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

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

What is the problem?

- The recurrent inundations in Villahermosa (last ones in 1999 & 2007) 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 hydraulics)

GRIJALVA USUMACINTA RIVER BASINS

Average annual runoff in Mm^3

Río Grijalva

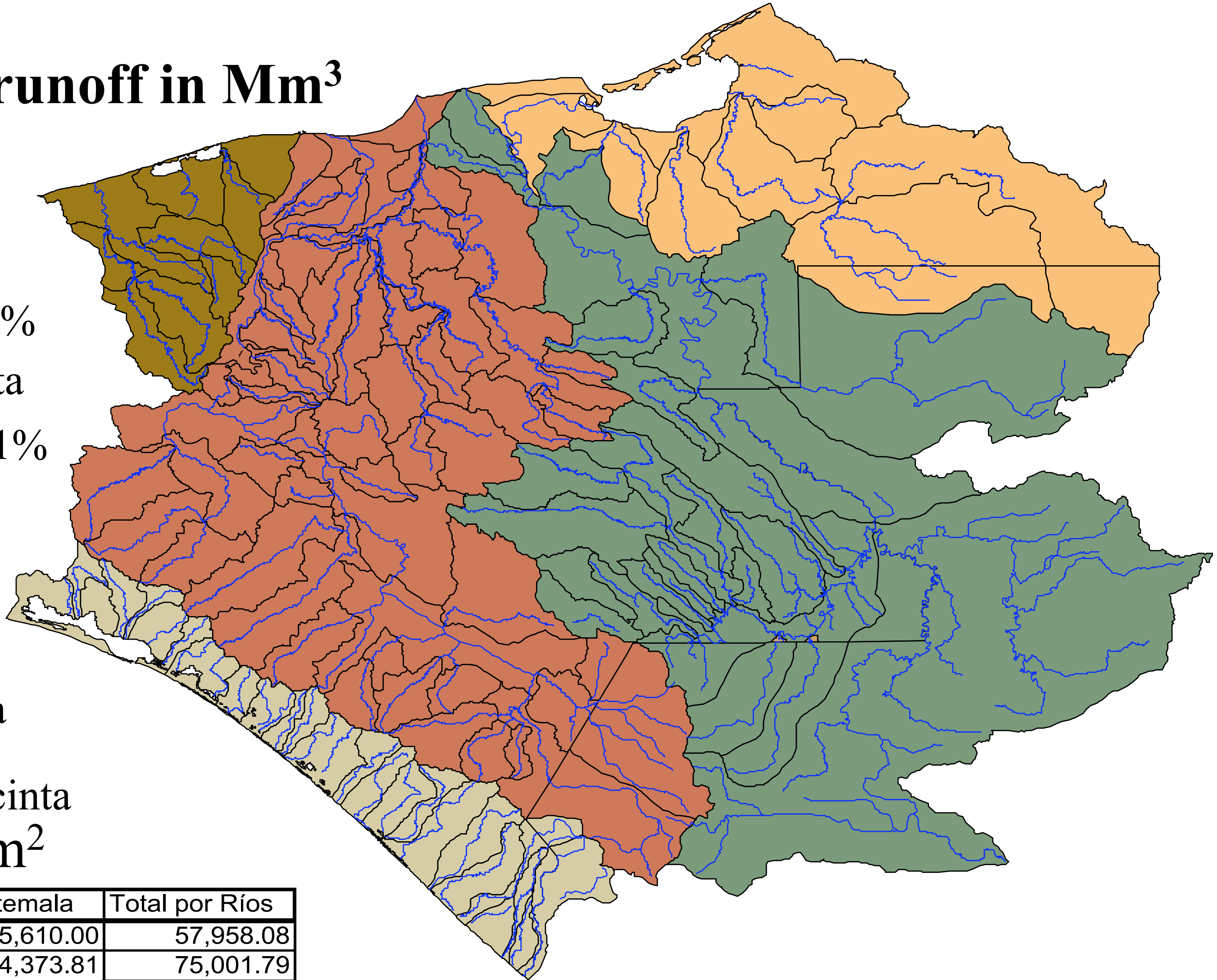
36,493.883 36.9%

Río Usumacinta

62,206.623 63.1%

Total

98,700.506



Basin Río Grijalva

Basin Río Usumacinta

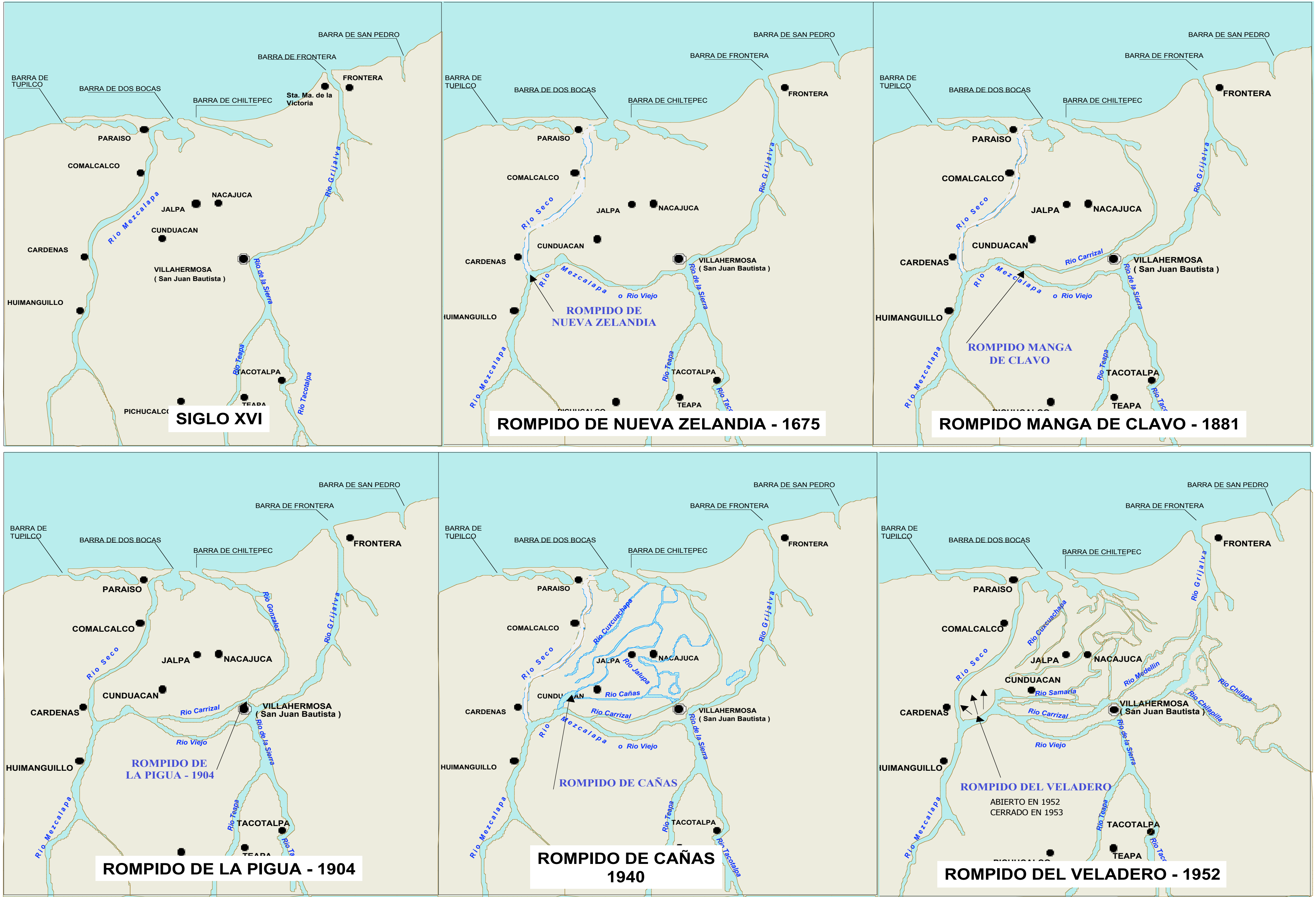
Areas in km^2

