Stream Rehabilitation Concepts, Guidelines and Examples

Pierre Y. Julien

Malaysia 2005

Objectives

<u>Part I</u> - Stream restoration and rehabilitation:

1. **Present and discuss important concepts, laws, criteria and guidelines**
2. **Present examples of stream rehabilitation**

Three Laws of Stream Restoration

#1 There is no cookbook approach to stream restoration projects.

Example Showing the Impact of Deforestation and Flood Control

Water Resources Development

Demographic Expansion

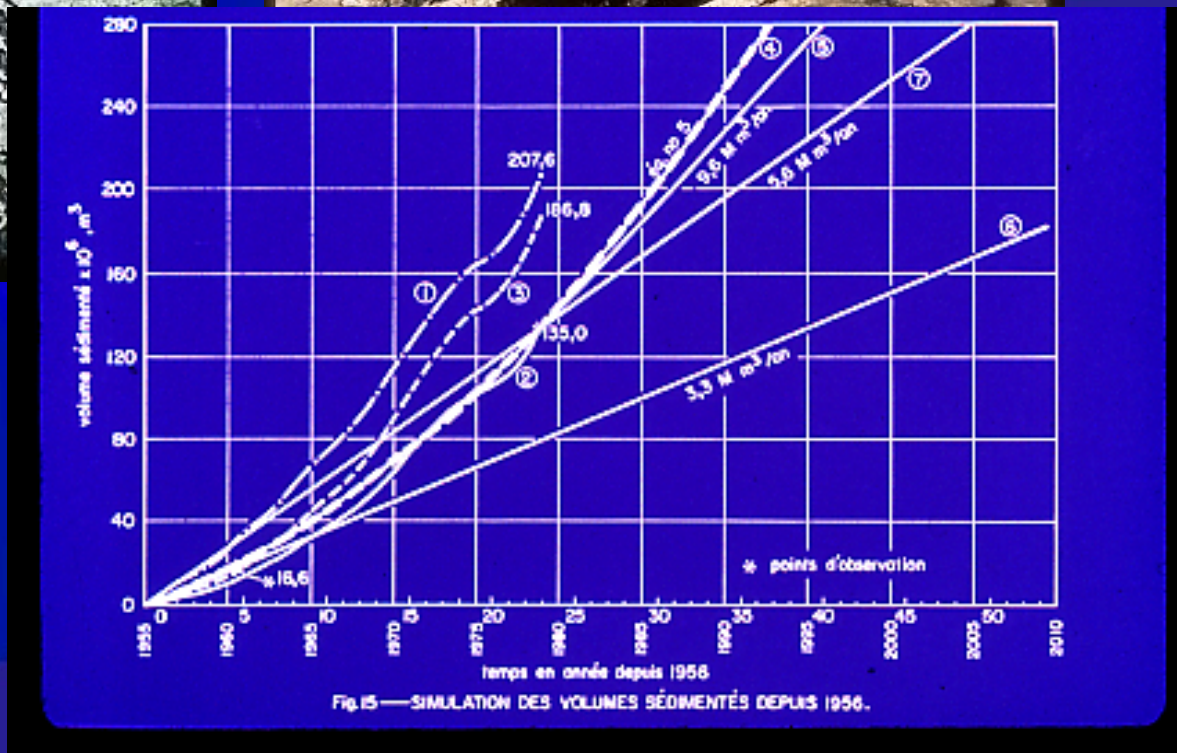
Lowland Slash and Burn

Subsistence Farming

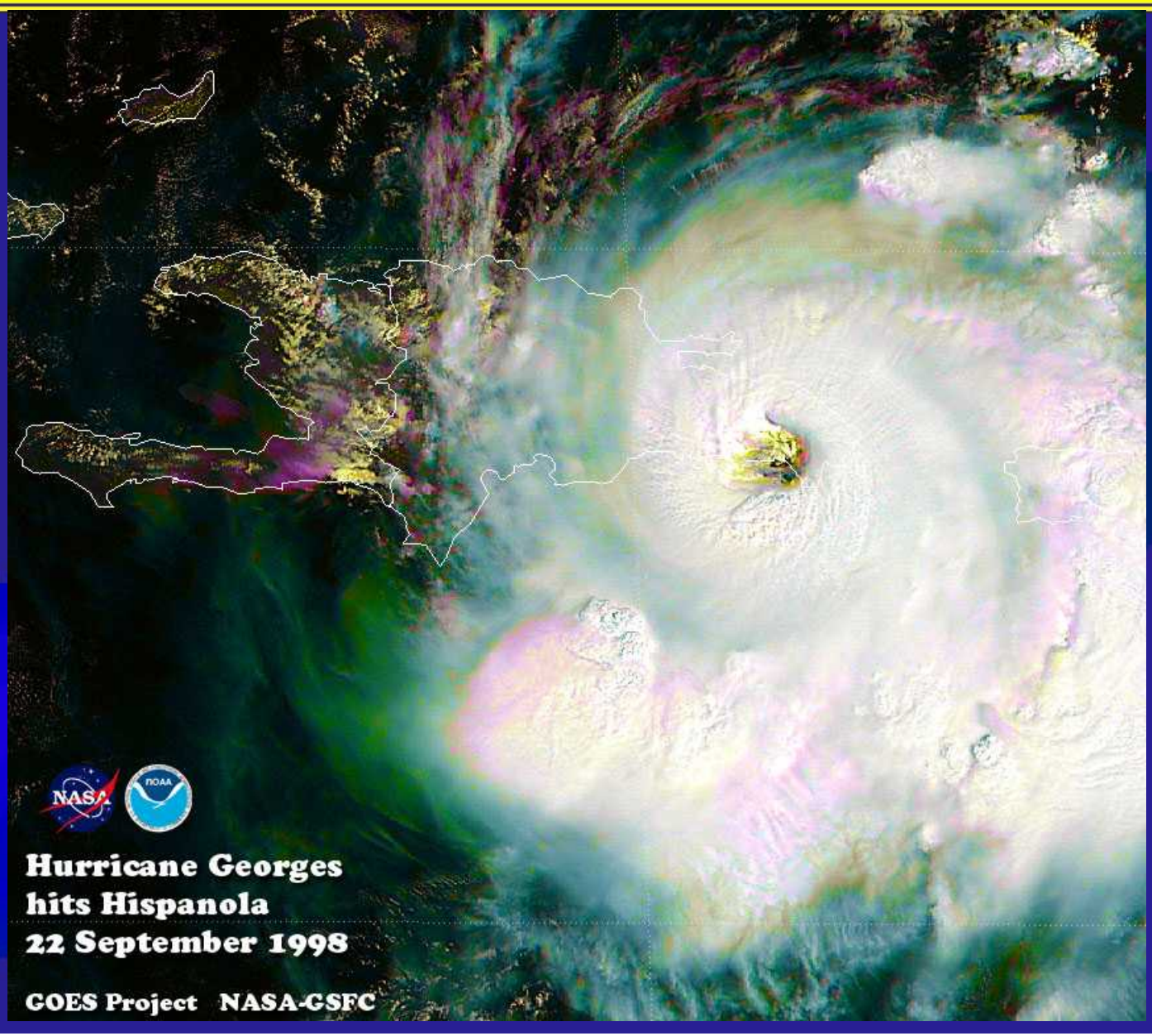
Farming Hilltops?

Watershed Deforestation

Peligre Dam (sedimentation)



Hurricane Impact



Emergency Spillway Operation

Flood Damages

Emergency Situation

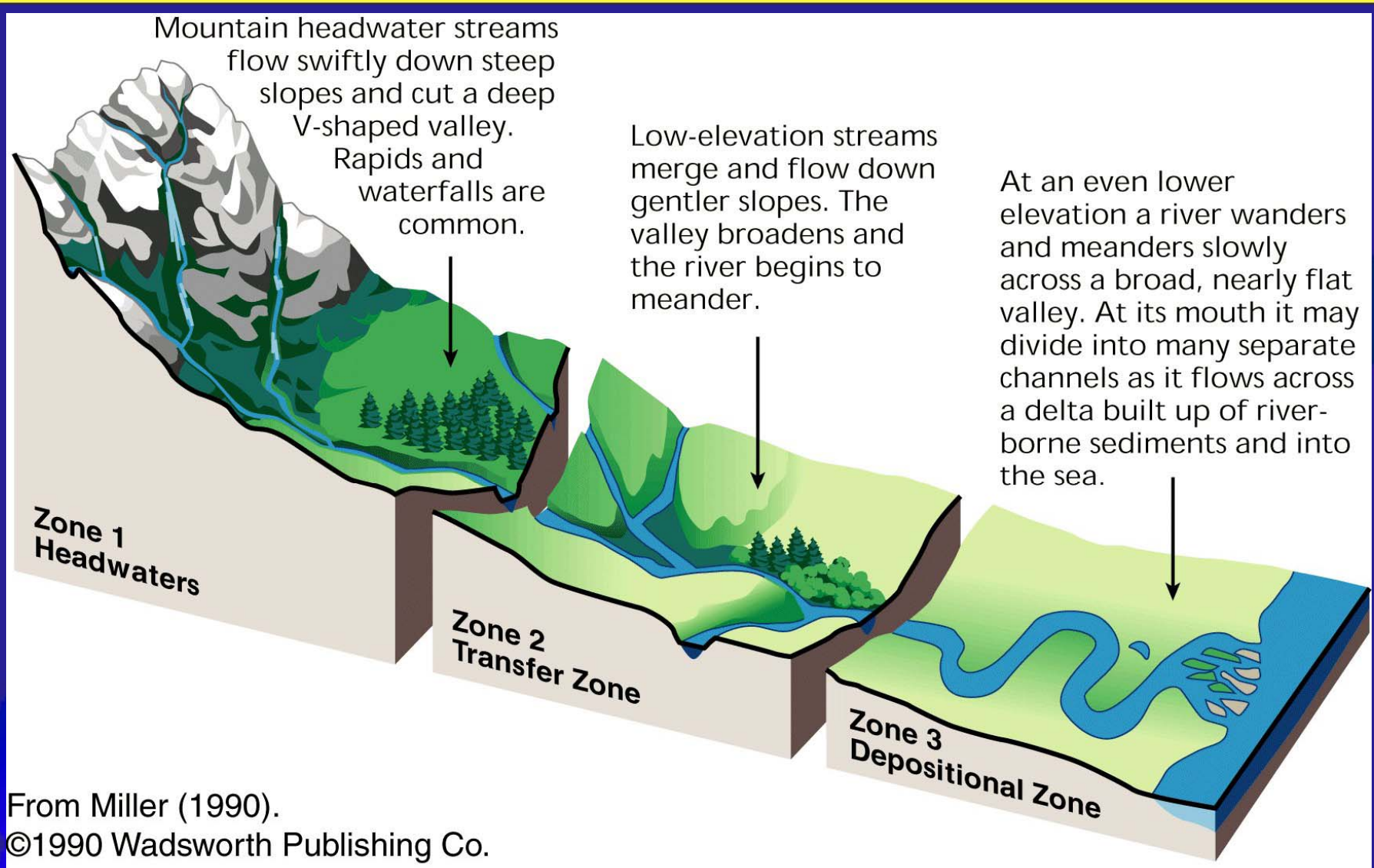
Citizens Blame their Government

Three Laws of Stream Restoration

#1 There is no cookbook approach to stream restoration projects.

#2 Solutions normally seek **equilibrium** conditions between water and sediment regime and stream ecology.

Concept of Equilibrium



From Miller (1990).

Fig. 1.27 – Three longitudinal profile zones.
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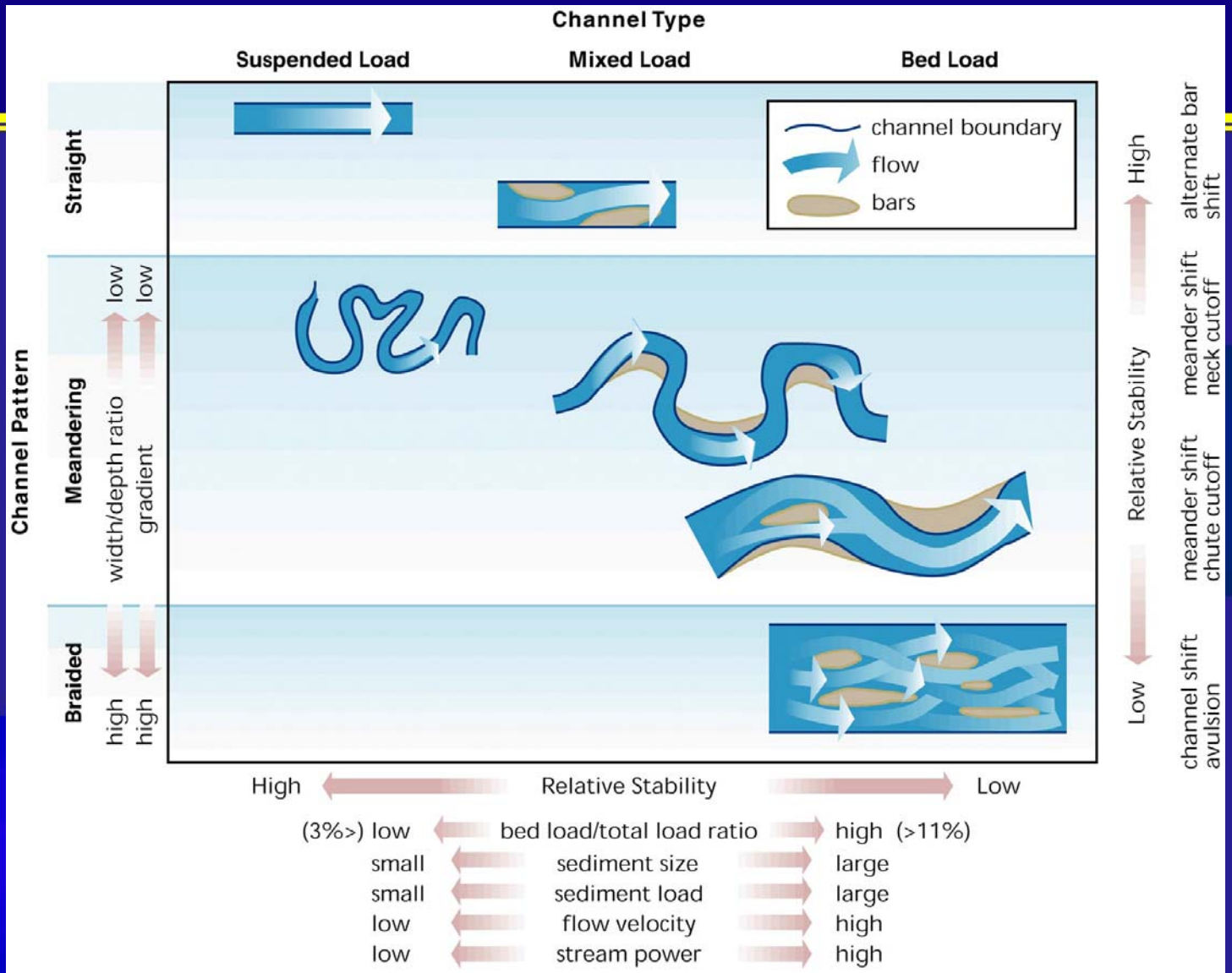

Source: Schumm, The Fluvial System. © 1977. Reprinted by permission of John Wiley and Sons, Inc.

Fig. 7.10 -- Classification of alluvial channels, per Schumm's classification system.
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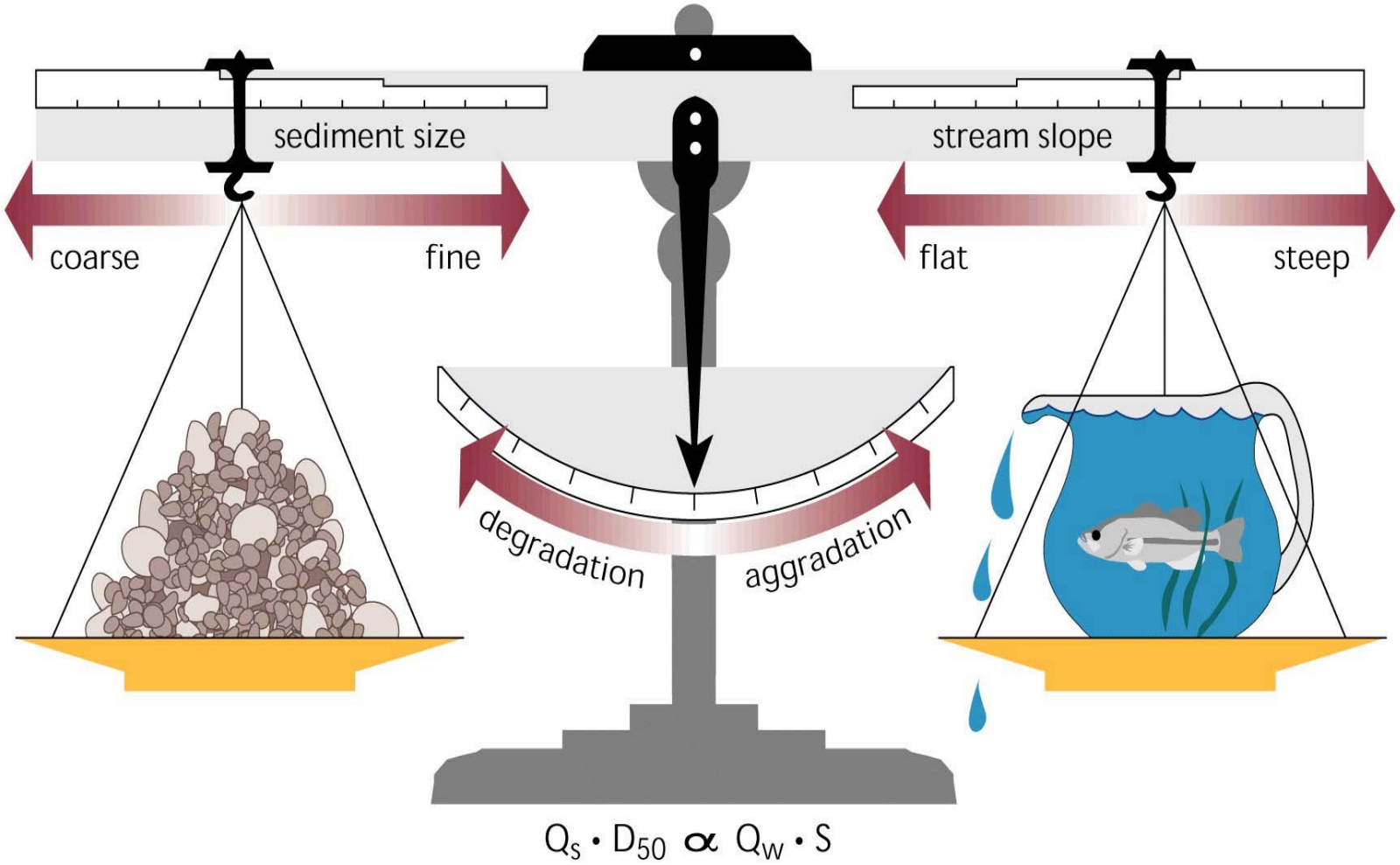
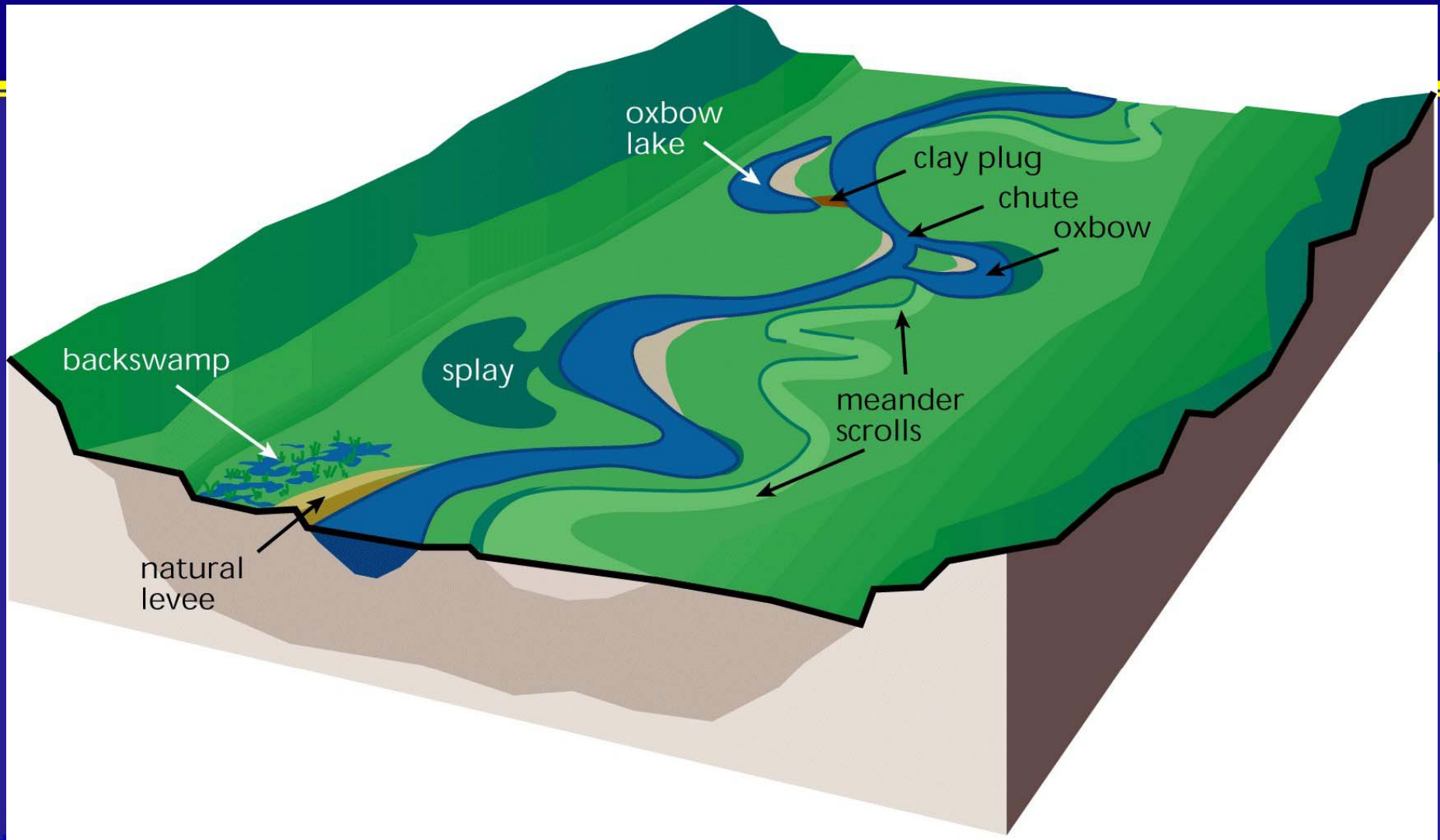
Concept of Equilibrium

