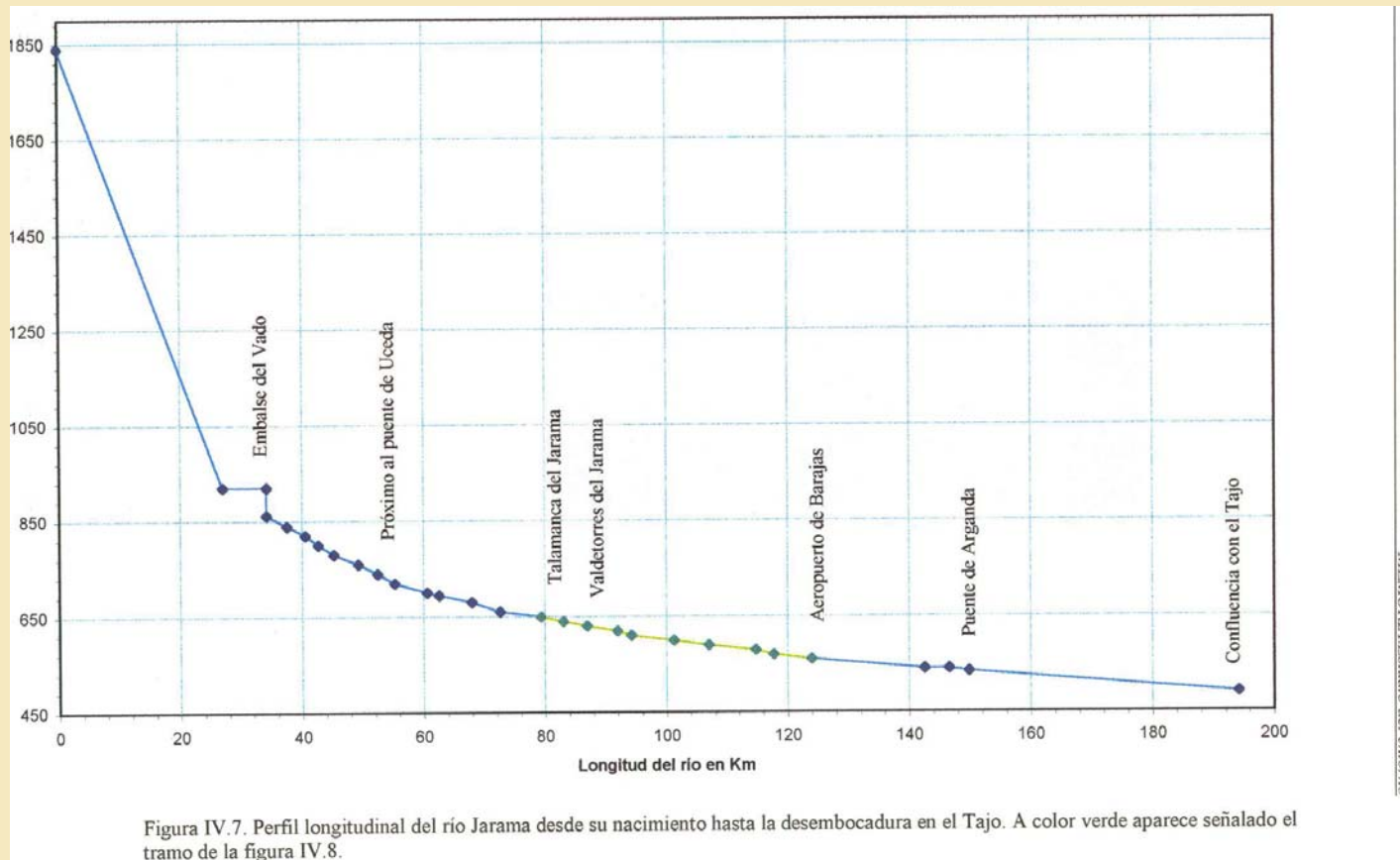
after Frissell et al., 1986

Axis of evaluation



Metrics (1)

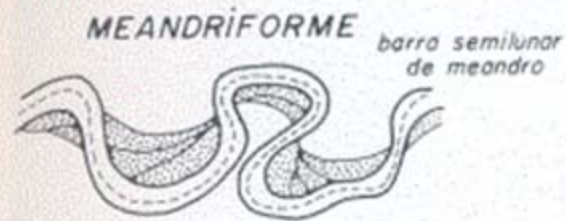
- Vertical profile:
- Δ baselevel
- Δ Hydraulic power



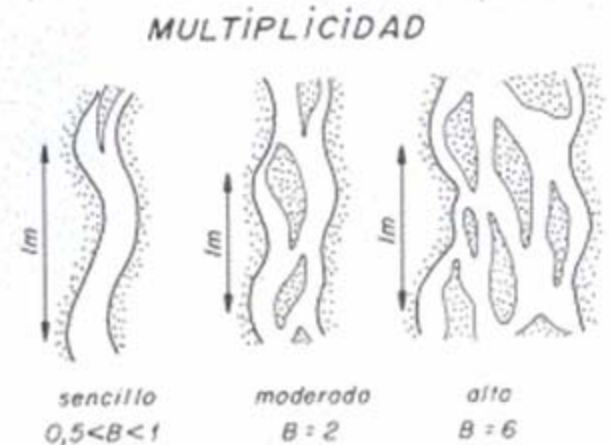
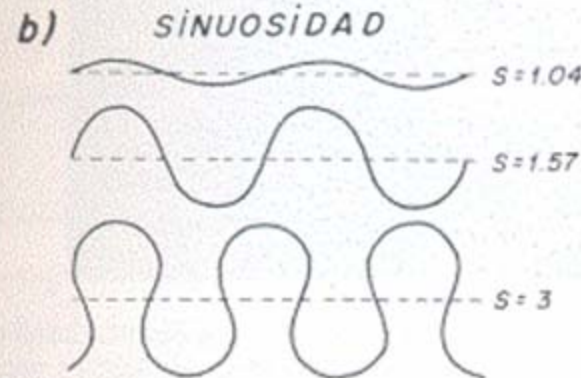
Metrics (2)

Planform:

- Δ sinuosity
- Δ multiplicity
- Δ available space



BRAIDED Y/O ANASTOMOSADOS



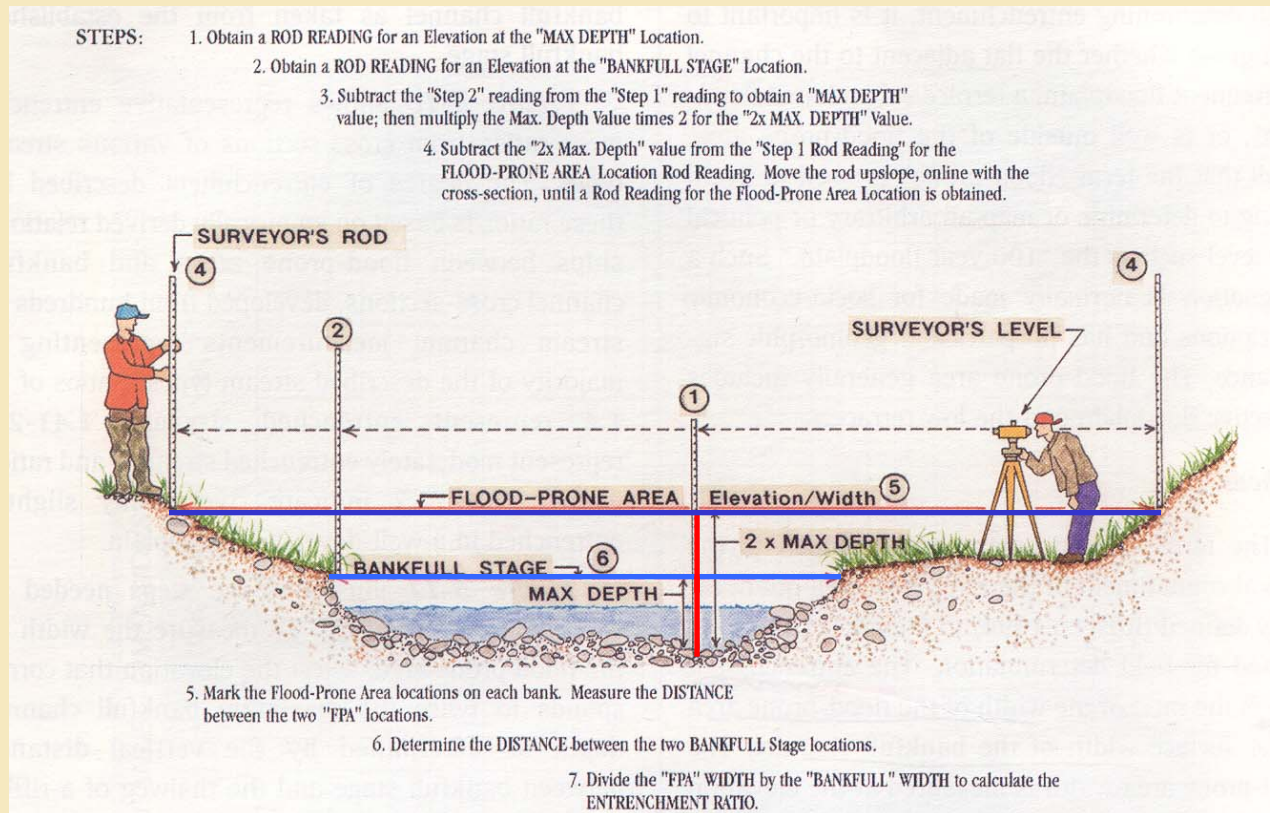
Rust (1978)

De Pedraza et al. (1996)

Metrics (3)

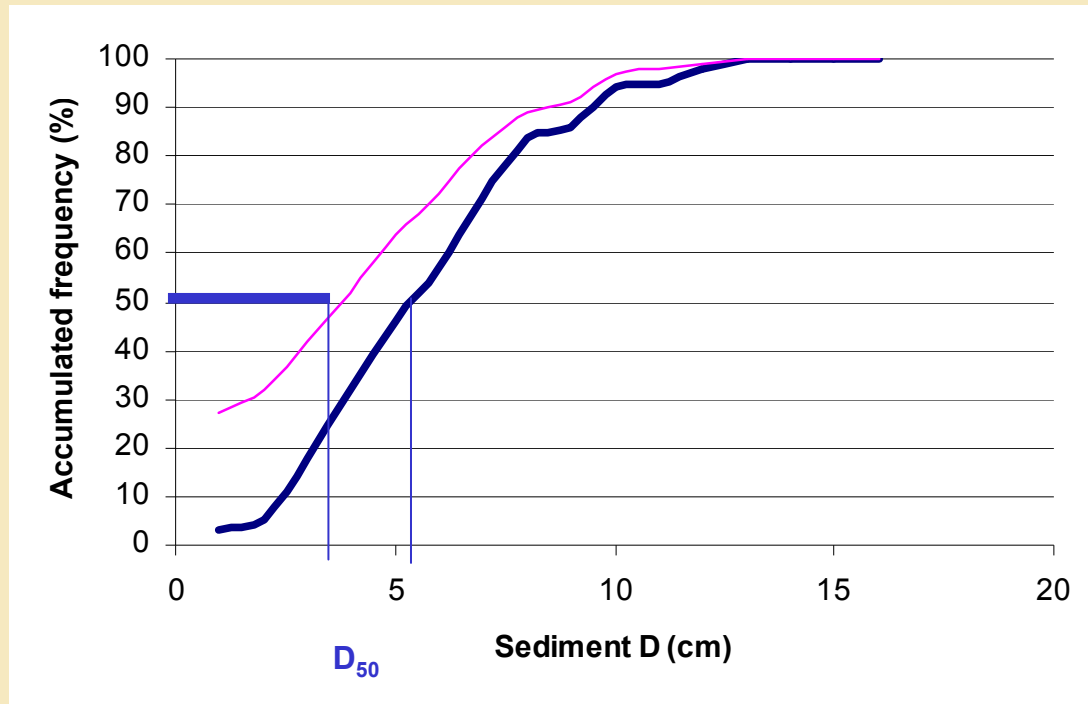
- Cross-section:

- Δ width
- Δ depth
- Δ entrenchment (floodprone width/ bankfull width)
- Δ width/depth ratio



Metrics (4)

- Sed. dynamics:
 - ΔD_{50}
 - Δ depositional bars



Select metrics depending on:

- Scale
- Objectives
- River type (geologic control vs. fluvial control)

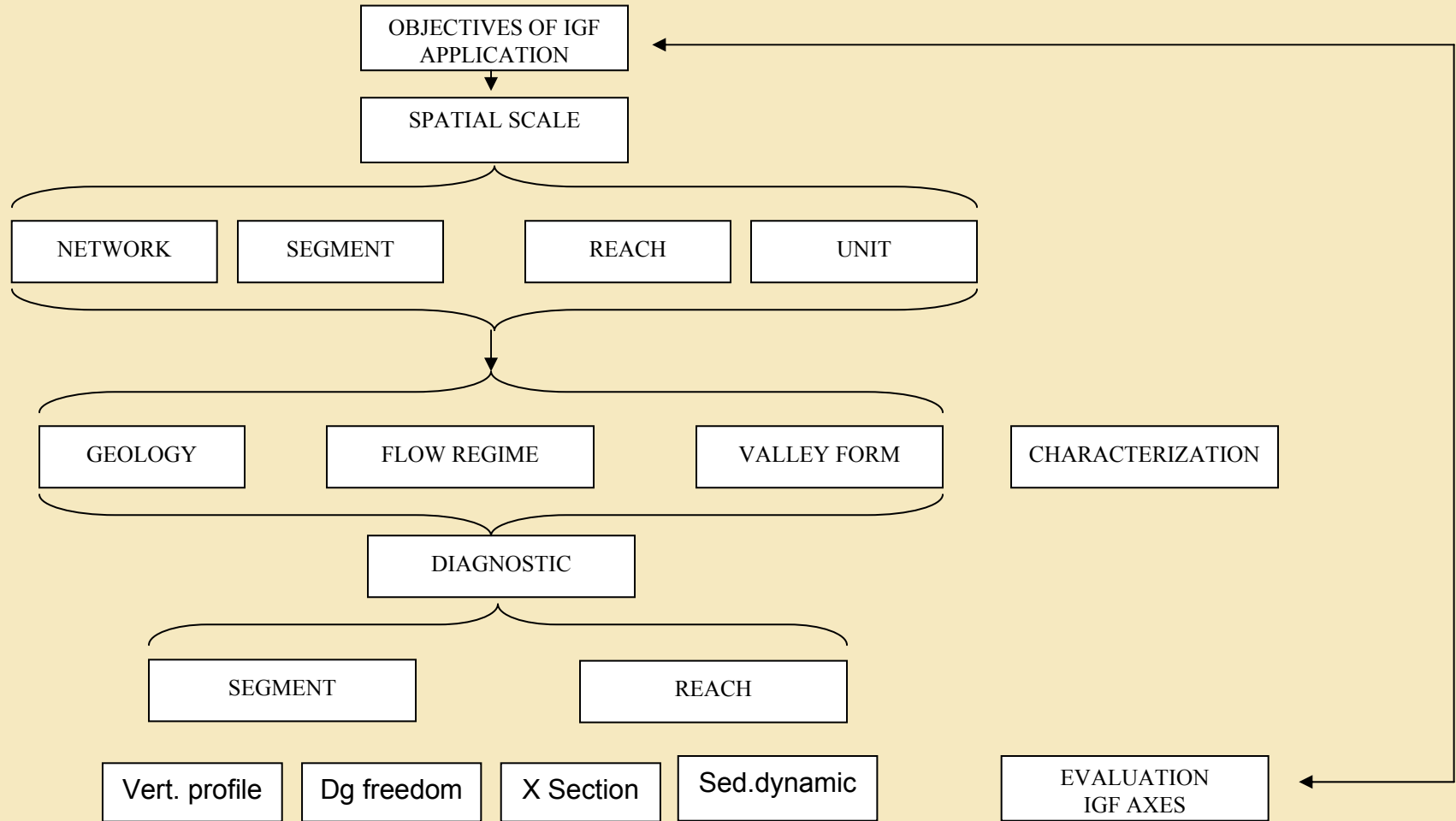
Evaluation sheets (2):

- Segment scale
- Reach scale

IGF condition (4):