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

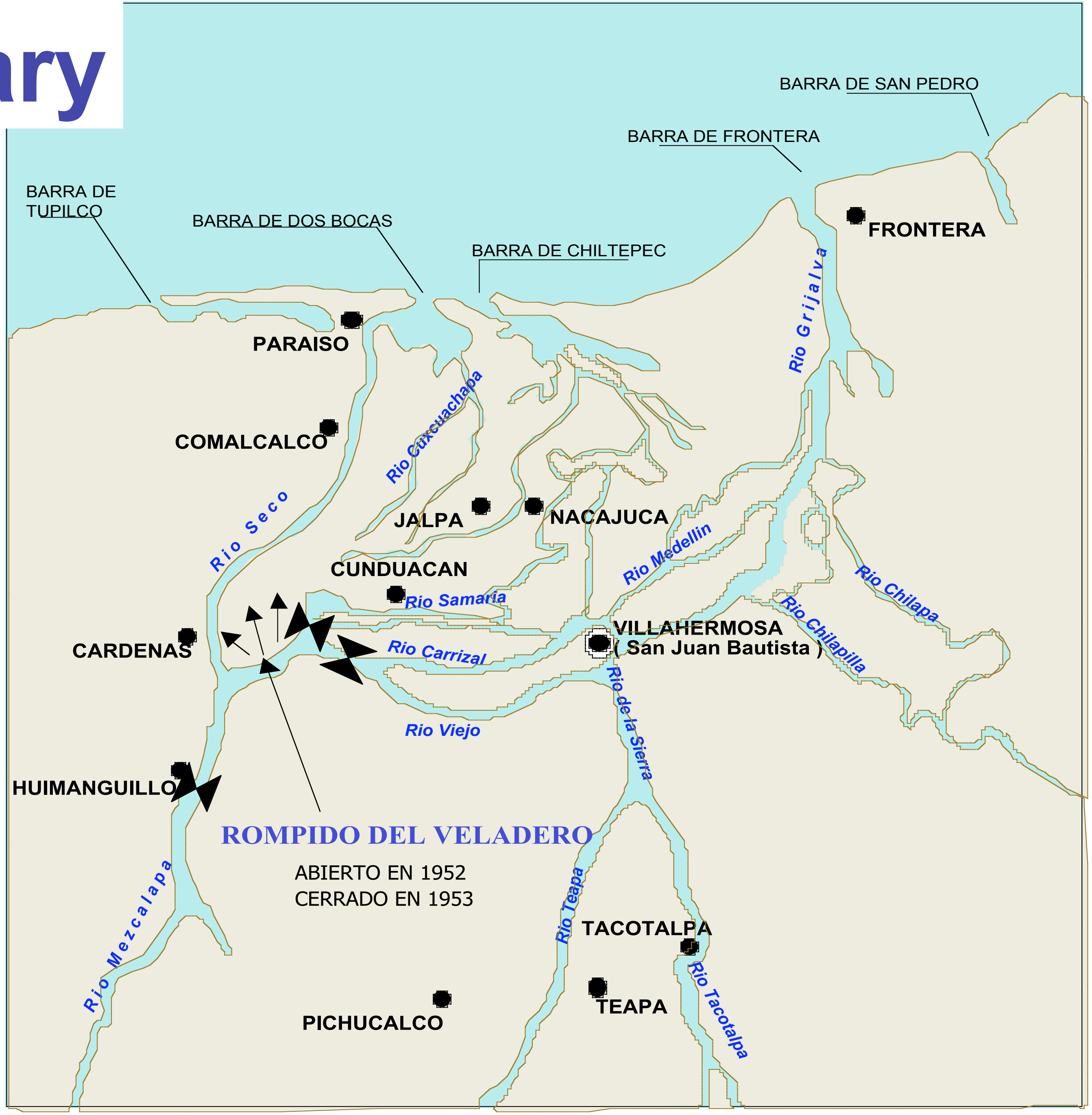
Potamological context

- 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
BARRA DE SAN PEDRO
BARRA DE FRONTERA
BARRA DE TUPILCO
BARRA DE DOS BOCAS
BARRA DE CHILTEPEC
FRONTERA
Sta. Ma. de la Victoria
PARAISO
COMALCALCO
JALPA
NACAJUCA
CUNDUACAN
CARDENAS
VILLAHERMOSA (San Juan Bautista)
HUIMANGUILLO
TACOTALPA
TEAPA
PICHUCALCO
Rio Grijalva
Rio Mezcalapa
Rio de la Sierra
Rio Teapa
Rio Tacotalpa
Rio Seco
o Rio Viejo
Rio Carrizal
Rio Viejo
Rio Gonzalez
Rio Cuxcuchapa
