TOWARDS AN INTEGRATED MANAGEMENT OF THE LOWER GRIJALVA RIVER (MEXICO)

First phase:

Controlling the flow and sediment discharge distribution at the bifurcation between the Samaria and Carrizal rivers


Mexico
TABASCO
CHIAPAS
Belize
Guatemala
Honduras
El Salvador
Image © 2005 MDA EarthSat

INTRODUCTION

- The inundations in Villahermosa require an **urgent solution**
- After the 1999 flood event, the authorities decided to:
  - *Construct a weir in the rio Carrizal*
  - *Investigate effective (definitive?) solutions to control the inundations*
- Nonetheless, the scheme should be designed taking into account the *potamological context*
  (potamology = science of rivers, more general than fluvial hidraulics)

GRIJALVA USUMACINTA RIVER BASINS

Average annual runoff in Mm^3

Río Grijalva

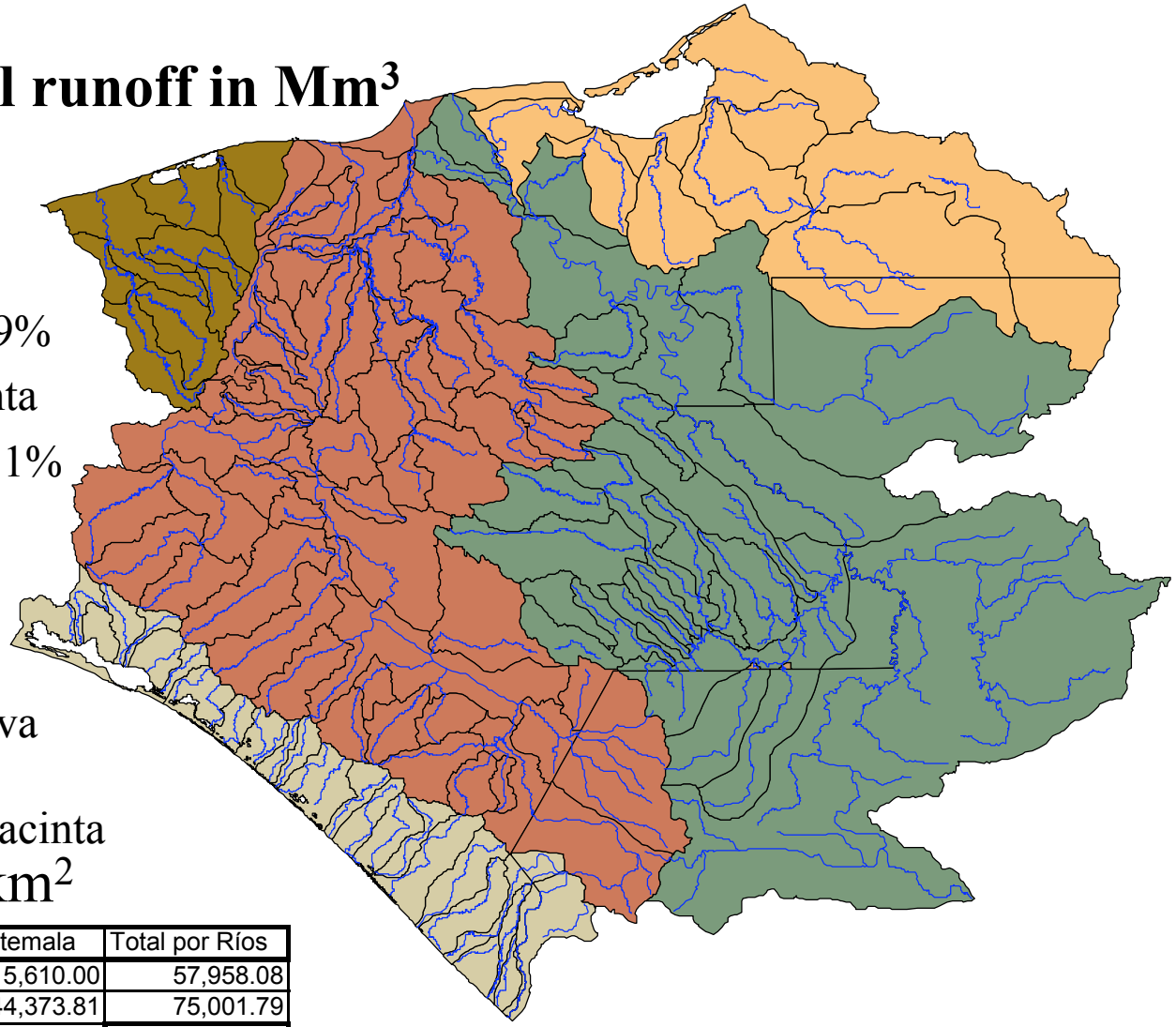
36,493.883 36.9%

Río Usumacinta

62,206.623 63.1%

Total

98,700.506



Basin Río Grijalva

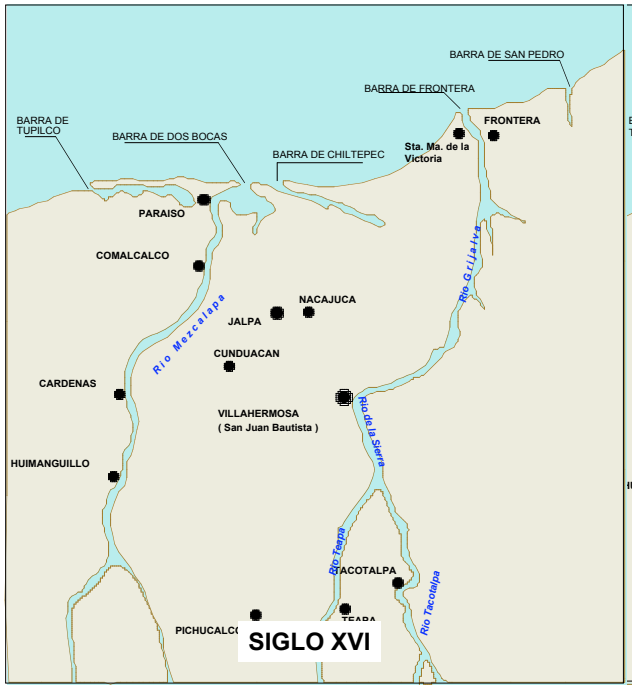
Basin Río Usumacinta

Areas in km^2

Río/País	México	Guatemala	Total por Ríos
Grijalva	52,348.08	5,610.00	57,958.08
Usumacinta	30,627.98	44,373.81	75,001.79
Total por paises	82,976.05	49,983.81	132,959.87
			Total de totales

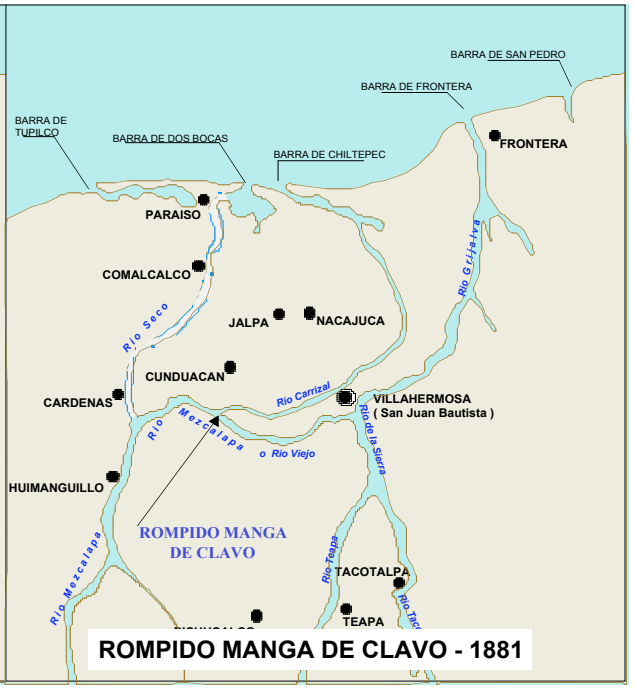
POTAMOLOGICAL CONTEXT

- The Grijalva river has the largest part of its basin in the Sierra Madre and enters its lower reach in the large coastal plain, before discharging in the Golf of Mexico
- The last stretch is within an alluvial fan (delta) in which several branches have developed through time by avulsion (change of the river course)