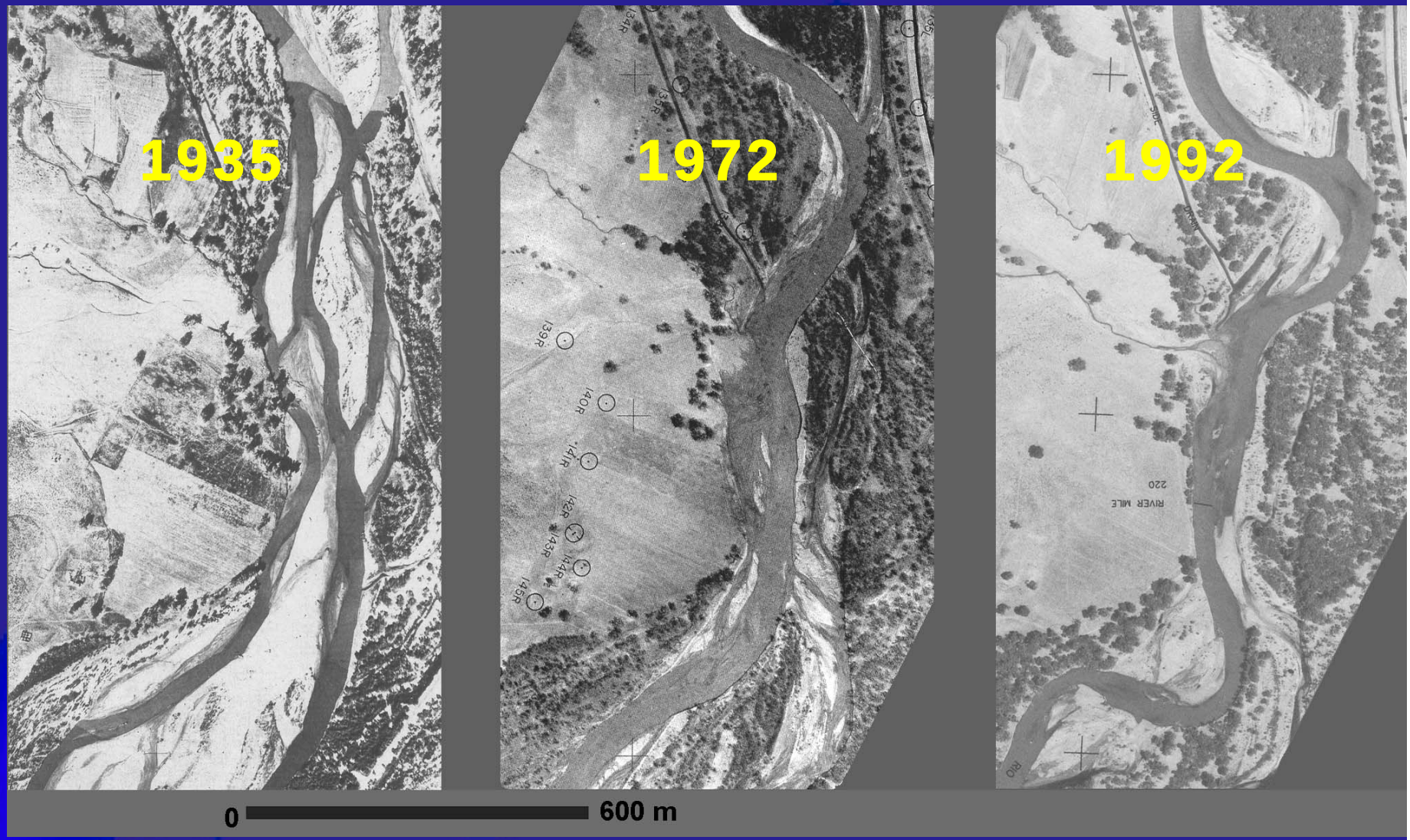


Time Scale

- Geological ~ 1,000,000 years
- Engineering ~ 100 years
- Aquatic life ~ 1 year


oxbow
lake
clay plug
chute
oxbow
backswamp
splay
meander
scrolls
natural
levee

Hydraulic geometry of the Rio Grande



Impact on Aquatic Life

Debris Deposition

Restoration vs Rehabilitation

Restoration

•returning a resource to some former condition.

Rehabilitation

•maximize the potential beneficial uses of a resource to some reasonable and practical level.

Three Laws of Stream Restoration

#1 There is no cookbook approach to stream restoration projects.

#2 Solutions normally require equilibrium conditions between sediment regime and stream ecology.

#3 Solutions need to be effective, environmentally acceptable and economical.

REQUIREMENTS OF BANK STABILIZATION

- Effective
- Environmentally Sound
- Economical

(Listed in order of necessity)

Effective

Effective

Effective

Effective

REQUIREMENTS OF BANK STABILIZATION

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Environmentally Sound

Environmentally Sound

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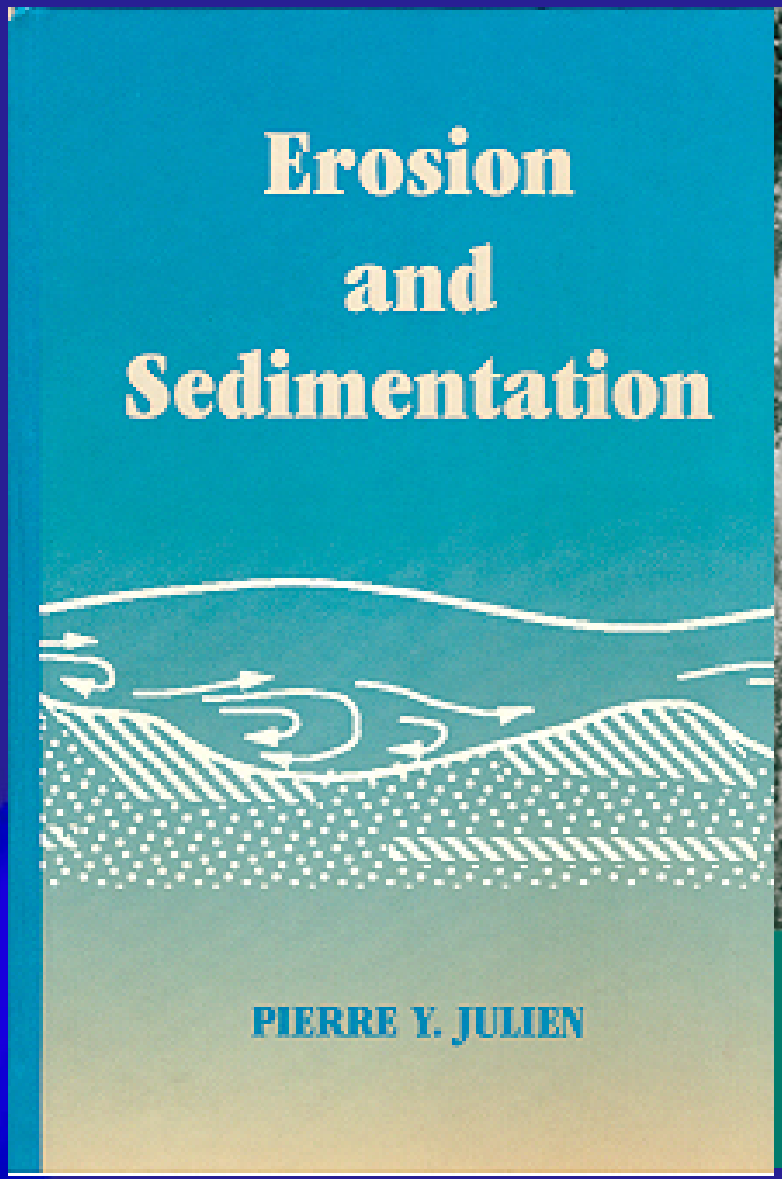
Economical

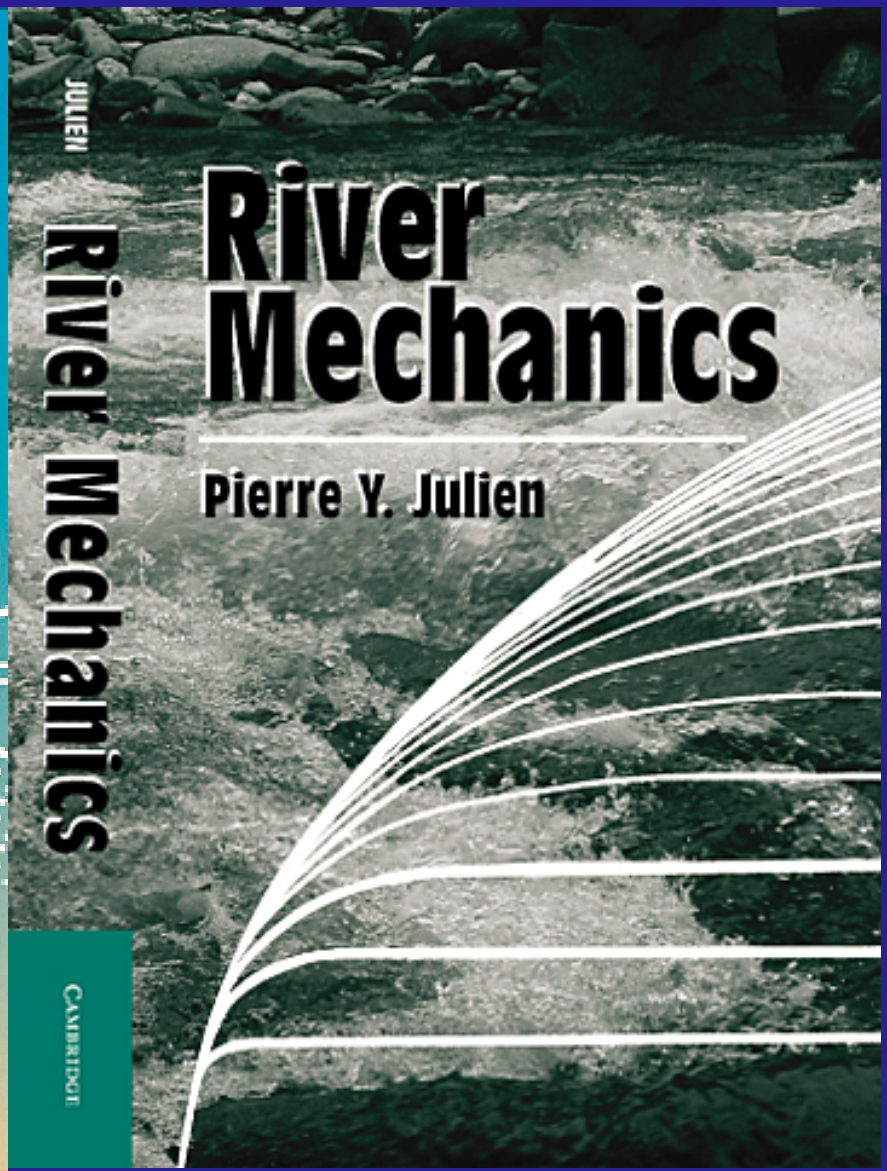
Economical

Economical

E, E and E!

Erosion and River Mechanics Textbooks





Objectives

Part II – Guidelines and Case Study

1. Guidelines for Stream Restoration Projects
2. Case-study on the Rio Grande

Stream Restoration Guidelines

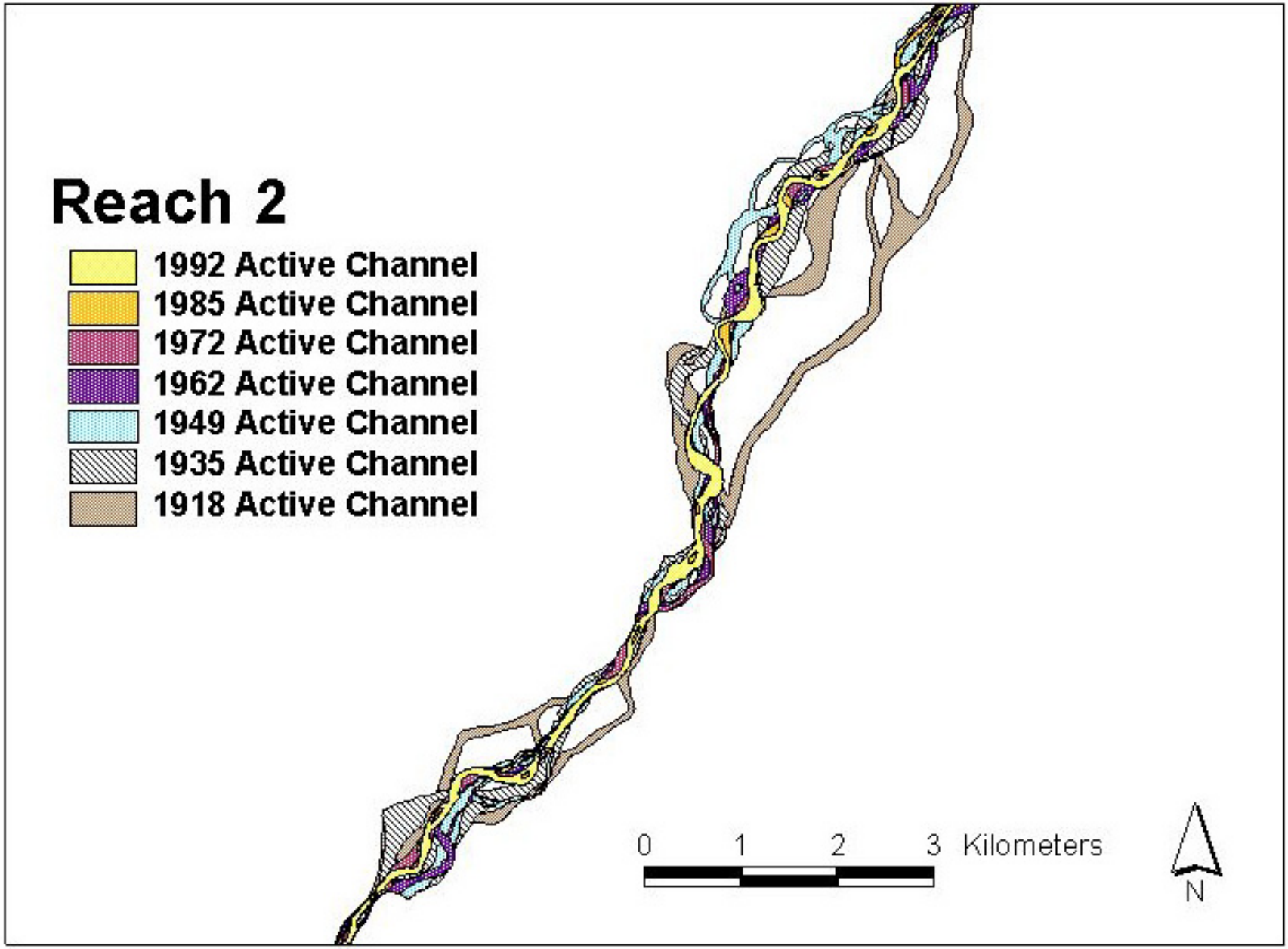
1. **OBJECTIVES** - Clearly define the engineering and ecological objectives. Restoration vs rehabilitation.

2. **PAST, PRESENT and FUTURE**
   – Consider present conditions in the perspective of past events and examine future changes.

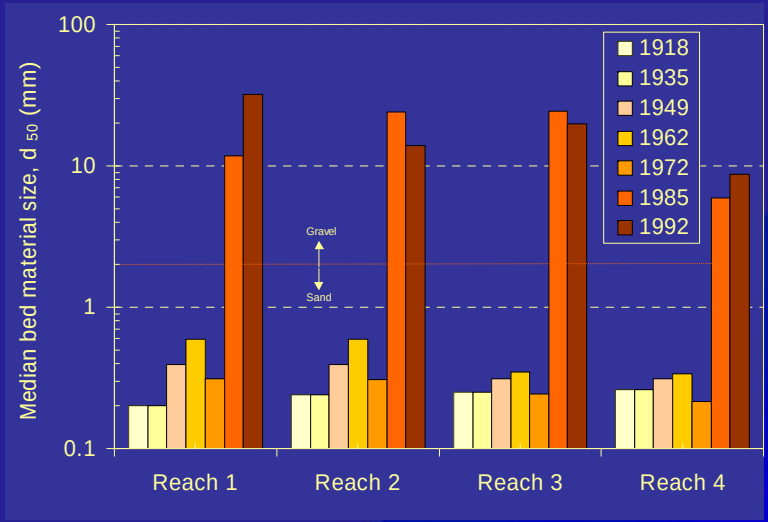
Project Goals

- **Protect Levee**
- **Create a Functioning Floodplain**
- **Improve Wildlife Habitat**

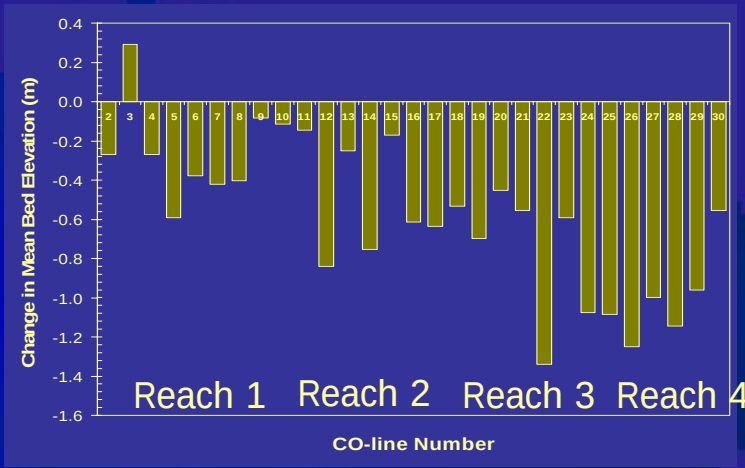
Changes in hydraulic geometry



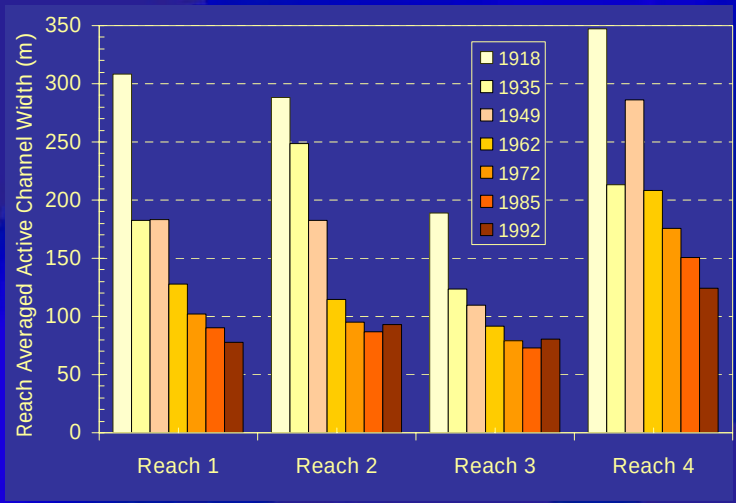
Hydraulic geometry of the Rio Grande



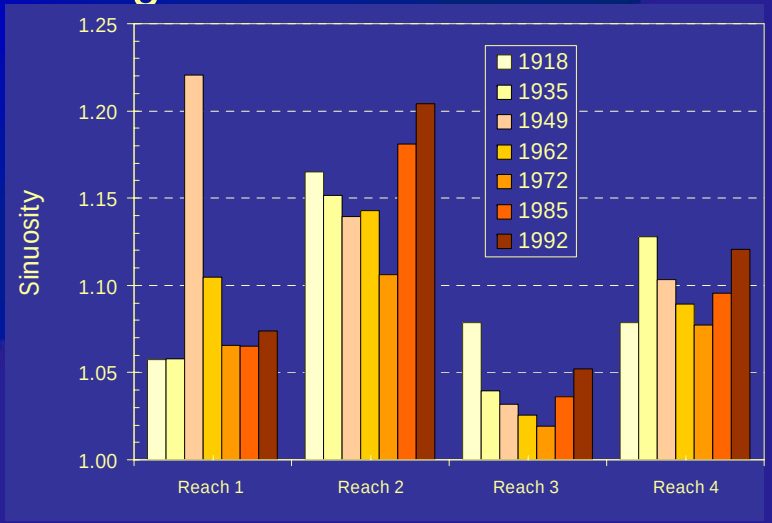
Bed material size



Change in Mean Bed Elevation



Active channel width



Sinuosity

Stream Restoration Guidelines

3. **UPPER WATERSHED** – Look at the geology, deforestation, land use changes, urbanization, climate and extreme events. Examine water and sediment supply, flood frequency curves, sediment mass curves sediment concentrations, water quality, etc.

4. **DOWNSTREAM REACH** – Look at possible changes in the downstream reach that may affect current conditions – like reservoirs, base level changes, headcutting, etc.