Rio Jalupa
Rio Cañas
Rio Samaria
Rio Medellin
Rio Chilapa
Rio Chilapilla
ROMPIDO DE NUEVA ZELANDIA
ROMPIDO MANGA DE CLAVO
ROMPIDO DE LA PIGUA - 1904
ROMPIDO DE CAÑAS
ROMPIDO DEL VELADERO
ABIERTO EN 1952
CERRADO EN 1953

Summary


BARRA DE SAN PEDRO
BARRA DE FRONTERA
BARRA DE TUPILCO
BARRA DE DOS BOCAS
BARRA DE CHILTEPEC
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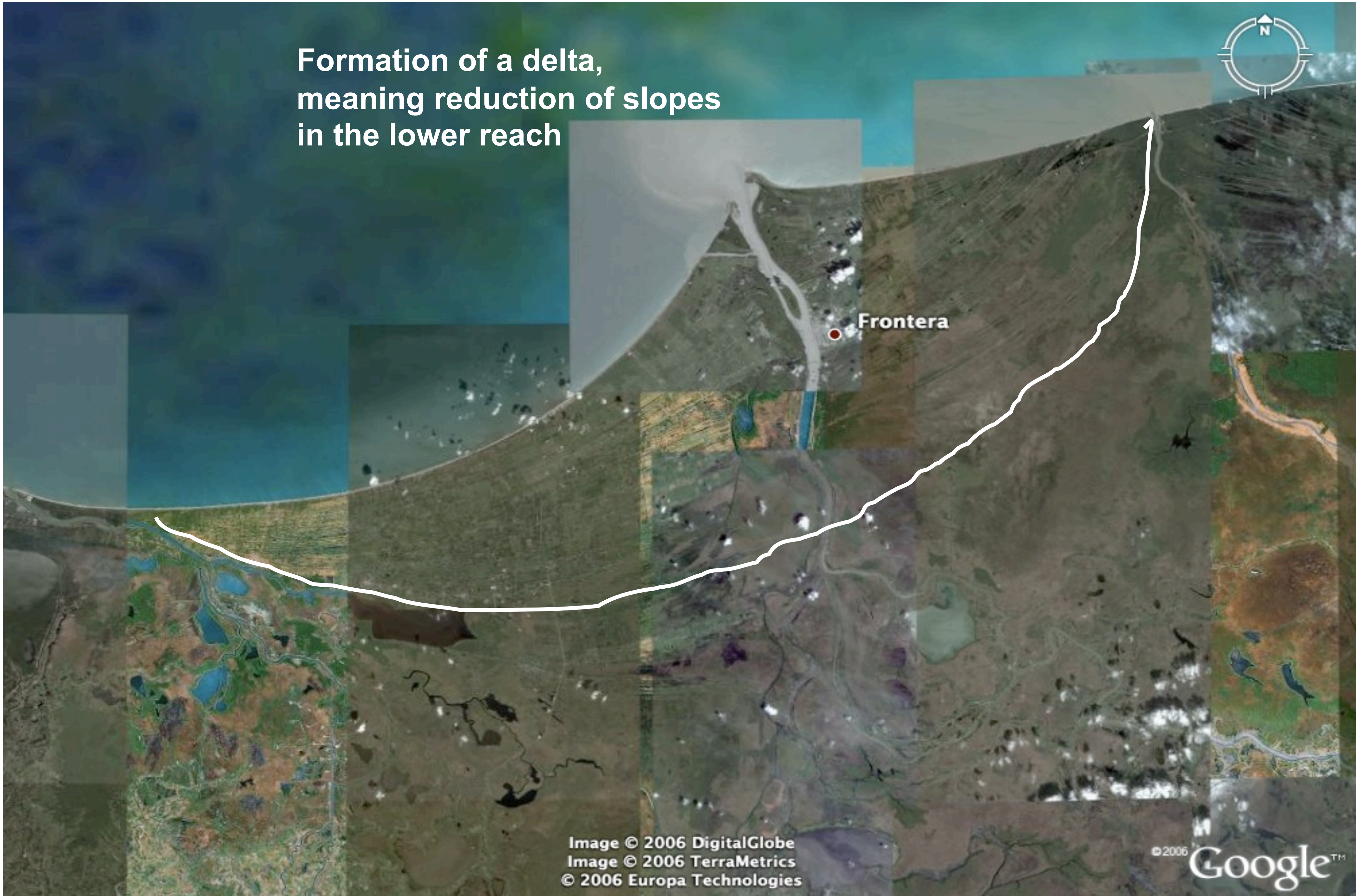
Rio Chilapa
Rio Chilapilla
Rio Viejo
Rio de la Sierra
Rio Mezcalapa
Rio Teapa
Rio Tacotalpa
ROMPIDO DEL VELADERO
ABIERTO EN 1952
CERRADO EN 1953