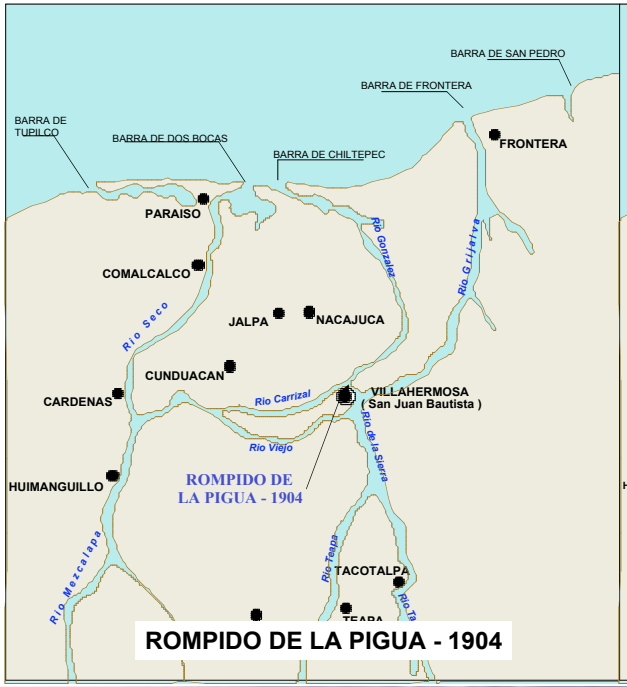


SIGLO XVI

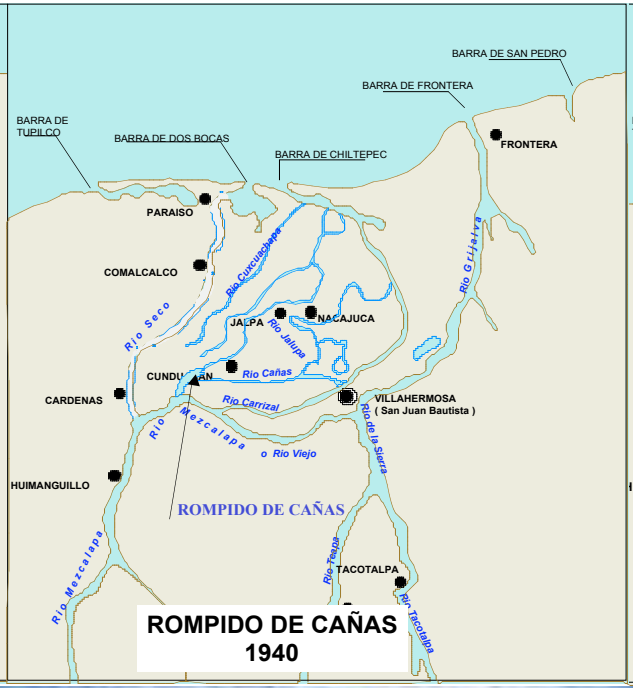
ROMPIDO DE NUEVA ZELANDIA - 1675



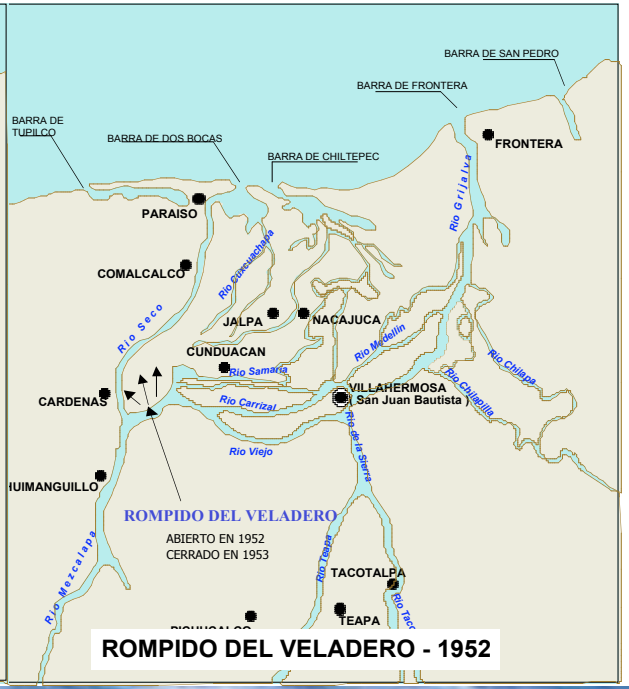
ROMPIDO MANGA DE CLAVO - 1881



ROMPIDO DE LA PIGUA - 1904

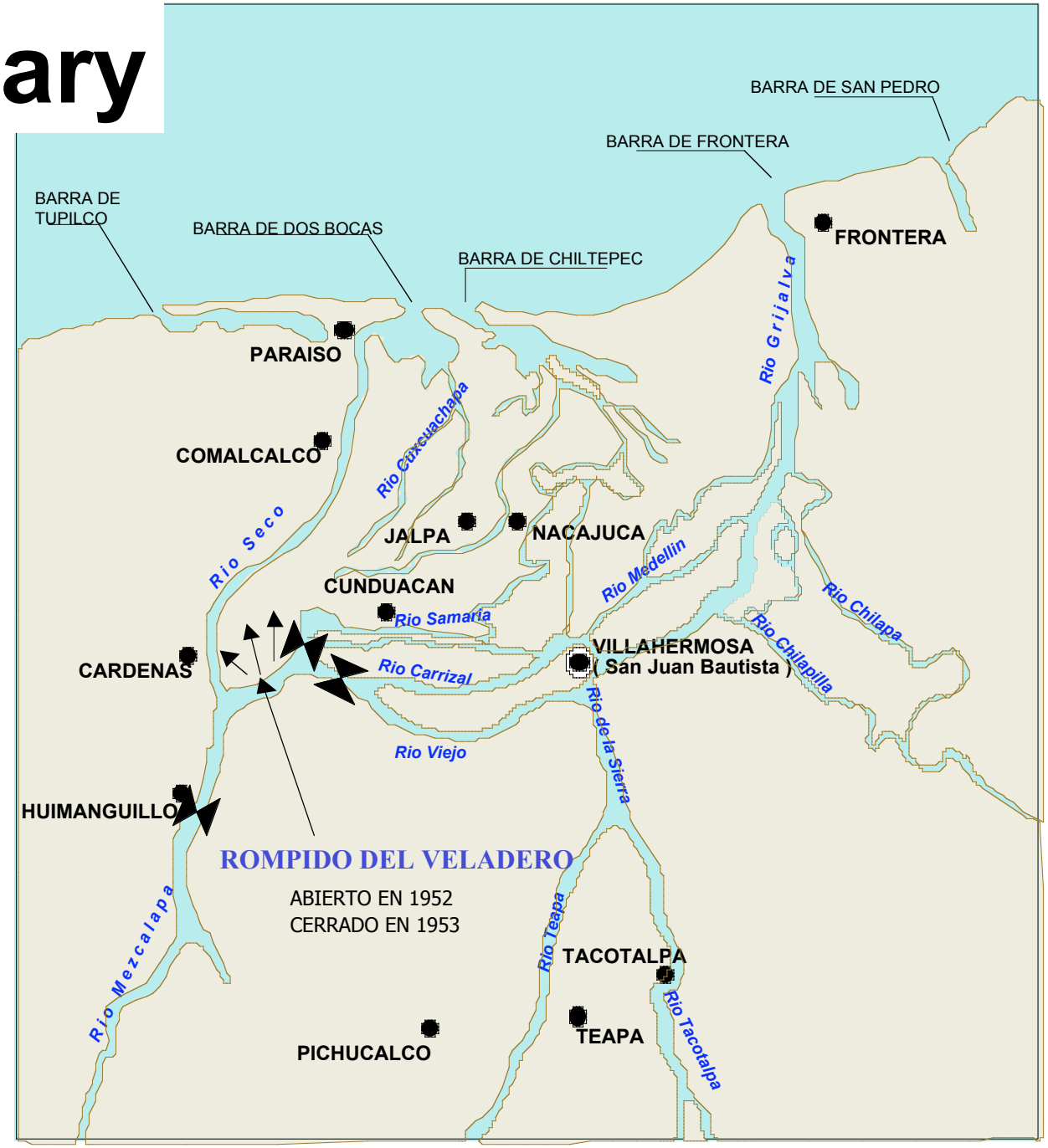


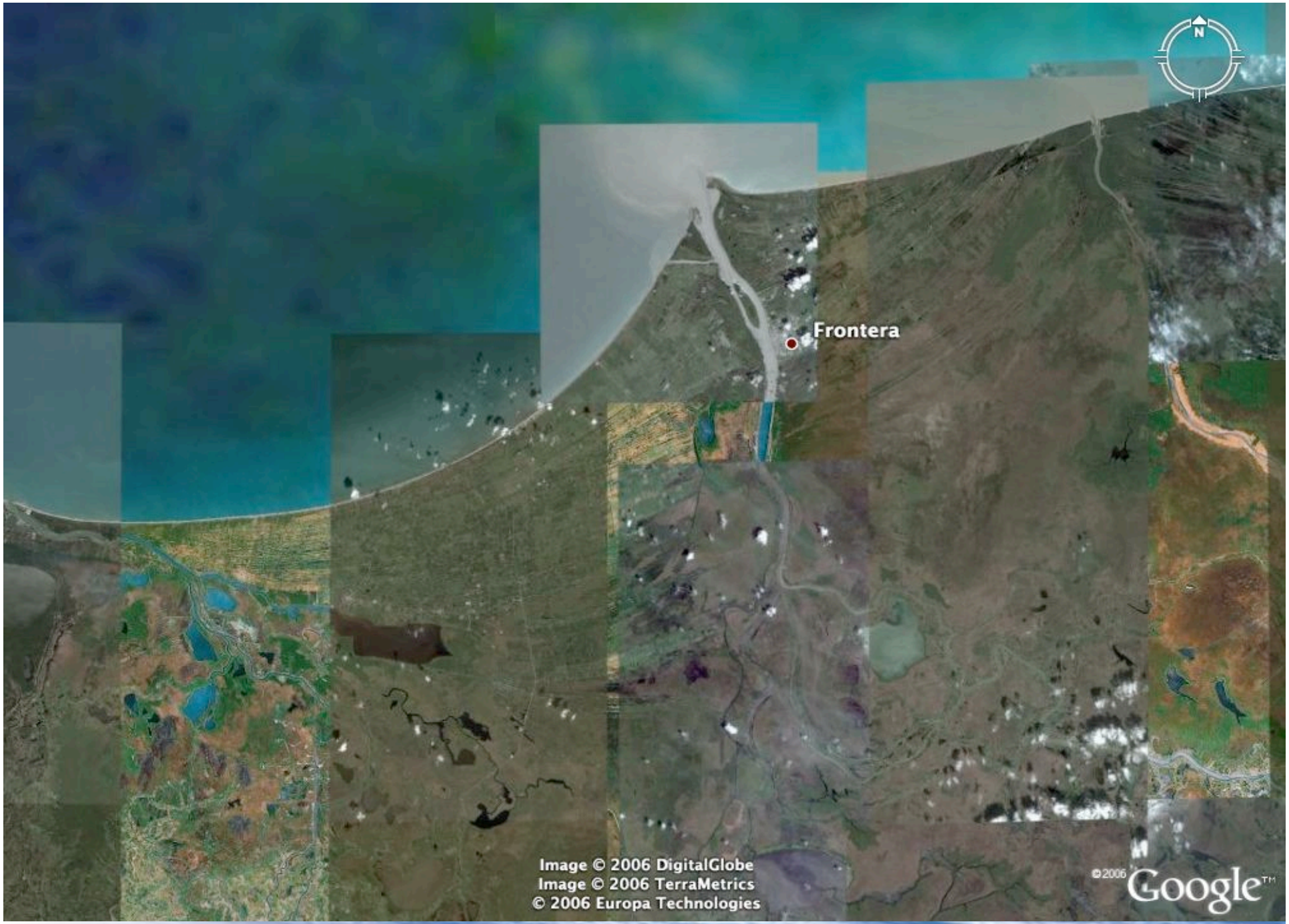
ROMPIDO DE CAÑAS 1940



ROMPIDO DEL VELADERO - 1952

Summary


BARRA DE SAN PEDRO
BARRA DE FRONTERA
BARRA DE TUPILCO
BARRA DE DOS BOCAS
BARRA DE CHILTEPEC
FRONTERA
PARAISO
COMALCALCO
Rio Grijalva
Rio Cupcuachapa
Rio Seco
JALPA
NACAJUCA
CUNDUACAN
Rio Medellin
Rio Chilapa
Rio Samaria
Rio Chilapilla
VILLAHERMOSA
(San Juan Bautista)
CARDENAS
Rio Carrizal
Rio de la Sierra
Rio Viejo
HUIMANGUILLO
ROMPIDO DEL VELADERO
ABIERTO EN 1952
CERRADO EN 1953
Rio Mezcalapa
Rio Teapa
TACOTALPA
Rio Tacotalpa
TEAPA
PICHUCALCO


N
Frontera
Image © 2006 DigitalGlobe
Image © 2006 TerraMetrics
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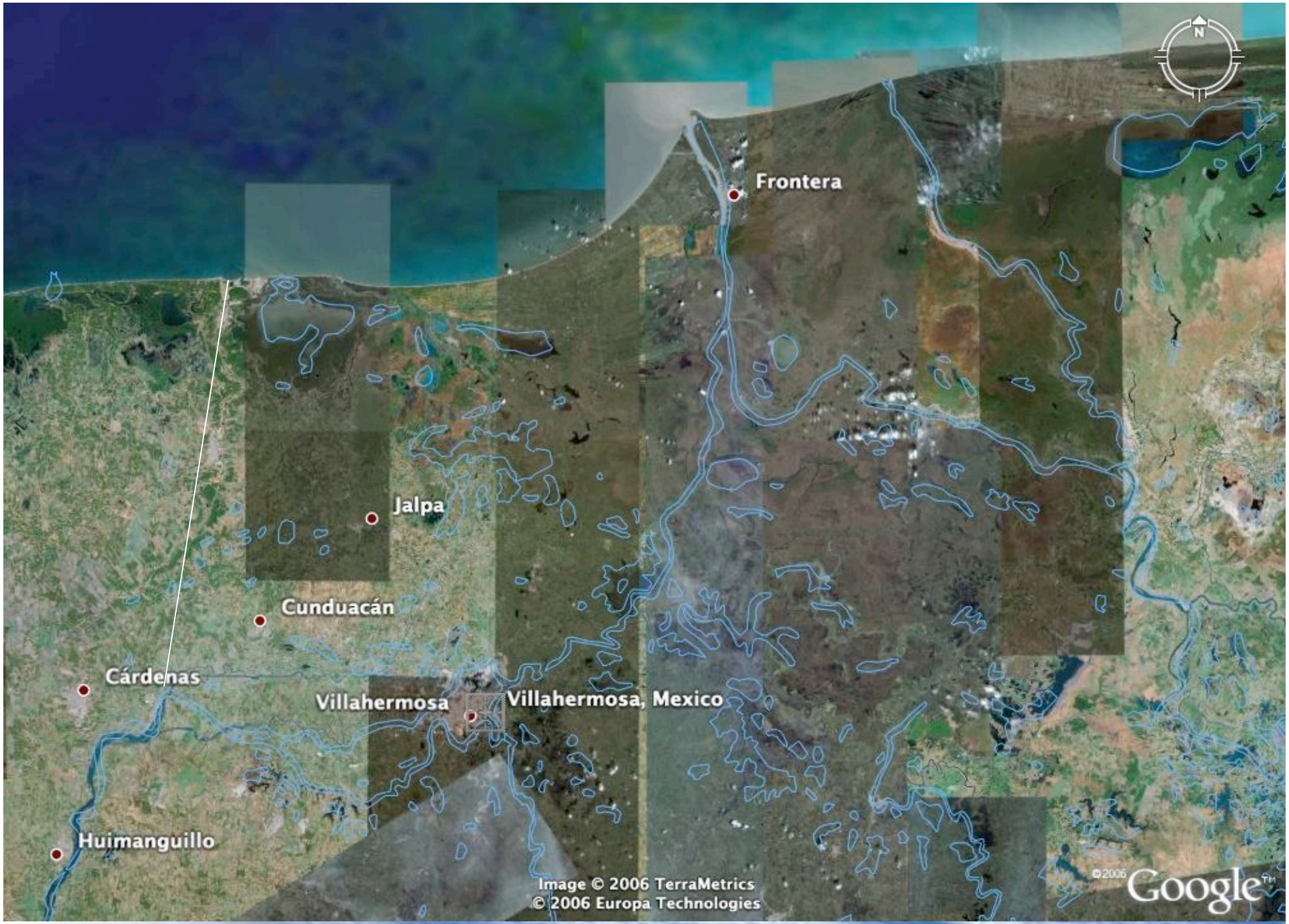
Frontera
Jalpa
Cunduacán
Cárdenas
Villahermosa
Villahermosa, Mexico
Huimanguillo
Image © 2006 TerraMetrics
© 2006 Europa Technologies
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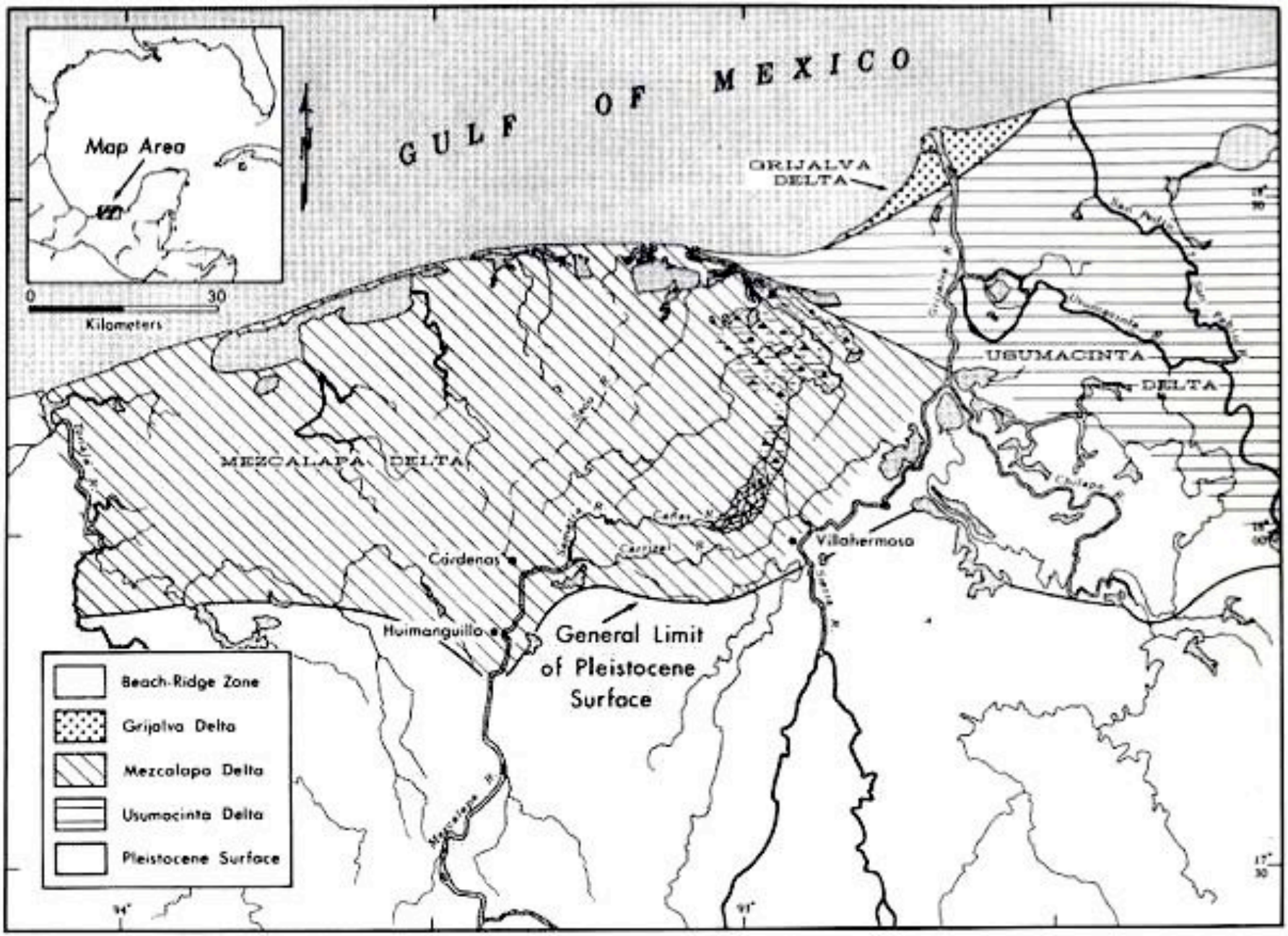
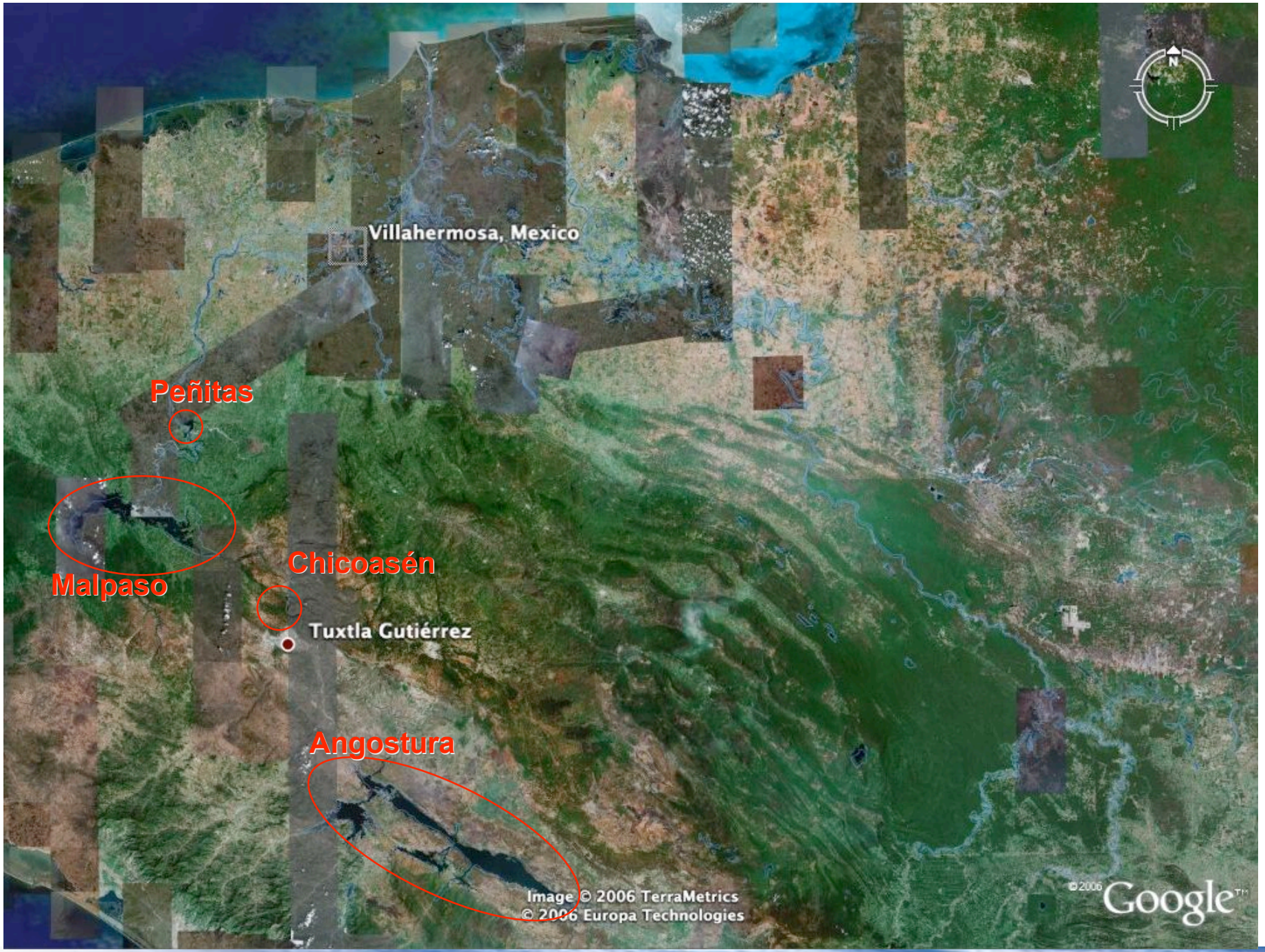