5. Woody Debris against Bridges

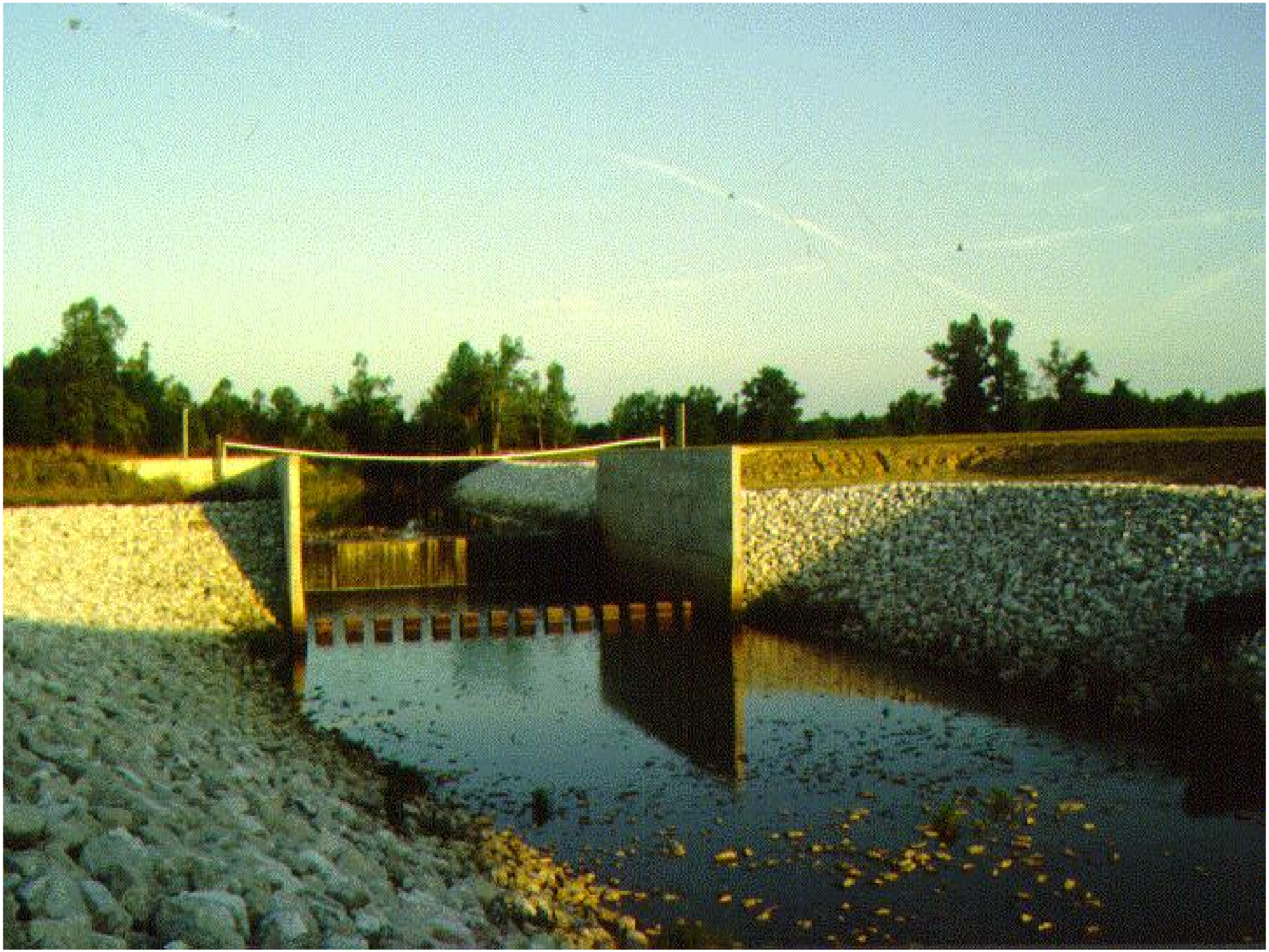
5. Woody Debris - Lower Mississippi River

Vertical Degradation

Headcutting

Headcutting

Bank Caving



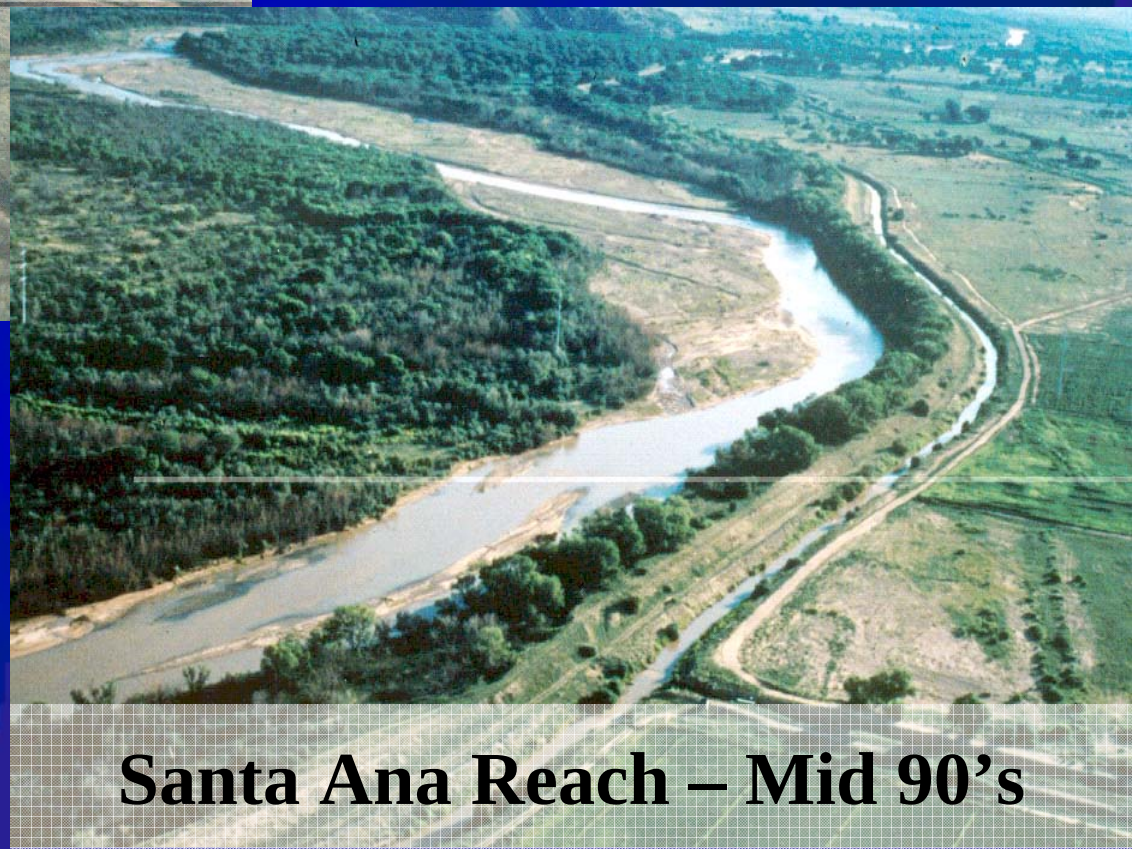
Stream Restoration Guidelines

5. **CHANNEL GEOMETRY** – Determine equilibrium downstream hydraulic geometry in terms of width, depth, velocity, slope, discharge and morphology.

6. **AQUATIC HABITAT**– determine appropriate aquatic habitat conditions including low and high flow periods, pools, riffles, spawning grounds, shade, aeration, migration, etc.

Rio Grande Restoration– Floodplain restoration

Santa Ana Reach - Mid 80's



Santa Ana Reach – Mid 90's

Rio Grande Restoration– Endangered Species

- **Bimodal sand/gravel bed**
- **Deep water h ~ 1.20 m**
- **Water velocities 1.4 m/s**

Restoration

- **Create wider channels**

- **Sandy/silty substrate**
- **Shallow water h < 0.4 m**
- **Water velocities**

0.1 m/s < V < 0.5 m/s

Stream Restoration Guidelines

7. **EXAMINE ALTERNATIVES** – Identify several different stream rehabilitation schemes that would suit the engineering and environmental needs.

8. **DESIGN SELECTION –** examine the various alternatives and select the best possible alternative and proceed with the design. Solution must be effective, environmentally sound and economical.


Link-Belt
HMC
EX

Gradient Restoration Facility

- **Raise Riverbed with GRF**

River Realignment

- **Construct Bio-engineering Bankline**

Floodplain Restoration

- **Excavated Sediment Placed near Pilot Channel**

Habitat Improvement

- **Sediment Storage Upstream from GRF**
- **Low Velocity Overbank Flows**
- **Planting and Natural Reseeding of Native Vegetation**

Stream Restoration Guidelines

9. **CONSTRUCTION** – Carefully plan the construction and consider the possible impact of possible extreme events during the construction period.

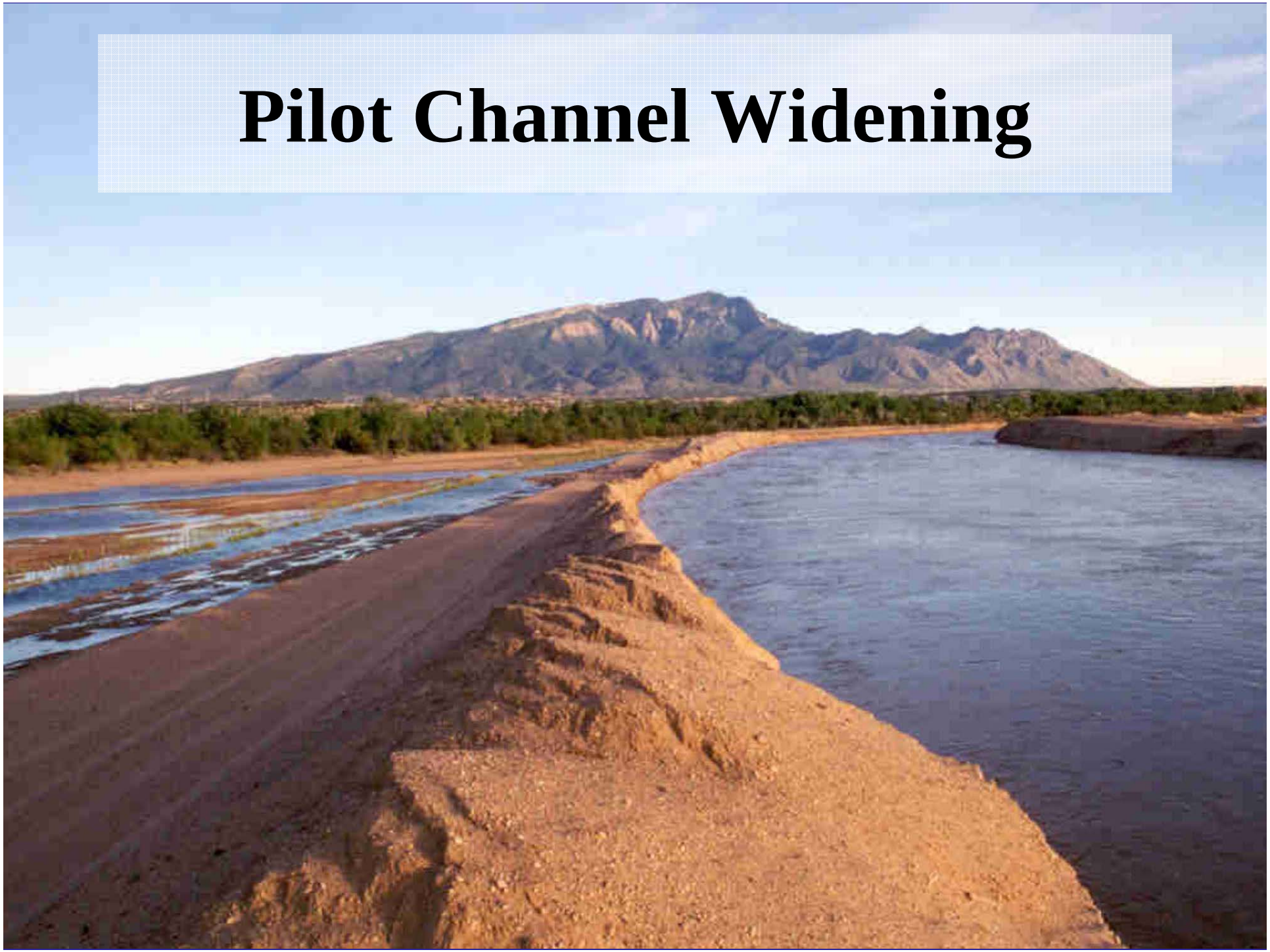
10. **MONITORING** – Things may not work as planned. A post-construction analysis and monitoring should be carried out until the objectives have been met.

Opening Pilot Channel

River Realignment

- **Divert River into Pilot Channel**

Pilot Channel Widening

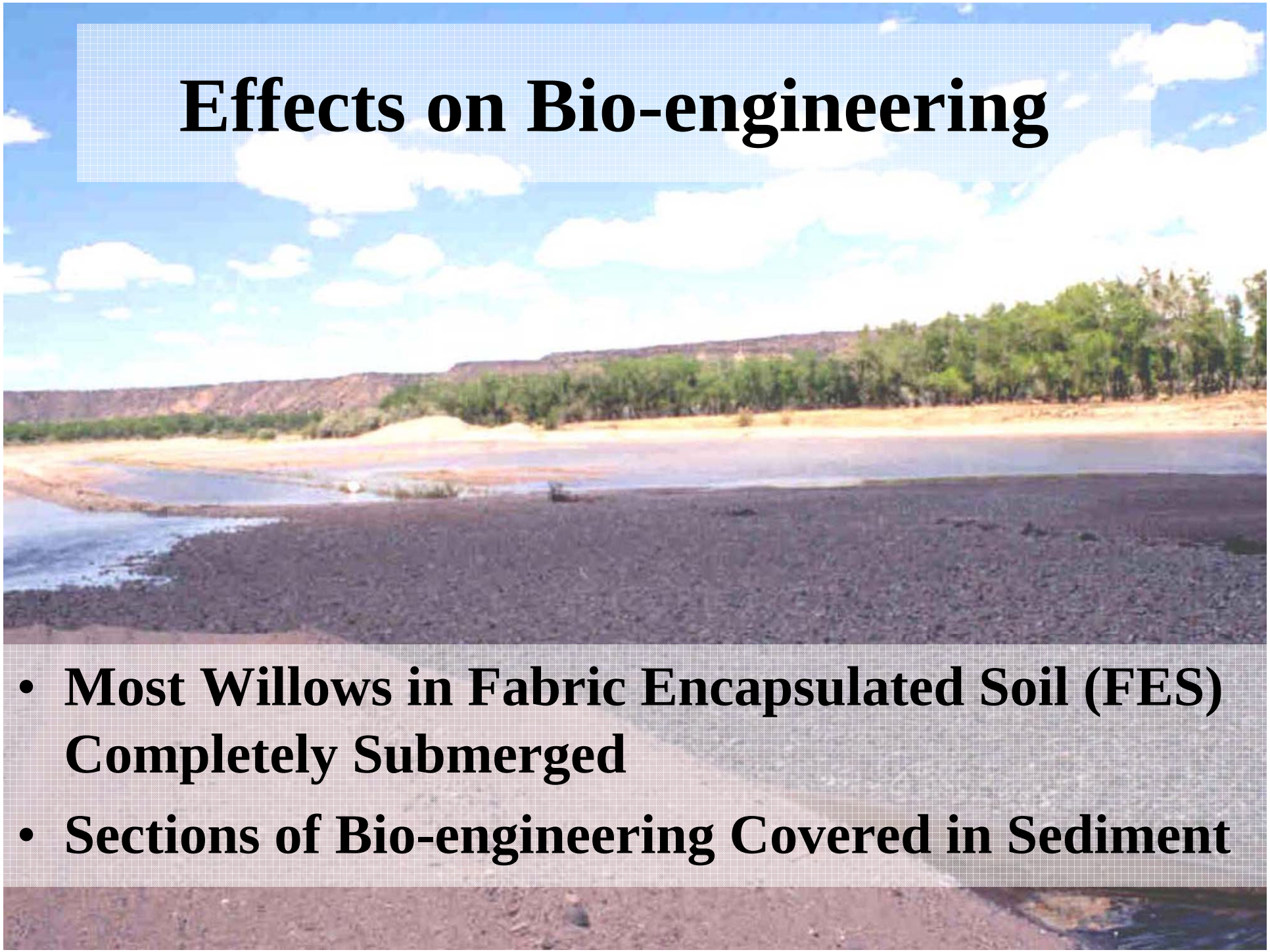


Spring Runoff - 2001

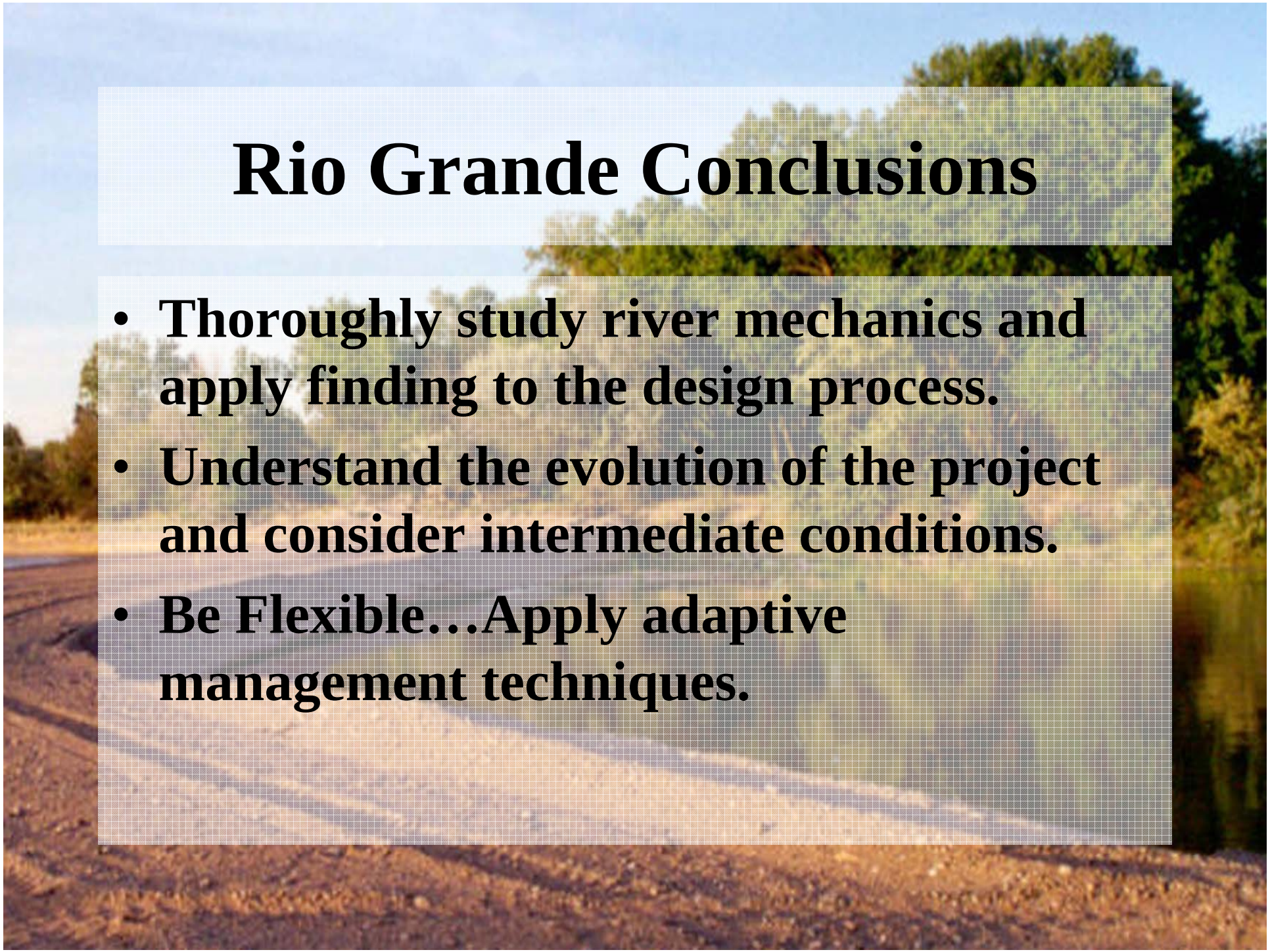
Post-Runoff Assessment

- More Gravel than Anticipated
- Mean Bed Elevation 2 ft Higher than Anticipated
- Pilot Channel 50-100 ft Narrower than Desired

Effects on Bio-engineering



- **Most Willows in Fabric Encapsulated Soil (FES) Completely Submerged**
- **Sections of Bio-engineering Covered in Sediment**



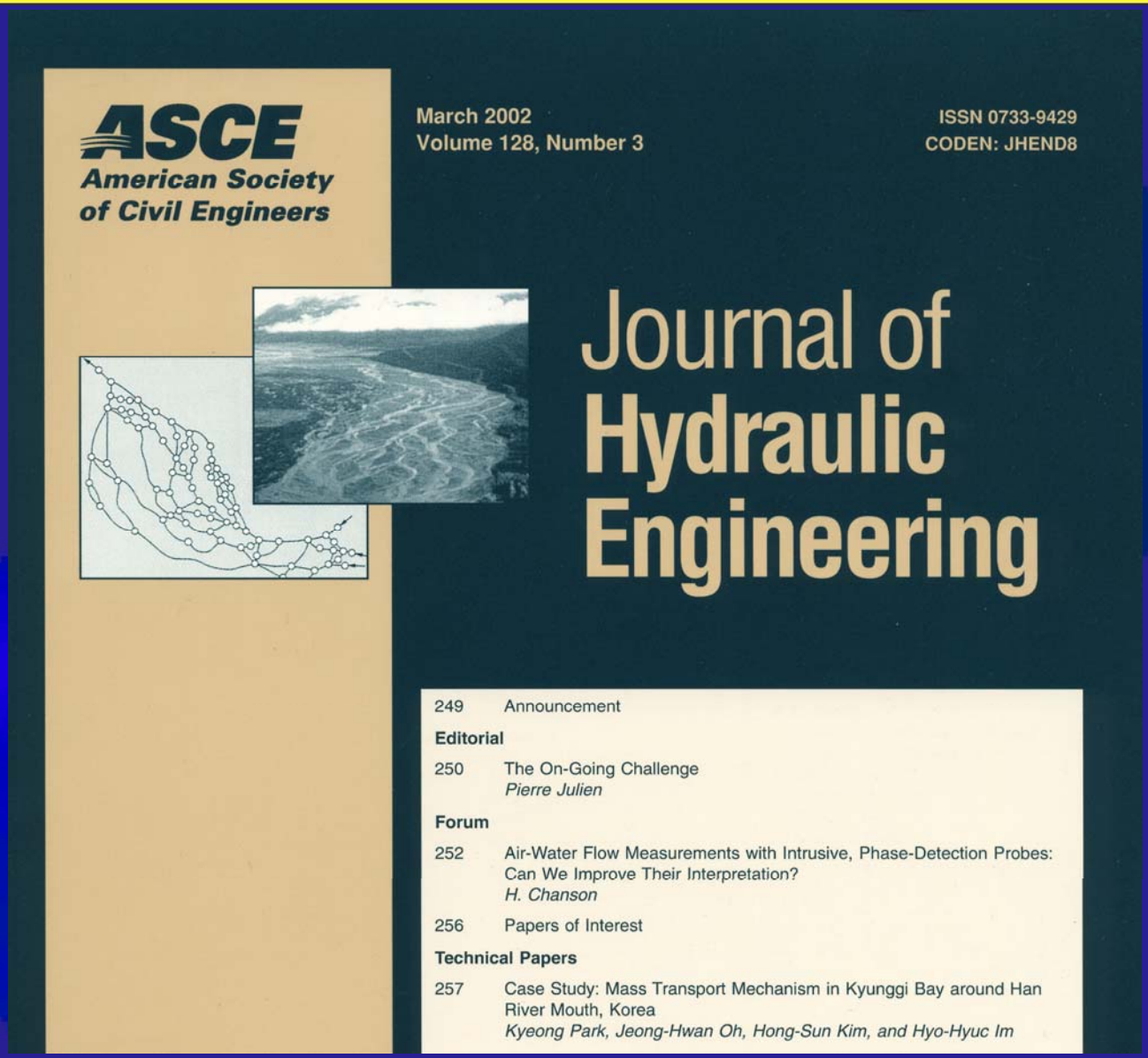
Rio Grande Conclusions

- **Thoroughly study river mechanics and apply finding to the design process.**
- **Understand the evolution of the project and consider intermediate conditions.**
- **Be Flexible…Apply adaptive management techniques.**

Stream Restoration Guidelines

1. Clearly define the **OBJECTIVES**
2. **PAST,** Present and **FUTURE**
3. Look at the **UPPER WATERSHED**
4. Look **DOWNSTREAM** for degradation
5. **EQUILIBRIUM** Hydraulic Geometry
6. Appropriate **AQUATIC HABITAT**
7. Examine various design **ALTERNATIVES**
8. **DESIGN** must be Effective, Environmentally sound and Economical
9. Plan **CONSTRUCTION** for the unexpected
10. Post-construction **MONITORING**

ASCE Journal of Hydraulic Engineering



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THANK YOU for your Attention!