Formation of a delta,
meaning reduction of slopes
in the lower reach
N
Frontera
Image © 2006 DigitalGlobe
Image © 2006 TerraMetrics
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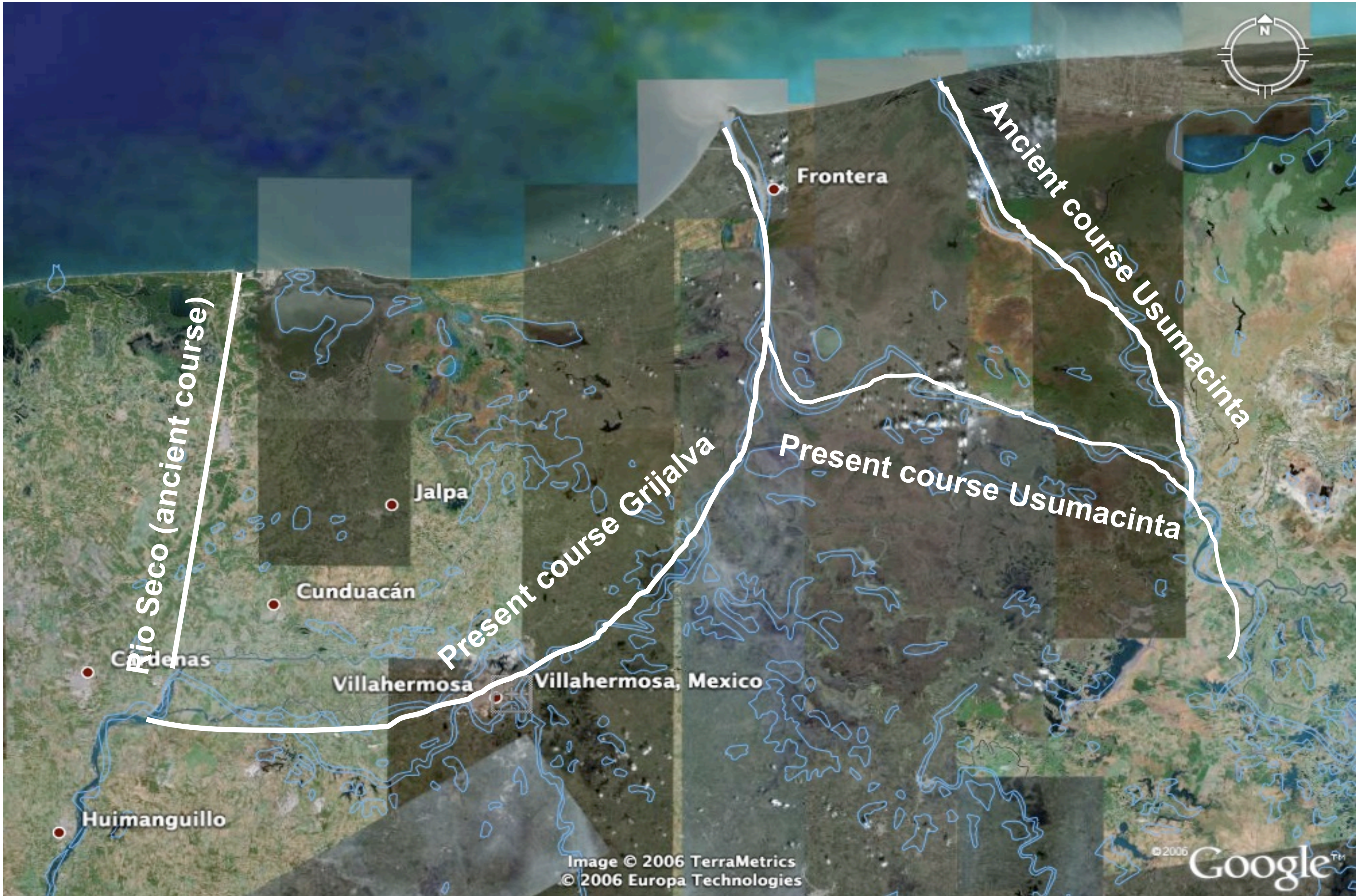