FIGURE 6. Geomorphologic divisions of the Tabasco Plain.


Villahermosa, Mexico
Peñitas
Malpaso
Chicoasén
Tuxtla Gutiérrez
Angostura
Image © 2006 TerraMetrics
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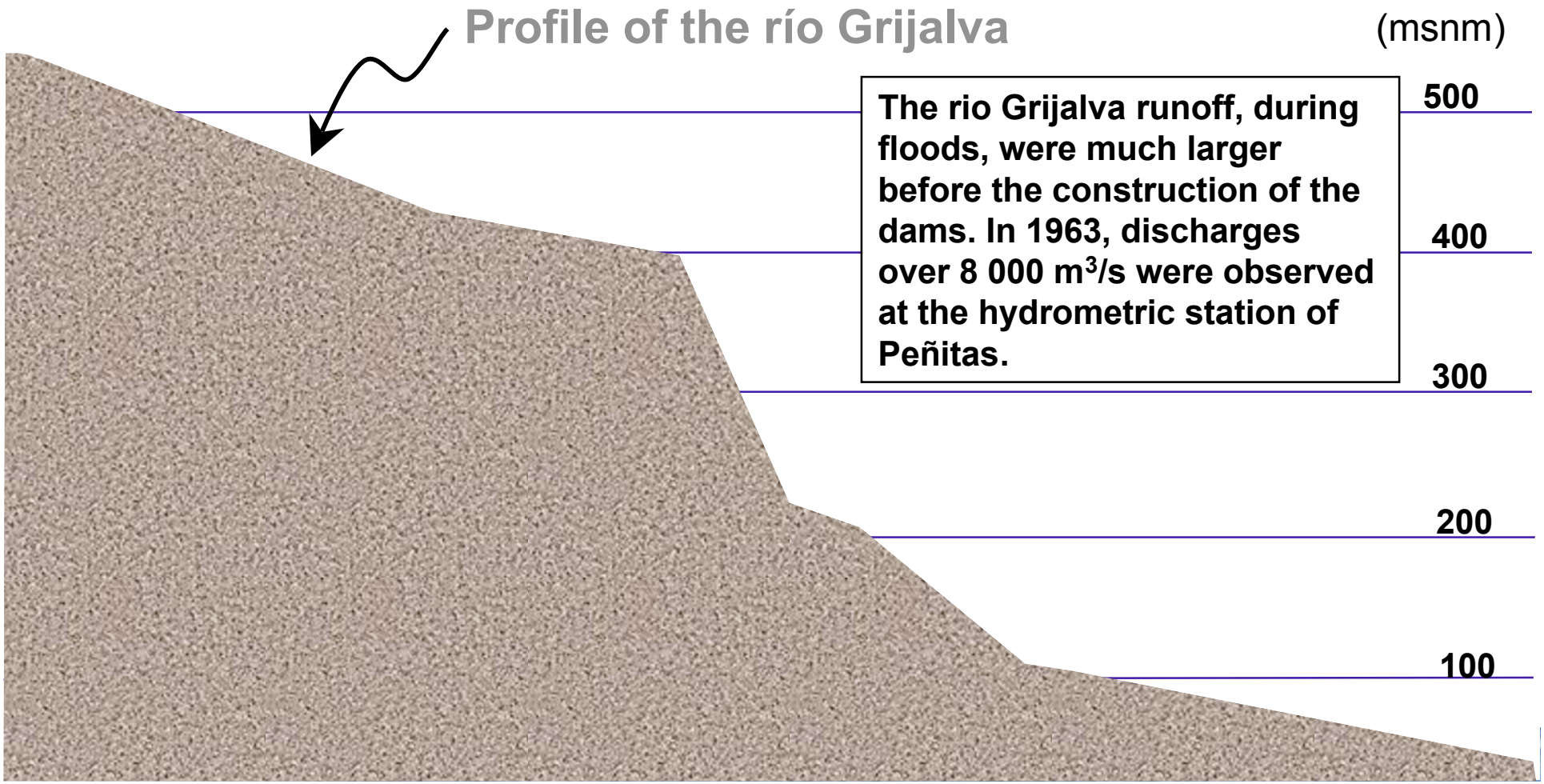
SCHEME OF DAMS ON THE RÍO GRIJALVA



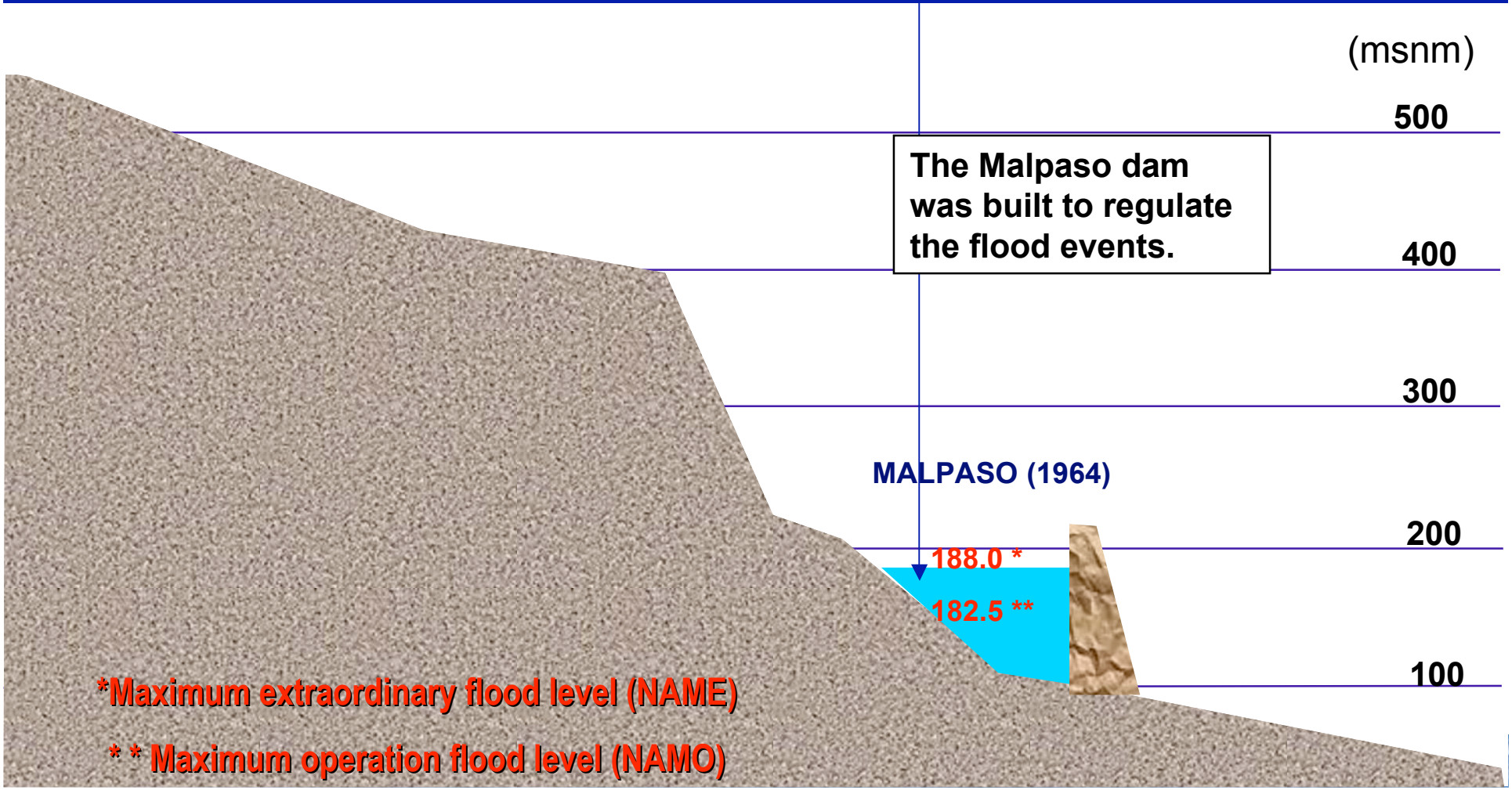
SCHEME OF DAMS ON THE RÍO GRIJALVA

CAPACITY
(In millions cubic meters)

14,000

(For flood regulation)

3,460



SCHEME OF DAMS ON THE RÍO GRIJALVA

CAPACITY
(In millions cubic meters)

14,000

(For flood regulation)

3,460

(msnm)

500

400

300

200

100

Discharges reduced with regulation by the reservoir, nonetheless, operation of spilway was needed in 1969, 1970 y 1973, before construction of Angostura.