- Optimum
- Sub-optimum
- Marginal
- Poor

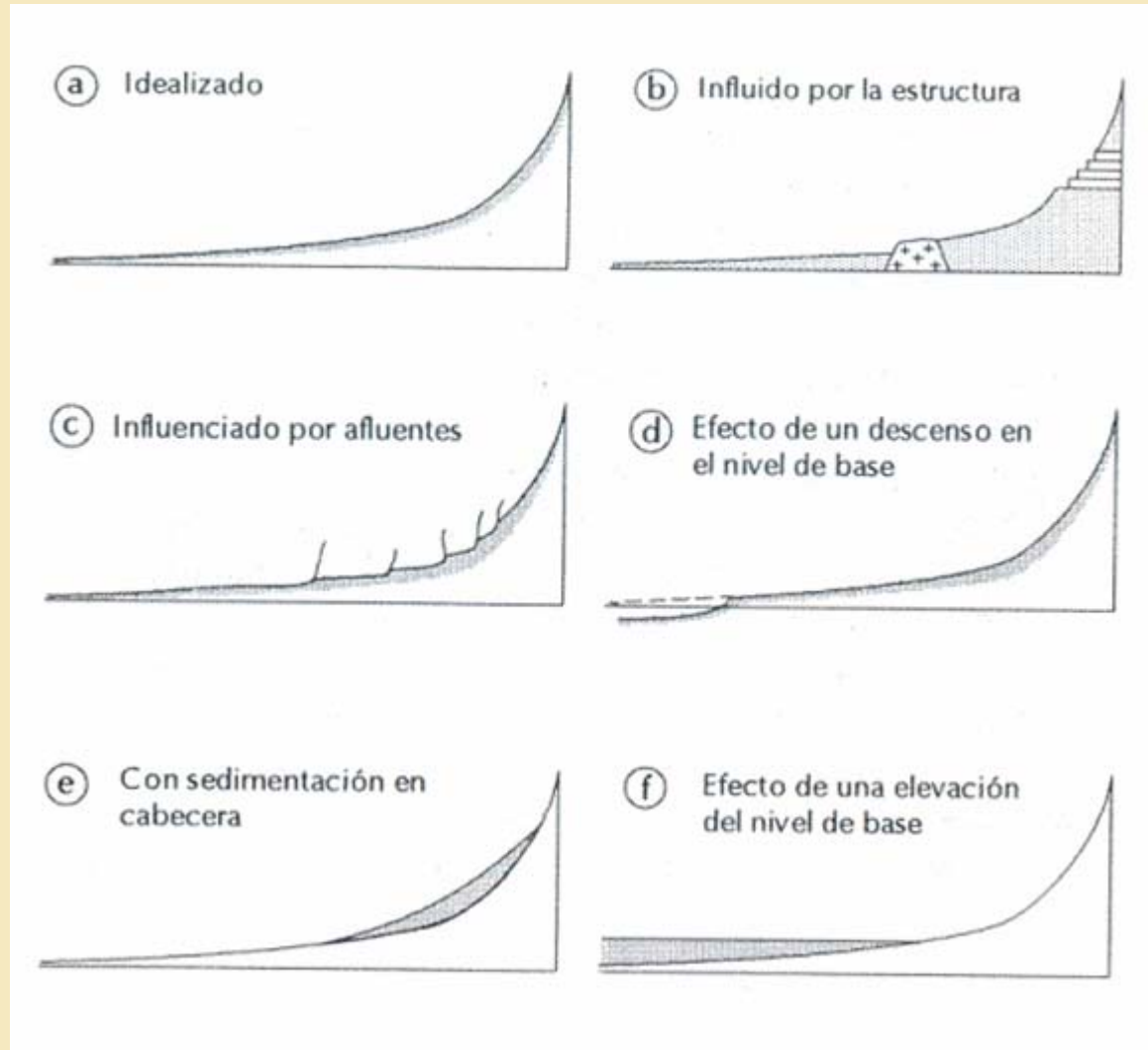
IGF logic framework



An aerial photograph of a mountainous region. The landscape is characterized by rolling green hills and valleys. There are several distinct patches of brown, eroded soil scattered across the green terrain, particularly on the slopes. A narrow, winding dirt road is visible on the left side of the image. The sky is filled with white and grey clouds, suggesting an overcast day. The overall scene depicts a natural environment with signs of soil erosion.

IGF EVALUATION IN FLUVIAL SEGMENTS (2-200 km)

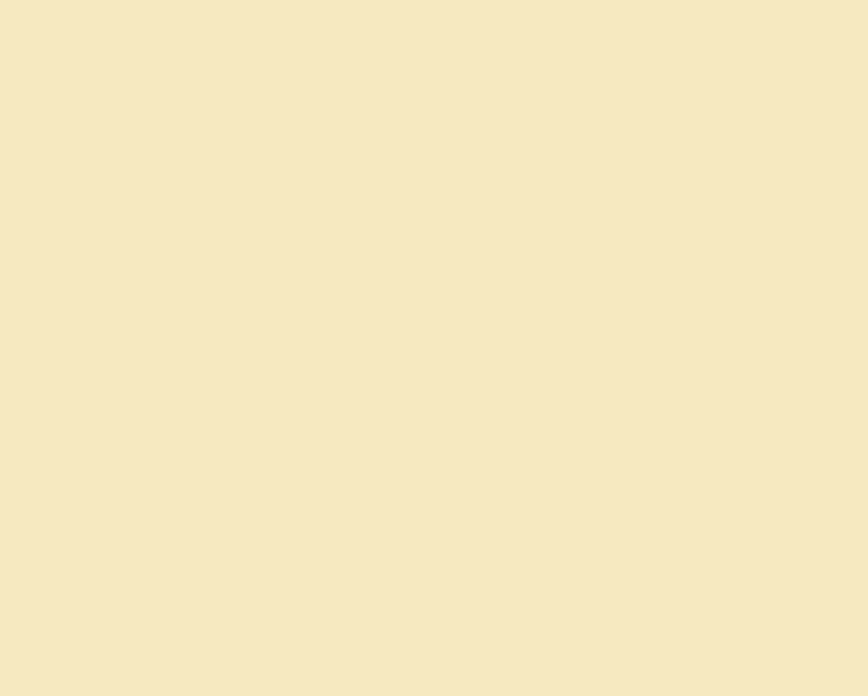
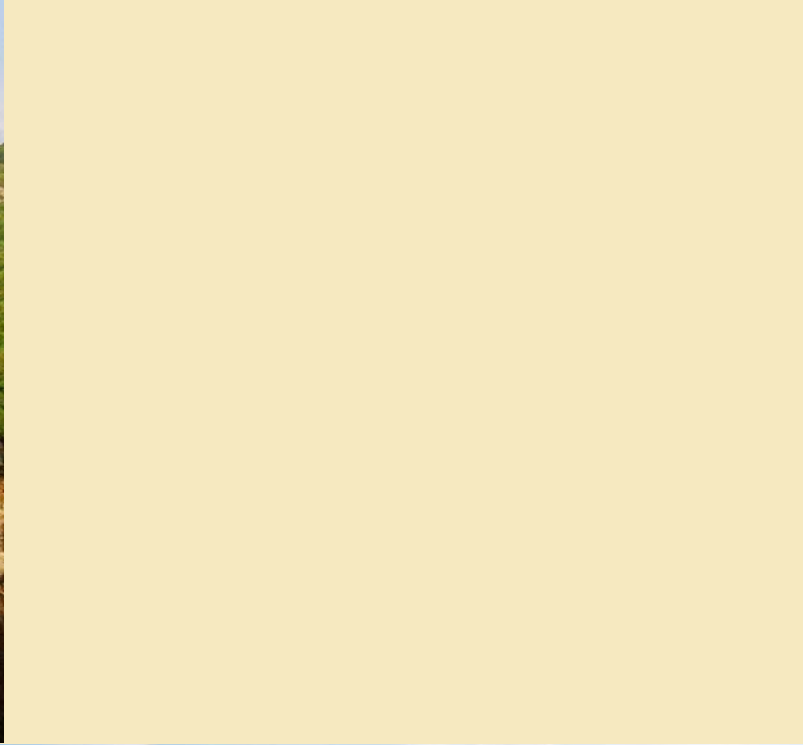
(1/4) Analysis of vertical profile (I)



(1/4) Analysis of vertical profile (II)

We assess the **correspondence between actual vertical profile and the river's evolutionary status and geologic history**. Four degrees are distinguished: Optimum, Suboptimum, Marginal and Poor.

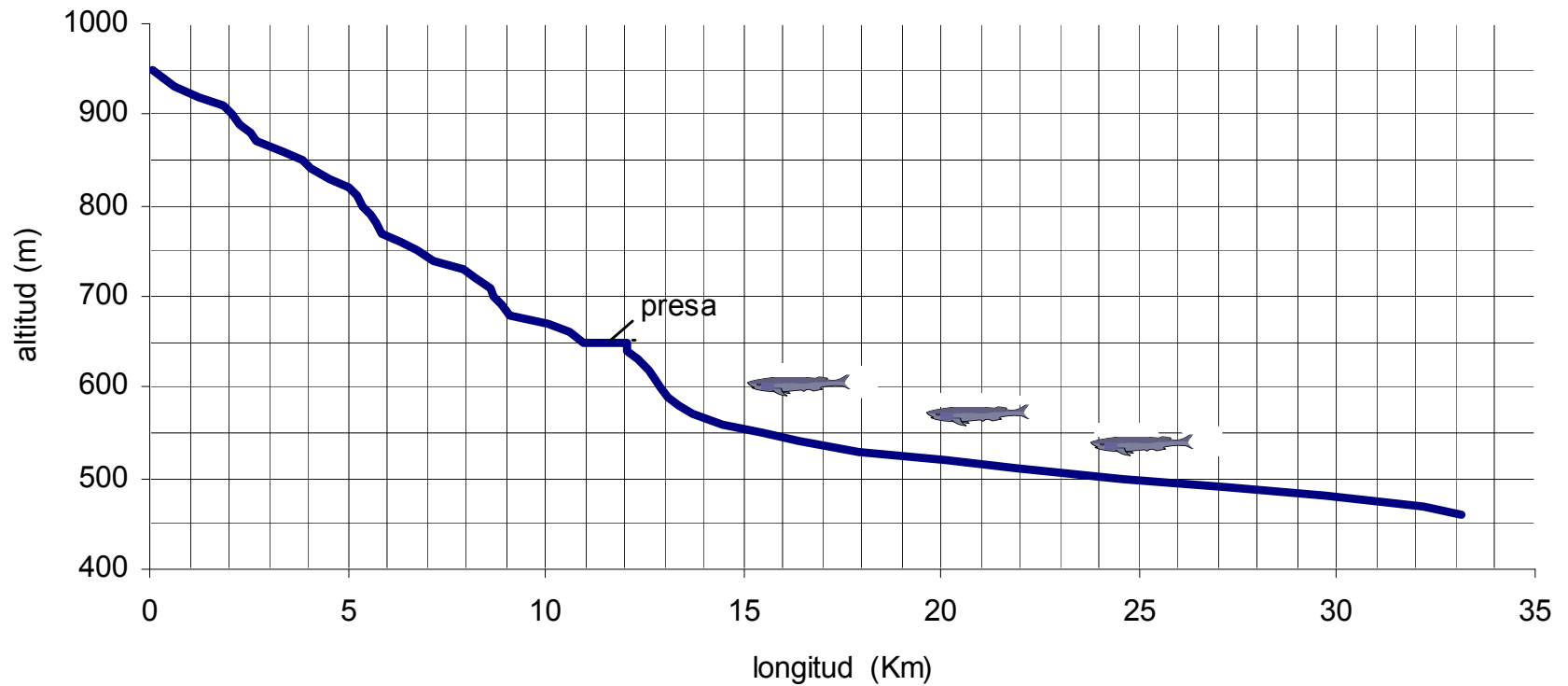
Parameter	Status			
	Optimum	Suboptimum	Marginal	Poor
1.- Vertical dynamic % impaired	Vertical profile corresponds completely to natural situation of studied segment and is adapted to the balance between geologic control and fluvial dynamic.	Slight alterations of natural vertical profile due to punctual activities (canalization, weirs, dragging, ...) that influence up and downstream affecting less than 25 % of the segment.	Profile shows significant alterations in 25-75% of its length or presents a heavy single alteration due to big dams, intensive canalization, deep dragging,...	Profile shows significant alterations in more than 75% of its length due to several big activities (canalization, big dams,...)
		< 25%	25- 75 %	> 75 %
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0



Río Perales (Madrid)



Río Perales (Madrid)



Impact of Cerro Alarcón Dam on vertical profile and fish fauna

(2/4) Lateral dynamics (planform) (I)

NATURAL (active or inactive): the river behaves naturally in planform: there are no restrictions to lateral movement and the channel is naturally connected to floodplain.

ARTIFICIAL:

- **Paralized (inactive):** the river shows natural pattern in planform but its dynamic has been stopped by direct or indirect human activity and pressure in neighbouring lands.
- **Modified (active):** planform changed intensively by direct human activity.

(2/4) Lateral dynamics (planform) (III)

We classify the status of lateral dynamic (degree of freedom) in four classes:

Parameter	Status			
	Optimum	Suboptimum	Marginal	Poor
2.- Lateral dynamic (degree of freedom)	Channel, riparian zone and floodplain are completely free to move and evolve naturally	Segment presents modifications from natural planform or else artificially stabilised dynamic by diffuse human pressure on banks or direct impacts (dragging, levees, ...) affecting less than 25 % segment length.	Segment presents alteration in its planform affecting 25-75% of its length or else its dynamic is completely paralyzed by human pressures.	Segment presents alterations in its planform affecting more than 75% of its length and becomes a channel without natural dynamic.
% impaired		< 25%	25- 75 %	> 75 %
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

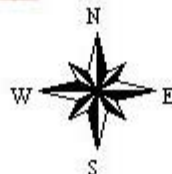
Río Jarama (La Marañoso)



1999



1956



(3/4) Cross section

This parameter evaluates the **correspondence between the morphology of cross section and natural factors as flow, lithology, topography and sediment dynamic**. We classify the status of the cross section in four classes:

Parameter	Status			
	Optimum	Suboptimoum	Marginal	Poor
3.- Cross section	Cross section morphology is completely naturel in absence of canalizations or dragging.	Slight alterations of cross sections due to rigidization, canalization, vehicle passess, bridges,...	Extended canalization in segment, with levees and structures affecting 25-75% of segment length.	Both sides comletely covered by gavion, concrete or other rigid material in more than 75% of segment.
% impaired		slight	25- 75 %	> 75 %
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

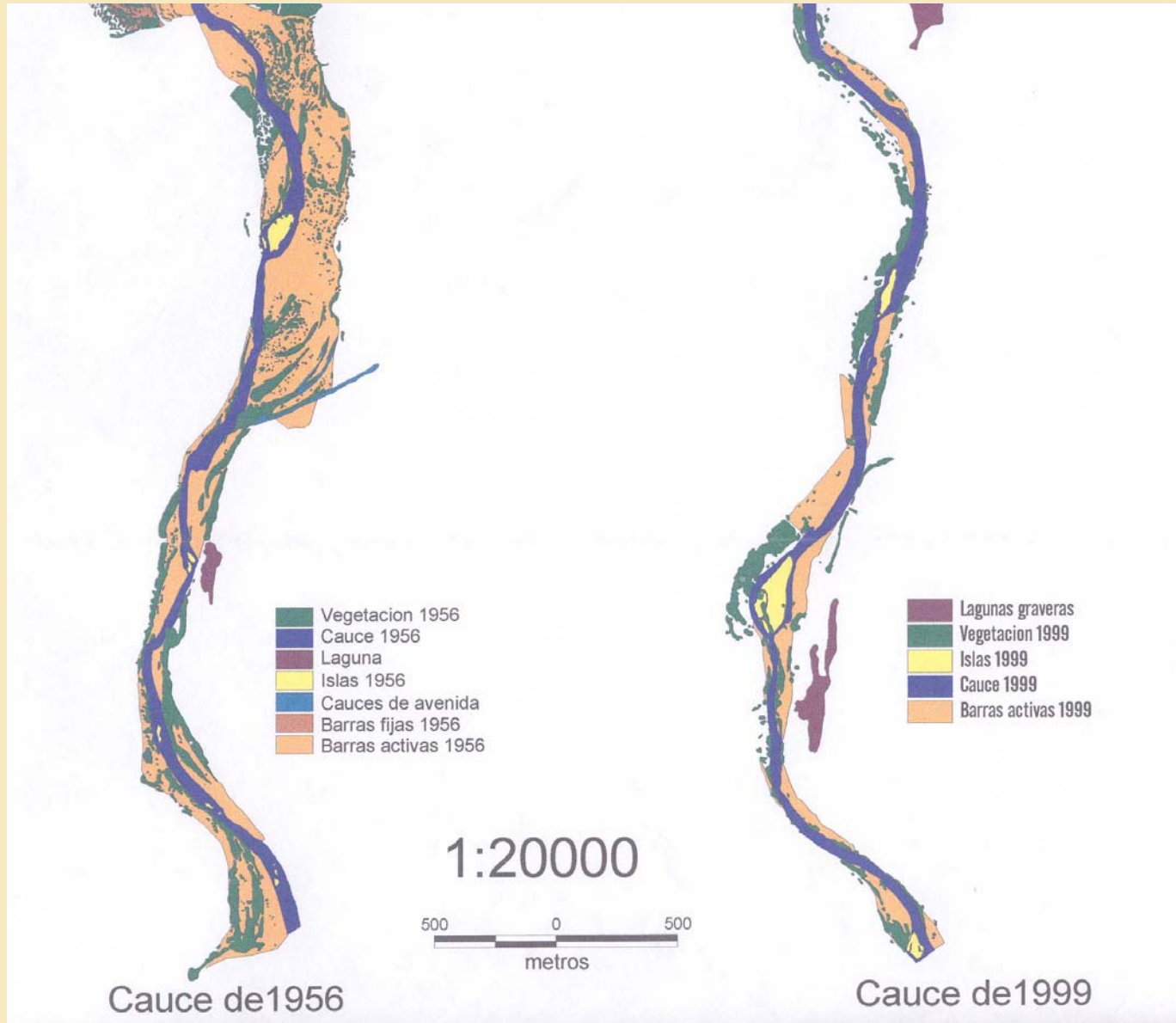


(4/4) Sedimentary dynamic (alluvial rivers)