Frontera
Ancient course Usumacinta
Rio Seco (ancient course)
Present course Grijalva
Present course Usumacinta
Jalpa
Cunduacán
Cárdenas
Villahermosa
Villahermosa, Mexico
Huimanguillo
Image © 2006 TerraMetrics
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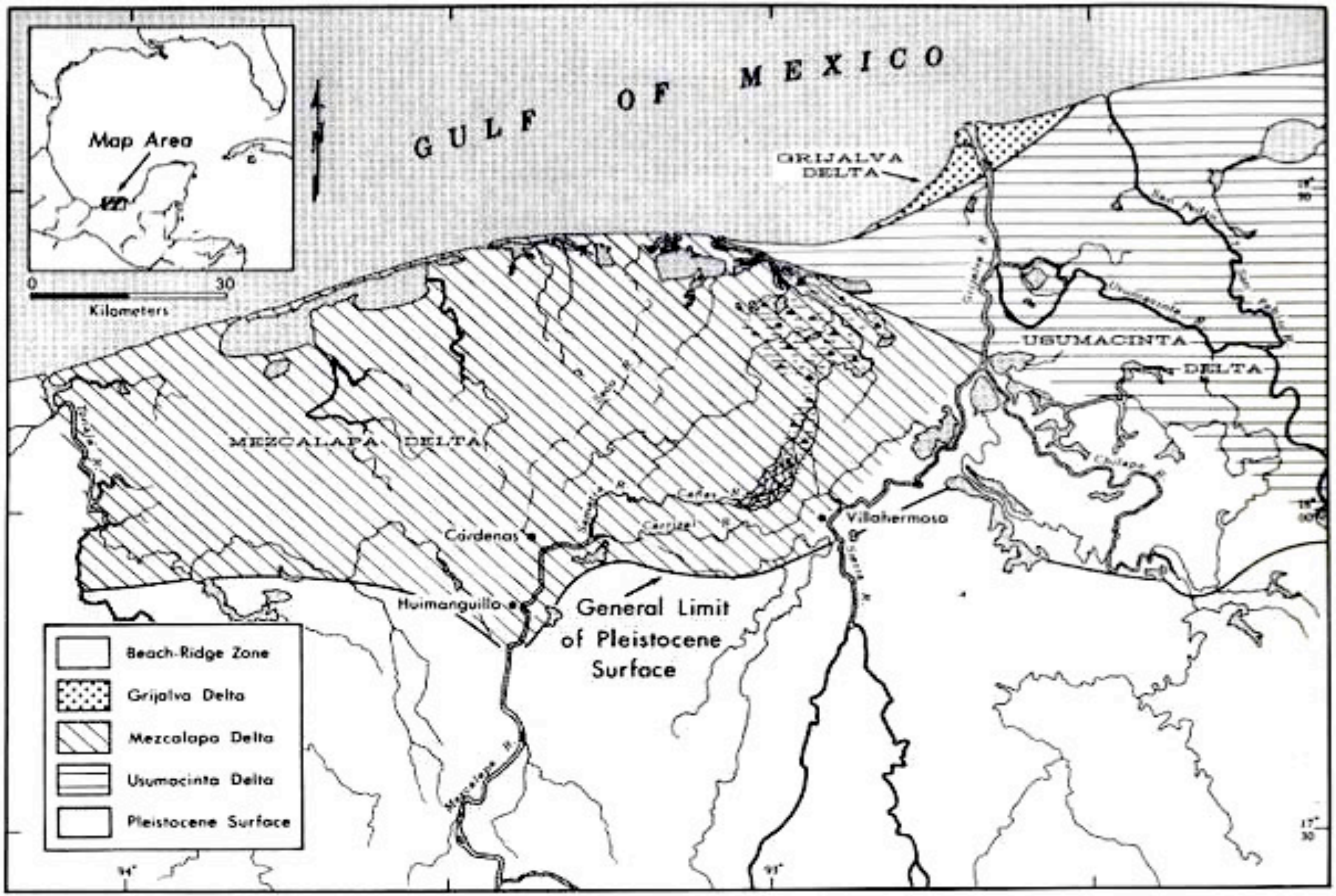
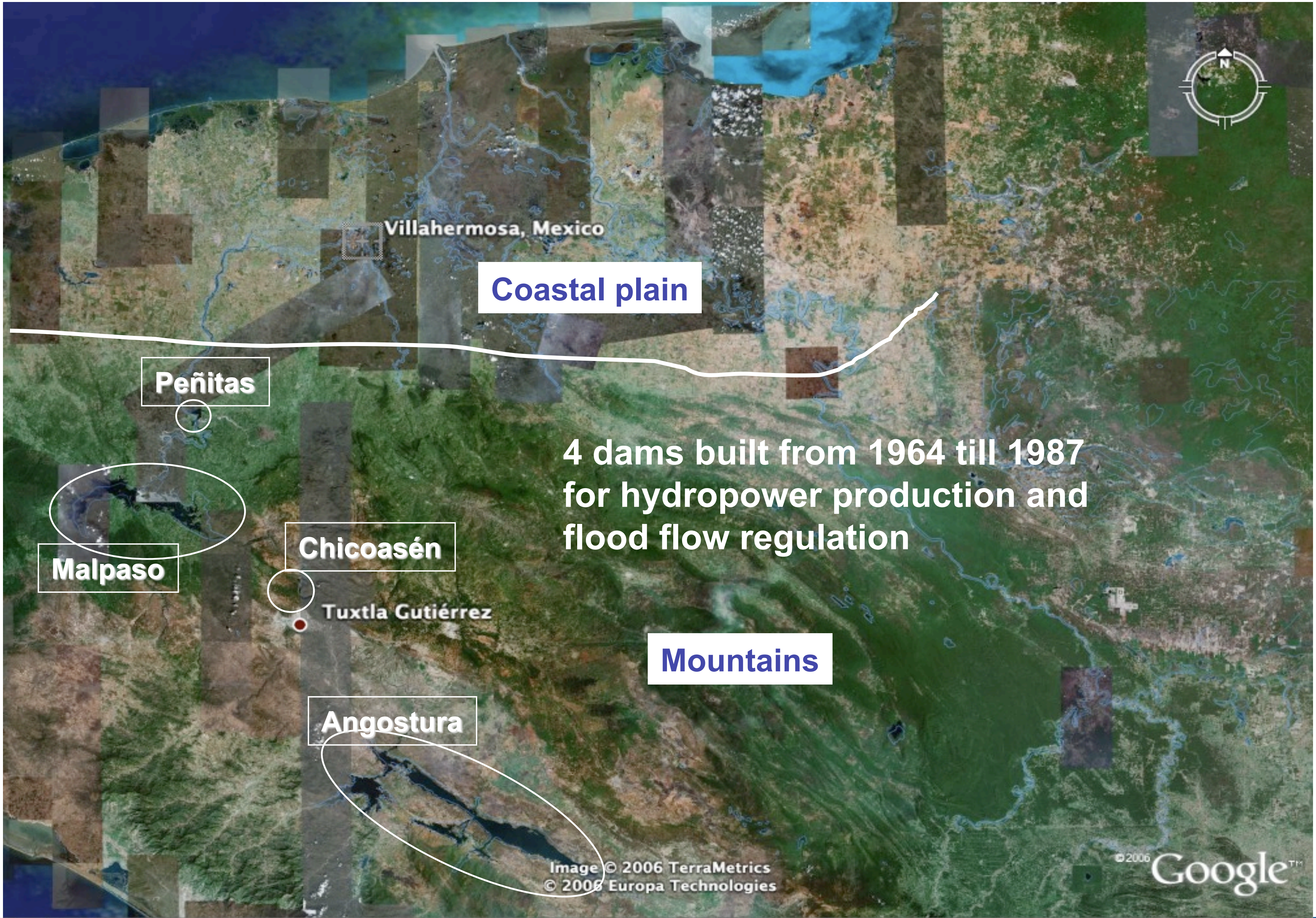