MALPASO (1964)

188.0 *

182.5 **

*Maximum extraordinary flood level (NAME)

* * Maximum operation flood level (NAMO)

SCHEME OF DAMS ON THE RÍO GRIJALVA

CAPACITY
(In millions cubic meters)

20,000		14,000	

(For flood regulation)

8,500		3,460	

ANGOSTURA (1975)

539.5*
533.0**

(msnm)

500

400

300

200

100

Is the reservoir with the largest regulation capacity of Mexico.

MALPASO (1964)

188.0 *
182.5 **

*Maximum extraordinary flood level (NAME)

* * Maximum operation flood level (NAMO)

SCHEME OF DAMS ON THE RÍO GRIJALVA

CAPACITY
(In millions cubic meters)

20,000	1,680	14,000	

(For flood regulation)

8,500	490	3,460	

ANGOSTURA (1975)
539.5*
533.0**

CHICOASÉN (1980)
395.0*
392.5**

MALPASO (1964)
188.0 *
182.5 **

(msnm)
500
400
300
200
100

Hydropower scheme with highest potential of 1 500 MW, but with little effect on flow regulation.

*Maximum extraordinary flood level (NAME)

* * Maximum operation flood level (NAMO)

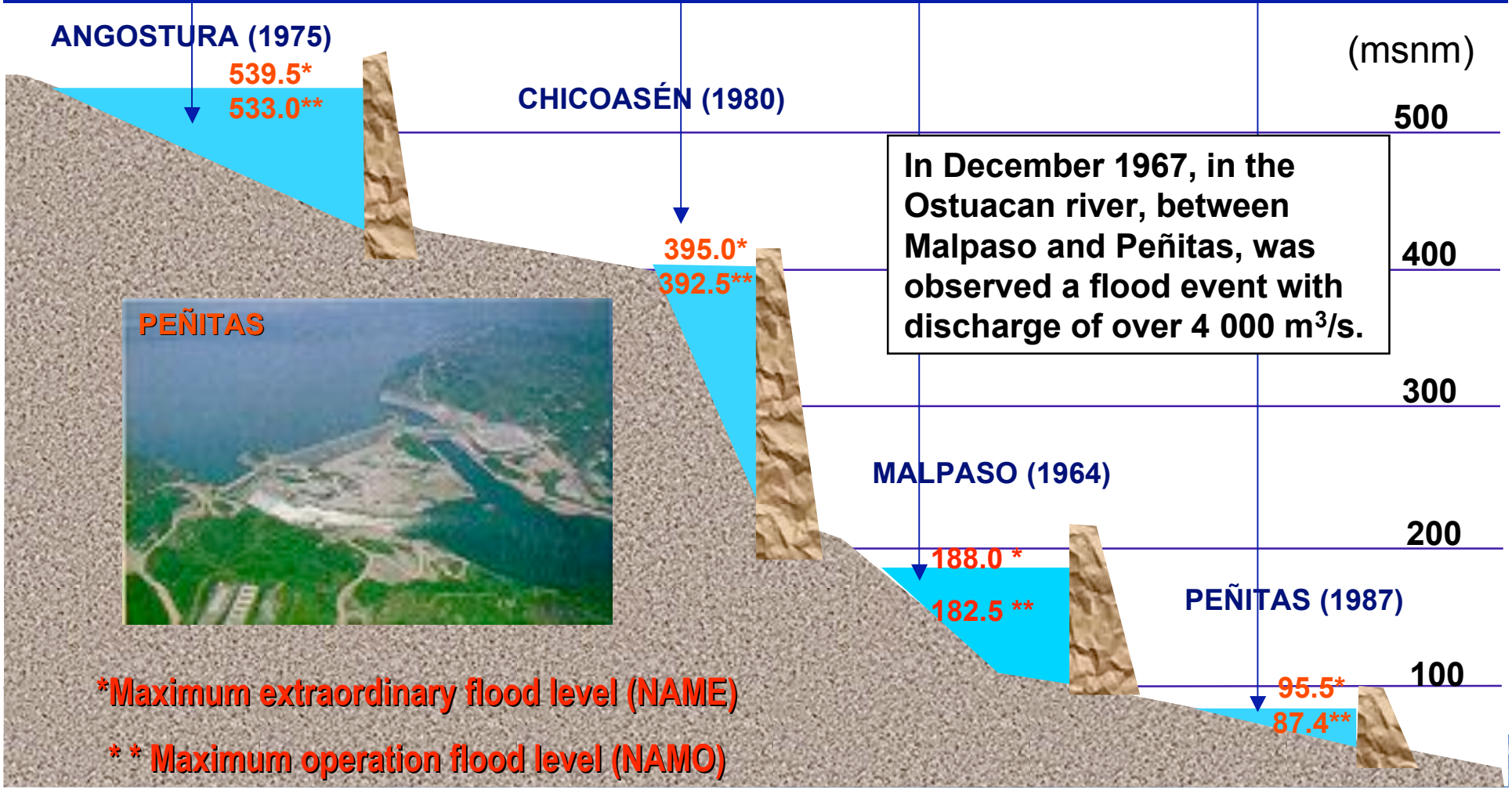
SCHEME OF DAMS ON THE RÍO GRIJALVA

CAPACITY
(In millions cubic meters)

20,000	1,680	14,000	1,485

(For flood regulation)

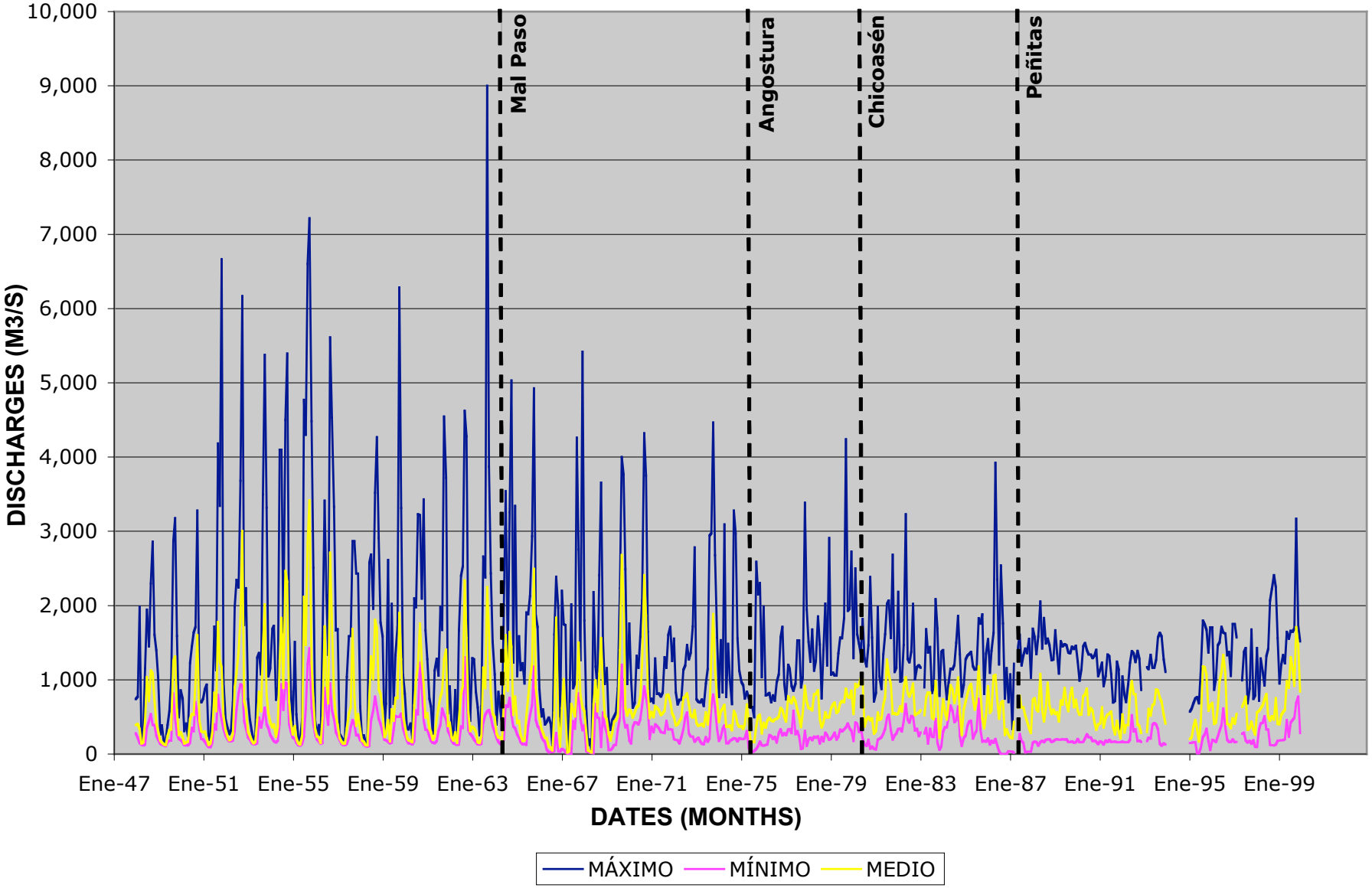
8,500	490	3,460	1,091



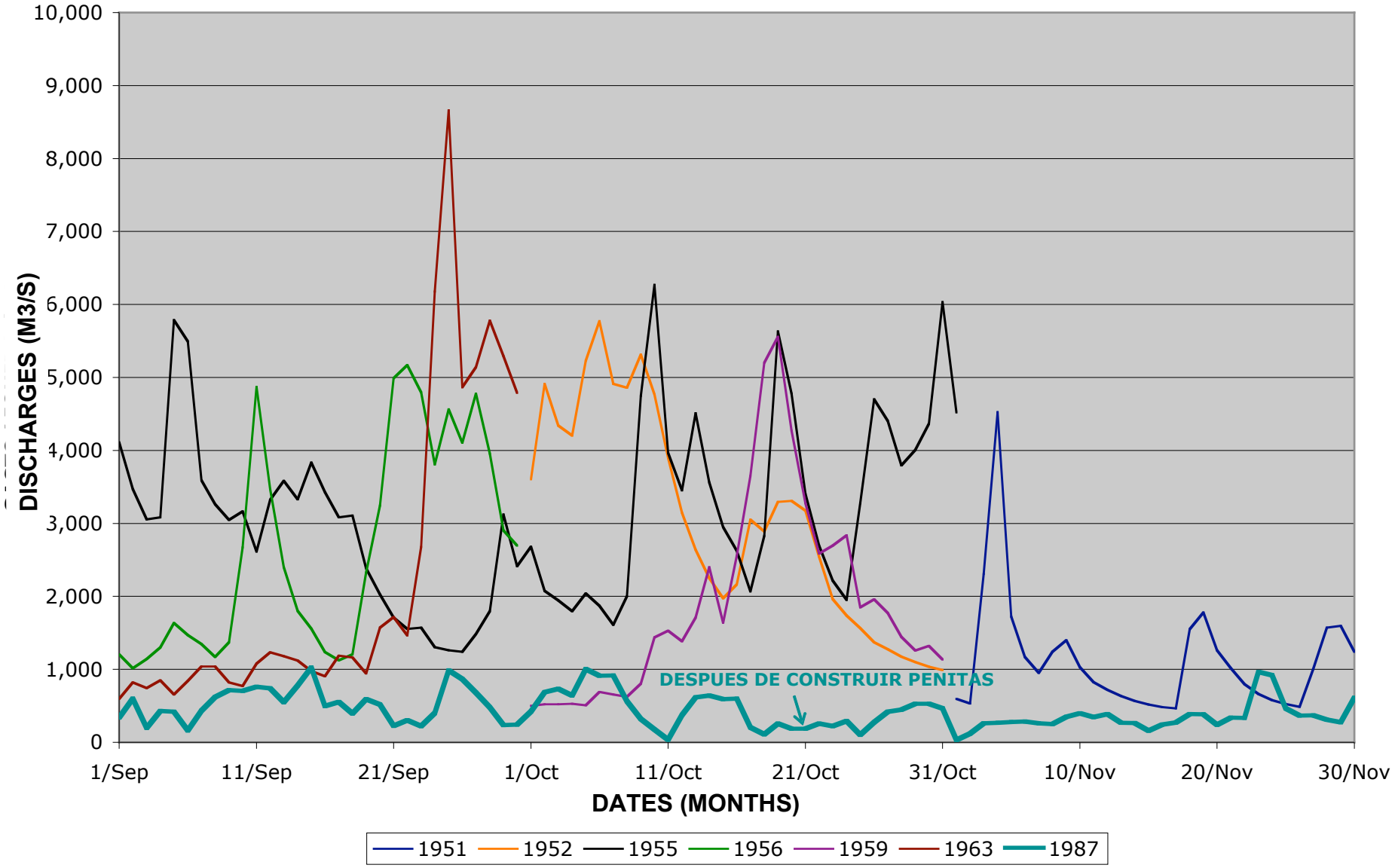
IMPACT OF THE DAMS

- 4 dams constructed between 1964 and 1987 had a significant impact on the hydrological regimen of the Mezcalapa river (Grijalva downstream of Peñitas)
- Natural flood events disappeared and the operation of Peñitas dam determines the discharges (little contribution of Platanar river)
- A compensation dam foreseen to avoid rapid discharge fluctuation during the day has not yet been constructed