This parameter evaluates the **status of erosion, transport and sedimentation processes in fluvial segments of alluvial rivers**. Area occupied by shifting and fixed bars is a good indicator of sedimentary status in alluvial rivers according to Vizcaíno et al. (2003). We classify the status of sedimentary dynamic in four classes in this fluvial type:

Parameter	Status			
	Optimum	Suboptimum	Marginal	Poor
4.- Sedimentary dynamic (alluvial rivers) % impaired	Area occupied by shifting and fixed bars and sediments corresponds with natural segment sedimentary dynamics	Area occupied by shifting and fixed bars and sediments is altered in 25-50% segment length with respect to natural segment dynamics.	Area occupied by shifting and fixed bars and sediments is altered in 50-75% segment length with respect to natural segment dynamics.	Area occupied by shifting and fixed bars and sediments is altered in more than 75% segment length with respect to natural segment dynamics.
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

Dynamic of bars (R. Jarama) 1956-1999





IGF EVALUATION IN A FLUVIAL REACH

(1/4) Vertical dynamic

Vertical dynamic at reach scale evaluates changes in baselevel due to geomorphological alterations. At reach scale we can detect incision processes, upstream erosion or channel elevation due to sediment deposit. We classify the vertical dynamic status in four classes:

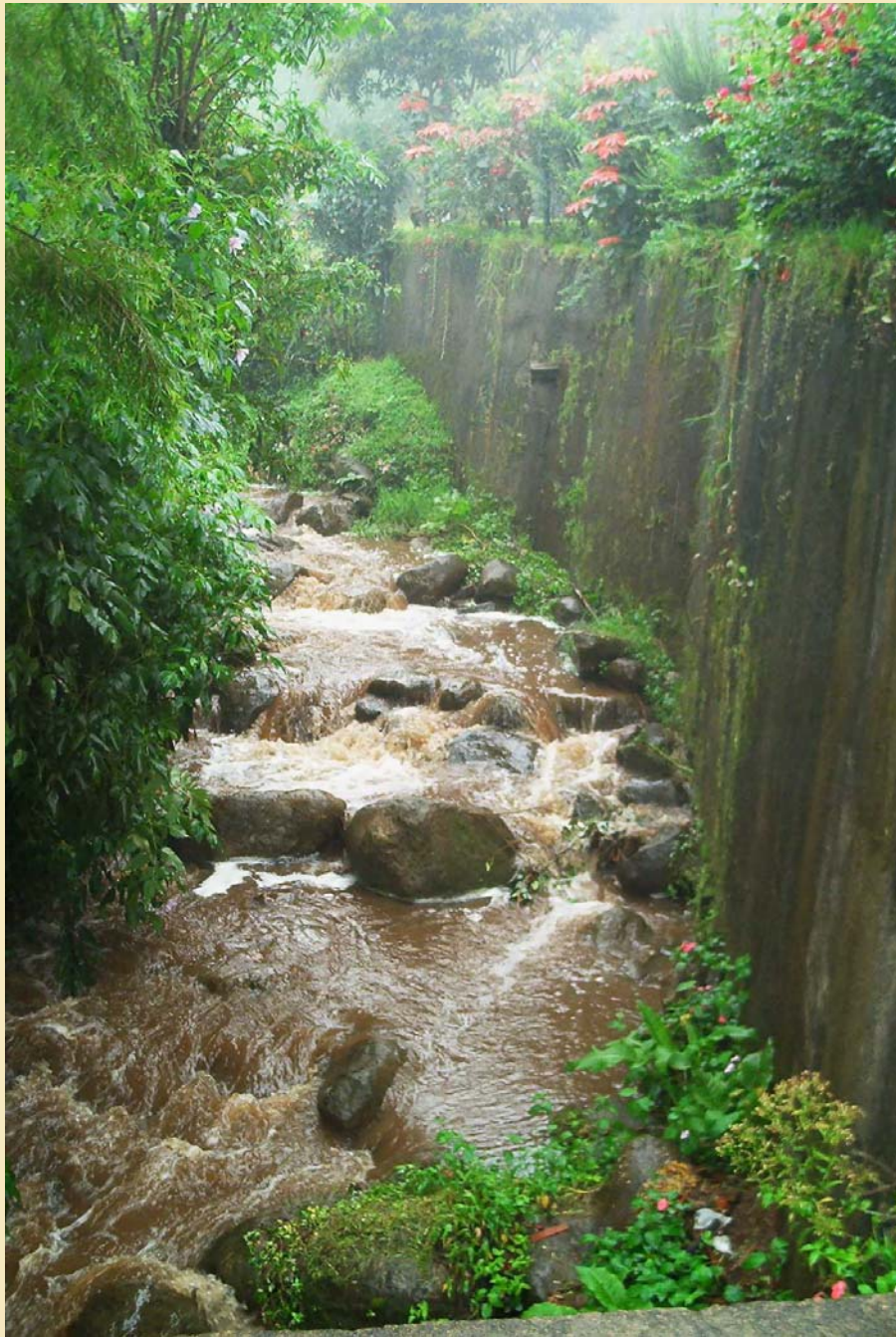
Parameter	Status			
	Optimum	Suboptimum	Marginal	Poor
1.- Vertical dynamic % impaired	Vertical profile corresponds completely to natural situation of studied reach and is adapted to the balance between geologic control and fluvial dynamic.	Slight alterations of natural vertical profile due to punctual activities (canalization, weirs, dragging, ...) that influence up and downstream affecting less than 25 % of the reach.	Profile shows significant alterations in 25-75% of its length or presents a heavy single alteration due to big dams, intensive canalization, deep dragging,...	Profile shows significant alterations in more than 75% of its length due to several big activities (canalization, big dams,...)
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0



(2/4) Lateral dynamic

Lateral dynamic represents at reach scale the degree of freedom in planform. We classify the degree of freedom in planform in four classes:

Parameter	Status			
	Optimum	Suboptimum	Marginal	Poor
2.- Lateral dynamic (degree of freedom) % impaired	Channel, riparian zone and floodplain are completely free to move and evolve naturally	Reach presents modifications from natural planform or else artificially stabilised dynamic by diffuse human pressure on banks or direct impacts (dragging, levees, ...) affecting less than 25 % segment length.	Reach presents alteration in its planform affecting 25-75% of its length or else its dynamic is completely paralyzed by human pressures.	Reach presents alterations in its planform affecting more than 75% of its length and becomes a channel without natural dynamic.
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0



(3/4) Stability of naturally stable banks

This parameter evaluates bank stability in naturally stable banks. It is not applied to natural unstable banks. We classify stability of banks in four classes:

Parameter	Status											
	Optimum			Suboptimum			Marginal			Poor		
3.- Banks stability	Banks without evidence of erosion. Low potential for future problems.			Banks moderately stable, small and unfrequent erosion areas, affecting 10-25% bank			Unstable banks, altered by artificial erosion in 25-50% of their length. High erosionability during flood events.			Very unstable banks, with lateral non-natural erosion processes affecting more than 50% of its length.		
% impaired				< 25%			25- 50 %			> 50 %		
Right bank	10	9		8	7	6	5	4	3	2	1	0
Left bank	10	9		8	7	6	5	4	3	2	1	0



(4/4) Sedimentary status (river bed)

At reach scale, this parameter **evaluates the erosion, sedimentation and transport processes in river bed, according to its morphology and generating factors**. We classify sedimentary status in four classes:

Parameter	Status			
	Optimum	Subóptimo	Marginal	Pobre
4.- Sedimentary status	Lecho natural, con diversidad de refugio para la fauna y en equilibrio con la dinámica fluvial del tramo.	Evidencia de cierto grado de sedimentación erosión o colmatación no naturales, afectando del 25-50% del lecho.	Colmatación, sedimentación o erosión no naturales evidente en un 50-75% del lecho. En algunos casos se dan fenómenos ligeros de incisión artificial por erosión remontante.	Colmatación/sedimentación no naturales en más del 75% del sustrato o proceso de incisión no natural del lecho en estado avanzado.
% impaired		25 - 50%	50- 75 %	> 75 %
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

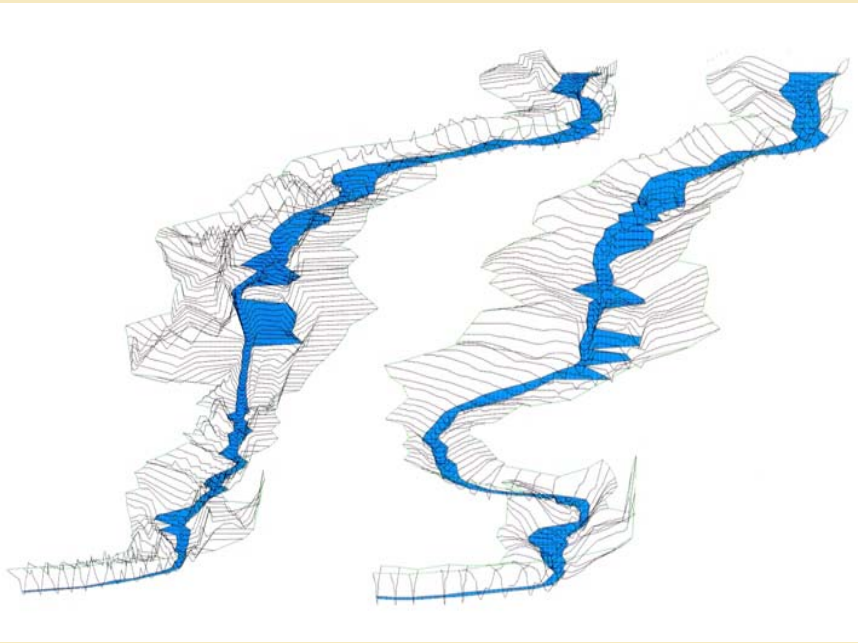


IGF TOTAL SCORE

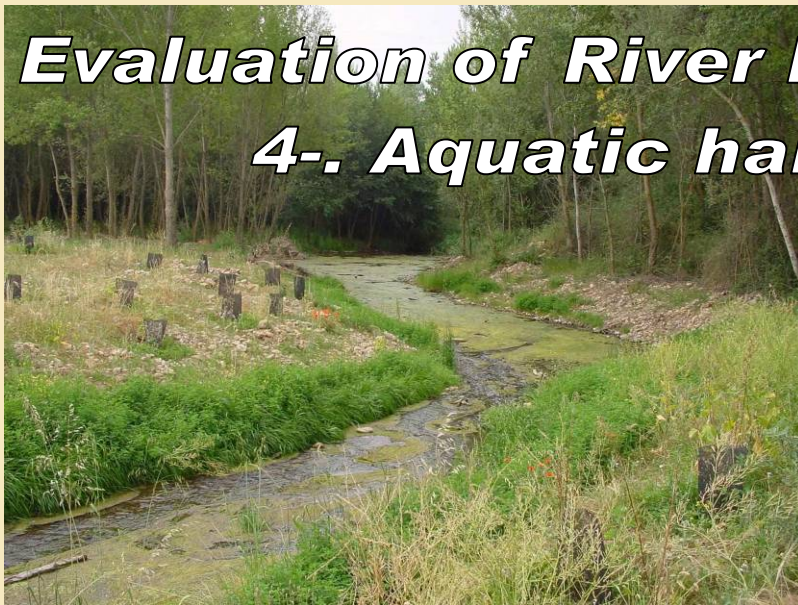
INDICE DE ESTADO GEOMORFOLÓGICO FLUVIAL (IGF- TRAMO) ESTUDIO GEOMORFOLÓGICO DE UN TRAMO FLUVIAL				
Parámetro	Estado			
	Óptimo	Subóptimo	Marginal	Pobre
1.- Dinámica vertical del cauce	El perfil longitudinal se corresponde con el estado natural del tramo, según el equilibrio entre control geológico y dinámica fluvial.	Se presentan pequeñas alteraciones de la naturalidad del perfil, basadas en actuaciones puntuales (graveras, canalizaciones, azudes, dragados...) de pequeña envergadura cuyo efecto repercute aguas arriba y aguas abajo afectando a menos de un 25 % del tramo.	El perfil longitudinal presenta alteraciones significativas en un 25-75% de su longitud, o bien presenta el impacto de una actuación de gran envergadura (presa, canalización, dragado,...)	El perfil longitudinal se encuentra alterado en más de un 75 % de su longitud o, por varias actuaciones de gran impacto.
Valoración	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2.- Dinámica lateral del cauce	Cauce, ribera y mancha de inundación constituyen un Sistema Fluvial con libertad natural de movimiento y evolución.	El tramo sufre modificaciones de su trazado natural o bien presenta una dinámica paralizada, con un trazado antiguo al que no se ha dejado evolucionar, por presión humana sobre las márgenes o actuaciones directas sobre el cauce (dragado, escolleras y muros laterales,...) en menos de un 25% de su trazo.	El río presenta alteraciones de trazado en un 25-75% de su recorrido, o bien se puede considerar que su dinámica está totalmente paralizada por efecto de la presión antrópica.	El río presenta alteraciones de su trazado en más del 75% de su recorrido, convertido en un canal sin dinámica natural.
Valoración	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
3.- Estabilidad de las orillas naturalmente firmes	Orillas sin evidencia de erosión. Escaso potencial de problemas de estabilidad futuros.	Orillas moderadamente estables, pequeñas e infrecuentes áreas de erosión, afectando a un 10-25% de la orilla	Orillas inestables, alteradas por erosión artificial en un 25-50% de las mismas. Erosionabilidad alta en crecidas.	Orillas muy inestables, con erosiones laterales no naturales muy notables que afectan a más del 50% de su longitud.
Orilla dcha.	10 9	8 7 6	5 4 3	2 1 0
Orilla izda.	10 9	8 7 6	5 4 3	2 1 0
4.- Estado sedimentario del cauce	Lecho natural, con diversidad de refugio para la fauna y en equilibrio con la dinámica fluvial del tramo.	Evidencia de cierto grado de sedimentación erosión o colmatación no naturales, afectando del 25-50% del lecho.	Colmatación, sedimentación o erosión no naturales evidente en un 50-75% del lecho. En algunos casos se dan fenómenos ligeros de incisión artificial por erosión remontante.	Colmatación/sedimentación no naturales en más del 75% del sustrato o proceso de incisión no natural del lecho en estado avanzado.
Valoración	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

IGF (TOTAL) = SUM (IGF axes)

Relative scoring (%) = TOTAL/80



***Evaluation of River Restoration Projects.
4-. Aquatic habitat modelling***



Aquatic Habitat Modelling (I)

- Aquatic habitat modelling includes the modelization of the following parameters:
 - Habitat availability in terms of: refuge, feeding areas, nesting/spawning areas
 - Quantification of habitat: area, volume,...
 - Habitat suitability for a given species depending on its preferences on flow velocity, depth, substrate.
- The input parameters for the modelization are:
 - Channel geometry (topography)
 - Hydraulic conditions (flow, initial depth,...)
 - Channel substrate.

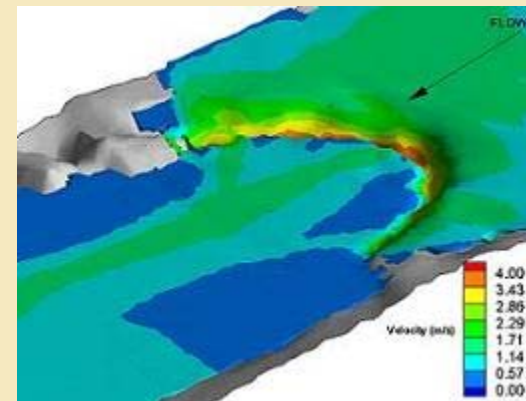
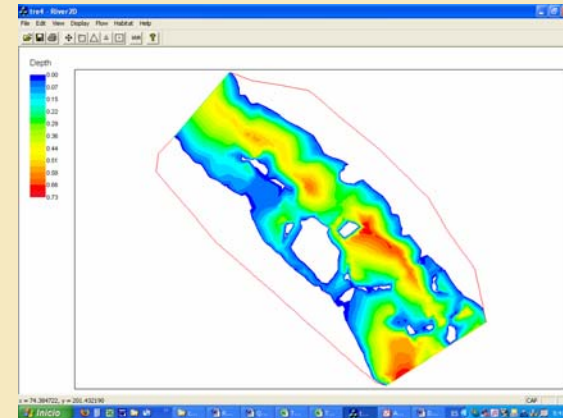
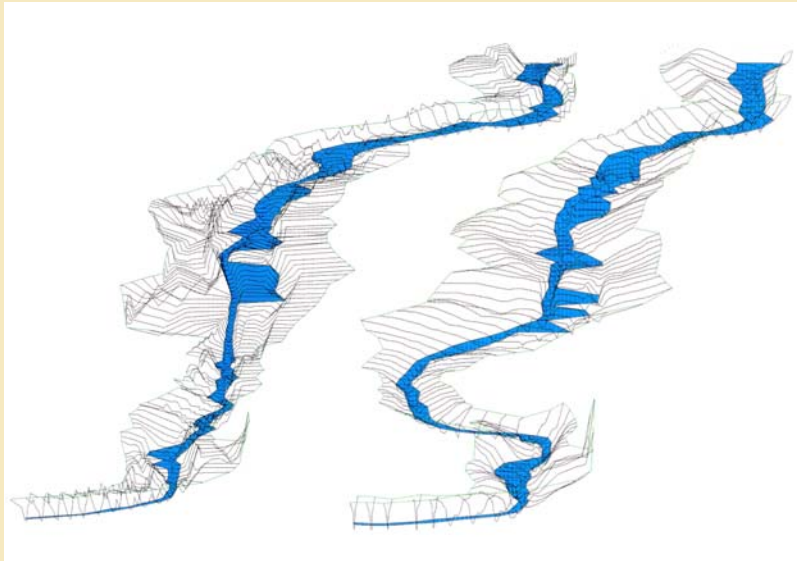
Aquatic Habitat Modelling (II)

- These studies depend on the **quality and continuity of the input topographic data**. Conventional fish habitat studies are limited by the feasibility of field survey in time and budget
- This limitation results in **differences between the level of river management and the level of models**; river management mostly operates at catchment or river sector level, while modeling uses the much smaller site level (Borsanyi et al., 2004)
- In order to facilitate **upscaling processes** from modeling to management units, intermediary methods between the micro- and the macroscale level were developed (Habitat Mapping (Maddock & Bird, 1996; Maddock, 1999); MesoHABSIM (Parasiewicz, 2001)).