FIGURE 6. Geomorphologic divisions of the Tabasco Plain.


Villahermosa, Mexico
Coastal plain
Peñitas
4 dams built from 1964 till 1987
for hydropower production and
flood flow regulation
Malpaso
Chicoasén
Tuxtla Gutiérrez
Mountains
Angostura
Image © 2006 TerraMetrics
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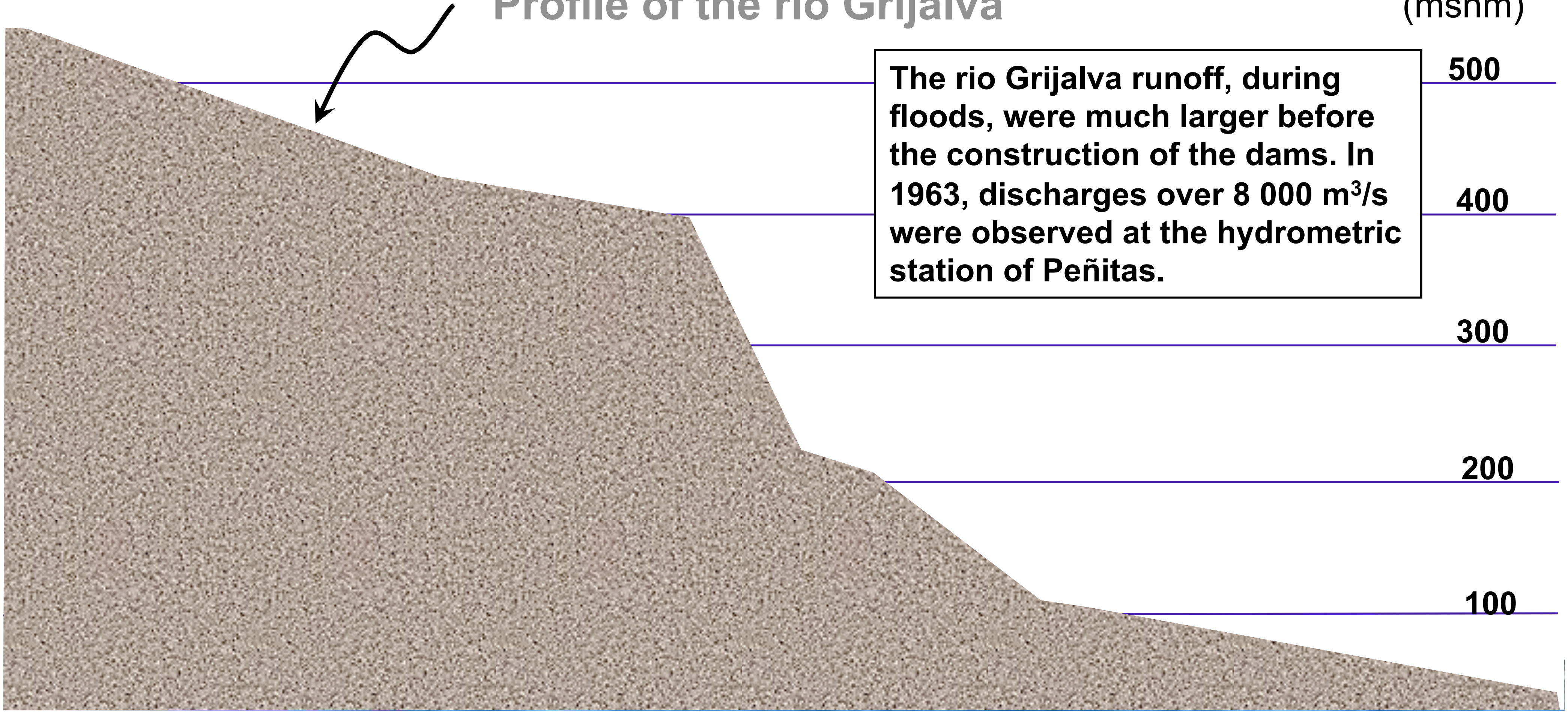
SCHEME OF DAMS ON THE RÍO GRIJALVA

Profile of the río Grijalva



The rio Grijalva runoff, during floods, were much larger before the construction of the dams. In 1963, discharges over 8 000 m^3/s were observed at the hydrometric station of Peñitas.