MONTHLY DISCHARGES IN PENITAS 1948 - 1999



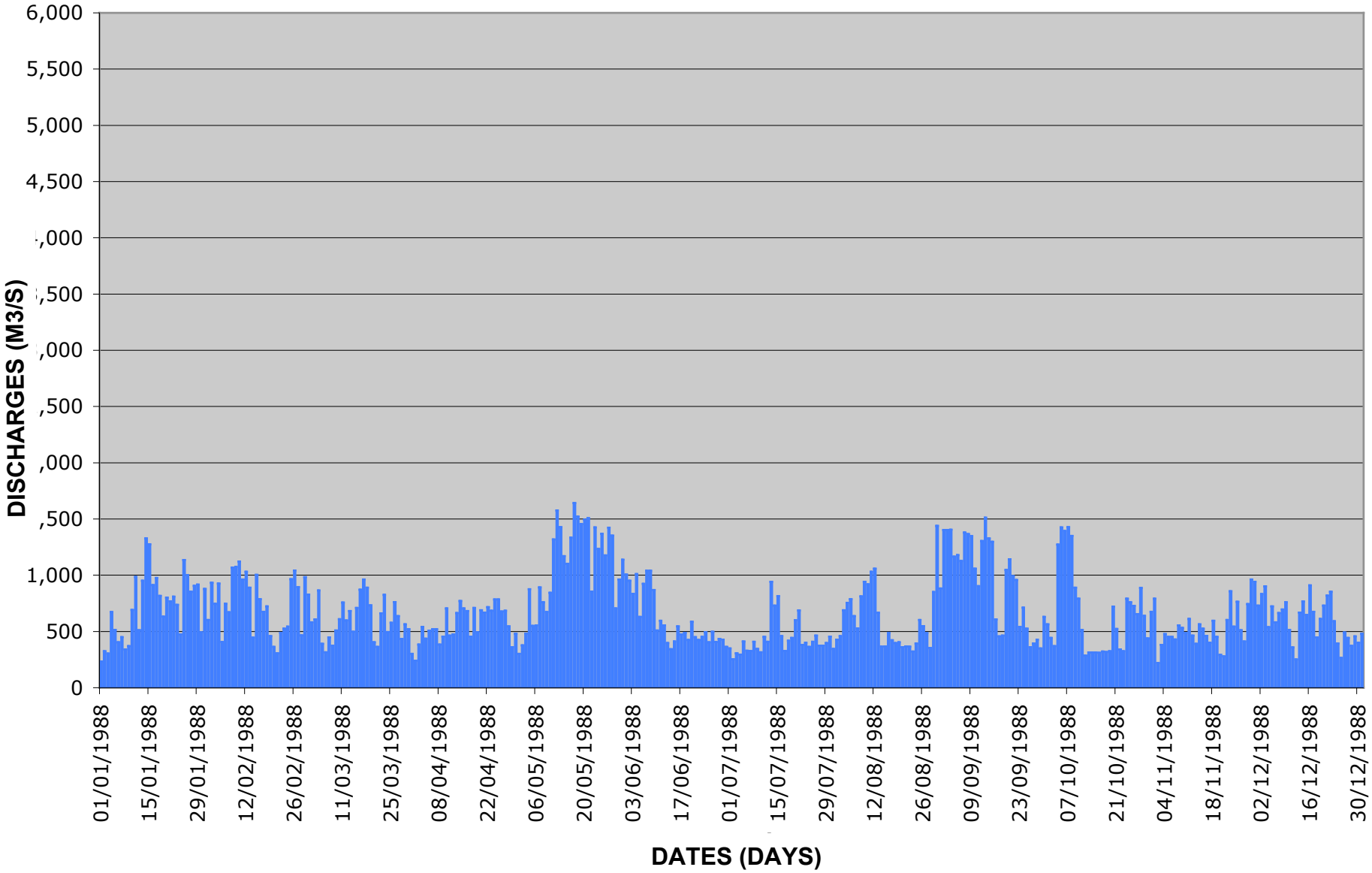
GRIJALVA FLOOD EVENTS BEFORE AND AFTER CONSTRUCTION OF PENITAS DAM



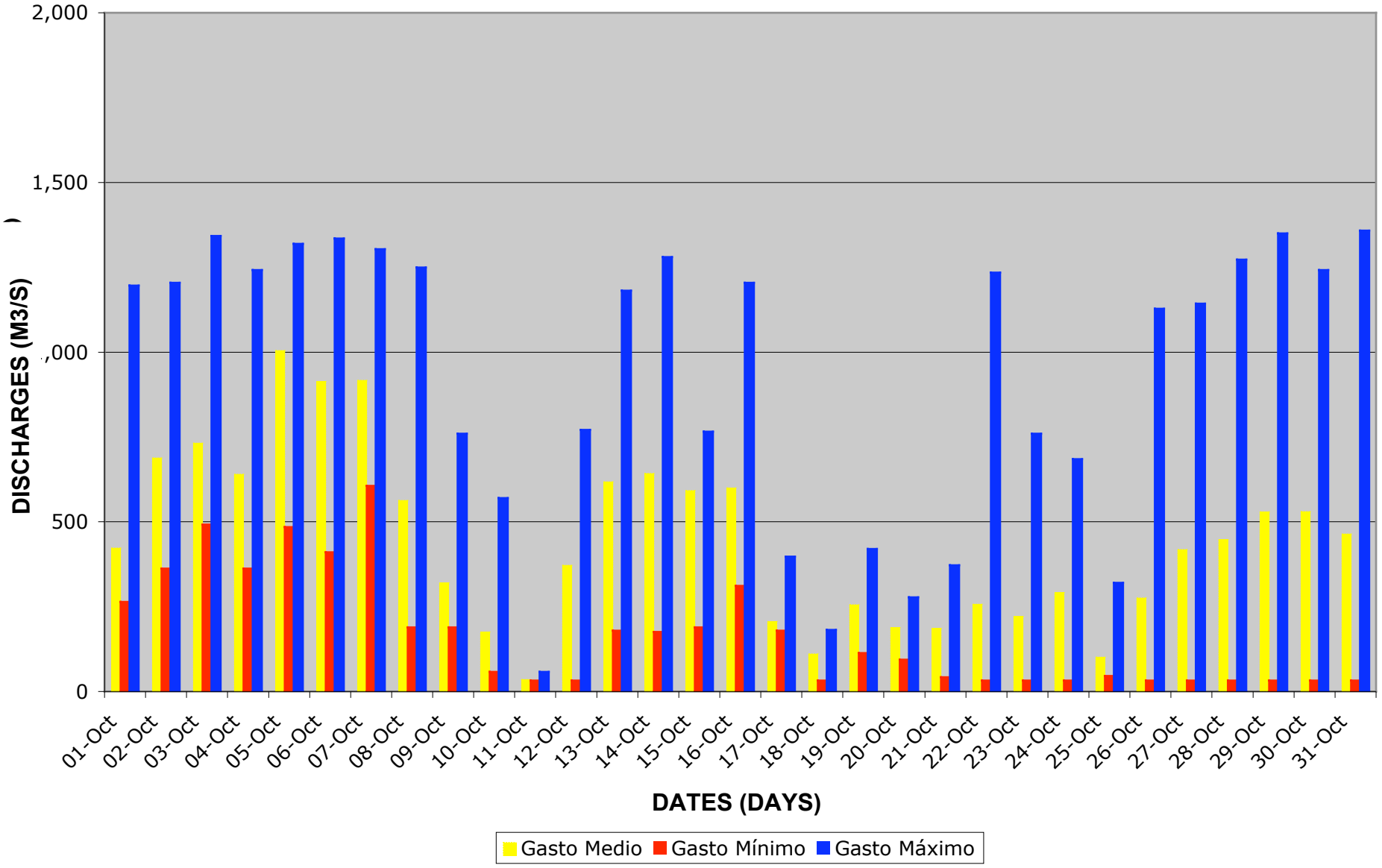
HYDROLOGICAL IMPACT

- Change in hydrological regimen, dry and flood seasons in quite constant monthly discharges, except in flood event periods
- Between 1987 and 1999, operation of Peñitas dam produced discharge fluctuations during the day between a very low and a very high value (depending on the electricity demand)

HYDROGRAM 1987, THE YEAR AFTER CONSTRUCTION OF PENITAS DAM



HYDROGRAM IN OCTOBER 1987, THE YEAR AFTER CONSTRUCTION OF PENITAS DAM



SEDIMENTOLOGICAL IMPACT

- Sedimentation in the dam reservoirs produce a deficit in sediment supply to the Lower Grijalva

- Only the Platanar river carries sediment to the Mezcalapa river, with large quantities of material from the Chichonal volcano eruption (1982), in total 9 millions cubic meters ashes

RIVER "RESPONSE"

- By sediment déficit, clair water has the tendency to erode the riverbed downstream of Peñitas dam (impact controlled by the nature of the riverbed: rocs)

- The water level gauging station just downstream of the dam hangs today above the waterlevel (was already replaced twice to follow the descent of the riverbed, degradation explained by Lane Balance)

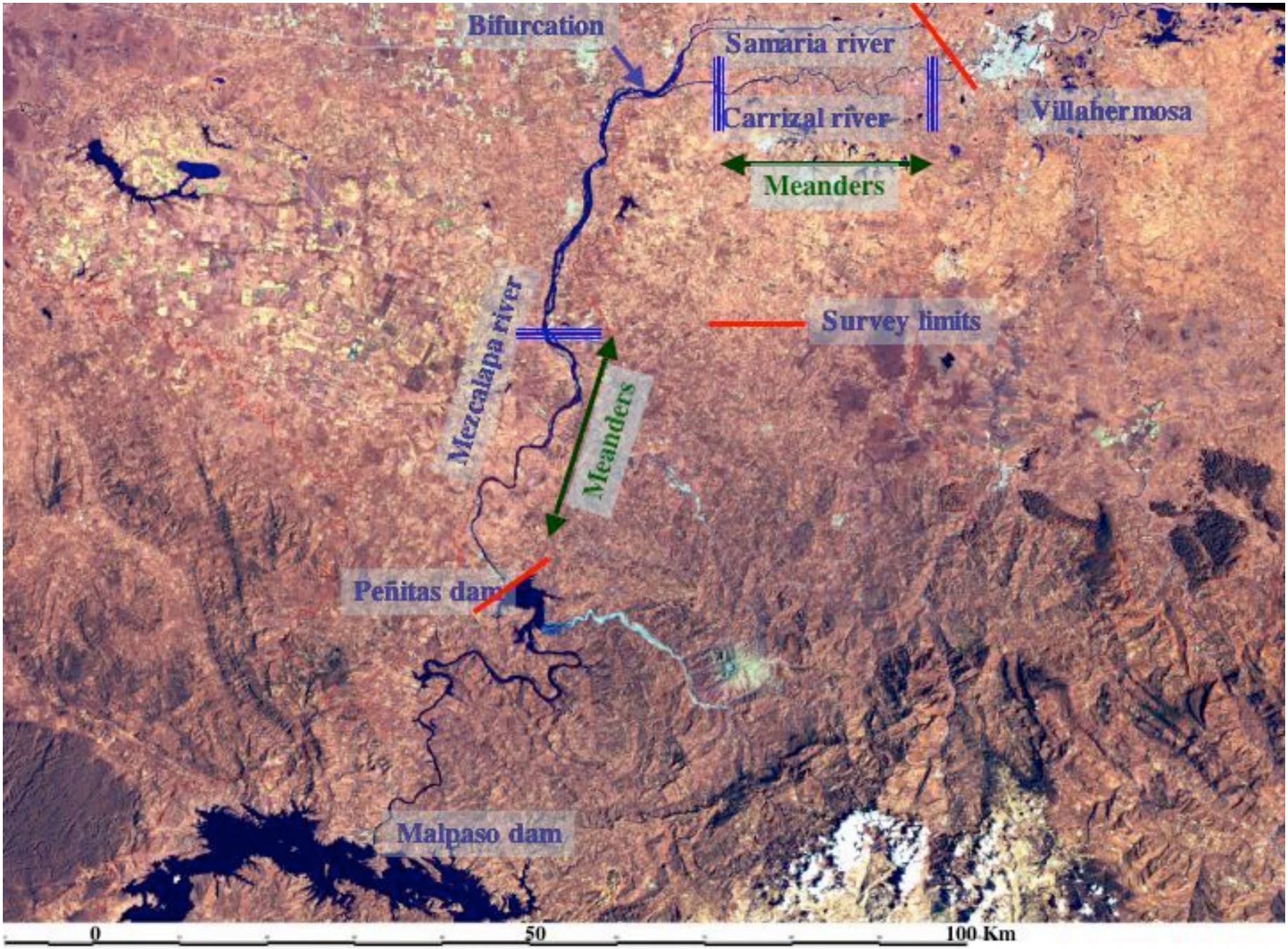
RIVER “RESPONSE”

- Products of this erosion move in downstream direction to deposit further, creating many and large sand- and gravel bars in the Mezcalapa