Dimensions (I)

- **1-D Modelling.** Uses cross-section topographic input data for which flow velocity and depth are modeled. Results are extrapolated to the channel between cross sections. One-dimensional, 1D, numerical simulations model downstream changes in hydraulics while neglecting vertical and lateral variation. Software: HEC-RAS,...
- **2-D Modelling.** Two-dimensional, 2D, models incorporate lateral differences in velocity and water surface elevation, but not vertical variation. Computes habitat using DTM grids (TIN or raster DTM). An average value of depth and velocity (modulus and direction) is calculated for the water column above each pixel. Software: RIVER 2D, GUAD 2D,...
- **3-D Modelling:** Three-dimensional, 3D, modeling simulates the motion of water in all directions and most accurately captures flow patterns. Velocity direction and modulus are calculated for each water cell in the modelled flow.
- Flow simulation and habitat analyses have been assessed based on conventional topography (cross sections) and 1D hydraulic models.
- Remote sensing, increasing calculation capabilities and higher field work costs have changed the actual scenario of environmental flows analysis.
- There is a **need of methodologies employing remote-sensed data coupled to 2D or 3D hydraulic models to allow efficient analysis of long river segments.**

Dimensions (II)

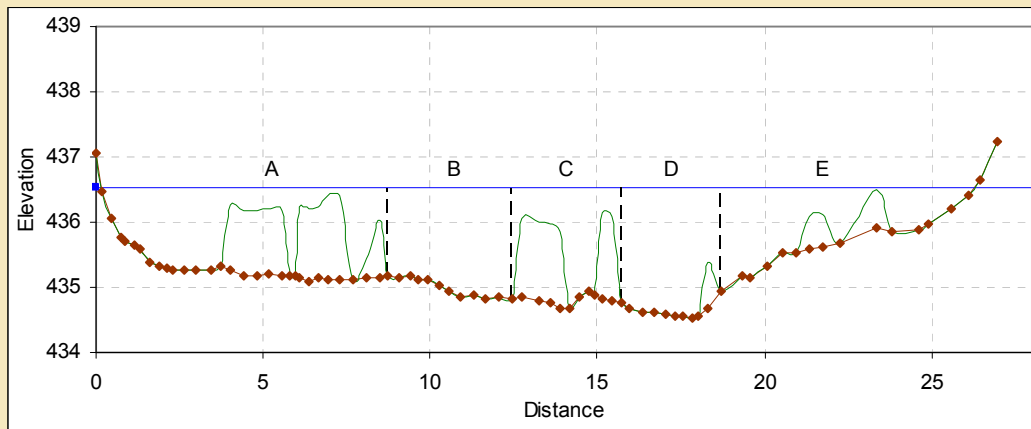


Topographic survey



Total Station

GPS



Remote sensing (LiDAR)

**Infrared pulse
(Topographic LiDAR) is
reflected in the water
surface**

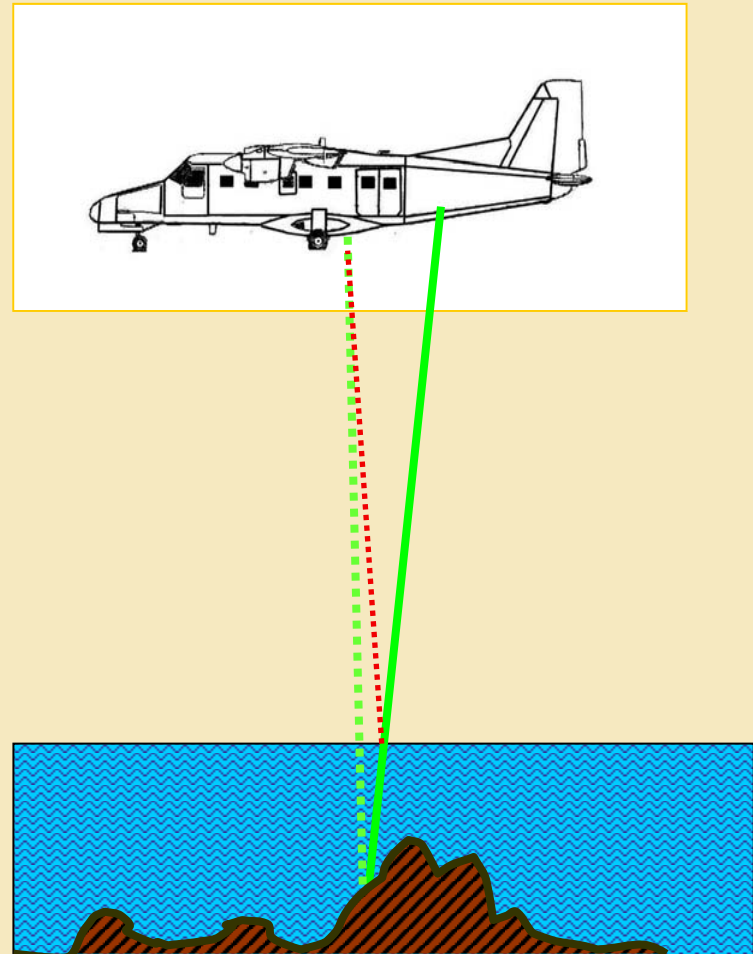
**Green-LiDAR
(Bathymetric LiDAR)
pulse reaches the
bottom substrate (> 50
m)**

**Depth is calculated by
means of differences in
time for each pulse:**

$$p = \Delta t \cdot c / 2$$

Optech

Quoted by ICC, 2005



Shoals/Hawk-Eye

II

LiDAR products

- Postprocessing work involves the application of filters and error controllers to get two final products:
- Digital Surface Model (dsm); 2 m pixel grid based on the analysis of the first and last LIDAR pulses (LEFT)
- Digital Terrain Model (dtm); 2 m grid obtained using the last LIDAR pulse. (RIGHT)

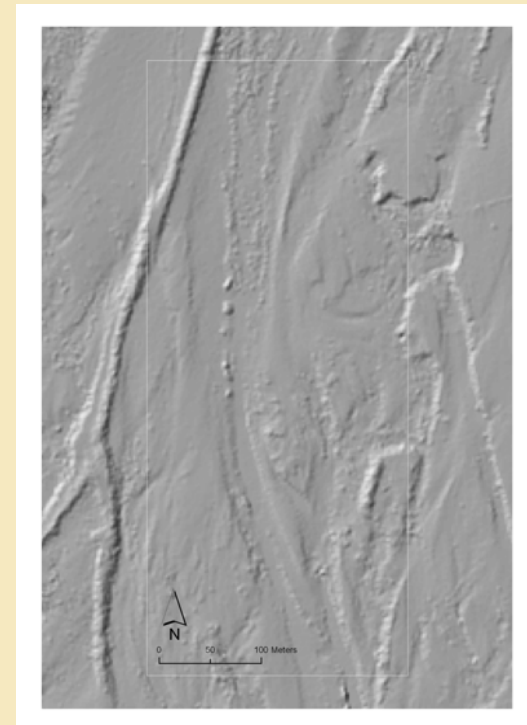
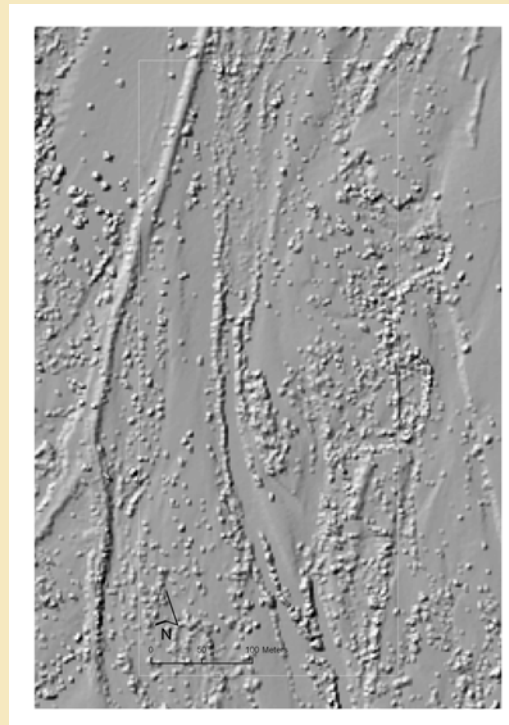
PRECISION

Horizontal:

RMSE < 0.50 m

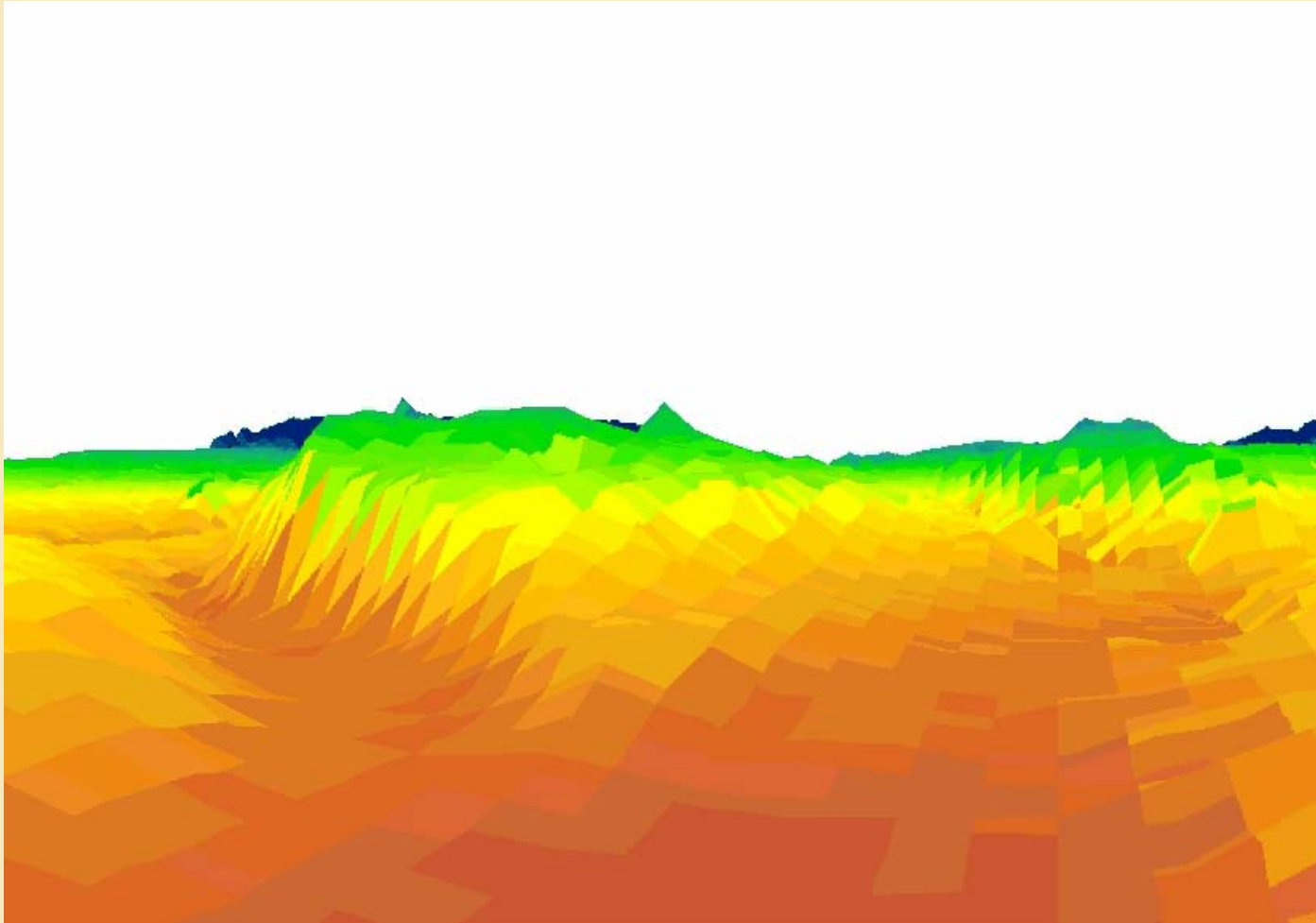
Vertical:

RMSE 0.15 m



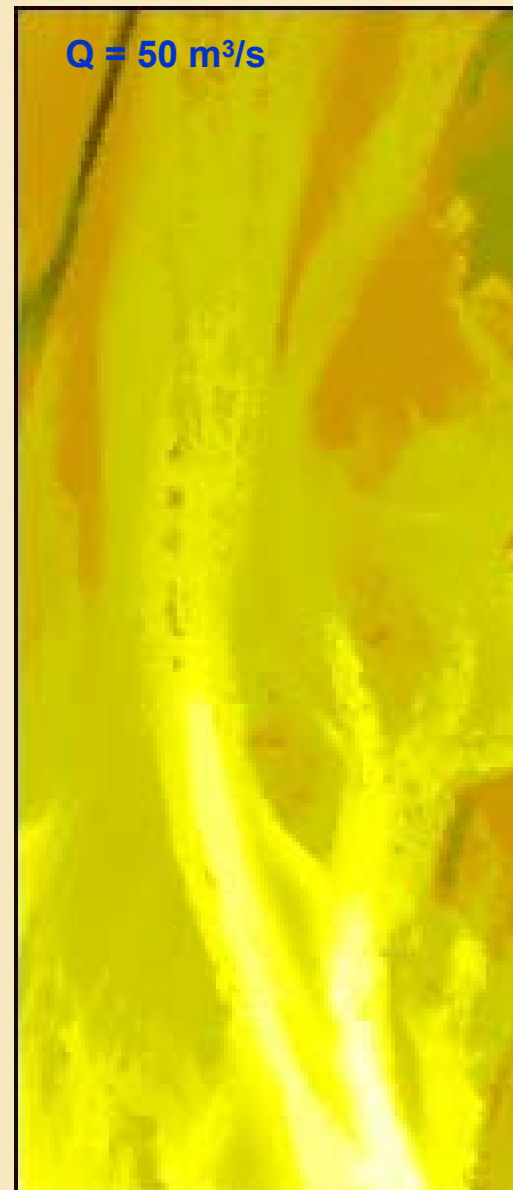
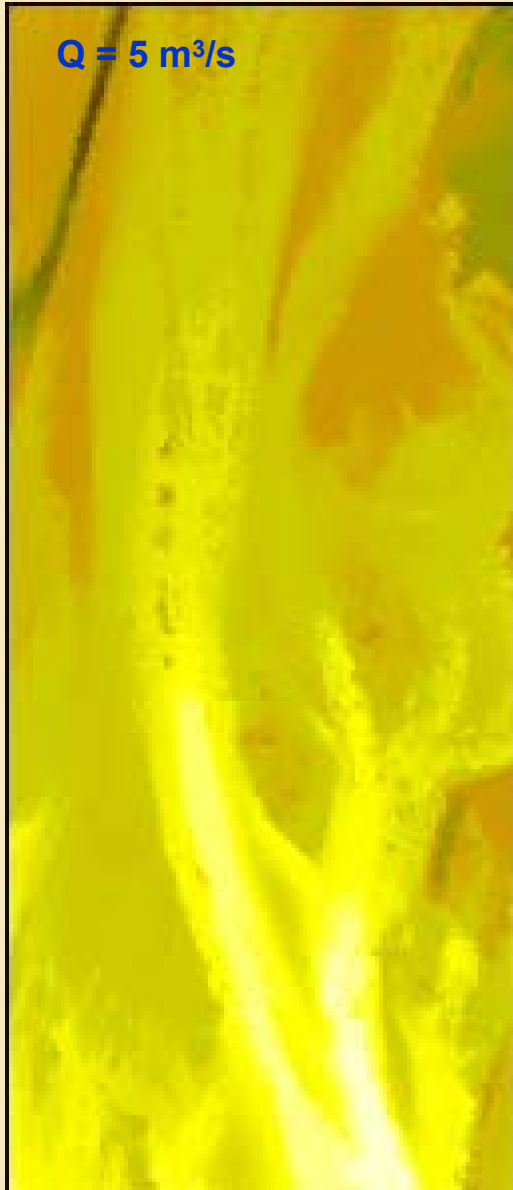