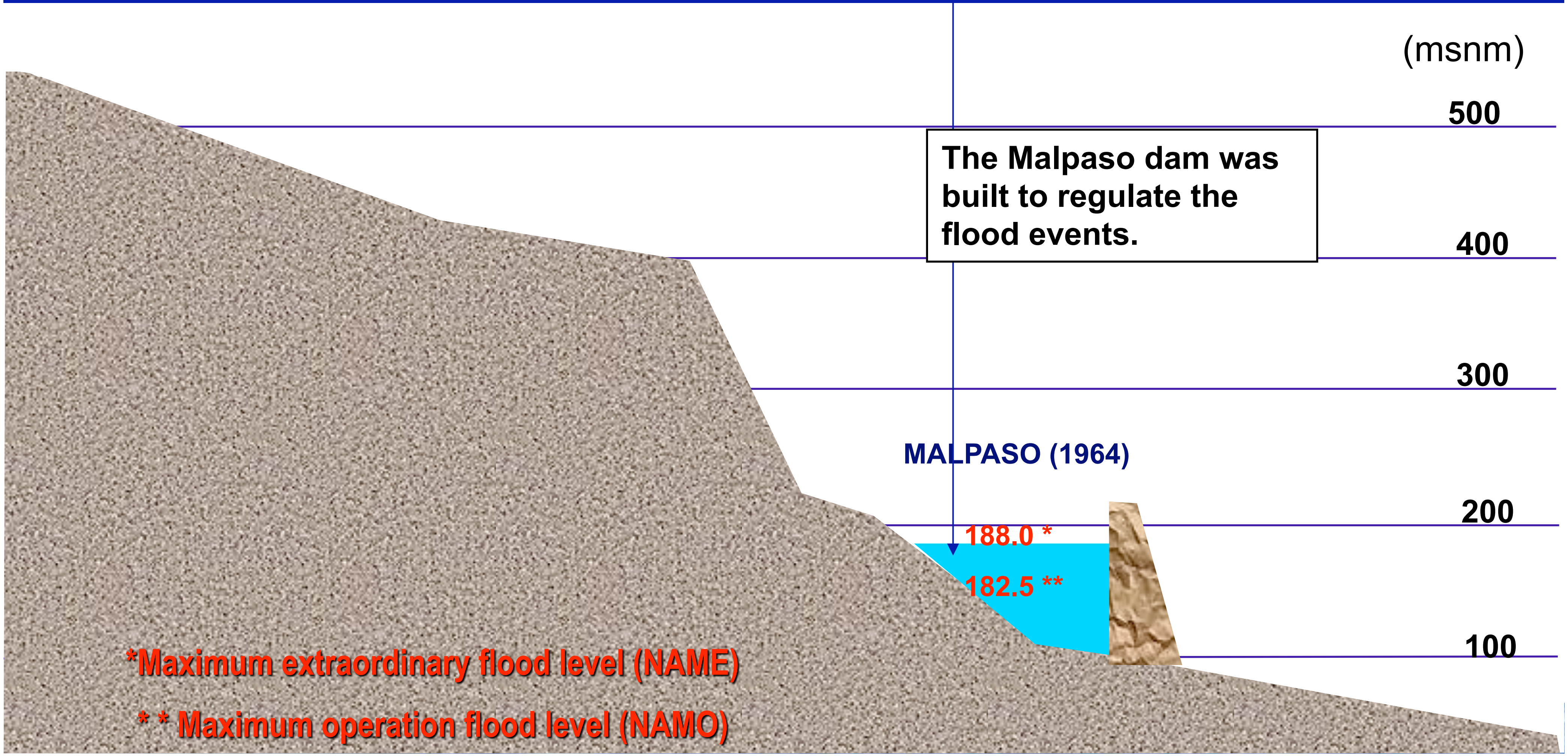
SCHEME OF DAMS ON THE RÍO GRIJALVA

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)

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

500
400
300
200
100

MALPASO (1964)

188.0 *
182.5 **

*Maximum extraordinary flood level (NAME)

* * Maximum operation flood level (NAMO)