Riverbank Stabilization Criteria and Examples

Pierre Y. Julien

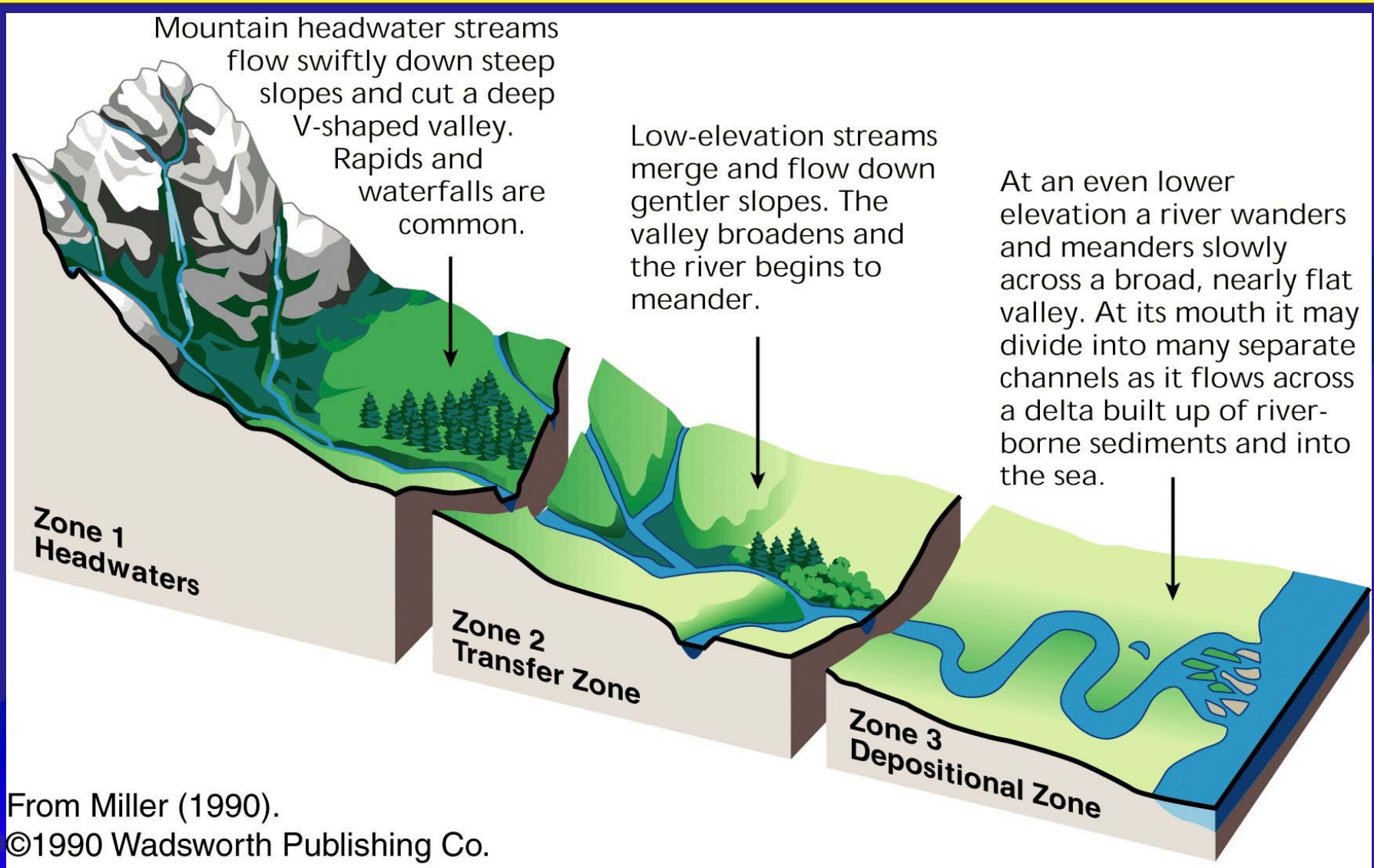
Malaysia 2005

Objectives

<u>Part III</u> – Stream Stabilization

1. **Present and discuss important concepts, criteria and guidelines for small rivers**
2. **Present examples of stream stabilization**

Concept of Equilibrium



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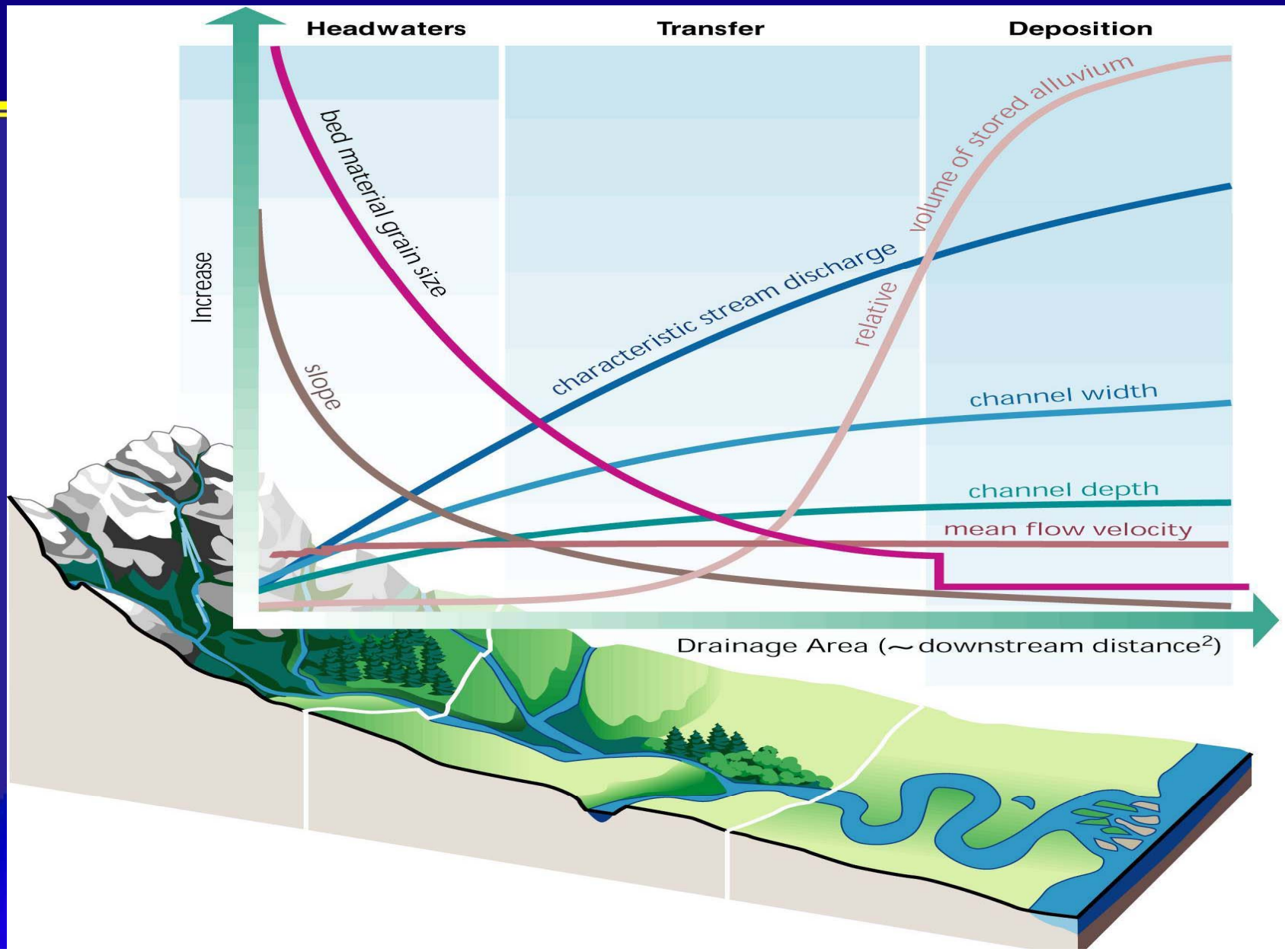
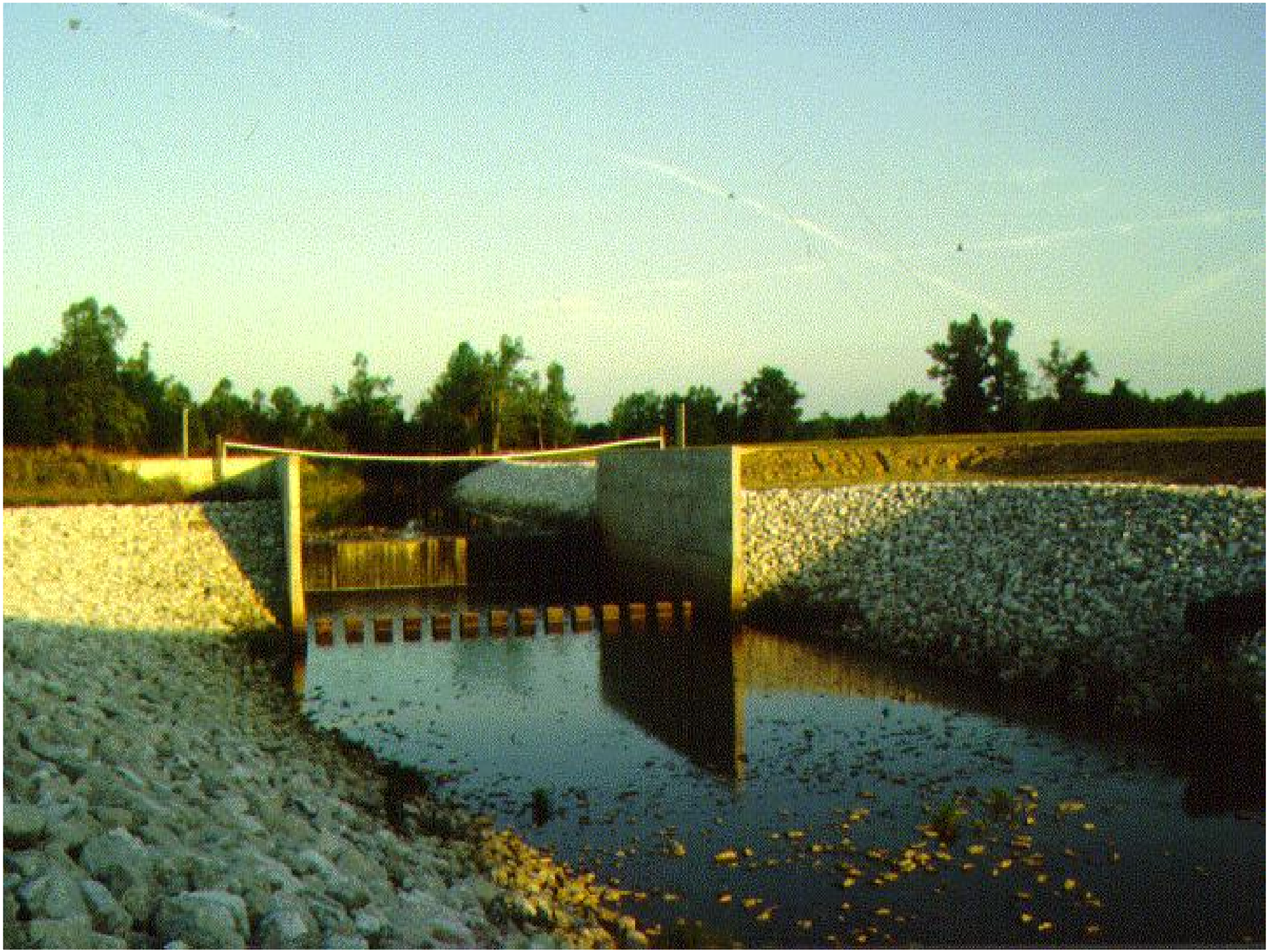

Headwaters
Transfer
Deposition
Increase
bed material grain size
slope
characteristic stream discharge
relative volume of stored alluvium
channel width
channel depth
mean flow velocity
Drainage Area (~ downstream distance²)

Vertical Degradation

Headcutting

Bank Caving

Headcutting



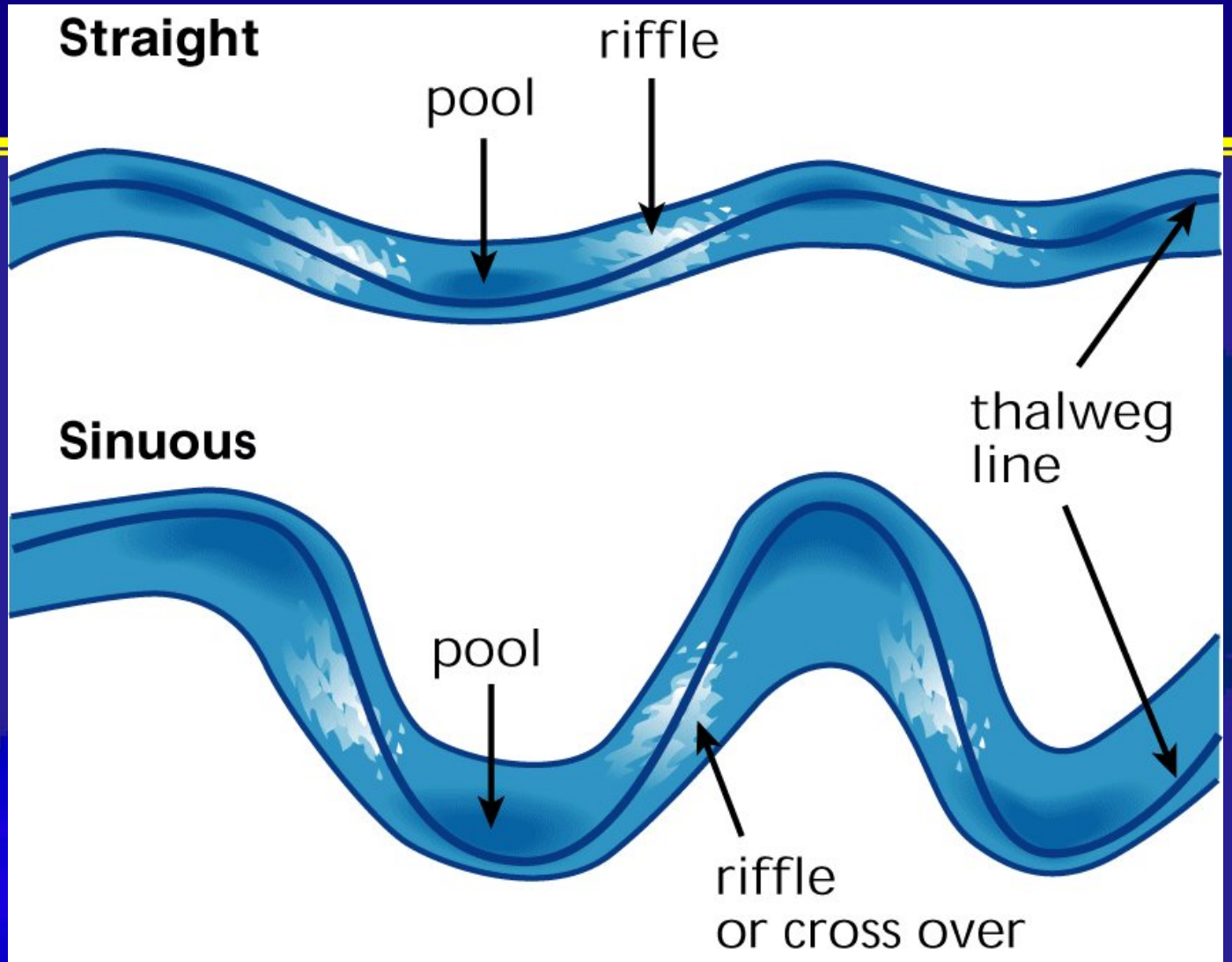
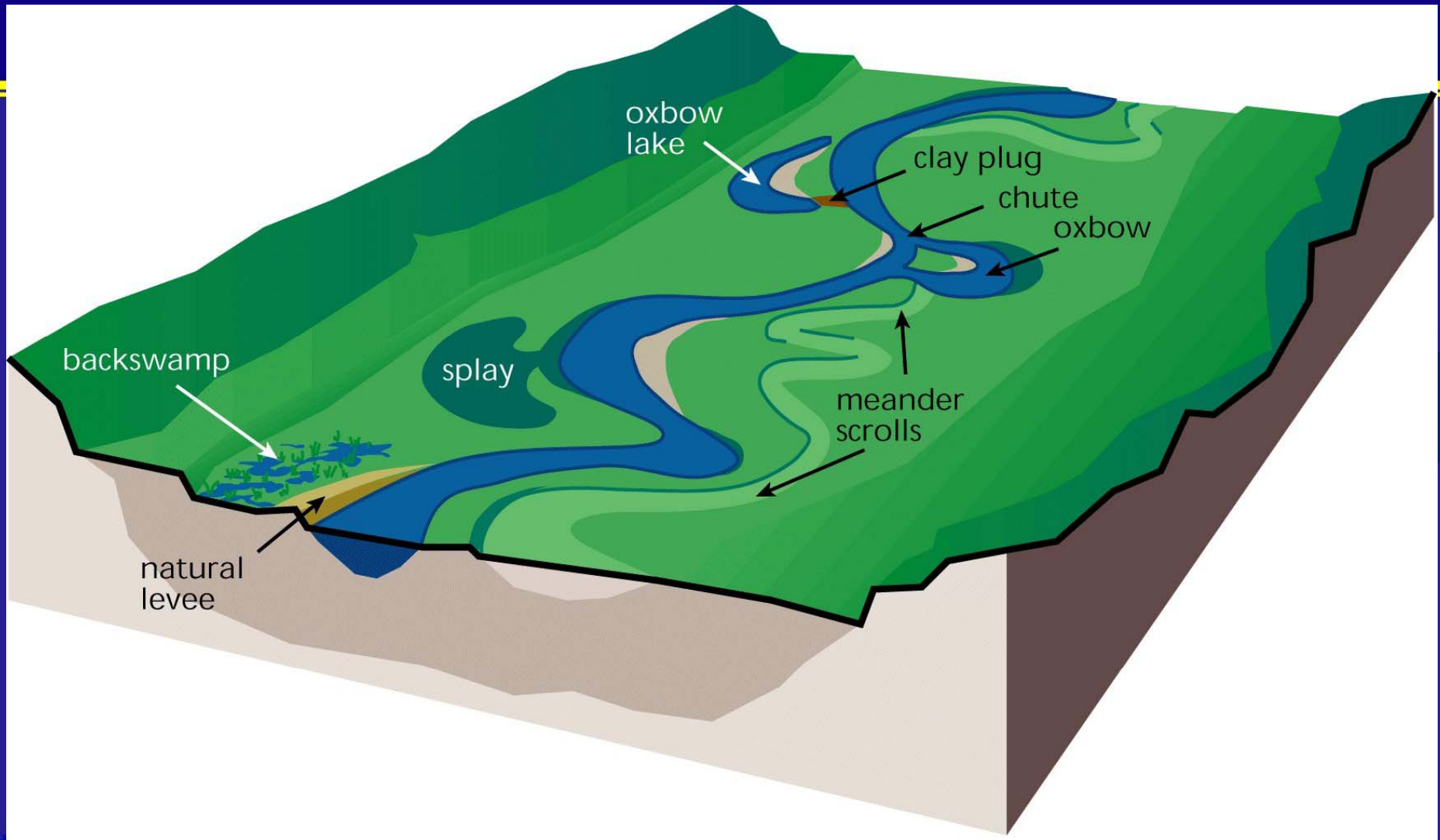


Fig. 1.33 – Sequence of pools and riffles in (a) straight and (b) sinuous streams.
In Stream Corridor Restoration: Principles, Processes, and Practices (10/98).
Interagency Stream Restoration Working Group (15 federal agencies)(FISRWG).