Airborne Hydrography, 2007

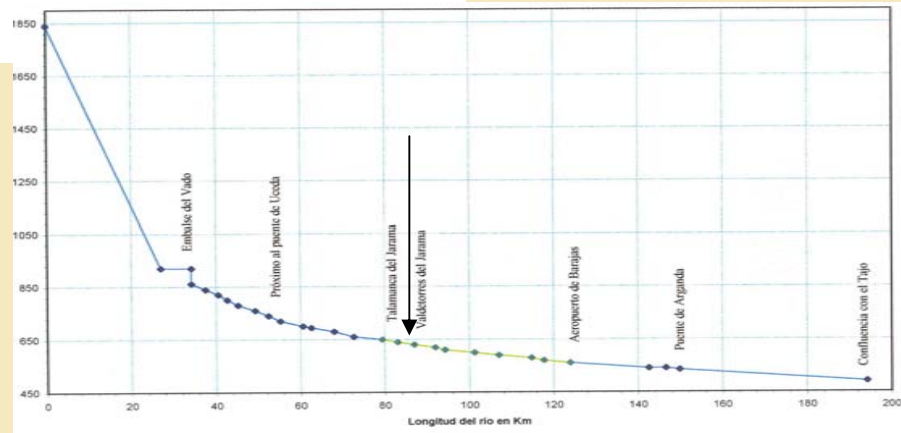
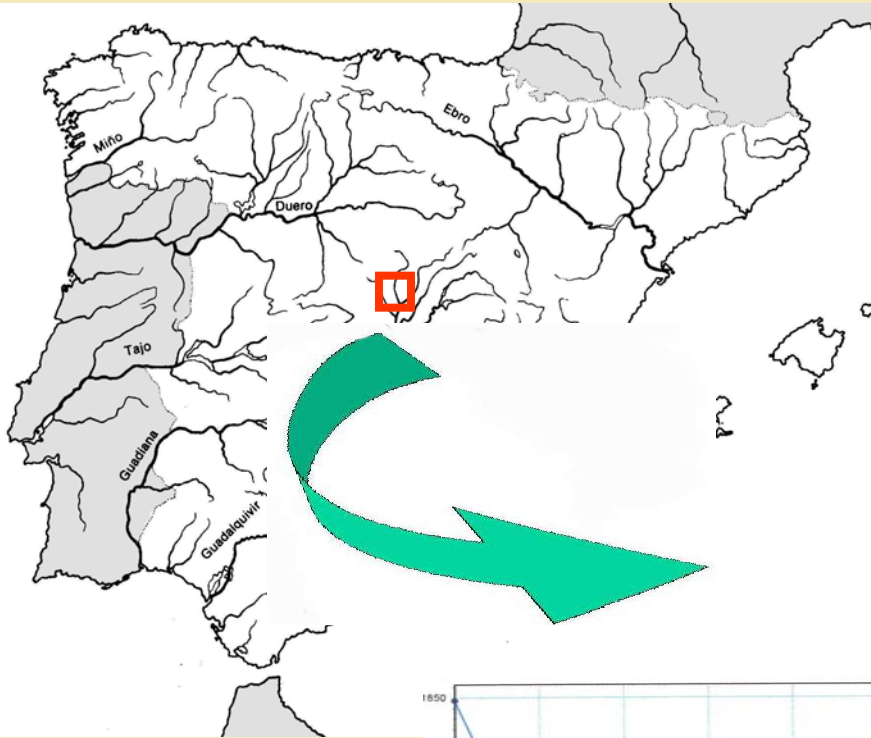


Vertical 5x

Hydraulic simulation (2D)



Jarama River: middle reach El Molar (Madrid)



Jarama River: middle reach El Molar (Madrid)

Altitude: **630 m**

Natural M.A. Flow: **15 m³/s**

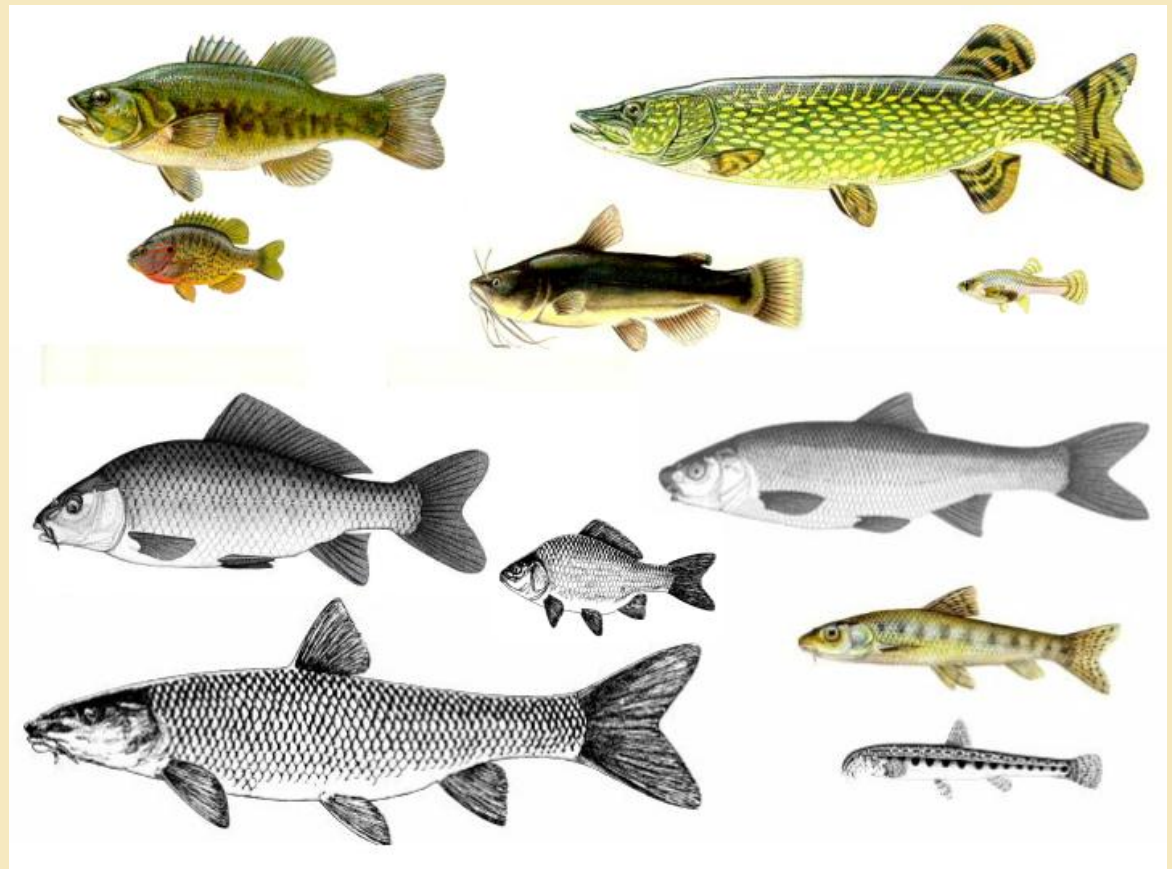
Actual M.A. Flow: **5 m³/s**

- Aloctonous sps.:

- Bass
- Catfish
- Sunfish

- Native Fishery:

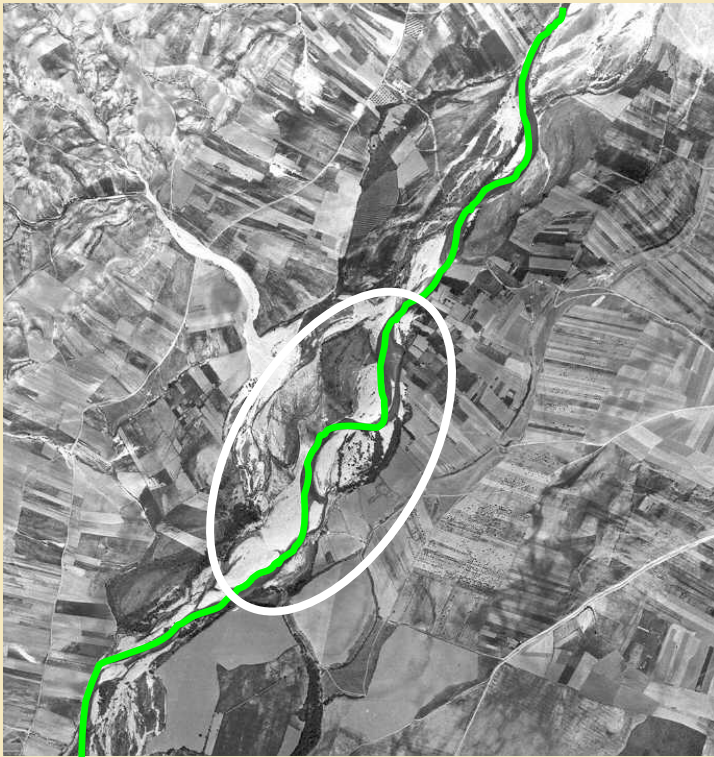
- Barbel
- Nase
- Cobitis





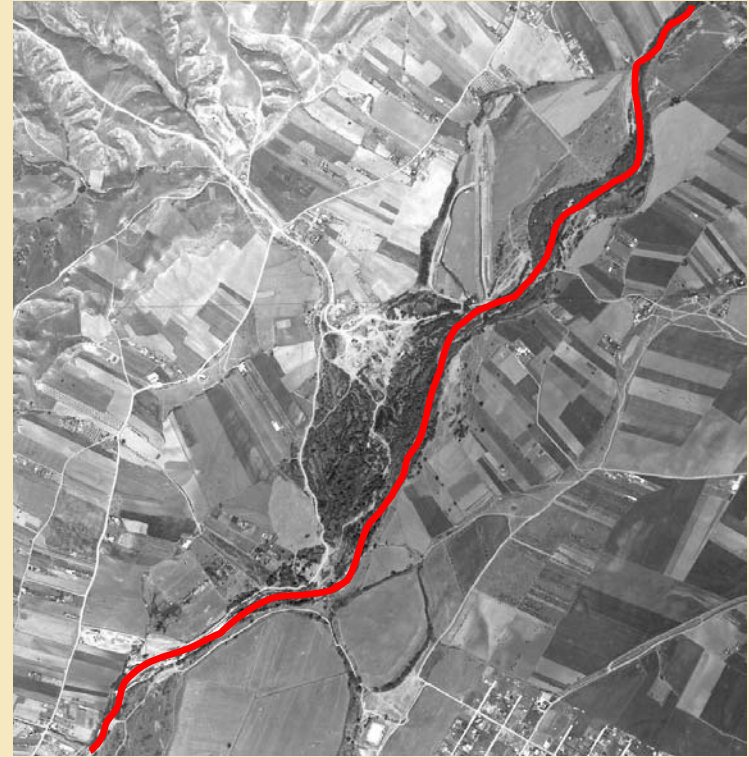
PRE-RESTORATION
SCENARIO 1956-2001
EVOLUTION

Diagnostic Evolution (1956-1995)



1956

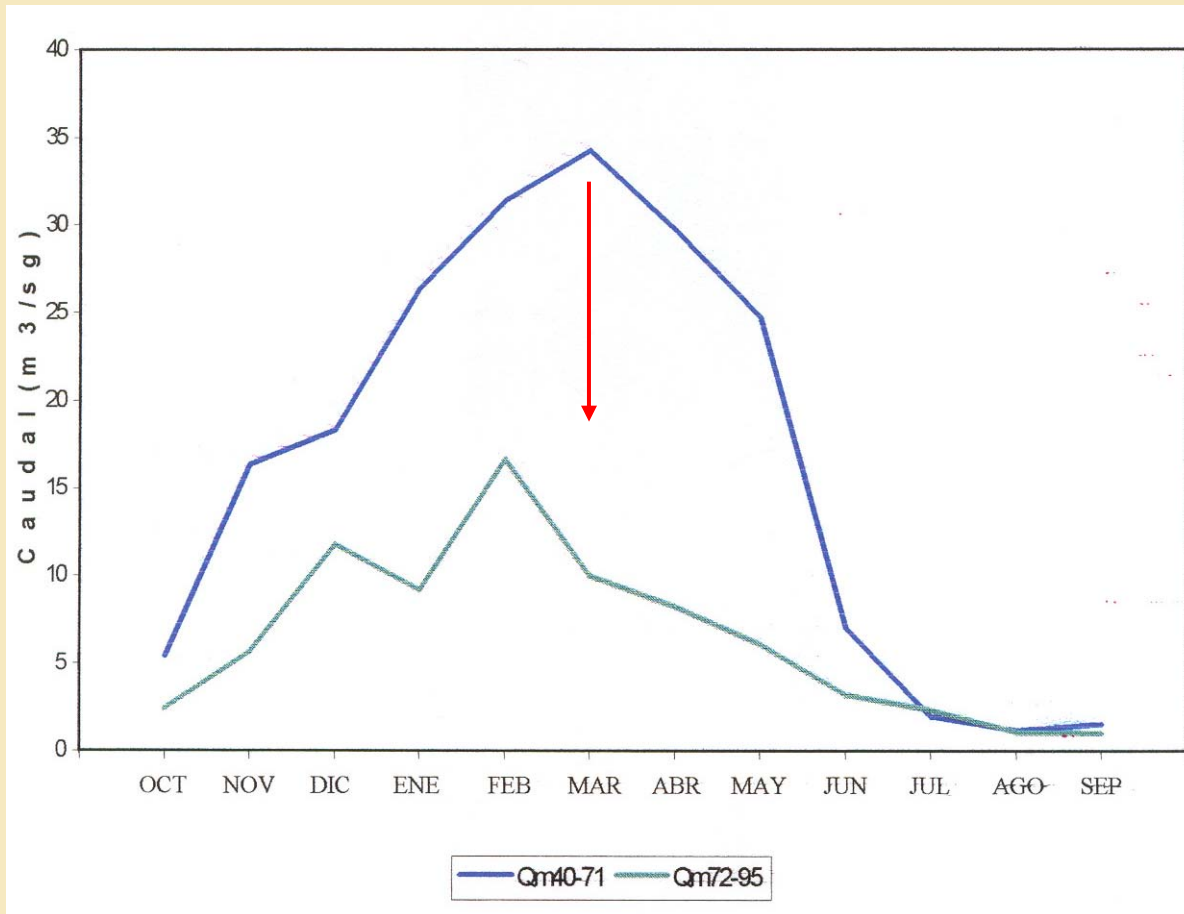
- Gravel mining (active until 1972), fine sediments.
- Agriculture and grazing in both slopes
- Remaining levees restraining fluvial dynamics
- Flow regulation



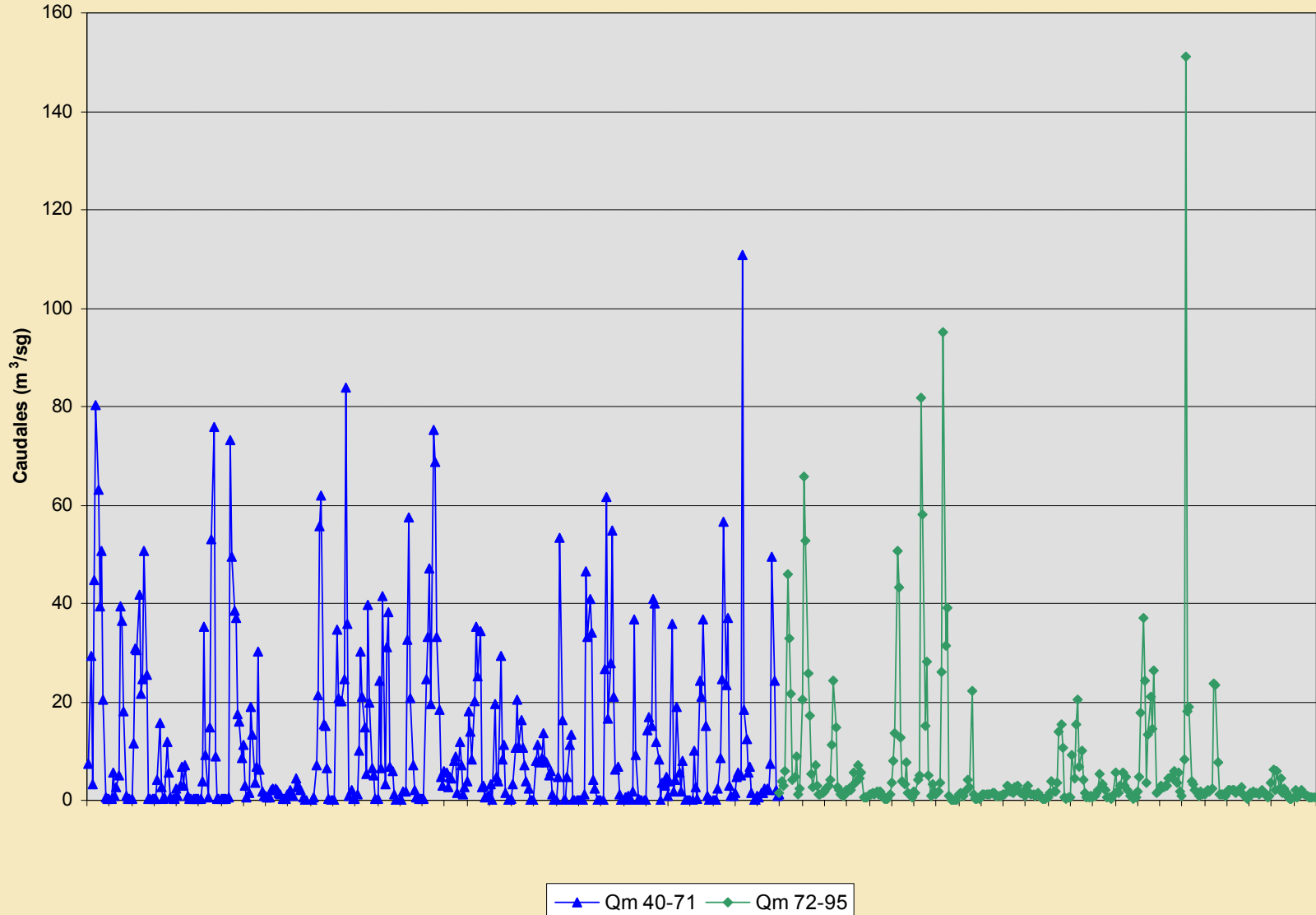
1995

Seves, 2000

Diagnostic (flow regime)