Río Mezcalapa in Huimanguillo, Puente Solidaridad

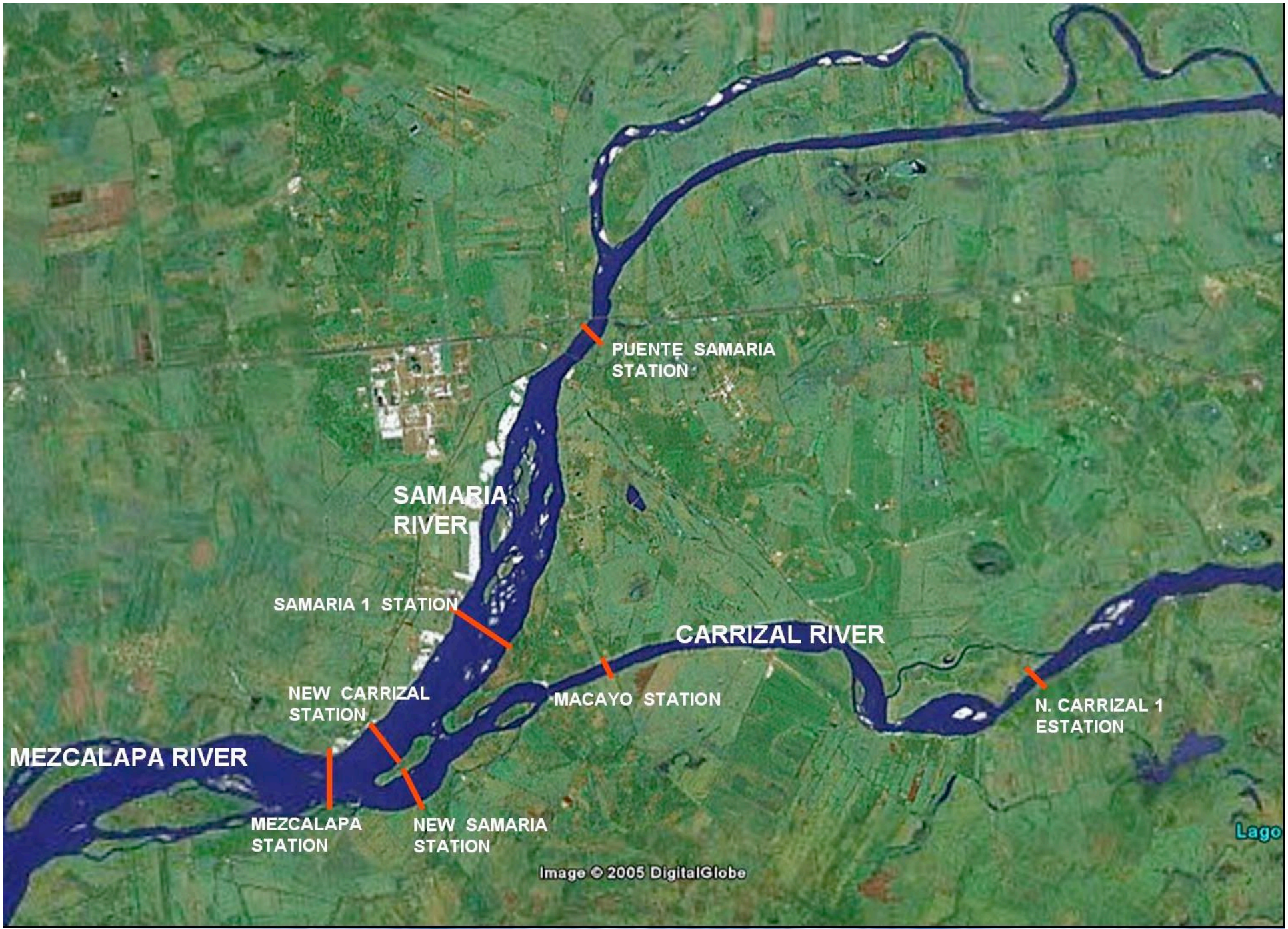
RIVER "RESPONSE"

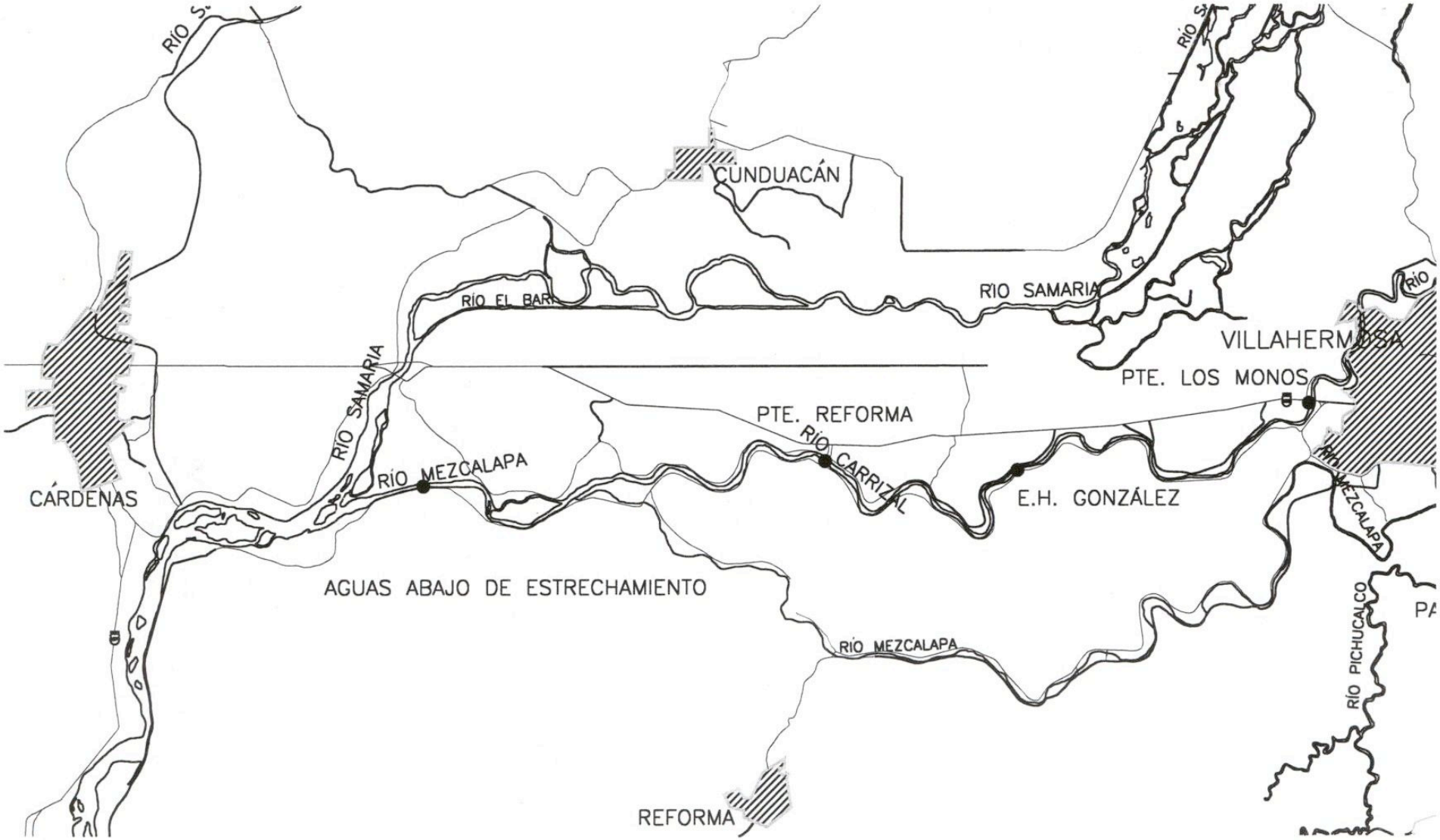
- A meandering river course would be more adequate to the new hydrological regimen
- The strong discharge fluctuation, in the presence of the large sand and gravel bancs, produced between 1987 y 1999 flow deviations towards the banks,
- what induced always more erosions, causing a braided riverbed in the lower part of the Mezcalapa


Bifurcation
Samaria river
Carrizal river
Villahermosa
Meanders
Survey limits
Mezcalapa river
Meanders
Peñitas dam
Malpaso dam
0
50
100 Km

BIFURCATION MEZCALAPA

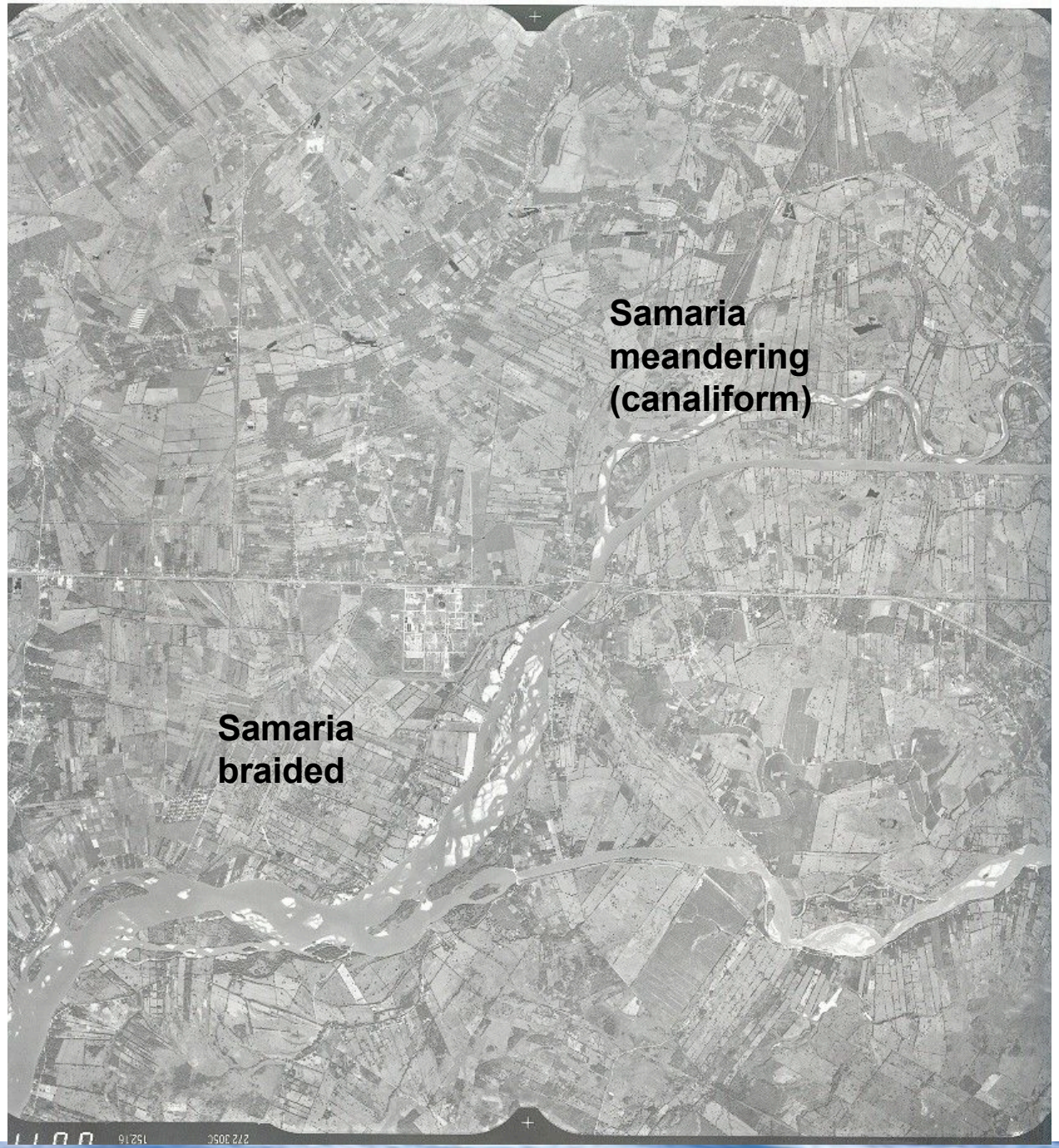
- The bifurcation of the Mezcalapa in Samaria and Carrizal rivers exists since 1940, when occurred the Cañas avulsion
- Information is missing on the development of the river between 1940 and 1964, when started construction of the dams
- However, aerial photographs reveal the tendency in the Mezcalapa to amplify its course, although not as much as in the Carrizal river


PUENTE SAMARIA
STATION
SAMARIA
RIVER
SAMARIA 1 STATION
CARRIZAL RIVER
NEW CARRIZAL
STATION
MACAYO STATION
N. CARRIZAL 1
ESTATION
MEZCALAPA RIVER
MEZCALAPA
STATION
NEW SAMARIA
STATION
Lago
Image © 2005 DigitalGlobe


RÍO S.
CÚNDUACÁN
RÍO SAMARIA
RÍO EL BARRIL
RÍO SAMARIA
VILLAHERMOSA
PTE. LOS MONOS
PTE. REFORMA
RÍO CARRIZAL
RÍO MEZCALAPA
CÁRDENAS
E.H. GONZÁLEZ
AGUAS ABAJO DE ESTRECHAMIENTO
RÍO MEZCALAPA
RÍO PICHUCALCO
REFORMA