oxbow
lake
clay plug
chute
oxbow
backswamp
splay
meander
scrolls
natural
levee

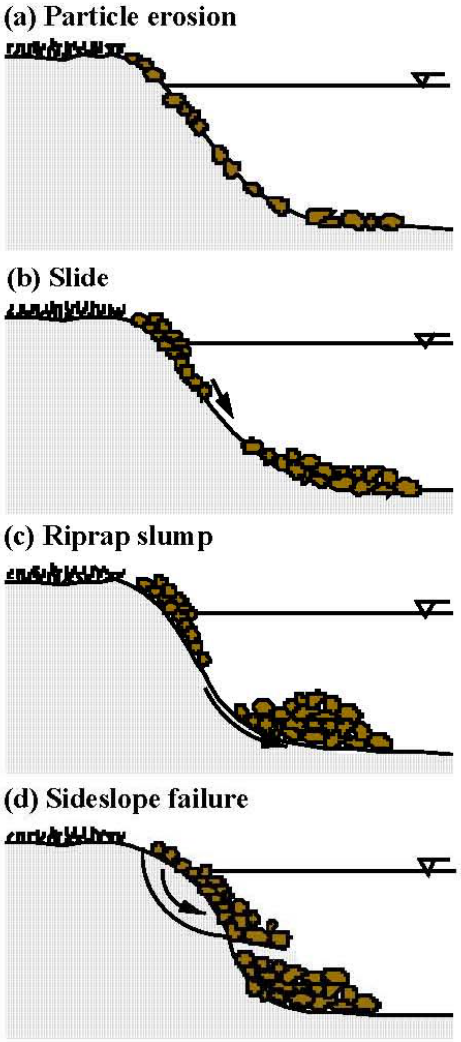

LOUISIANA
PARISH
LOUISIANA
PARISH
LOUISIANA
PARISH

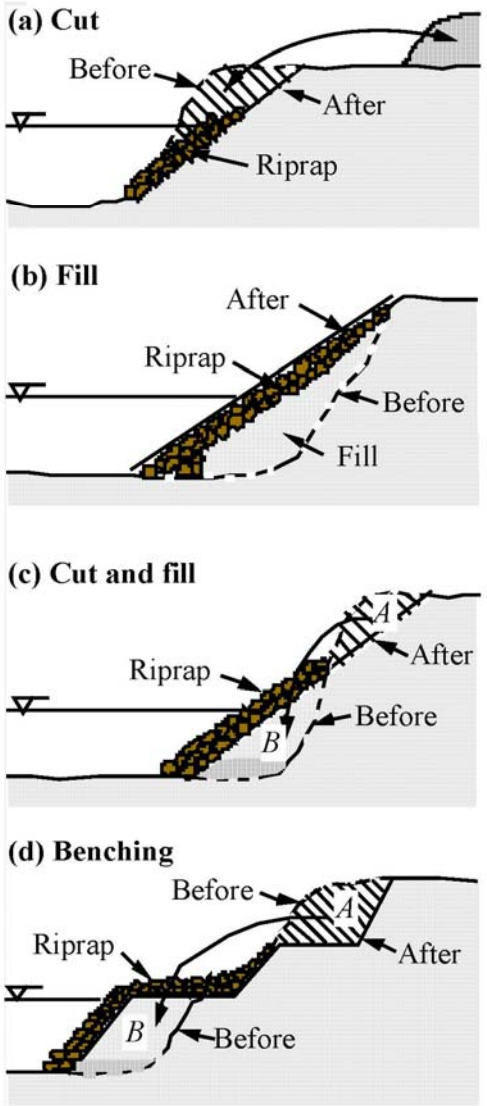
Bank Protection

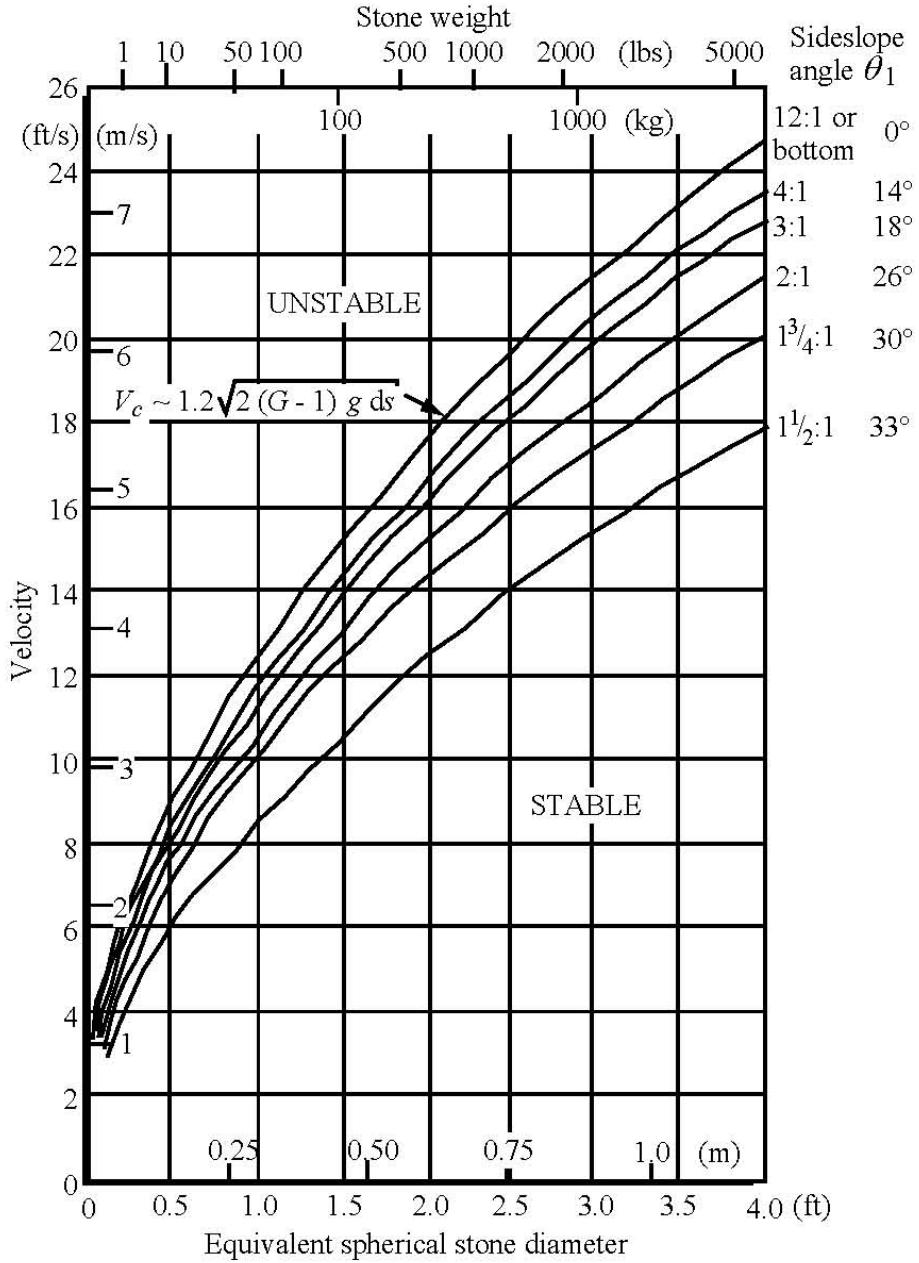
REQUIREMENTS OF BANK STABILIZATION

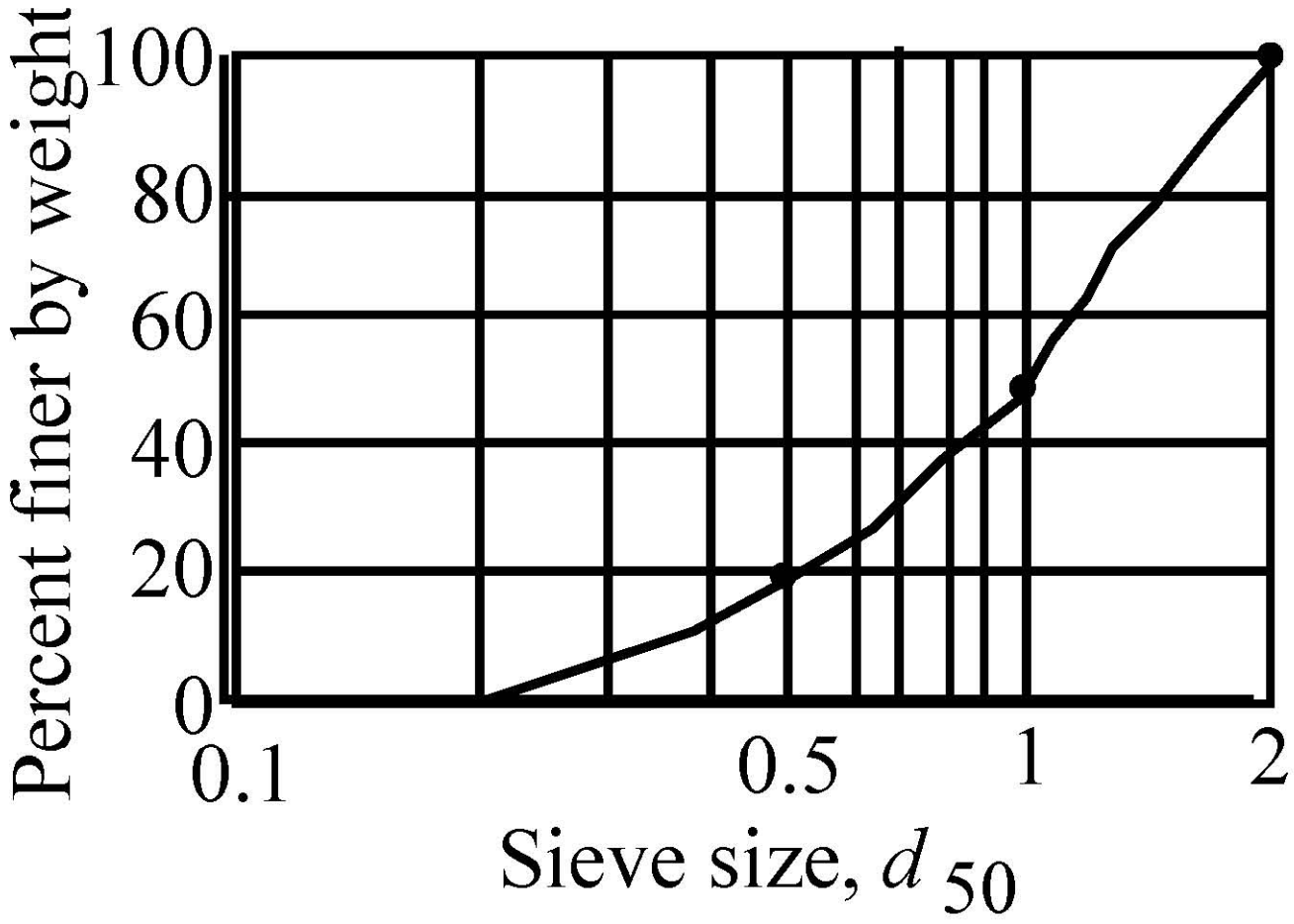
- Effective
- Environmentally Sound
- Economical

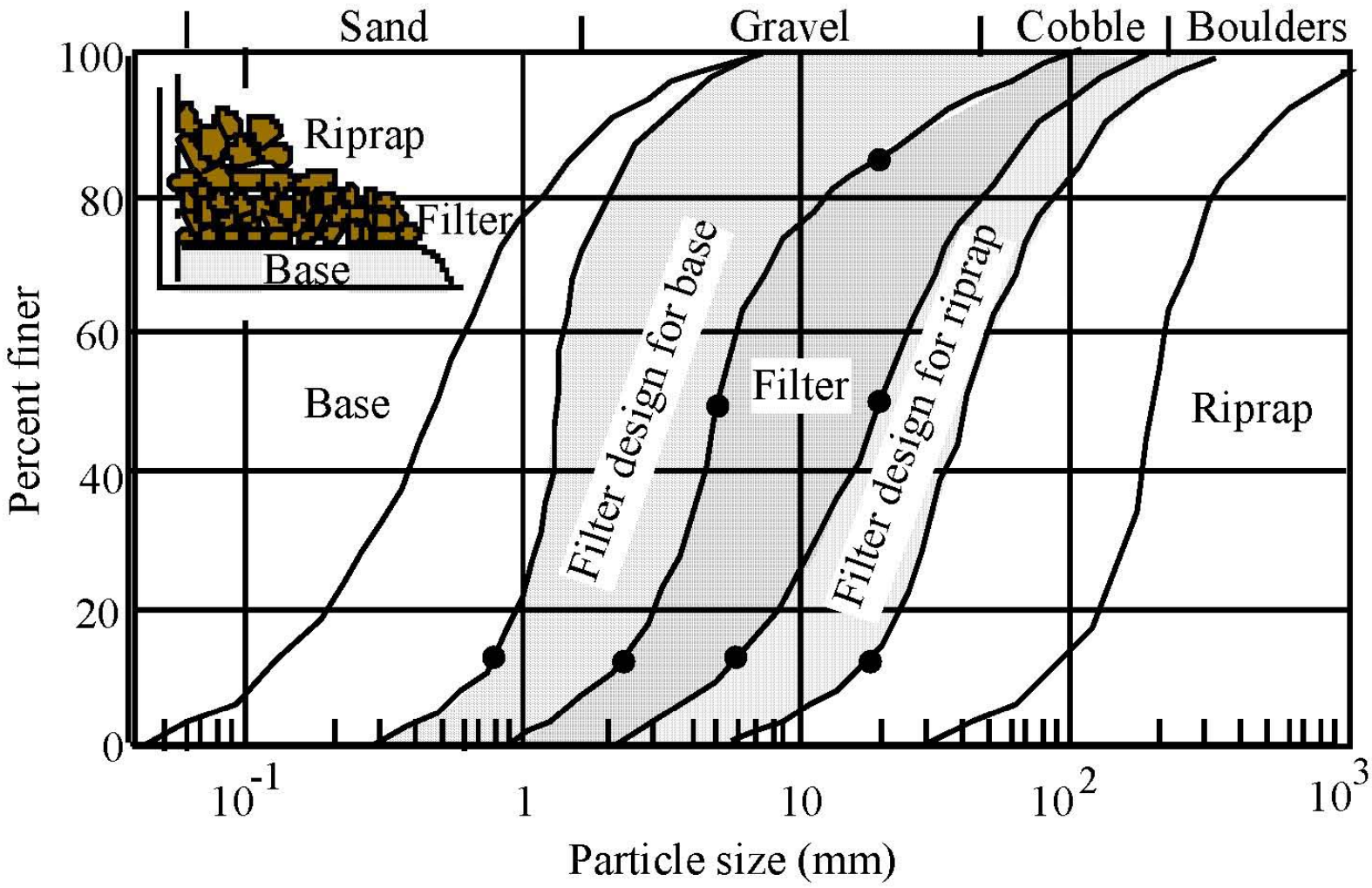
(Listed in order of necessity)

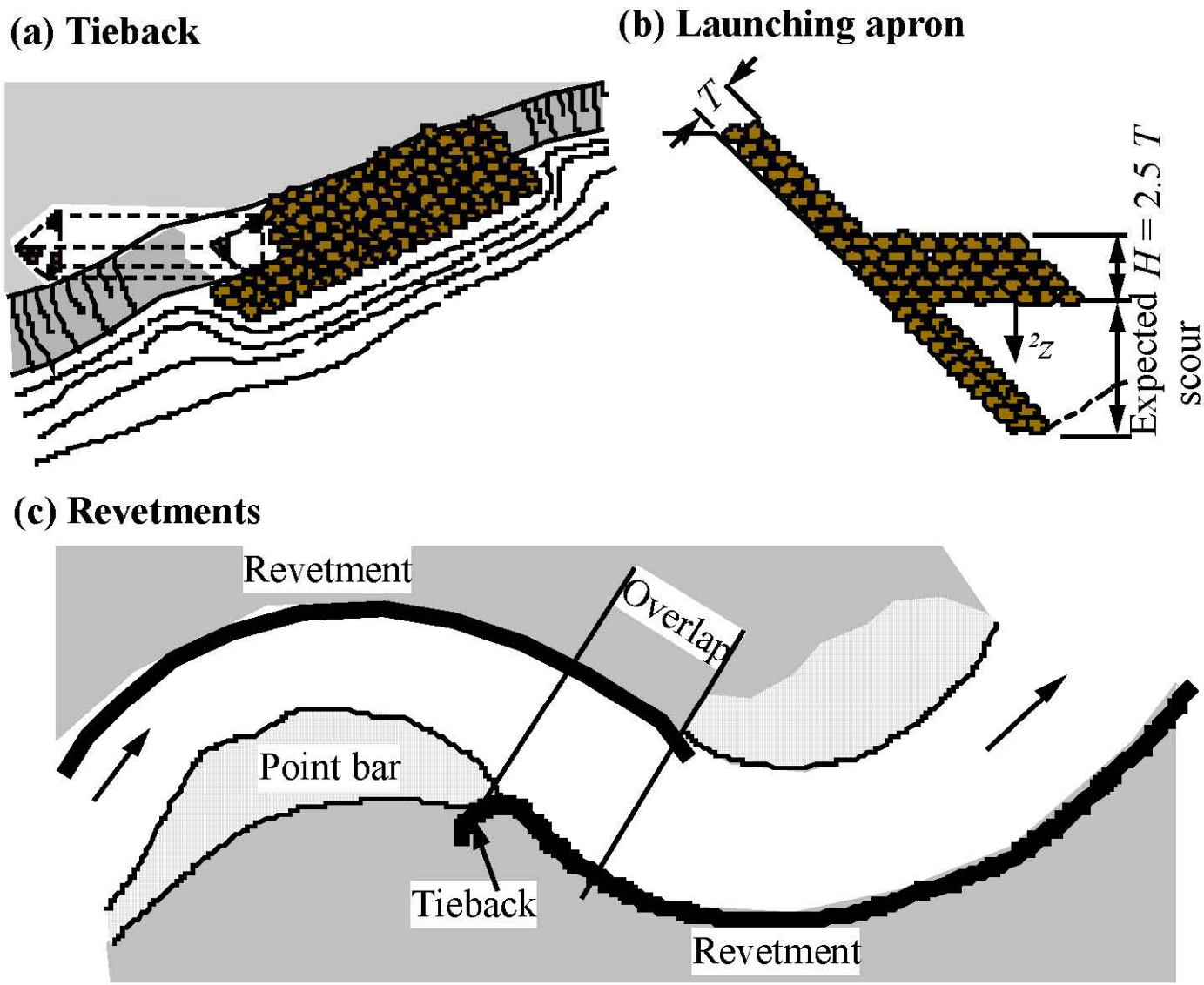

(a) Particle erosion
(b) Slide
(c) Riprap slump
(d) Sideslope failure


(a) Cut
Before
After
Riprap
(b) Fill
After
Riprap
Before
Fill
(c) Cut and fill
A
After
Riprap
Before
B
(d) Benching
Before
A
Riprap
After
B
Before

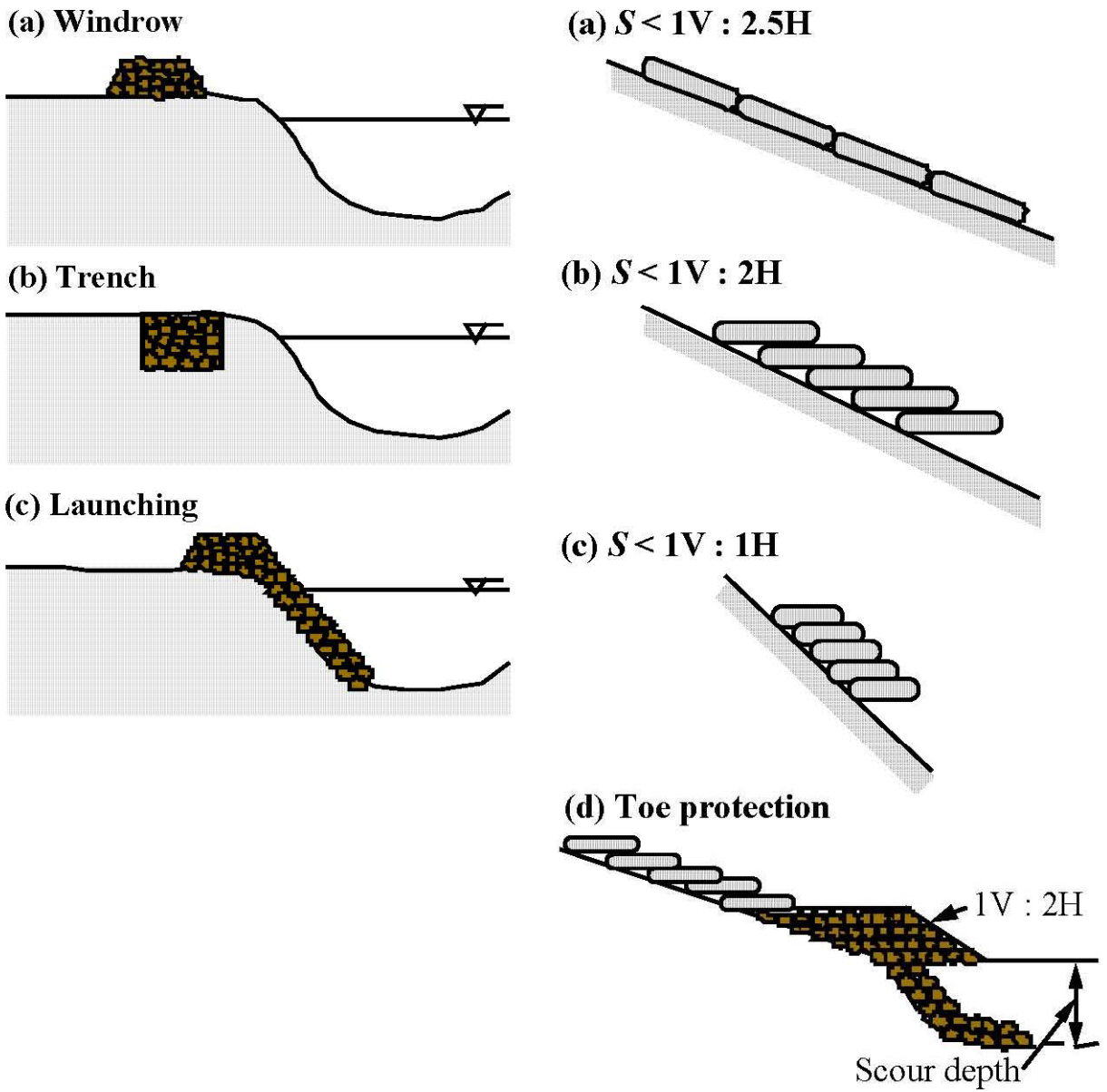

Stone weight
1 10 50 100 500 1000 2000 (lbs) 5000
100 1000 (kg)
Sideslope angle θ_1
12:1 or bottom 0°
4:1 14°
3:1 18°
2:1 26°
1¾:1 30°
1½:1 33°
(ft/s) (m/s)
26 24 22 20 18 16 14 12 10 8 6 4 2 0
7 6 5 4 3 2 1
UNSTABLE
STABLE
$V_c \sim 1.2\sqrt{2\,(G-1)\,g\,ds}$
Velocity
0.25 0.50 0.75 1.0 (m)
0 0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 (ft)
Equivalent spherical stone diameter


Percent finer by weight
100
80
60
40
20
0
0.1
0.5
1
2
Sieve size, d_{50}


Sand
Gravel
Cobble
Boulders
100
80
60
40
20
0
Riprap
Filter
Base
Base
Filter design for base
Filter
Filter design for riprap
Riprap
Percent finer
10^{-1}
1
10
10^{2}
10^{3}
Particle size (mm)


(a) Tieback
(b) Launching apron
T
2Z
Expected H = 2.5 T scour
(c) Revetments
Revetment
Overlap
Point bar
Tieback
Revetment


'96 3 26


(a) Windrow
(b) Trench
(c) Launching
(a) S < 1V : 2.5H
(b) S < 1V : 2H
(c) S < 1V : 1H
(d) Toe protection
1V : 2H
Scour depth