River Jarama flow regime

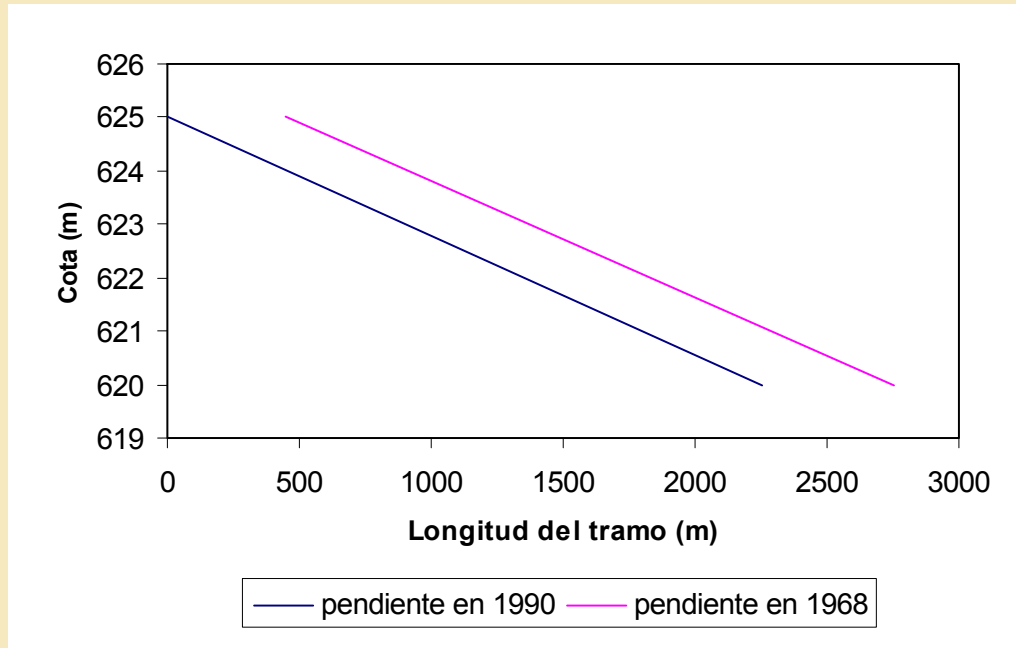


River Jarama Mean monthly flow values from 1940-95. Blue line before the construction of large reservoirs (El Atazar, Pinilla & El Vado)

Diagnostic (flow regime)

1. Reduction in monthly peak flows and bankfull flows.
2. Reduction in mean annual flow
3. Change of regime: reduction of high flows frequencies

Diagnostic (profile) (1)

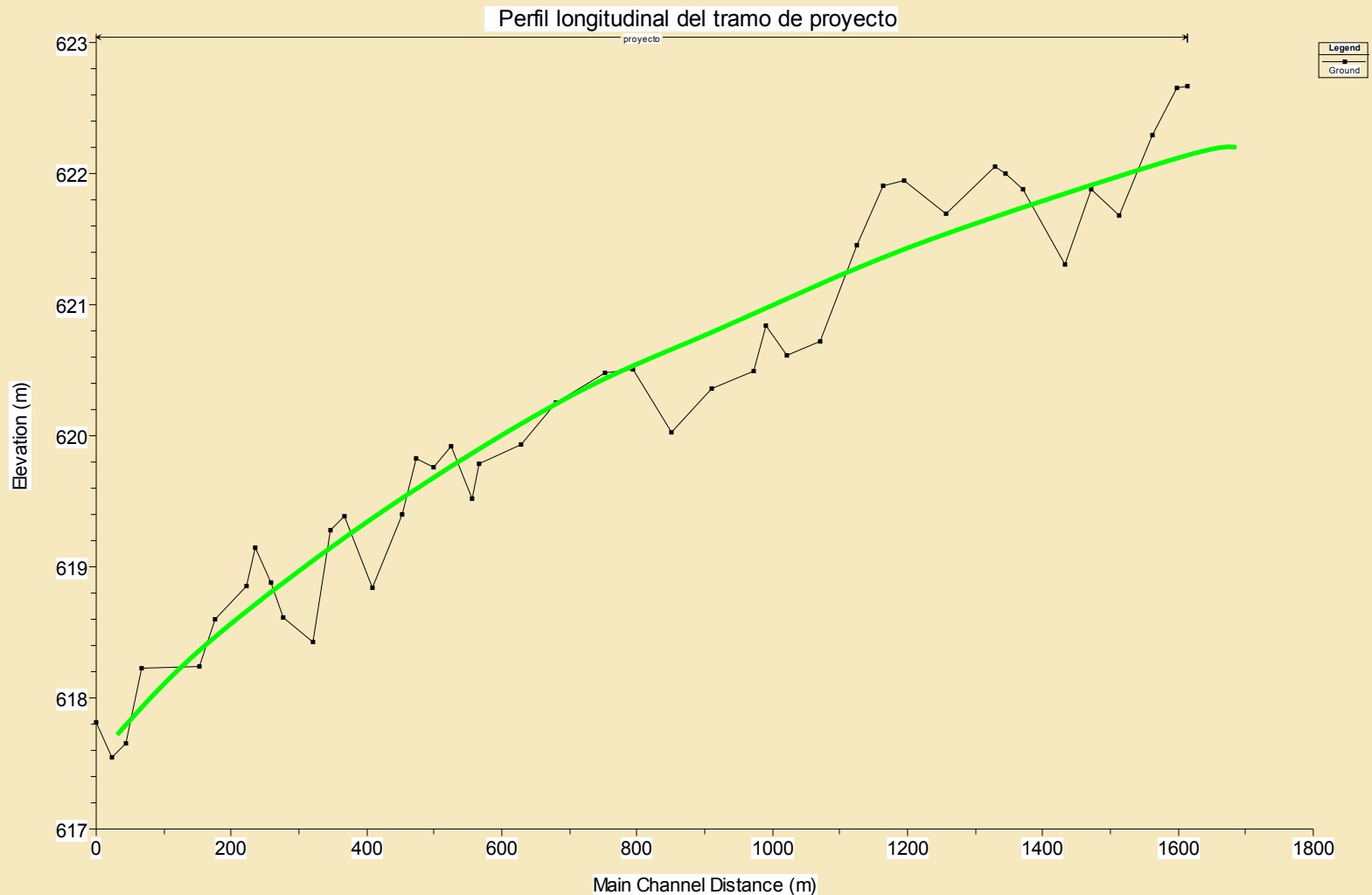


Year	Slope (%)	Base level (m)
1968	0.22	621
1995	0.22	620

River Jarama base level lowered due to:

- Gravel extractions directly from river bed, and also from the riparian system
- Decrease of bed load and transported sediments

Diagnostic (profile) (2)



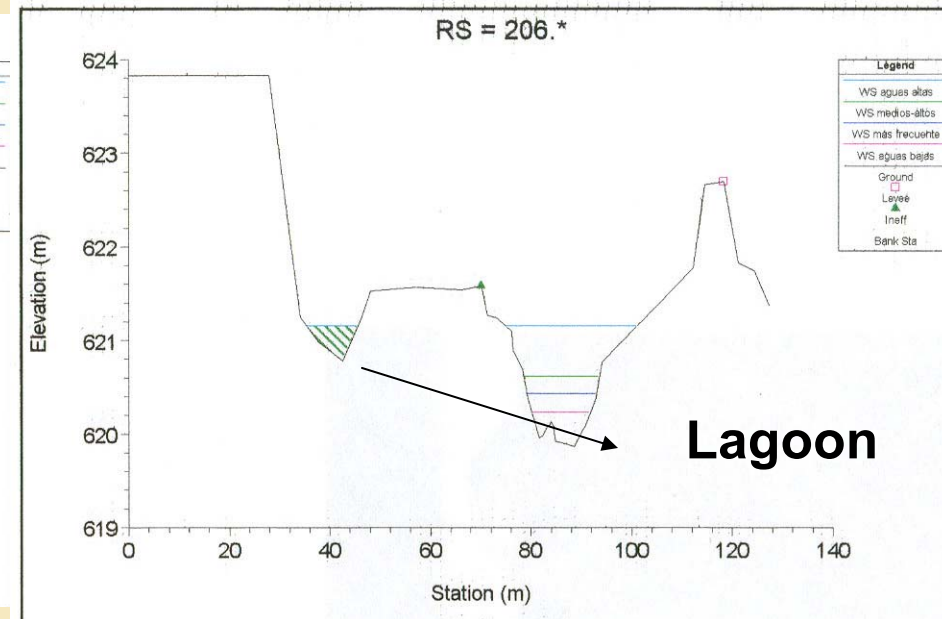
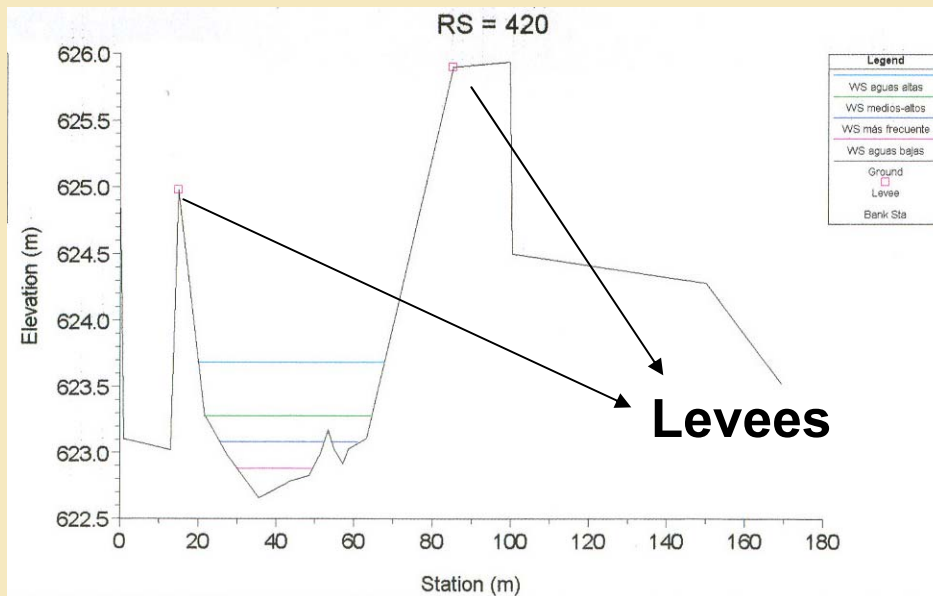
Longitudinal profile of the project reach (43 sections)

Diagnostic (planform)

Year	Sinuosity	Length (m)	Surface (ha)	Width (m)
1956	↓ 1.20	↓ 3500	↓ 18.7	↓ 53
1968	↓ 1.12	↓ 3100	↓ 9.2	↓ 29
1995	↓ 1.04	↓ 3000	↓ 11.7	↓ 39

- Loss of fluvial space due to channel confinement
- Decrease of channel width
- Reduction of channel length and sinuosity (rectification)
- Unadequate depth/width relationship

Diagnostic (cross sections)



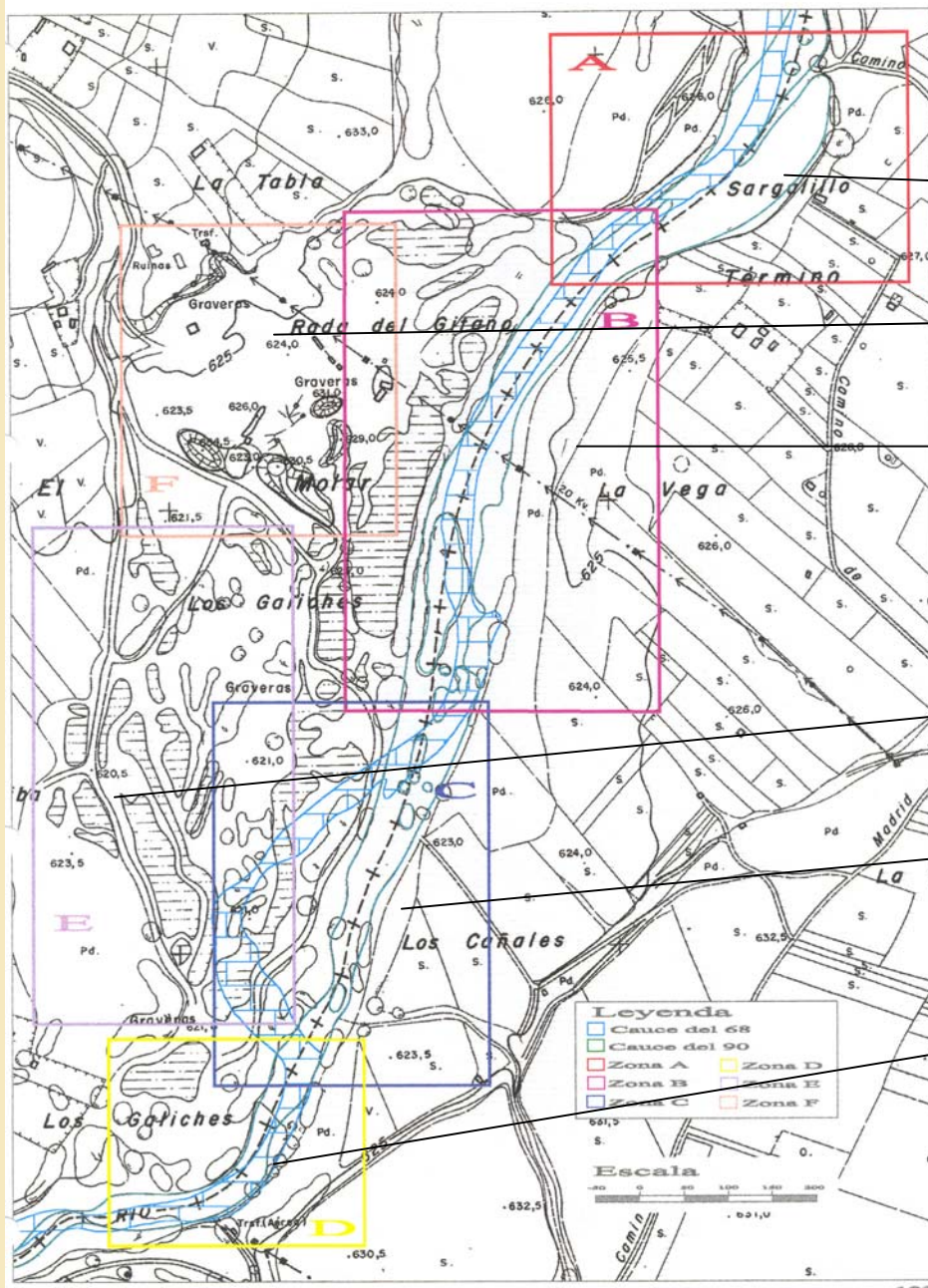
- Channel confinement due to remaining levees
- Big depressions under phreatic level remaining from old gravel minery.

Diagnostic (sedimentary dynamic)



- Affected by selective gravel mining (leaving big boulders in the 70's)
- Affected by flow regulation
- High levels of suspended solids entering reach from upstream active gravel mines.