1996

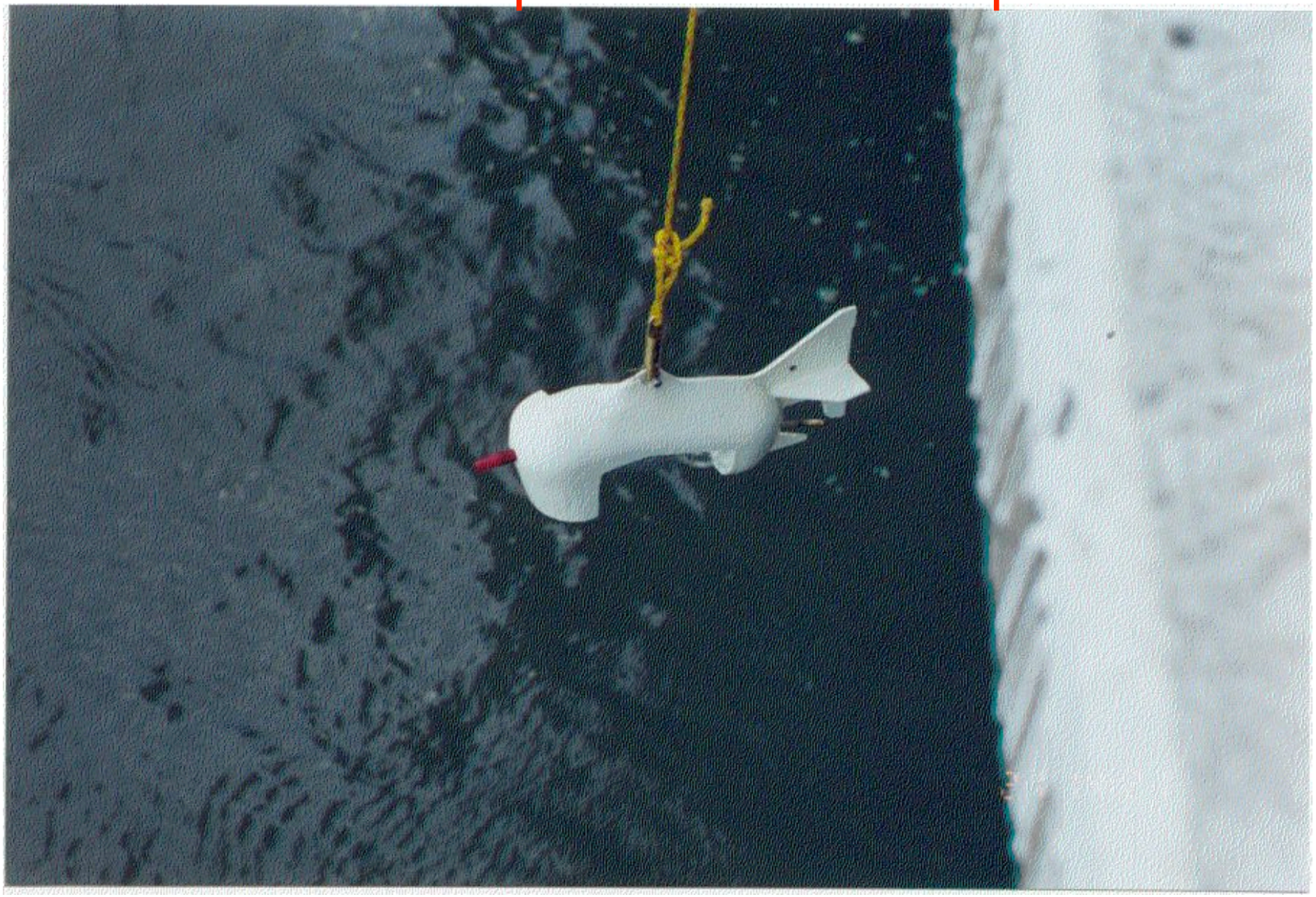
2000



BIFURCATION MEZCALAPA

- Impact of Samaria bridges:
  - Produce backwater, with effect on sedimentation when flood retreats
  - Tendency to outflank by bank erosion
- Results in daily fluctuations of discharges (between 1987 y 1999)
- Power of the flow distributes in a wide riverbed, reducing the sediment transport capacity

US DHS-59 for suspended load transport



US BL-84 for bedload transport

US BL-84 for bedload transport

Operated from a small unit

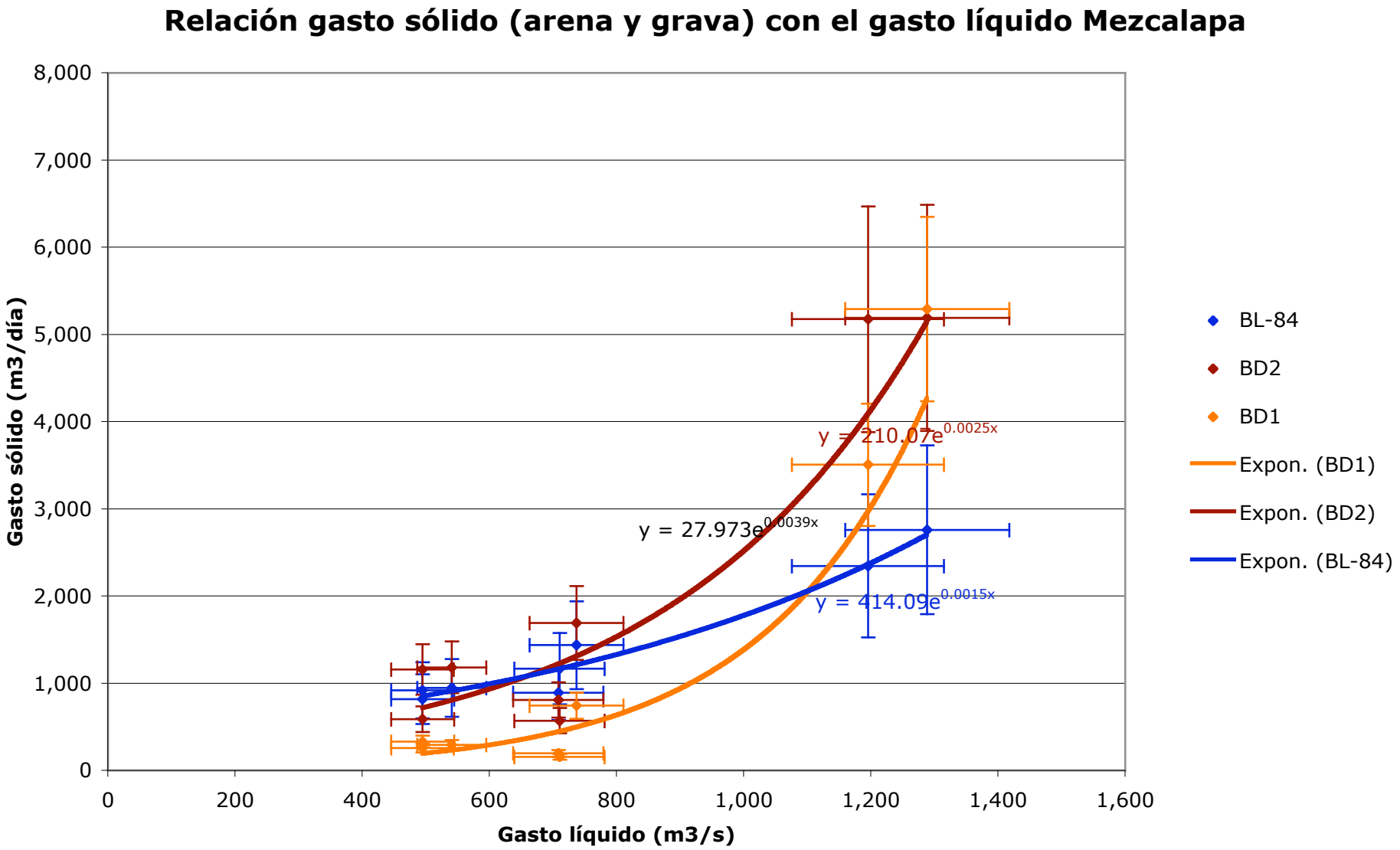
Delft Bottle BD2 for near-bed load transport

Operated from a small unit

Delft Bottle BD1 for suspended load transport

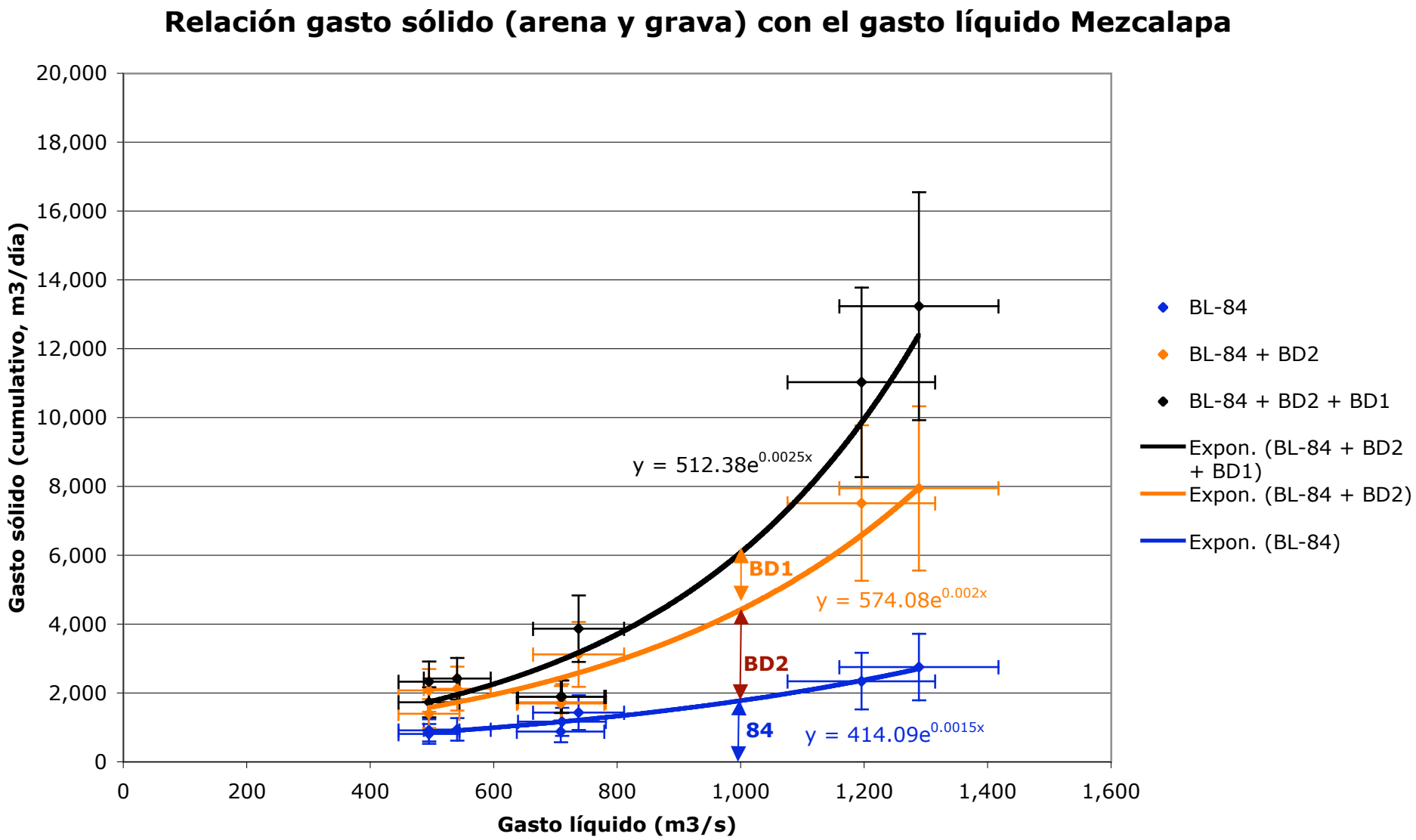
Fitting the tail; operated from a small unit

Flow and sediment transport relationship Mezcalapa

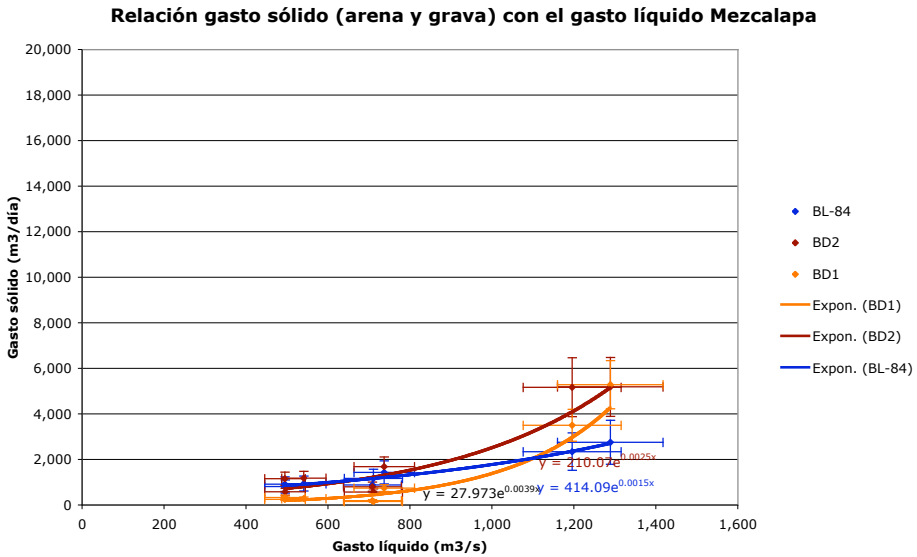


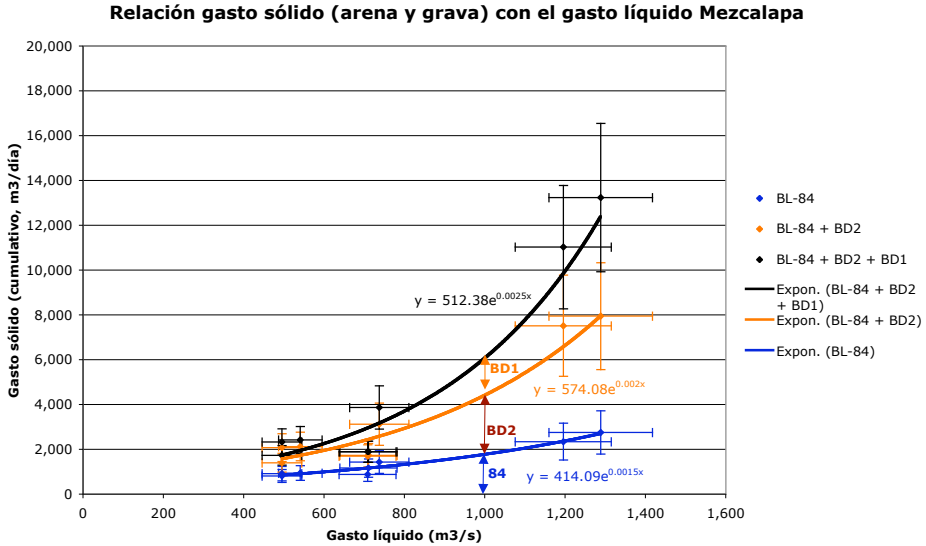
Transporte sólido: BL-84 = por arrastre; Botella de Delft BD2= cerca del fondo; Botella de Delft BD1= suspensión