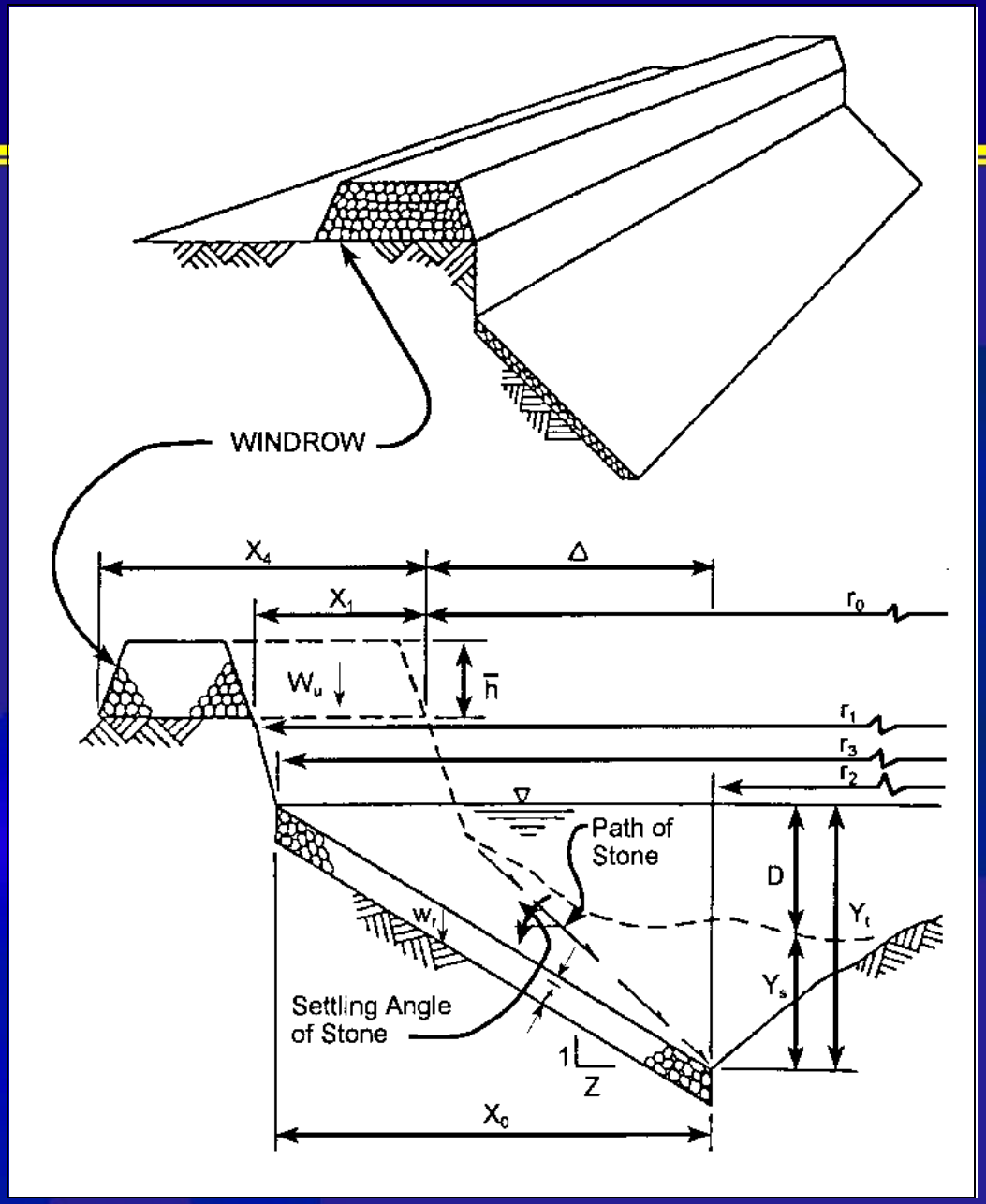
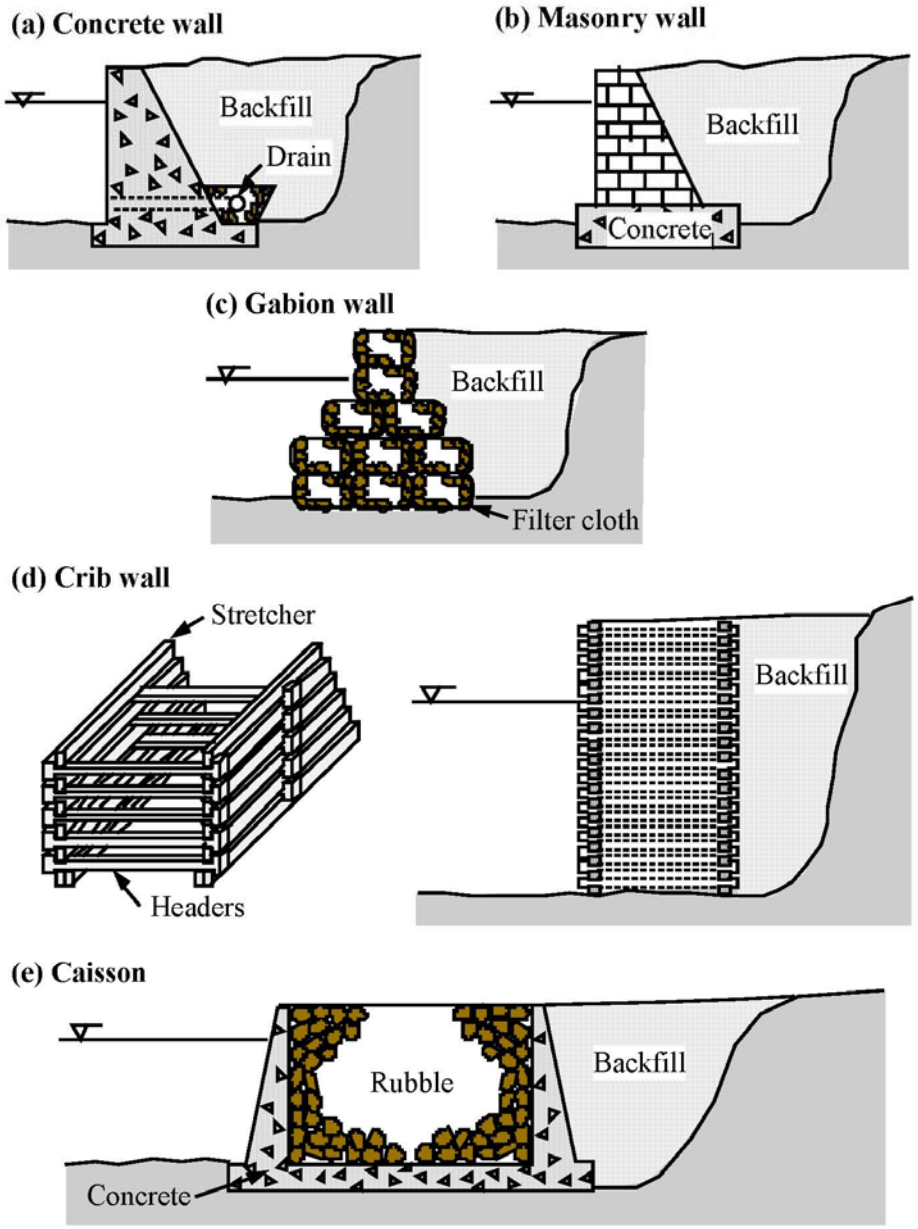


Figure 7.3 Schematic Diagram of Windrow Revetment

Figure 7.5 Placement of Windrow Rock in Excavated Trench on Top Bank


APR 1 '91


(a) Concrete wall
Backfill
Drain
(b) Masonry wall
Backfill
Concrete
(c) Gabion wall
Backfill
Filter cloth
(d) Crib wall
Stretcher
Headers
Backfill
(e) Caisson
Rubble
Backfill
Concrete

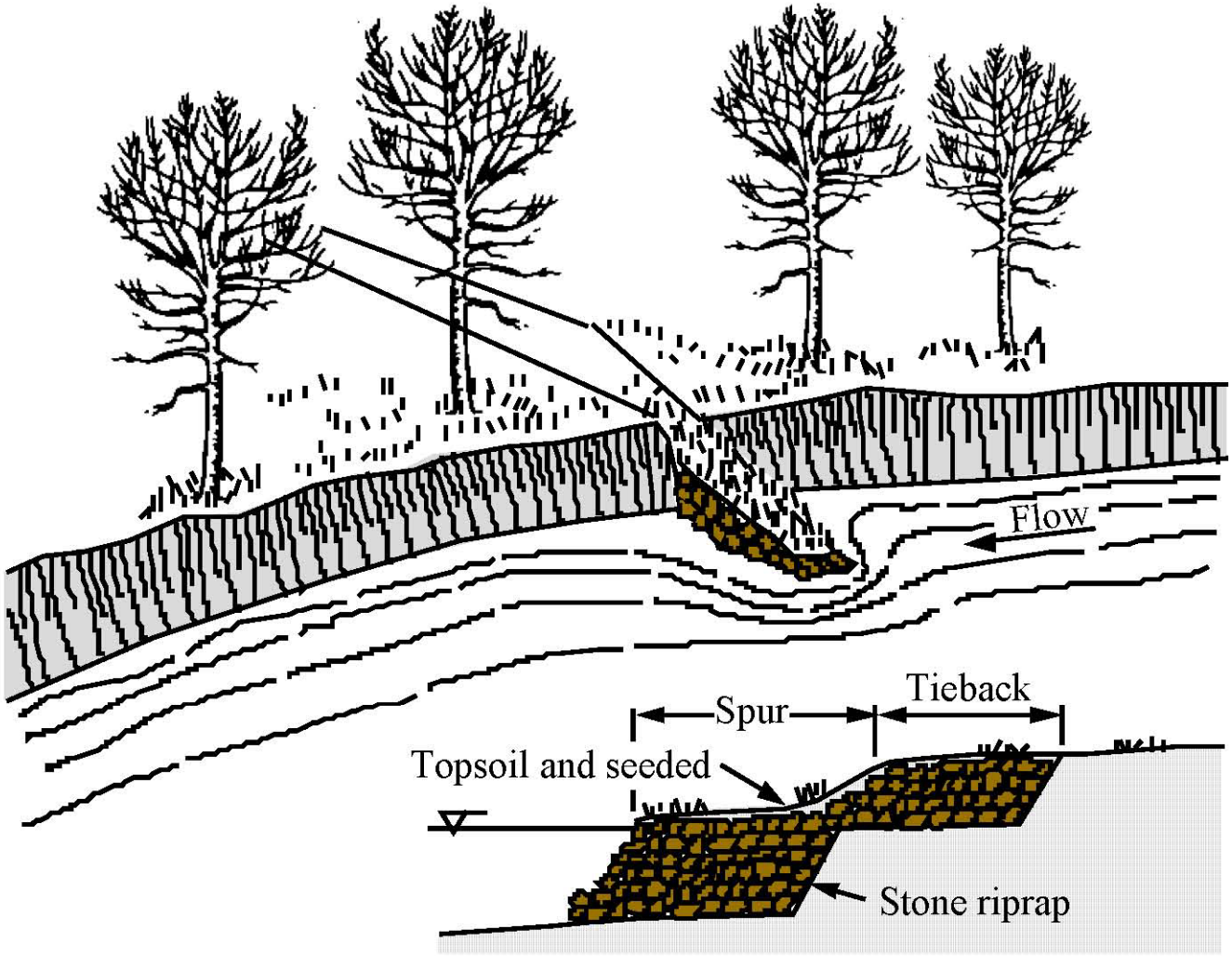
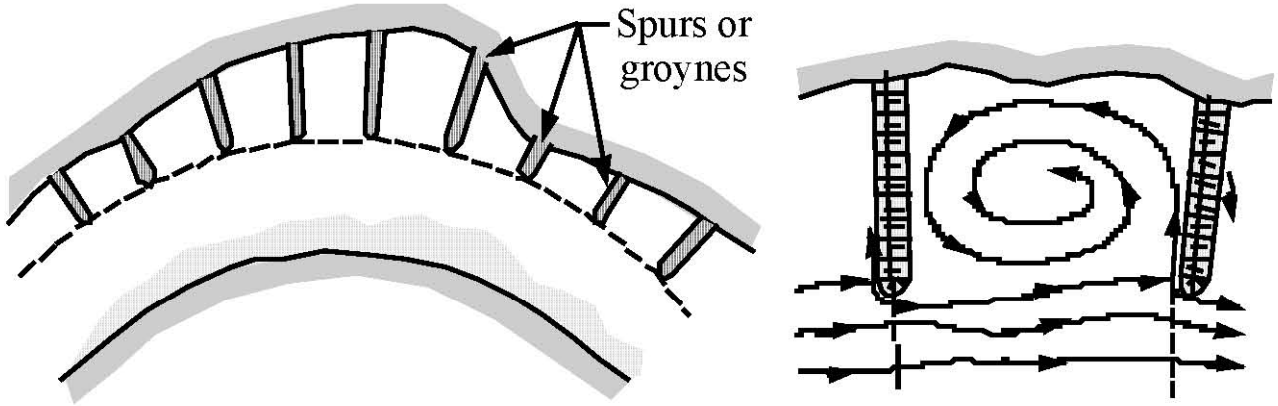
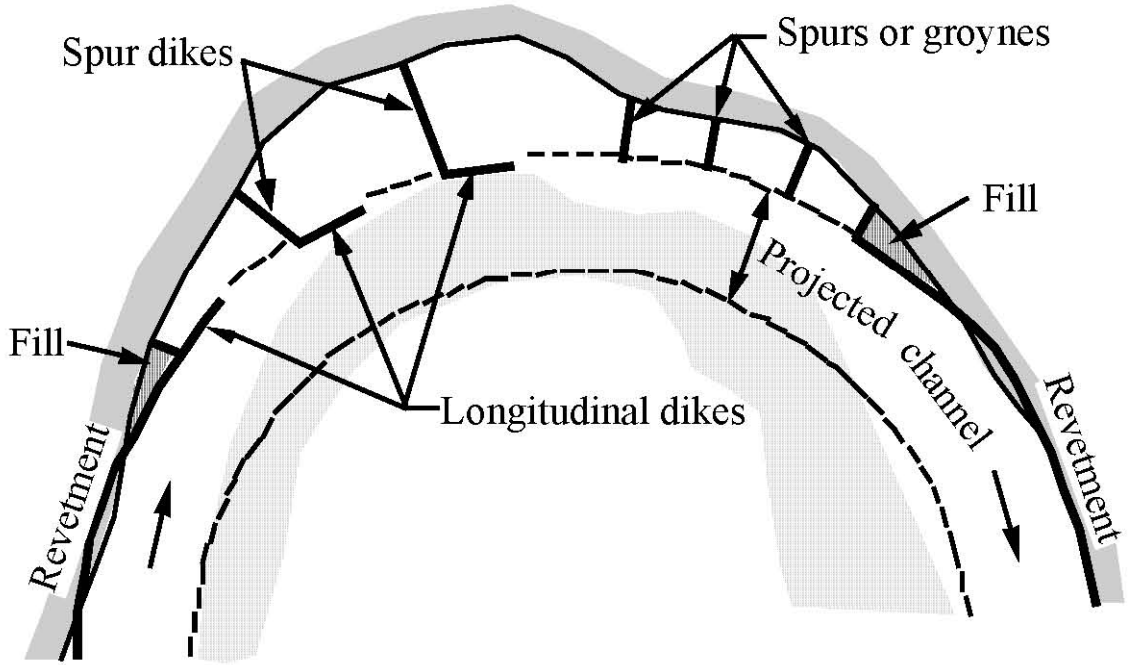

Flow
Tieback
Spur
Topsoil and seeded
Stone riprap

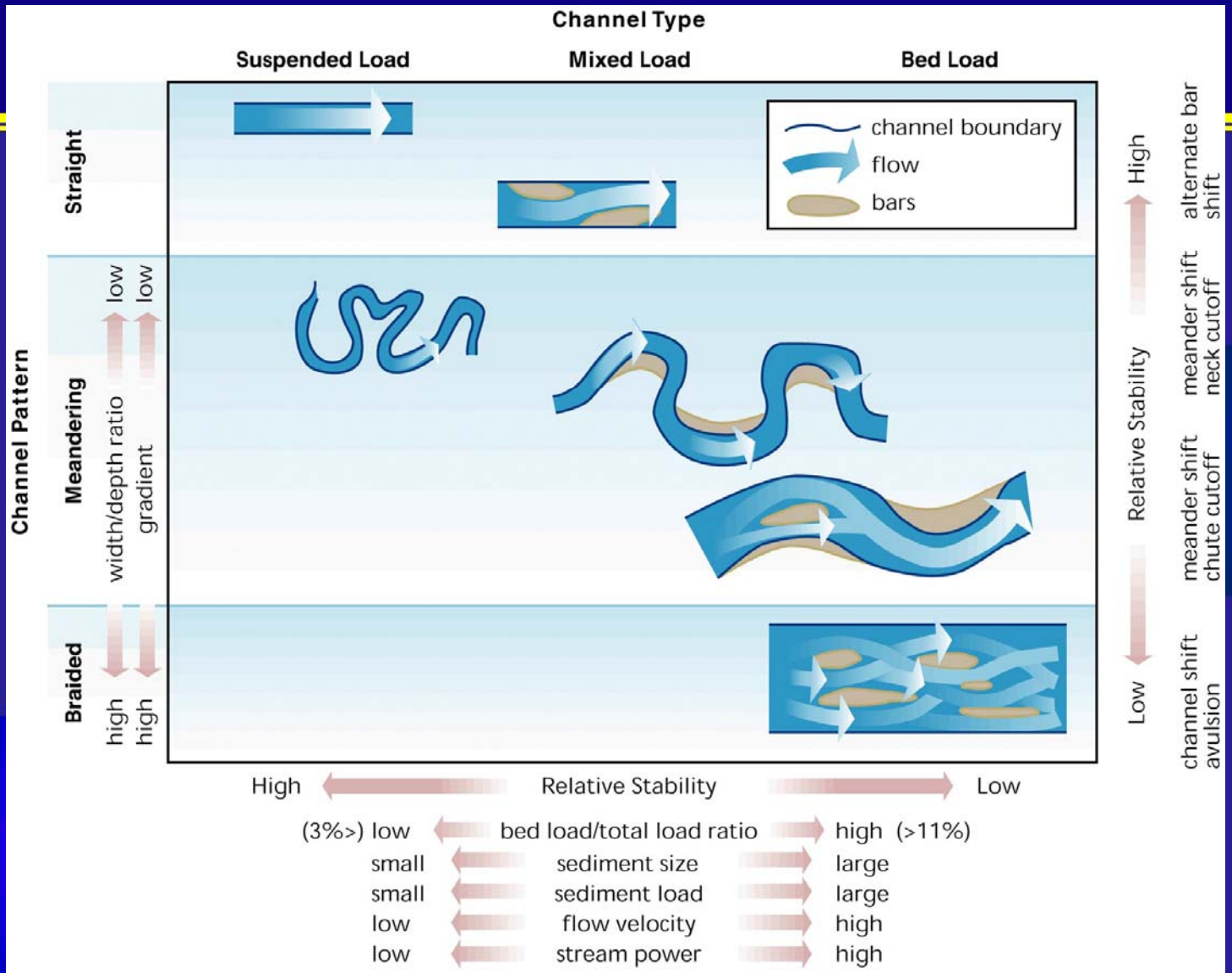
Figure 8.2 Typical Impermeable Dikes

(a) Spurs or groynes



(b) Groynes and spur dikes





Source: Schumm, The Fluvial System. © 1977. Reprinted by permission of John Wiley and Sons, Inc.

Fig. 7.10 -- Classification of alluvial channels, per Schumm's classification system.
In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98.
Interagency Stream Restoration Working Group (FISRWG)(15 Federal agencies of the US).

Jetty fields and vegetation of the Rio Grande

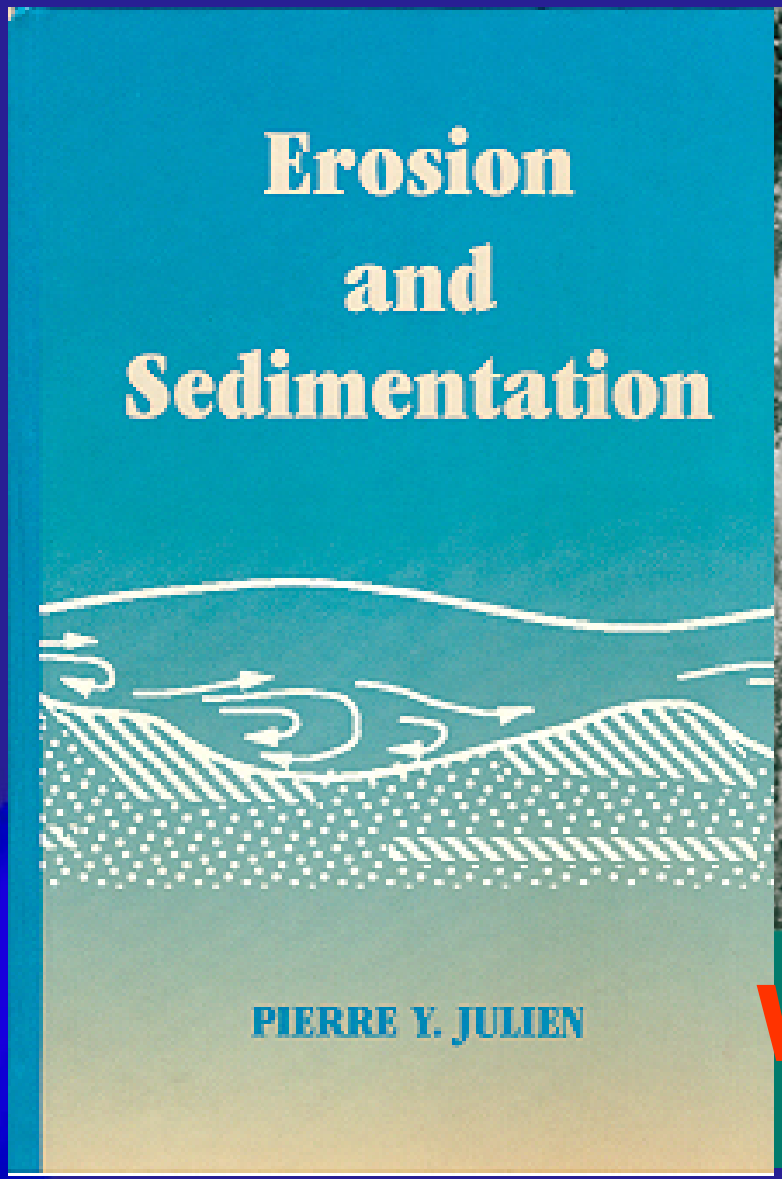
Jetty System (near Bernardo), USACE 1963