Zonation



Zone A

Right bank- 1

Zone B

Right bank- 2

Zone C

Zone D

Shallow habitat with unadequate width/depth relationship (Zone A)



Levees in initial situation (Zone B)



LEVEE (right bank)

Main channel

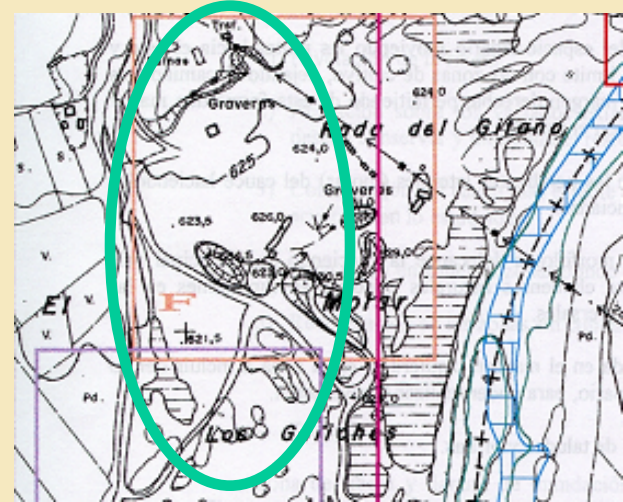
Depression
(lagoon)



DYKE (floodplain)

Zones E and F (floodplain)

Presence of obsolete buildings and depressions from gravel mining



IGF evaluation (previous)

Parameter	Status			
	Optimum	Suboptimum	Marginal	Poor
1.- Vertical dynamic	Vertical profile corresponds completely to natural situation of studied reach and the balance between geologic control and dynamic	Slight alterations of natural vertical profile, due to punctual activities (canalization, small dams, dragging, ...) that influence up and downstream affecting less than 25% of reach.	Profile shows significant alterations in 25-75% in length or presents a heavy alteration due to big activity (canalization, big dams, dragging, ...)	Profile shows significant alterations in more than 75% of its length due to several big activities (canalization, big dams, dragging, ...)
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2.- Lateral dynamic	Channel, riparian zone and floodplain are completely free to move and evolve naturally	Segment presents modifications from natural planform or artificially stabilised dynamic by diffuse human pressure on banks or direct impacts (dredging, levees, ...) affecting less than 25% of segment.	Segment presents alterations in its planform affecting 25-75% of its length, or its dynamic is completely paralyzed by human pressures.	Segment presents alterations in its planform affecting more than 75% of its length and becomes a channel without natural dynamic.
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

IGF evaluation (previous)

Parameter	Status																				
	Optimum			Suboptimum			Marginal			Poor											
3.- Stability of naturally stable banks	Banks without evidence of erosion. Low risk of future problems.			Moderately stable banks, small not continuous erosion patches affecting 10-25% bank.			Unstable banks, impacted by non-natural erosion in 25-50% length. High erosionability during spates.			Very unstable banks, with non-natural bank failures affecting more than 50% of reach.											
Right bank.	10	9		8	7	6	5	4	3	2	1	0									
Left bank	10	9		8	7	6	5	4	3	2	1	0									
4.- Sedimentary status	Natural river bed with diverse refuge for fauna and balanced with fluvial reach dynamic.			Evidence of a certain degree of non natural sedimentation, erosion or embeddedness affecting 25-50% of river bed.			Non natural incision (upstream erosion), sedimentation, erosion or embeddedness affecting 50-75% of reach bed.			Non natural incision (upstream erosion), sedimentation, erosion or embeddedness affecting more than 75% of reach bed.											
Scoring	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0

IGF scoring (TOTAL) = 17

Relative scoring = 17/80 = 21%

A photograph of a rocky stream bed. The stones are light-colored and rounded, scattered across the frame. Green plants with small leaves are growing between the rocks, some reaching upwards. The overall scene is a natural, somewhat overgrown stream bed.

RESTORATION IMPLEMENTATION

2001

Objectives and scale

- **Rehabilitate the fluvial ecosystem according to actual flow regulation and watershed conditions**
- **Implement a self-regulated physical habitat structure**
- **Defense and conservation of natural values from future impacts**
- **Promote Public Use**

SCALE: 1,2 km

Restoration (phylosophy and actions)

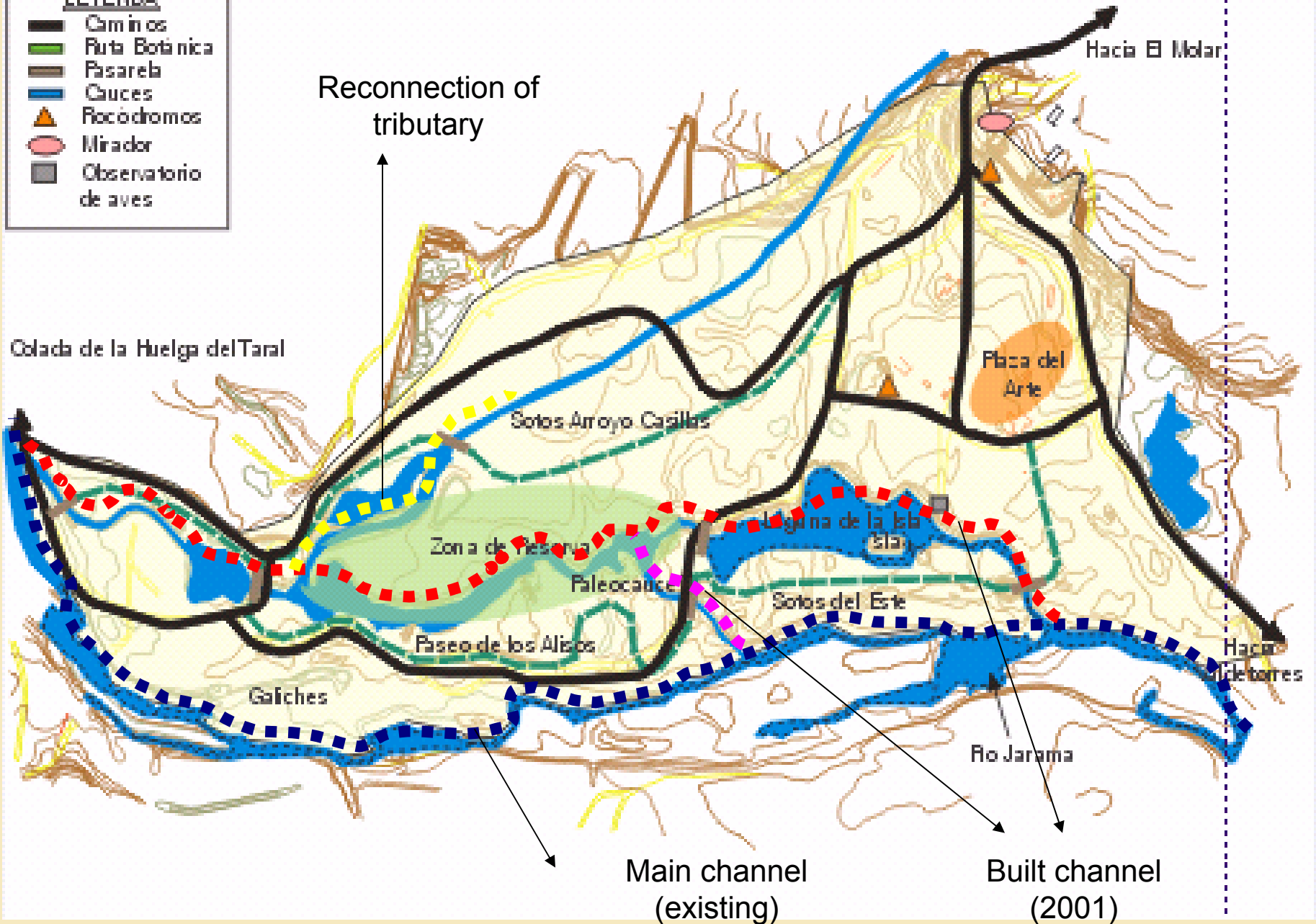
“Give the river freedom and space to build its own morphology”

ACTIONS

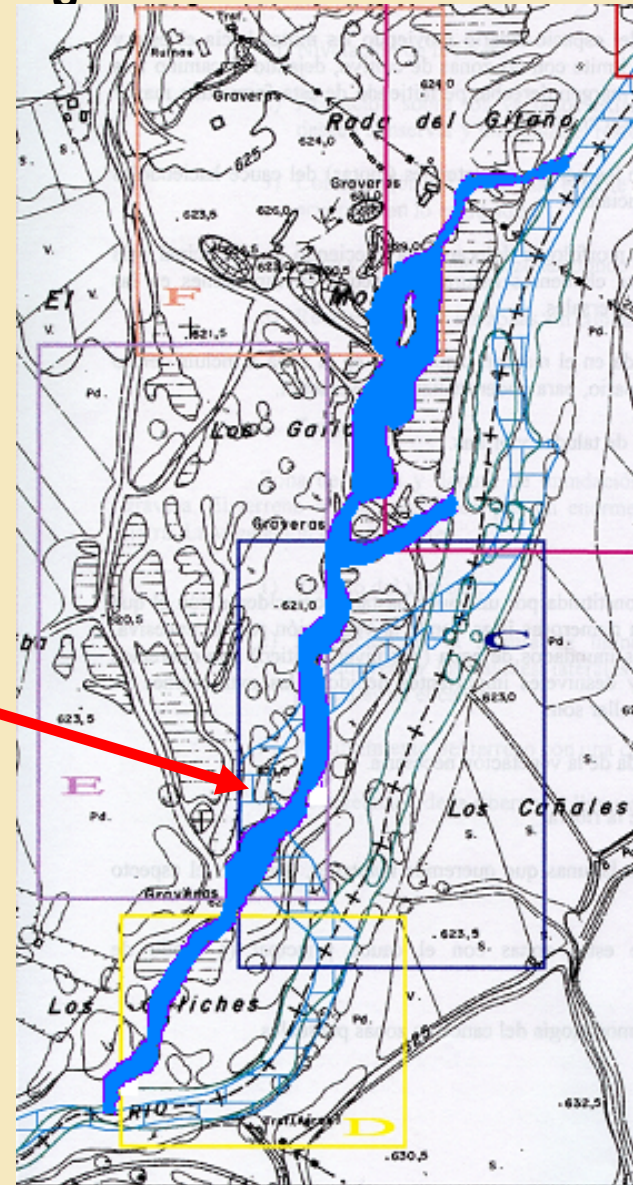
- Re-build planform and cross-sections according to 1968's situation
- Promote sinuosity and better width/depth relationships increasing biological habitat suitability
- Elimination of remnant levees and obstacles to fluvial dynamic, respecting existing vegetation.
- Levelling of holes and old mines in floodplain
- Revegetation

LEYENDA

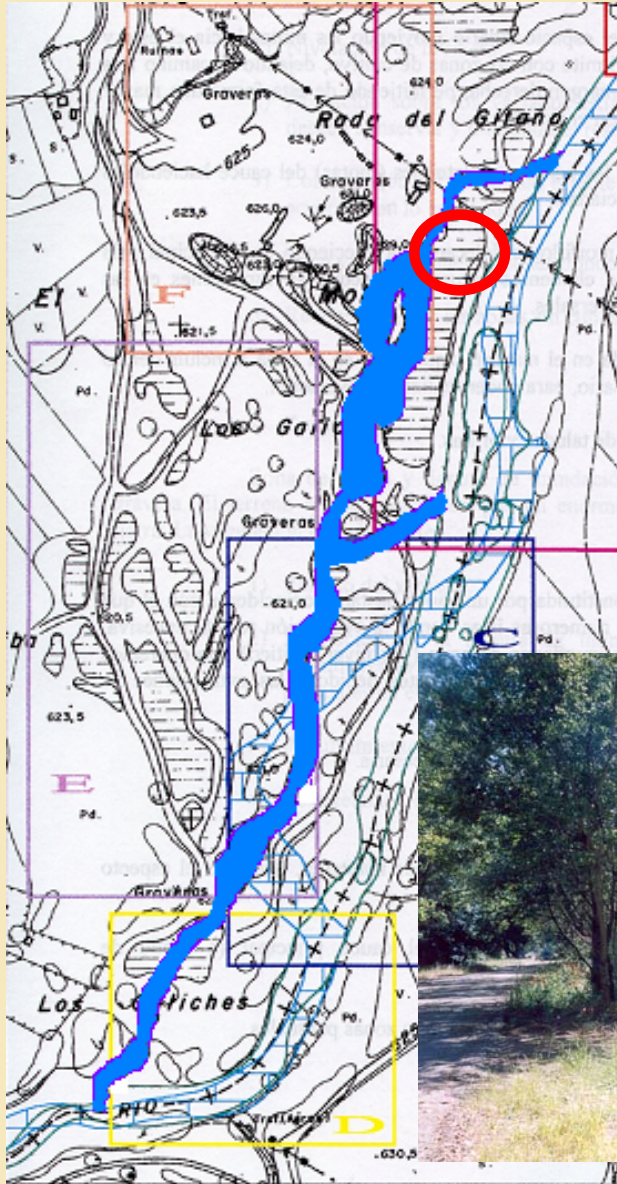
- Caminos
- Ruta Botánica
- Pisarela
- Cuques
- Picodromos
- Mirador
- Observatorio de aves



Conection of tributary Arroyo de la Casilla to main secondary channel linking existing lagoons.



Restoration of many open holes, aisolated by dykes and covered by freatic vegetation



Lagoon construction



Recovered natural channel, downstream the lagoon



Costruction of a secondary channel (conectivity and braided)



Water quality at entrance and at out-let (2002) (filter)



Adequation to public use (pre-existing constructions).





POST-PROJECT
APPRAISAL 2001-2005

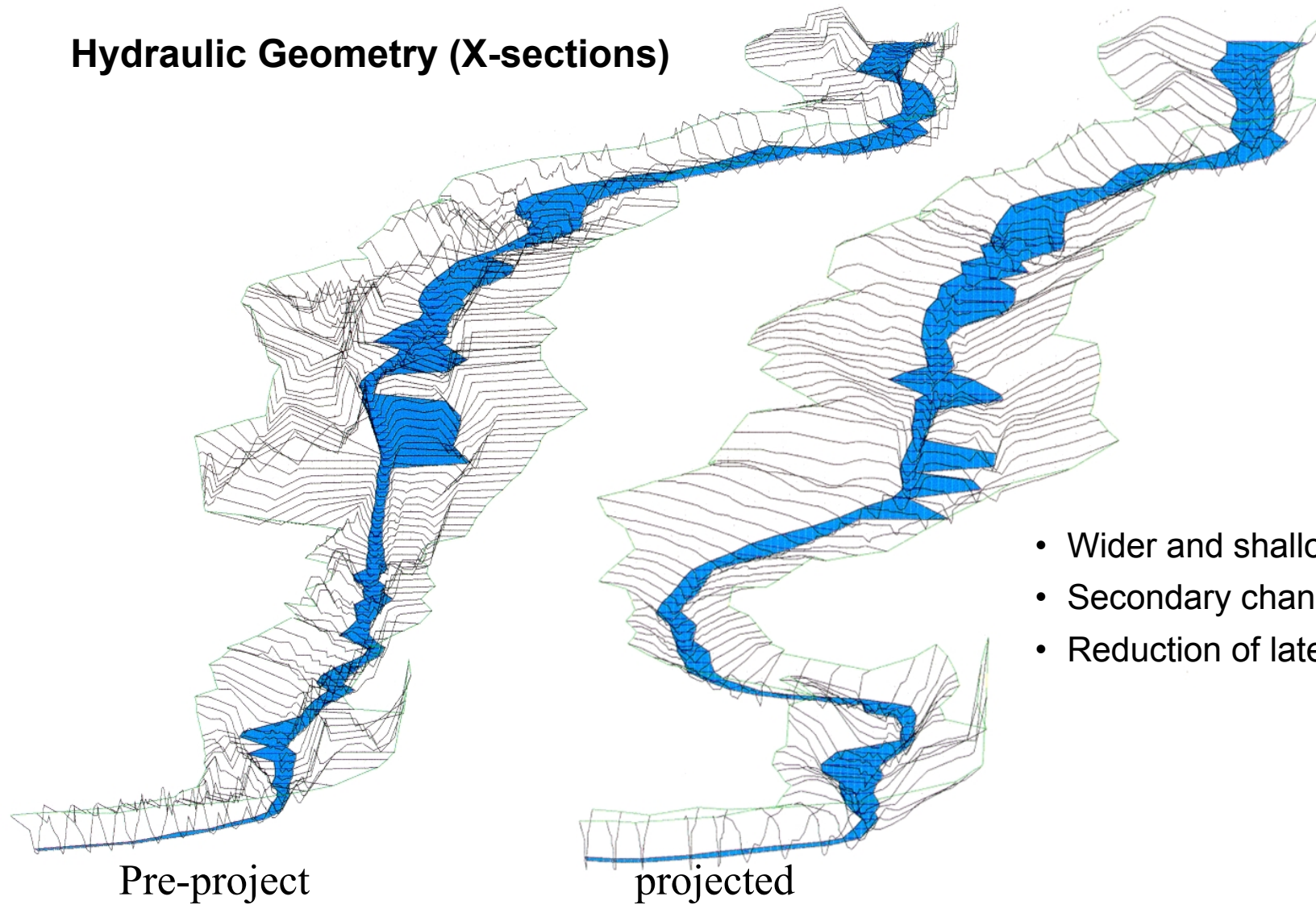
SUCCESS CRITERIA

- Re-naturalization of fluvial dynamic
- Regeneration of riparian vegetation
- Enhancement of aquatic habitat: fish community.
- Social involvement

BASELINE SURVEYS

- 1999 pre-project surveys:
macroinvertebrates, riparian vegetation,
topography, fauna, IGF,...
- Annual biological surveys.
- Topography (after 5 years, 2006)
- Survey of social use of facilities

Hydraulic Geometry (X-sections)



Study hydraulic conditions from topographic cross sections (pre-project) and from designed ones (HEC-RAS).