Flow and sediment transport relationship Mezcalapa



Relationship flow - sediment discharges

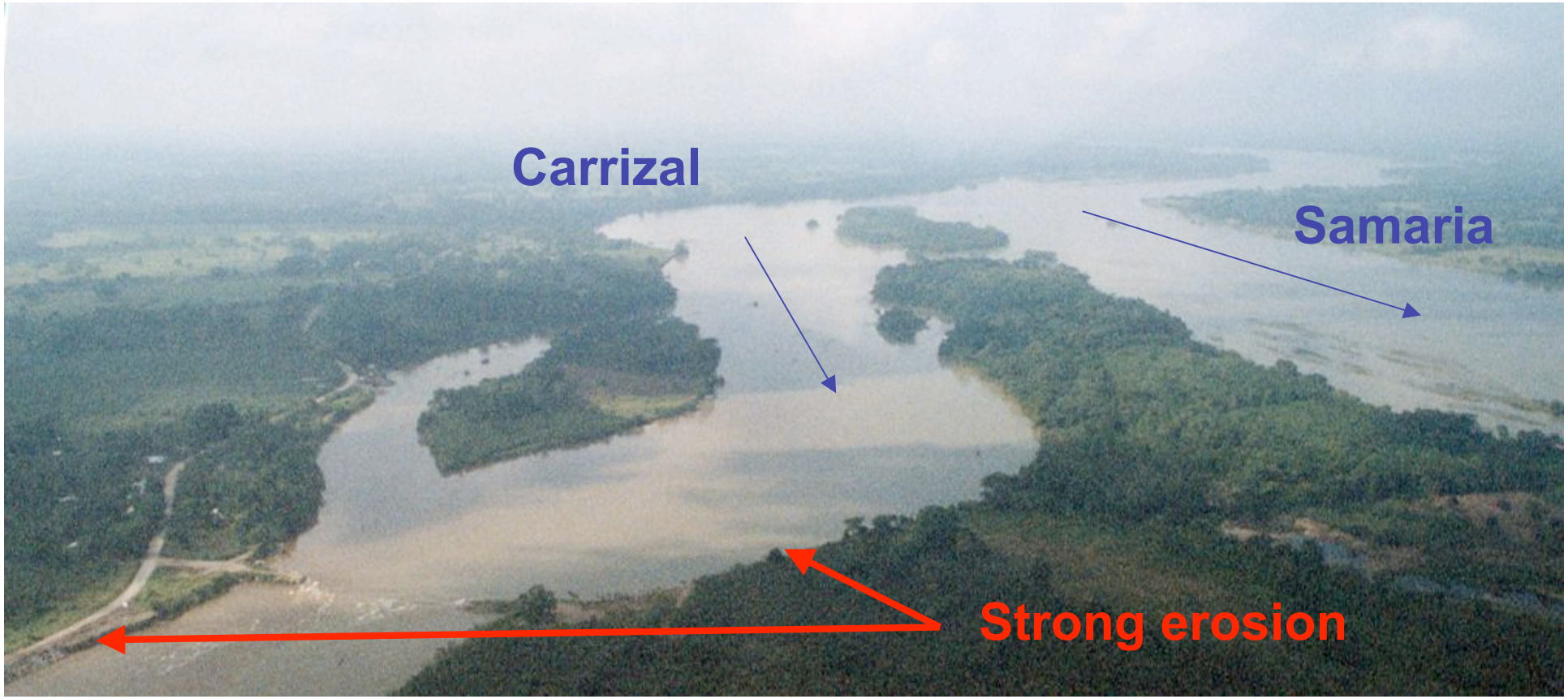




- At low discharges, bottom transport is significant but increases slowly with discharge
- Transport close to the bottom increases more rapidly, because of the increase in turbulence
- Transport in suspensión, very low at mild discharges, augments more rapidly with discharges than transport close to the bottom

THE WEIR

- The studies of the weir (numerical and scale models) did not properly contemplate “sediment”
- The weir induced formation of an ample sand bar in the centre of the river, upstream
- The result has been outflanking with strong erosion of the left river border, what produced more downstream an orientation of the flows to the banks, with strong erosion



- The Carrizal riverbed will continue widening, with agradation of the bed
- However, the Samaria riverbed rises probably more rapidly

WEIR STRUCTURE TO CONTROL FLOW IN CARRIZAL

IMPACT OF WEIR STRUCTURE

- Besides bank erosions, the sediment deficit may cause ever more degradation of the riverbed, with a risk for destruction of bridges and other fluvial structures (Comment: there was a very important exploitation of riverbed material in Carrizal)
- … or the destruction of the weir during a flood event, by deepening of the riverbed

IMPACT SAMARIA BRIDGES

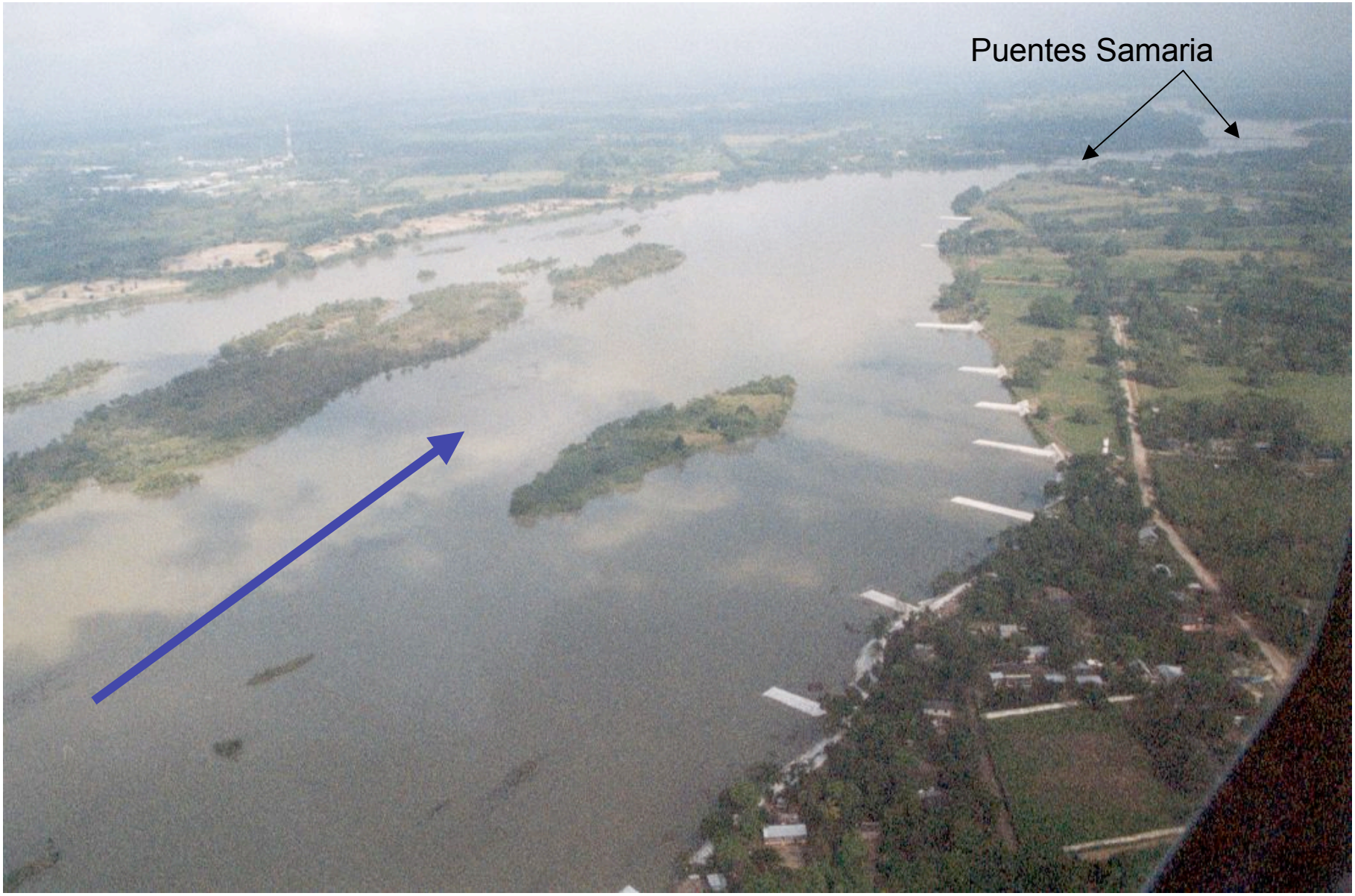
- The Samaria bridges continue having effects on sediment retention of sediments, riverbed aggradation and formation of bars & canals

- This riverbed shape would cause even more bank erosion, resulting as usual with ever more protection

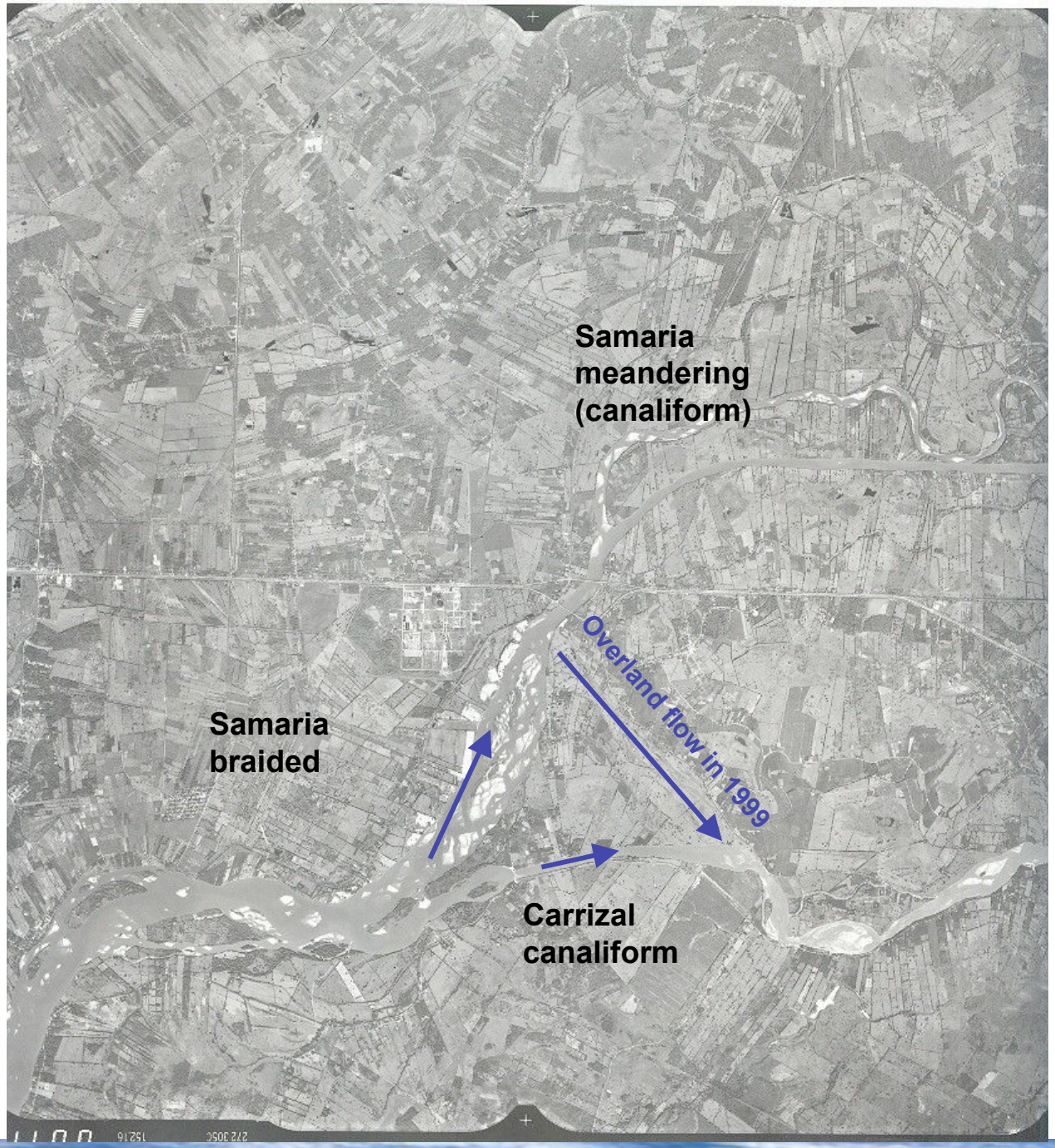
IMPACT SAMARIA BRIDGES

- A groyne field has been constructed to protect the right bank of the Samaria upstream of the bridges.
- However, these protection works are not very effective, as the river flow attacks the bank with an oblique orientation.

IMPACT SAMARIA BRIDGES



2000


Samaria
meandering
(canaliform)
Overland flow in 1999
Samaria
braided
Carrizal
canaliform

SOLUTIONS ?

1. Avoid rapid fluctuations of the flow discharge en Peñitas (new compensation dam?)
2. Training the Samaria river between the bifurcation and Samaria bridges (proposal with three tipes of structures):
   - A guiding structure with piles, mesh and stones
   - A series of permeable groynes, with piles and mesh, and longitudinal one connecting them (retard structures)
   - Bottom vanes to incise the channel (Possibly, through helical flow effect)

RIVER TRAINING PROJECT