Bernardo Gage

Timber Pile Revetment

Revetment Capout

Erosion and River Mechanics Textbooks

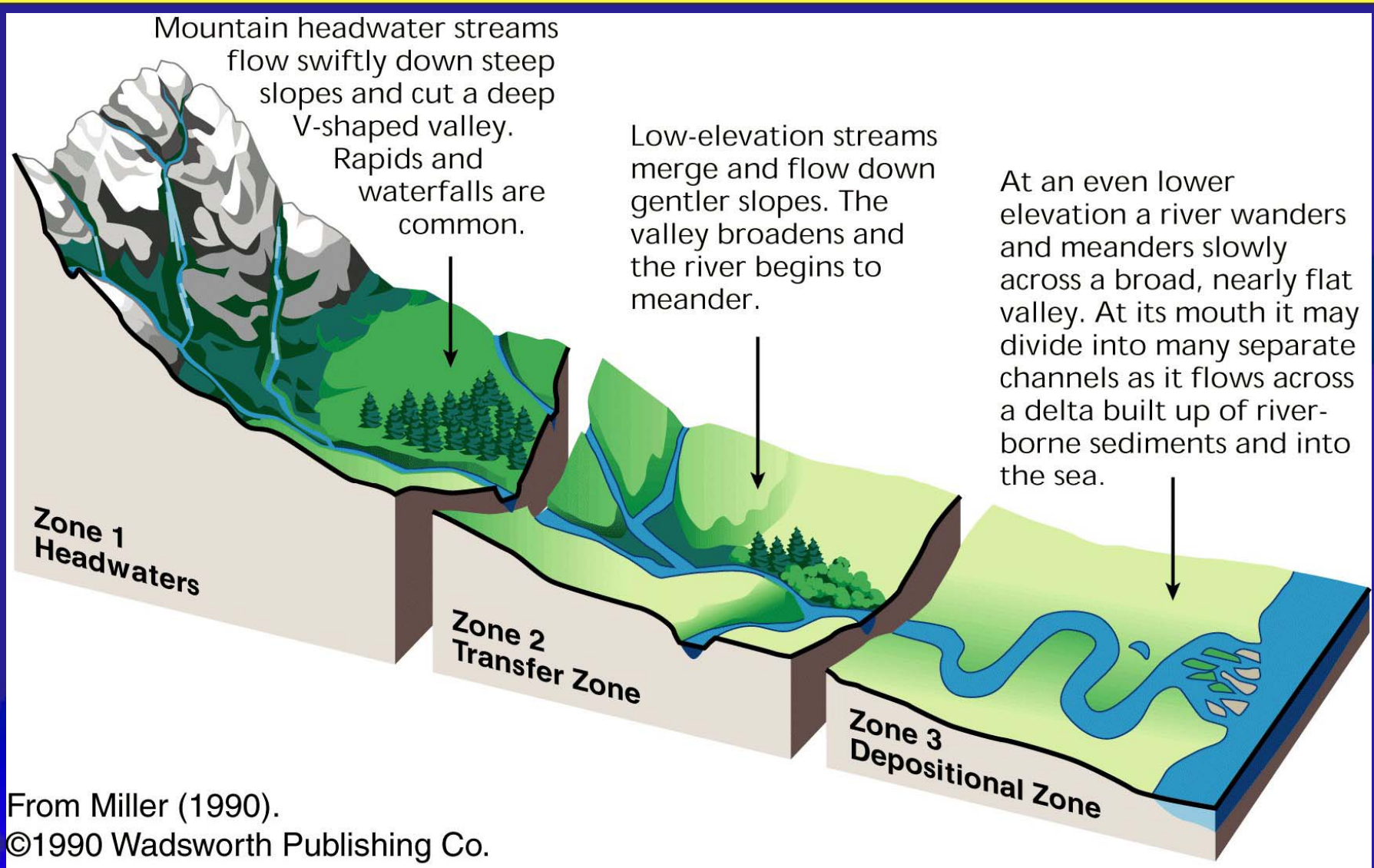


Objectives

<u>Part IV</u> – Riverbank Stabilization

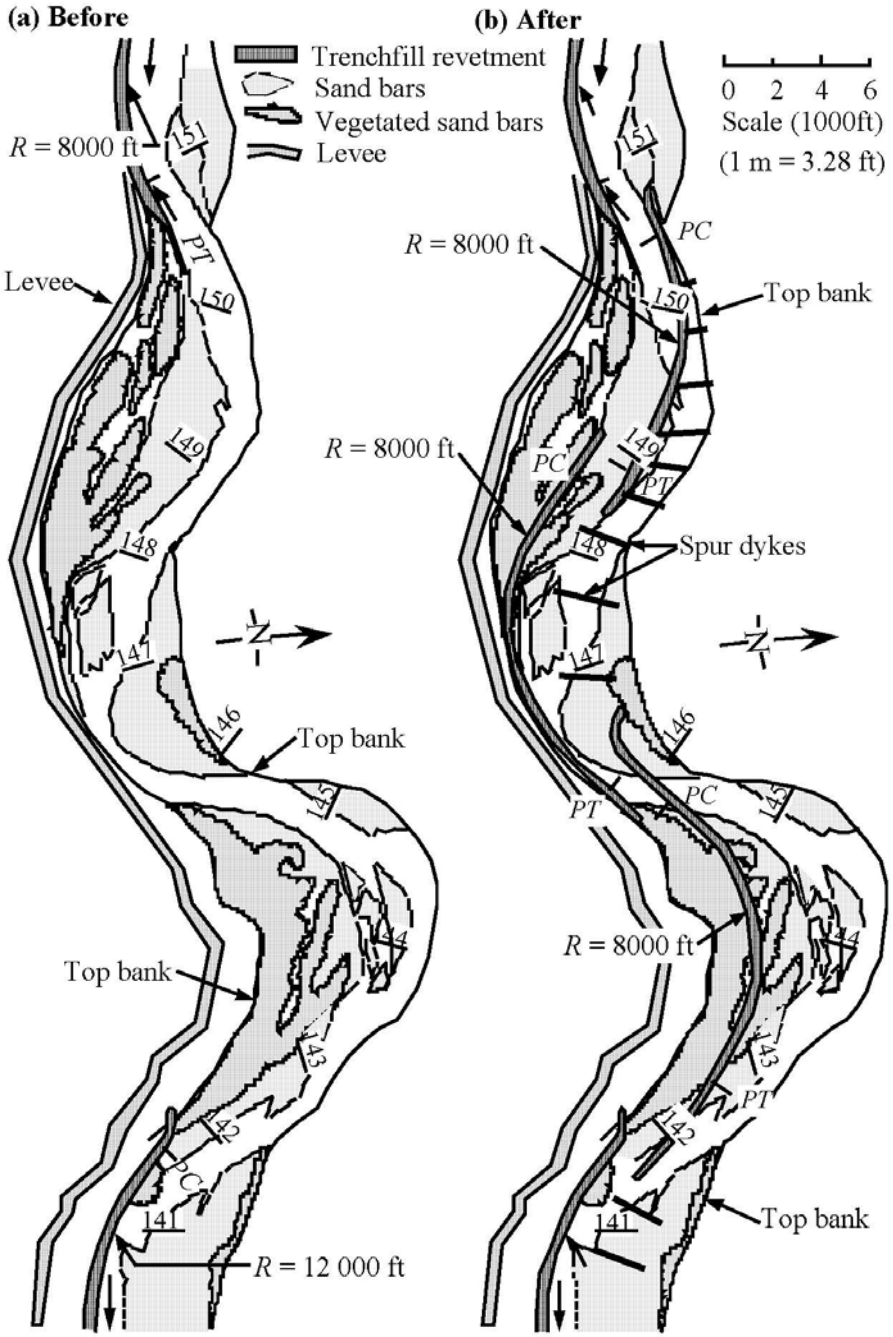
1. **Present and discuss important concepts, criteria and guidelines for large rivers**
2. **Present examples of riverbank stabilization**

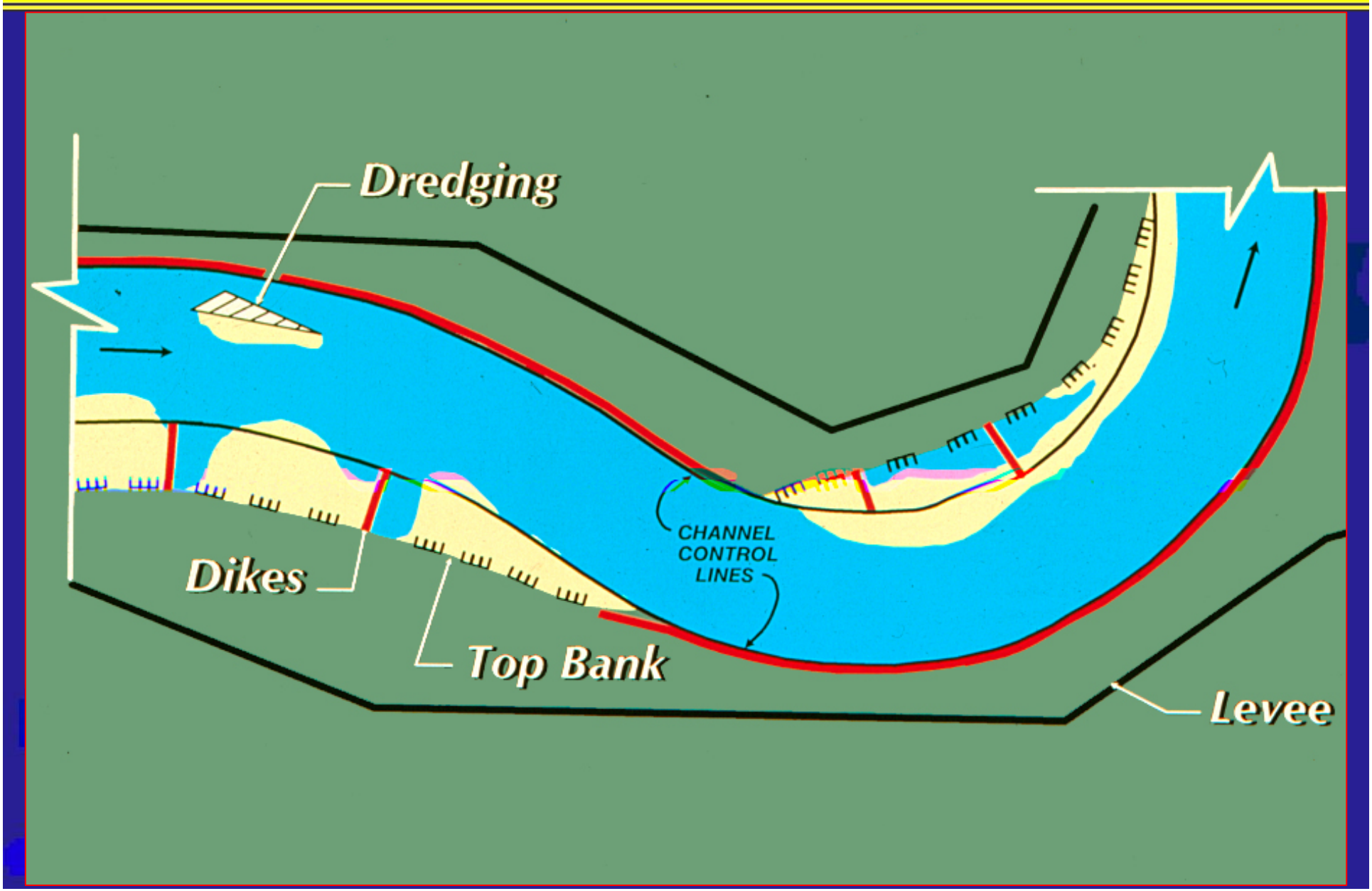
Concept of Equilibrium



From Miller (1990).

Fig. 1.27 – Three longitudinal profile zones.
In Stream Corridor Restoration: Principles, Processes, and Practices, 10/98.
Interagency Stream Restoration Working Group (15 Federal Agencies of the US).

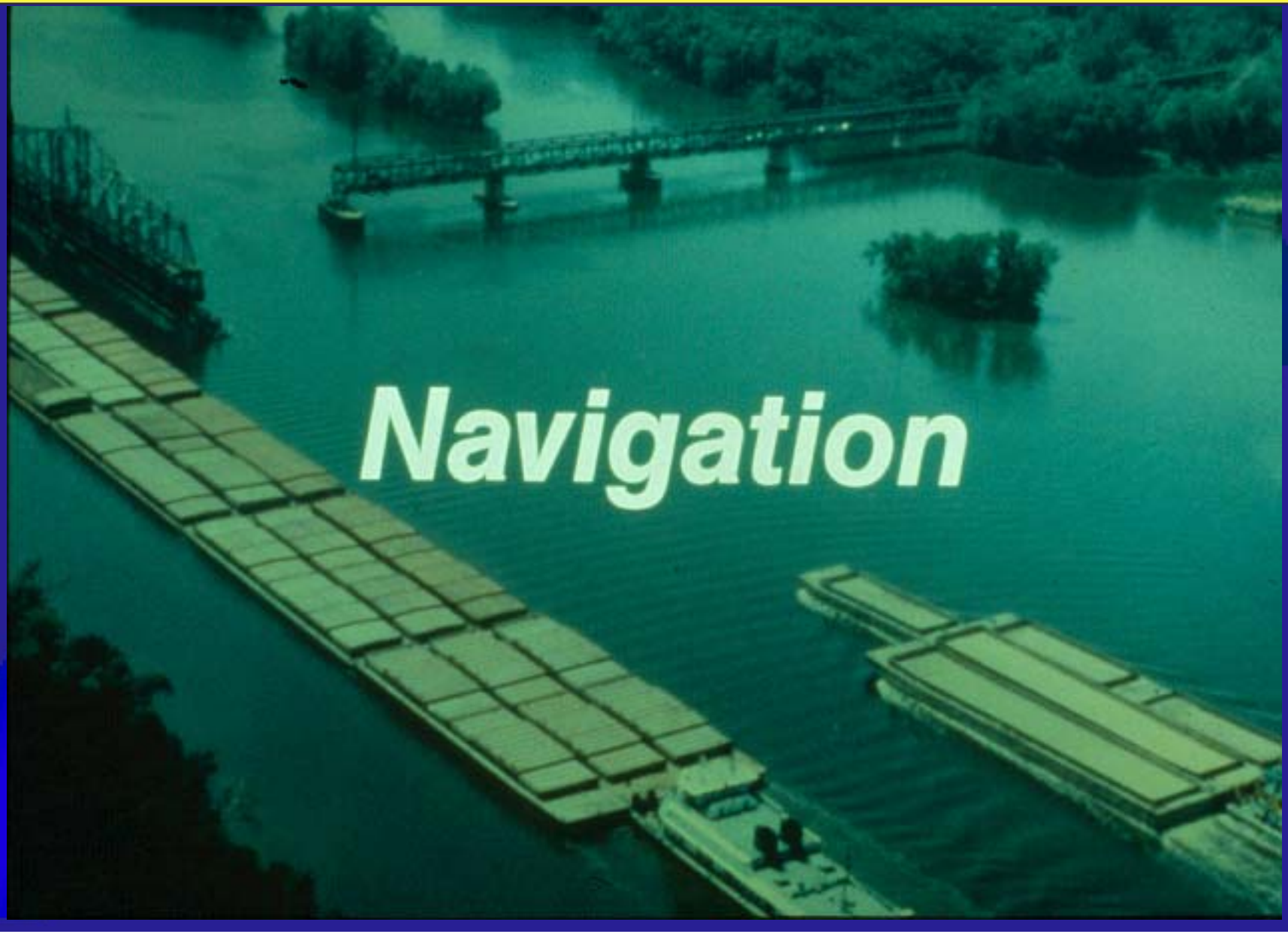

(a) Before
(b) After
Trenchfill revetment
Sand bars
Vegetated sand bars
Levee
0 2 4 6
Scale (1000ft)
(1 m = 3.28 ft)
R = 8000 ft
Levee
Top bank
Spur dykes
R = 12 000 ft
PC
PT
151
150
149
148
147
146
145
144
143
142
141

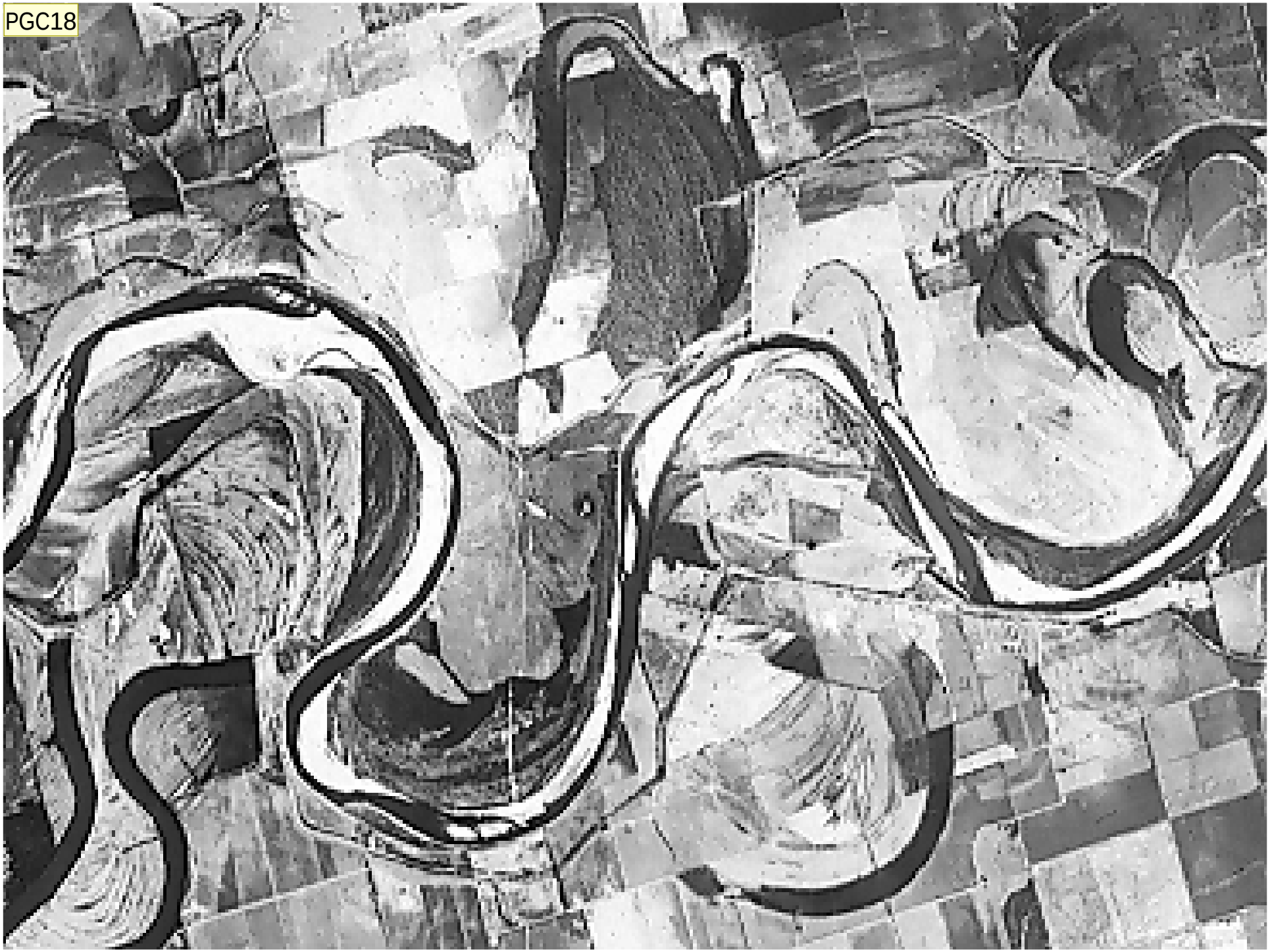

Dredging
CHANNEL
CONTROL
LINES
Dikes
Top Bank
Levee

Stonefill Revetment

Channel Contraction

Channel Control Dikes


Navigation

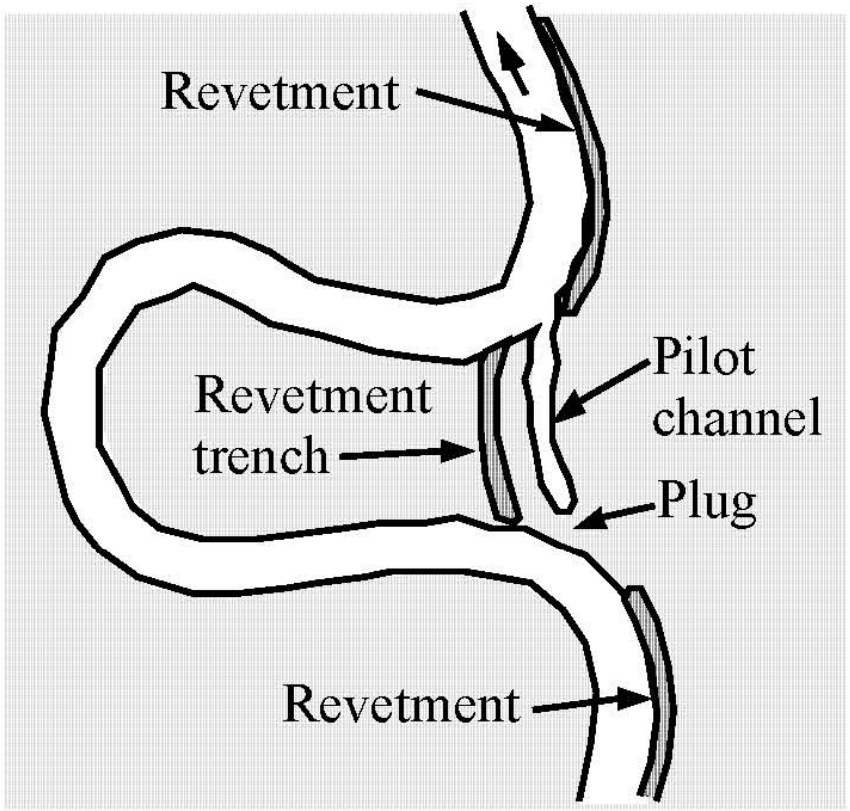

PGC18

Slide 151

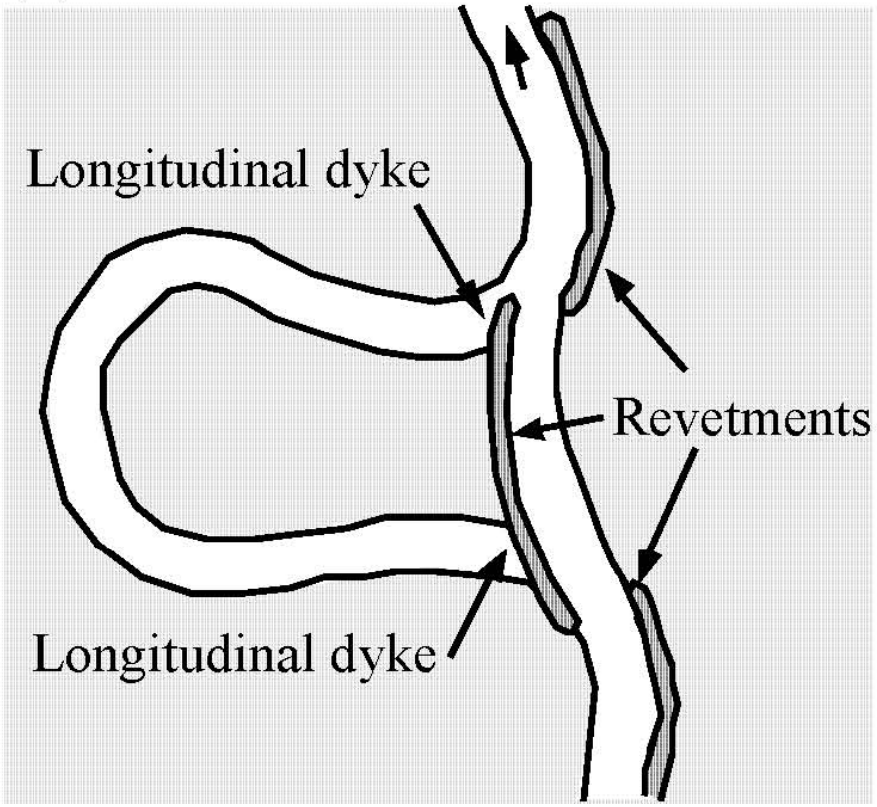
PGC18 Numerical model evaluated the hydrodynamics of the location and recommendations were made to construct 4 dikes on the right bank. After construction, the problem was immediately converted from unmanageable to a manageable situation. It is anticipated that proposed numerical stdies will similarly identify a manageable solution.