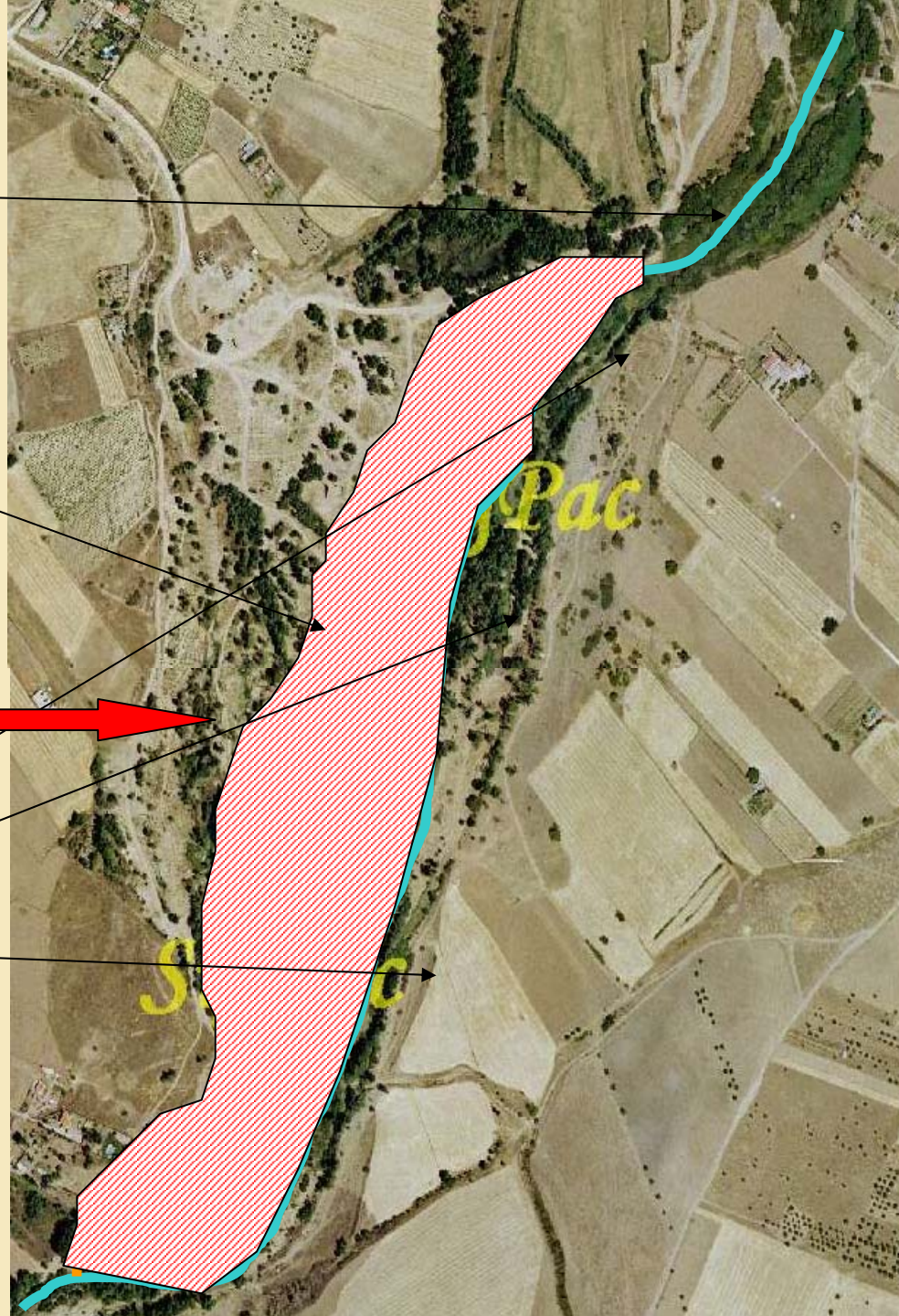
Old channel

Secondary channel

Space given to river

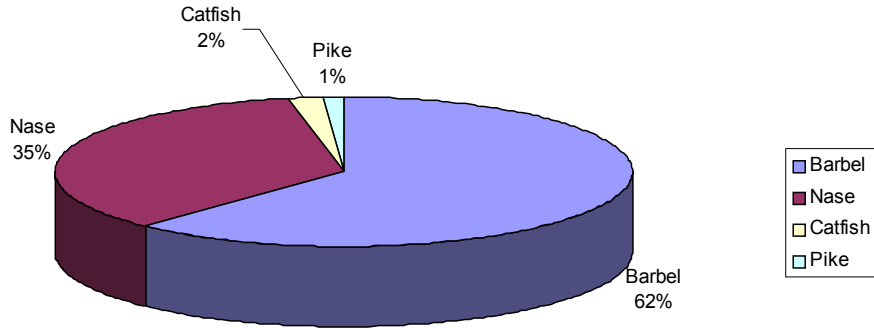
Remaining levees
(Left bank)

Farmer's resistance

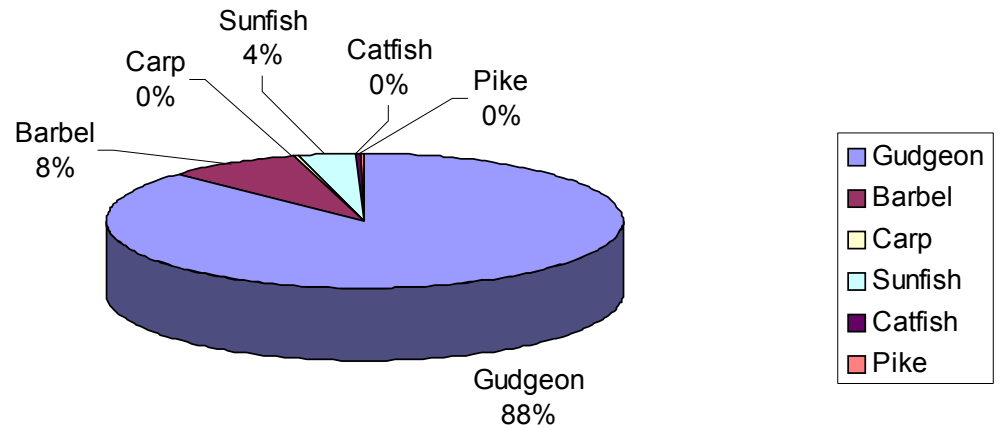


POST-PROJECT MONITORING (I)

1999 Composition (%)



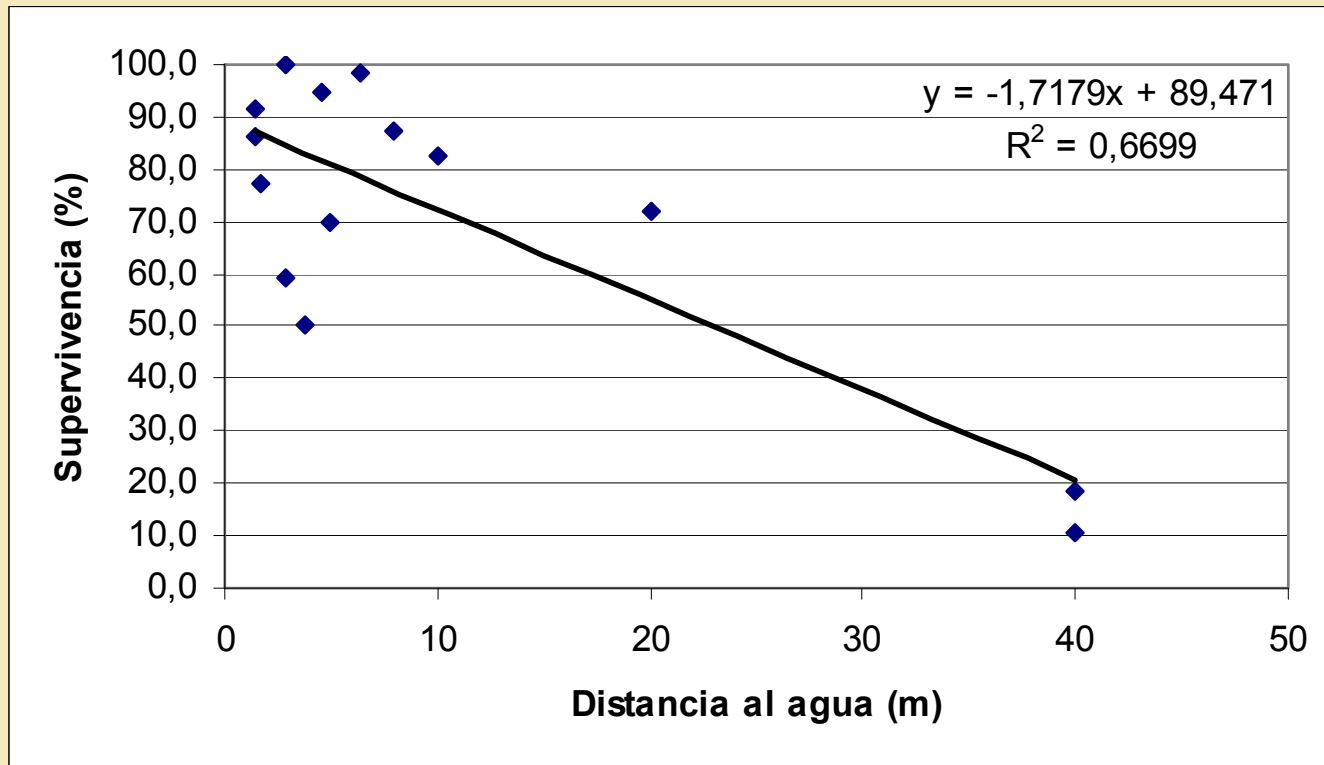
2004 Density (ind/m2)



Regeneration in banks affected by gravel extraction



POST-PROJECT MONITORING (III)



Decrease of survival related to distance to river

Mora, 2004

Flow entrance to secondary channel (active profile)



Jul-2003

Active sedimentary dynamic



POST-PROJECT MONITORING (II)

Secondary analytical procedures (IGF evaluation)

Parameter	Status			
	Optimum	Suboptimum	Marginal	Poor
1.- Vertical dynamic	Vertical profile corresponds completely to natural situation of studied reach and the balance between geologic control and dynamic	Slight alterations of natural vertical profile, due to punctual activities (canalization, small dams, dragging, ...) that influence up and downstream affecting less than 25% of reach.	Profile shows significant alterations in 25-75% in length or presents a heavy alteration due to big activity (canalization, big dams, dragging, ...)	Profile shows significant alterations in more than 75% of its length due to several big activities (canalization, big dams, dragging, ...)
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0
2.- Lateral dynamic	Channel, riparian zone and floodplain are completely free to move and evolve naturally	Segment presents modifications from natural planform or artificially stabilised dynamic by diffuse human pressure on banks or direct impacts (dredging, levees,...) affecting less than 25% of segment.	Segment presents alterations in its planform affecting 25-75% of its length, or its dynamic is completely paralyzed by human pressures.	Segment presents alterations in its planform affecting more than 75% of its length and becomes a channel without natural dynamic.
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

IGF evaluation (after)

Parameter	Status			
	Optimum	Suboptimum	Marginal	Poor
3.- Stability of naturally stable banks	Banks without evidence of erosion. Low risk of future problems.	Moderately stable banks, small not continuous erosion patches affecting 10-25% bank.	Unstable banks, impacted by non-natural erosion in 25-50% length. High erosionability during spates.	Very unstable banks, with non-natural bank failures affecting more than 50% of reach.
Right bank.	10 9	8 7 6	5 4 3	2 1 0
Left bank	10 9	8 7 6	5 4 3	2 1 0
4.- Sedimentary status	Natural river bed with diverse refuge for fauna and balanced with fluvial reach dynamic.	Evidence of a certain degree of non natural sedimentation, erosion or embeddedness affecting 25-50% of river bed.	Non natural incision (upstream erosion), sedimentation, erosion or embeddedness affecting 50-75% of reach bed.	Non natural incision (upstream erosion), sedimentation, erosion or embeddedness affecting more than 75% of reach bed.
Scoring	20 19 18 17 16	15 14 13 12 11	10 9 8 7 6	5 4 3 2 1 0

IGF scoring (TOTAL) = 45

Relative scoring = 45/80 = 56%

Δ IGF (%) = 35

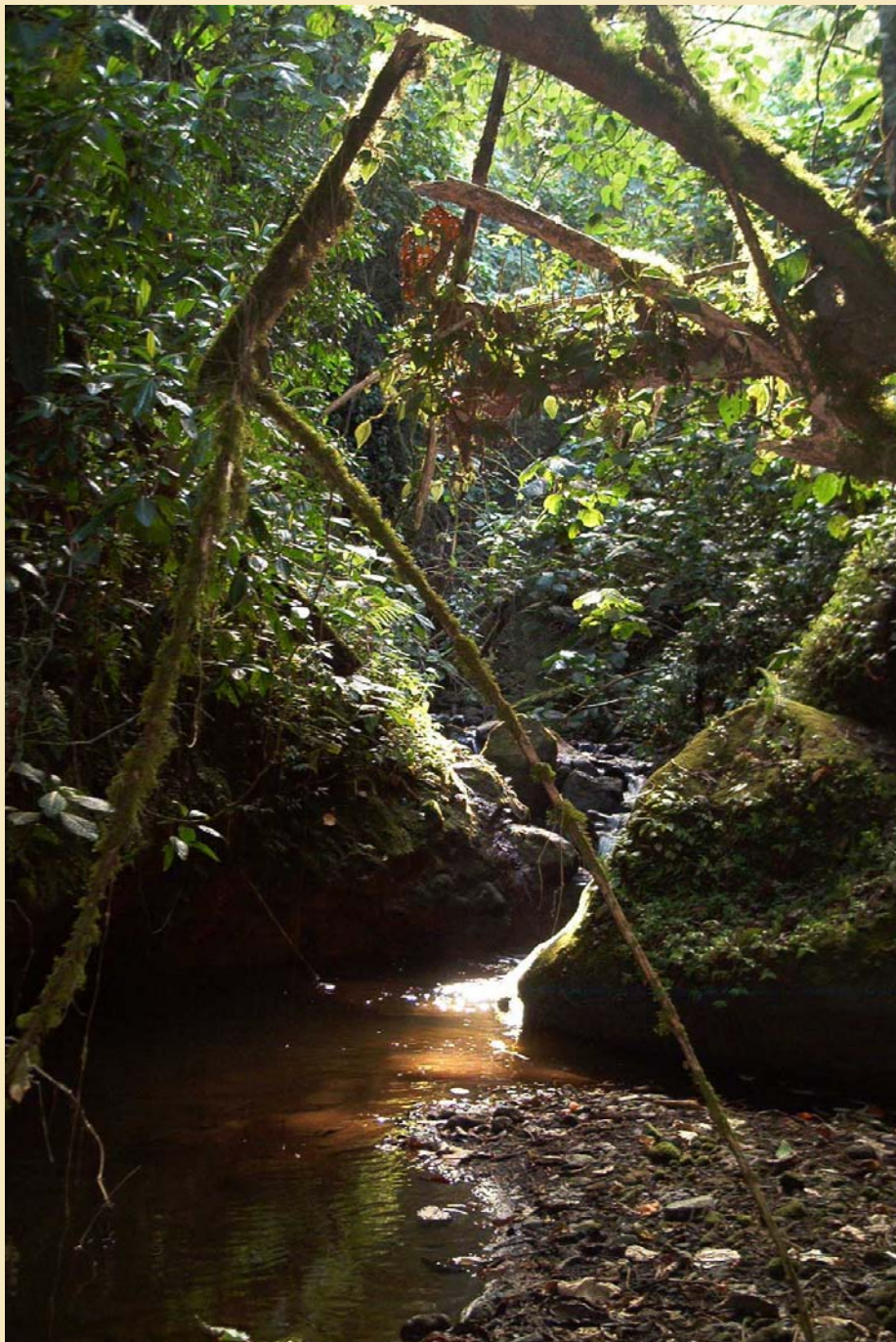
Problems

- Eutrophication and water warming below main lagoon
- Fine sediments coming from upstream
- Aloctonous sps.
- Levees in left bank
- No funds for monitoring results



Conclusions

- 1. Main goal of the restoration was to give the river freedom and space to build its own morphology.**
- 2. IGF was sensitive to changes in fluvial geomorphology related to restoration activities.**
- 3. IGF could be a good indicator of the degree of success in restoration projects.**
- 4. We propose the extent of IGF application in different ecotypes and watersheds, to check its performance under different conditions.**
- 5. Post-project appraisal allows the identification of critical problems for an adaptive management scheme.**



Thank you!

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 ecohidráulica



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