Phil Combs, 8/29/2002

(a) Pilot channel



(b) Cutoff



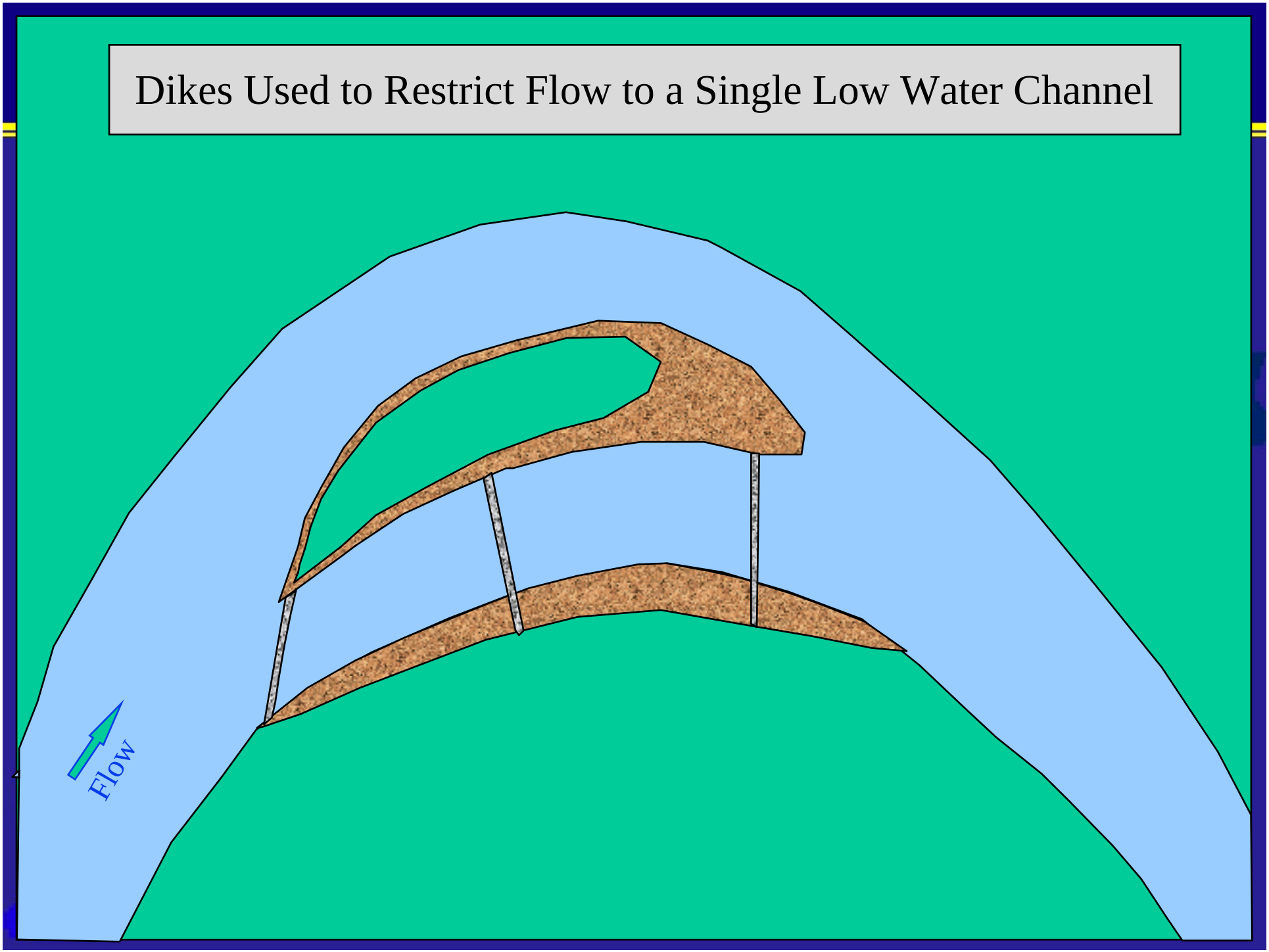
Channel Realignment

Oxbow Preservation

Access to Oxbows

Trenchfill Revetment

Dikes Used to Restrict Flow to a Single Low Water Channel



Construction Dredging

Additional Contraction Structures

PGC1

Dykes

Slide 160

PGC1 Typical dike construction on the Mississippi River

Phil Combs, 8/29/2002

Environmental Considerations

PGC2

Typical Stone Dyke

PGC2 Typical rock dike construction

Phil Combs, 8/29/2002

Rough Concrete Surface

Vented Dykes

PGC7

Geobags

Slide 166

PGC7 Photo of completed soft dike with geotextile bags containing river sediment

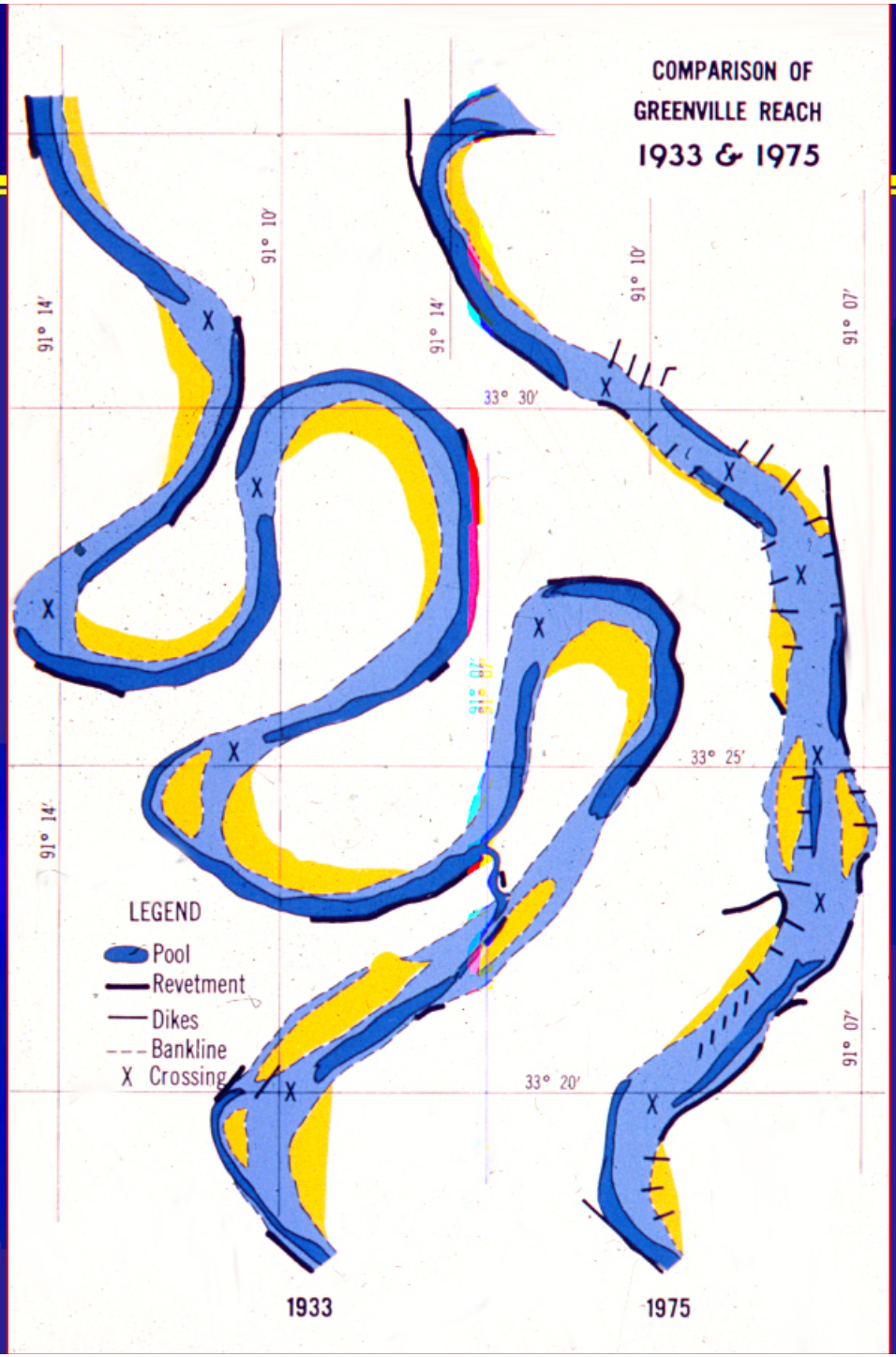
Phil Combs, 8/29/2002

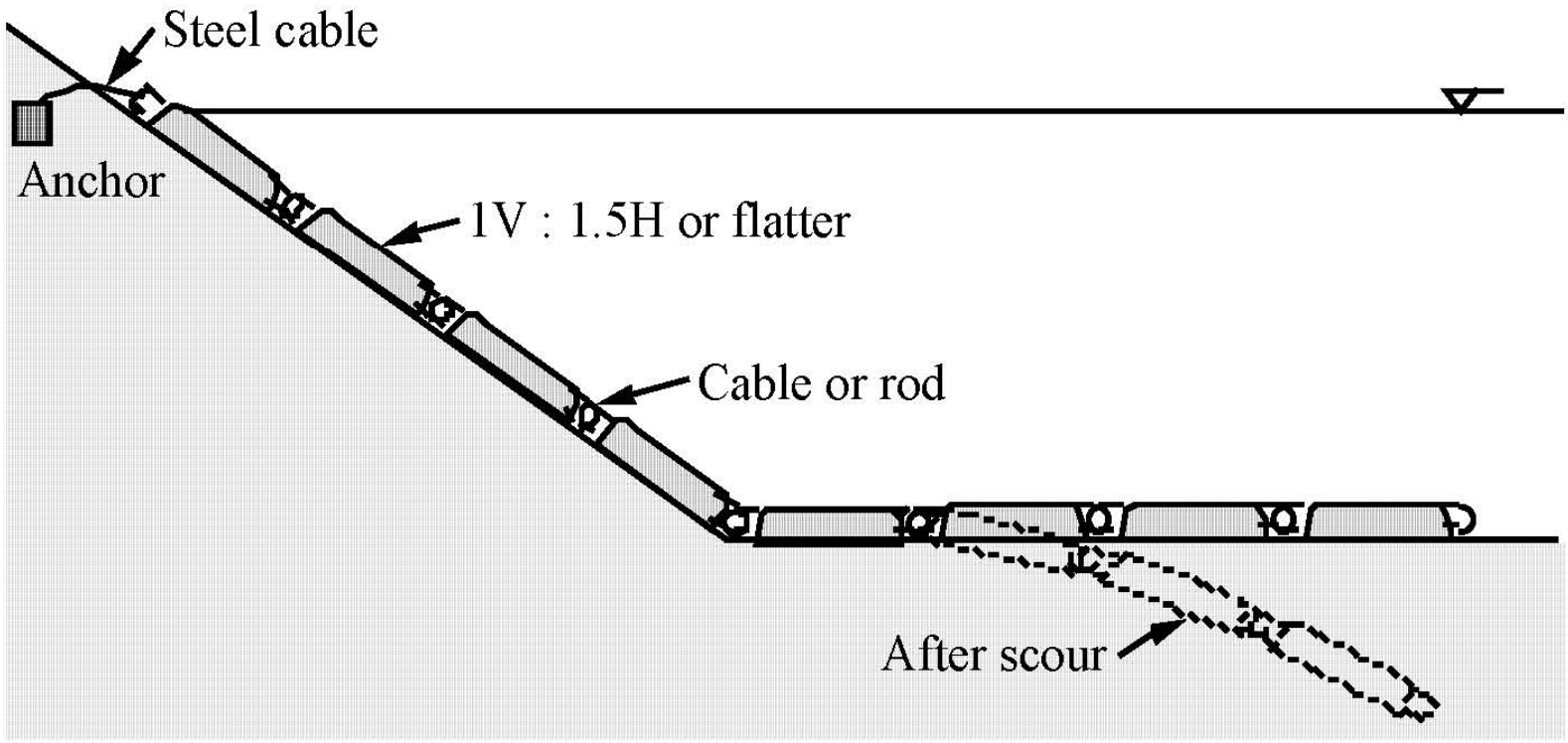
PGC8

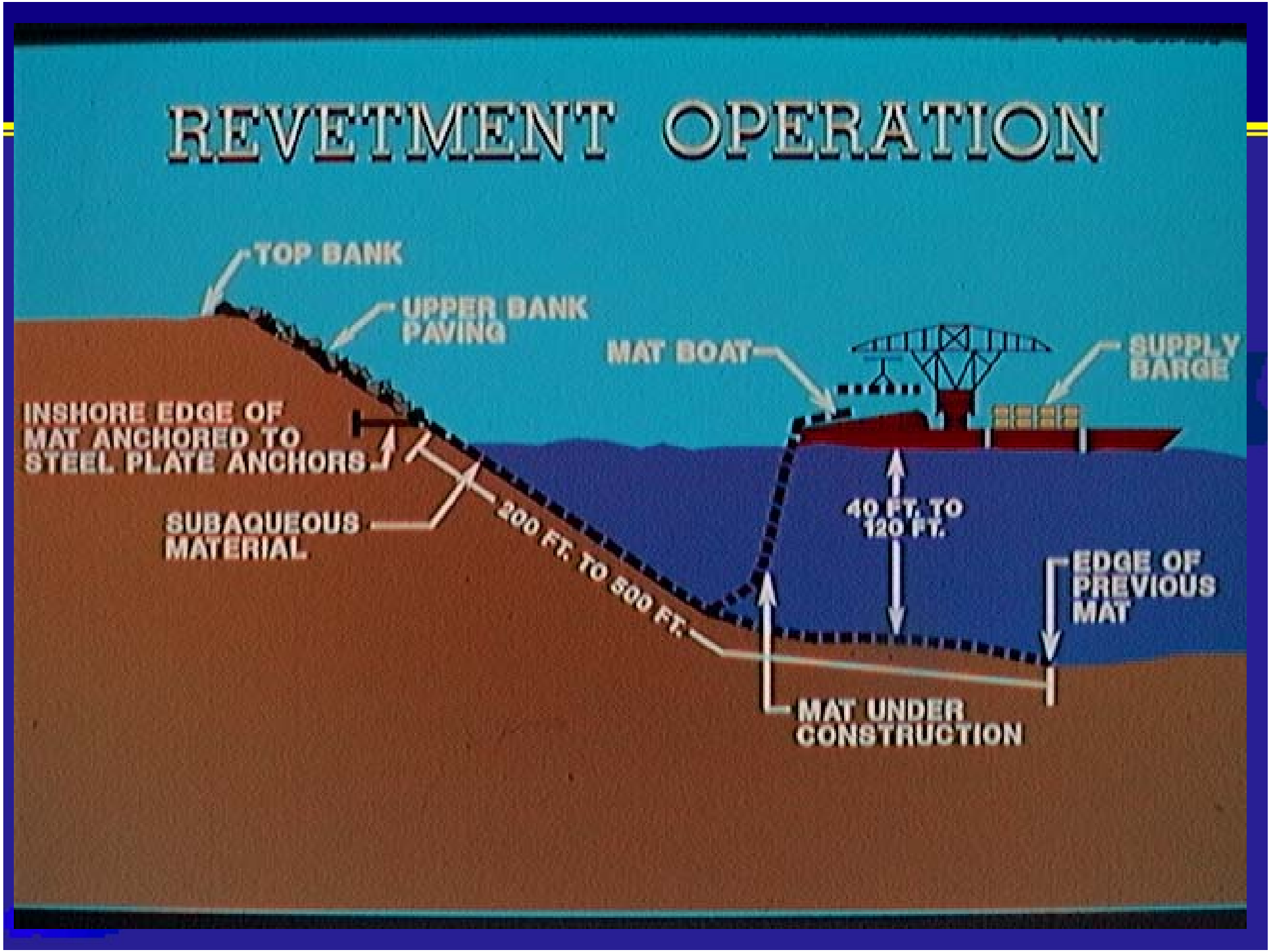
Geo Containers

PGC8 Completed geotextile tube to serve as soft dike

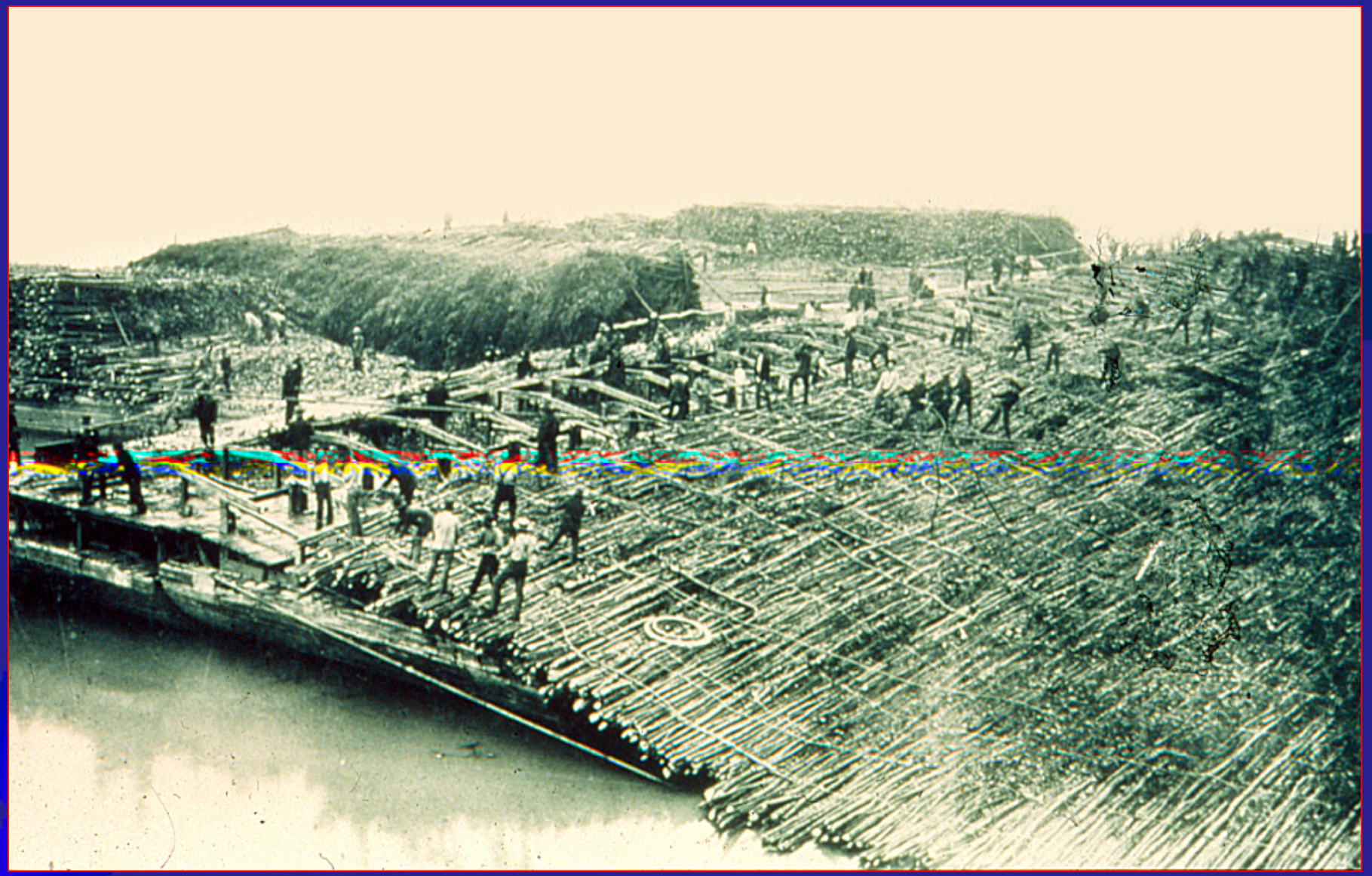
Phil Combs, 8/29/2002


COMPARISON OF
GREENVILLE REACH
1933 & 1975
91° 14′
91° 10′
91° 07′
33° 30′
33° 25′
33° 20′
LEGEND
Pool
Revetment
Dikes
Bankline
X Crossing
1933
1975


Steel cable
Anchor
1V : 1.5H or flatter
Cable or rod
After scour

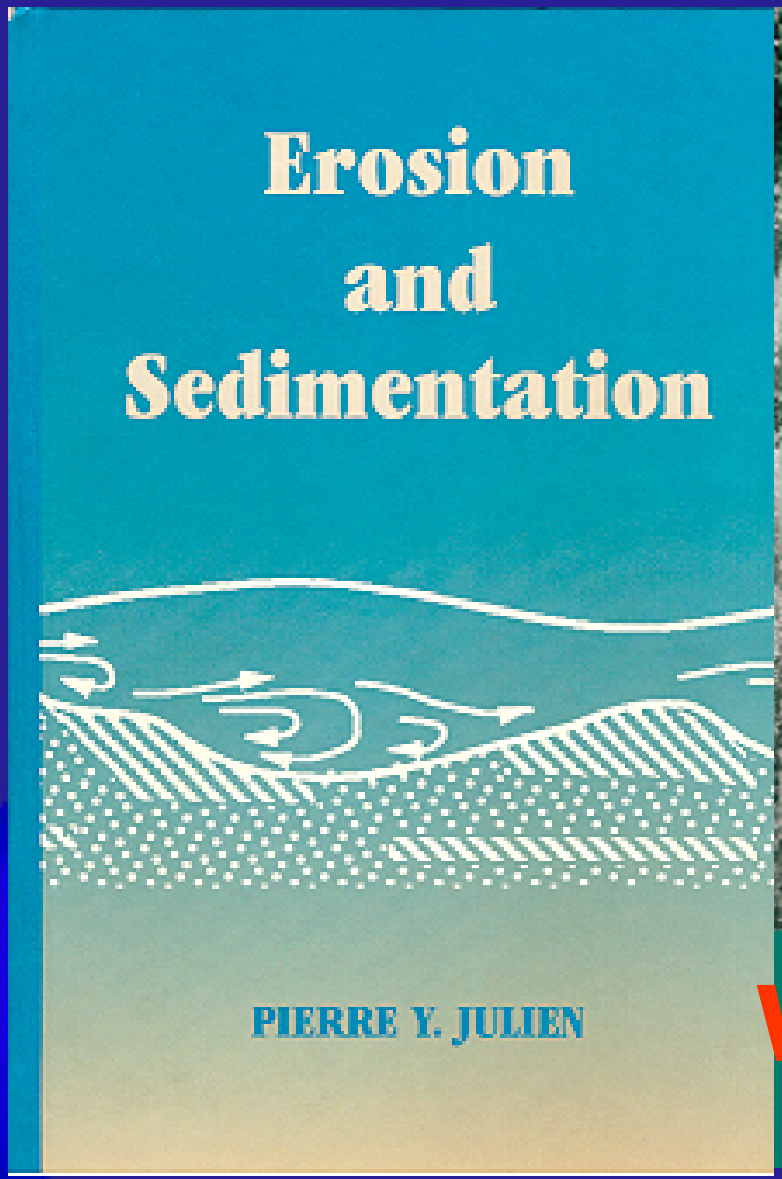

REVETMENT OPERATION
TOP BANK
UPPER BANK PAVING
MAT BOAT
SUPPLY BARGE
INSHORE EDGE OF MAT ANCHORED TO STEEL PLATE ANCHORS
SUBAQUEOUS MATERIAL
200 FT. TO 500 FT.
40 FT. TO 120 FT.
EDGE OF PREVIOUS MAT
MAT UNDER CONSTRUCTION

Willow Mats



ARTICULATED CONCRETE MATTRESS

Erosion and River Mechanics Textbooks



pierre@engr.colostate.edu

THANK YOU for your Attention!