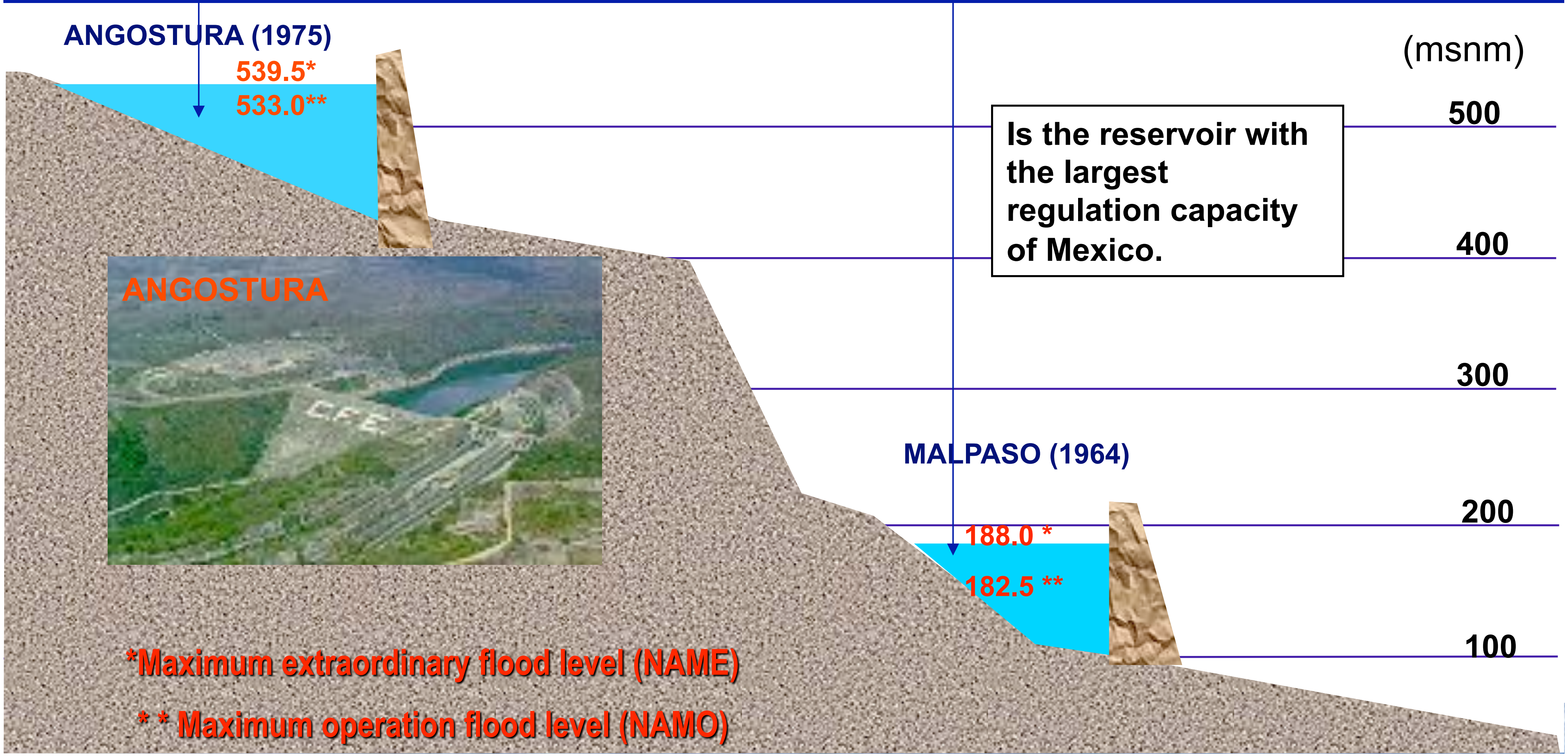
SCHEME OF DAMS ON THE RÍO GRIJALVA

CAPACITY
(In millions cubic meters)

20,000		14,000	

(For flood regulation)

8,500		3,460	



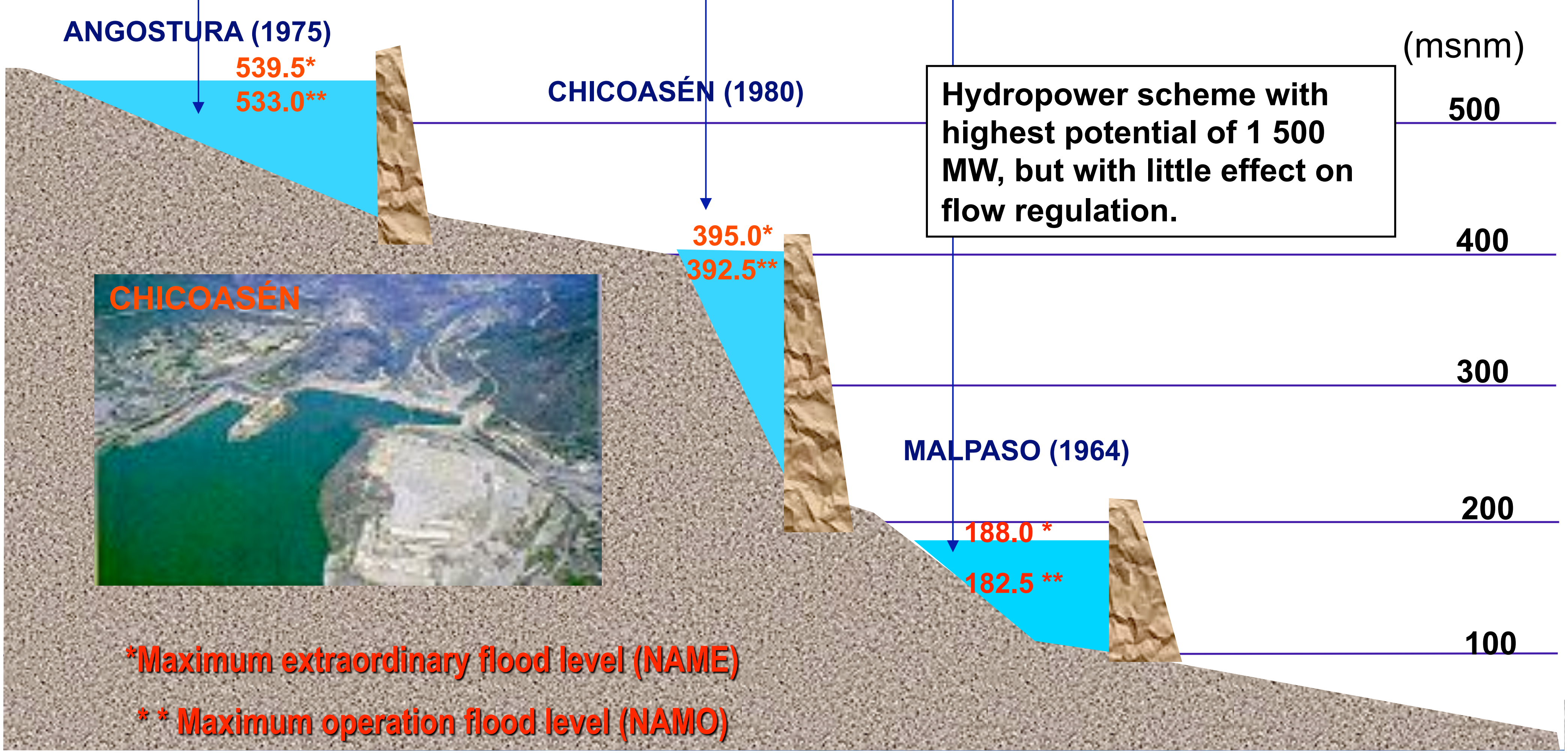
SCHEME OF DAMS ON THE RÍO GRIJALVA

CAPACITY
(In millions cubic meters)

20,000	1,680	14,000	

(For flood regulation)

8,500	490	3,460	



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)

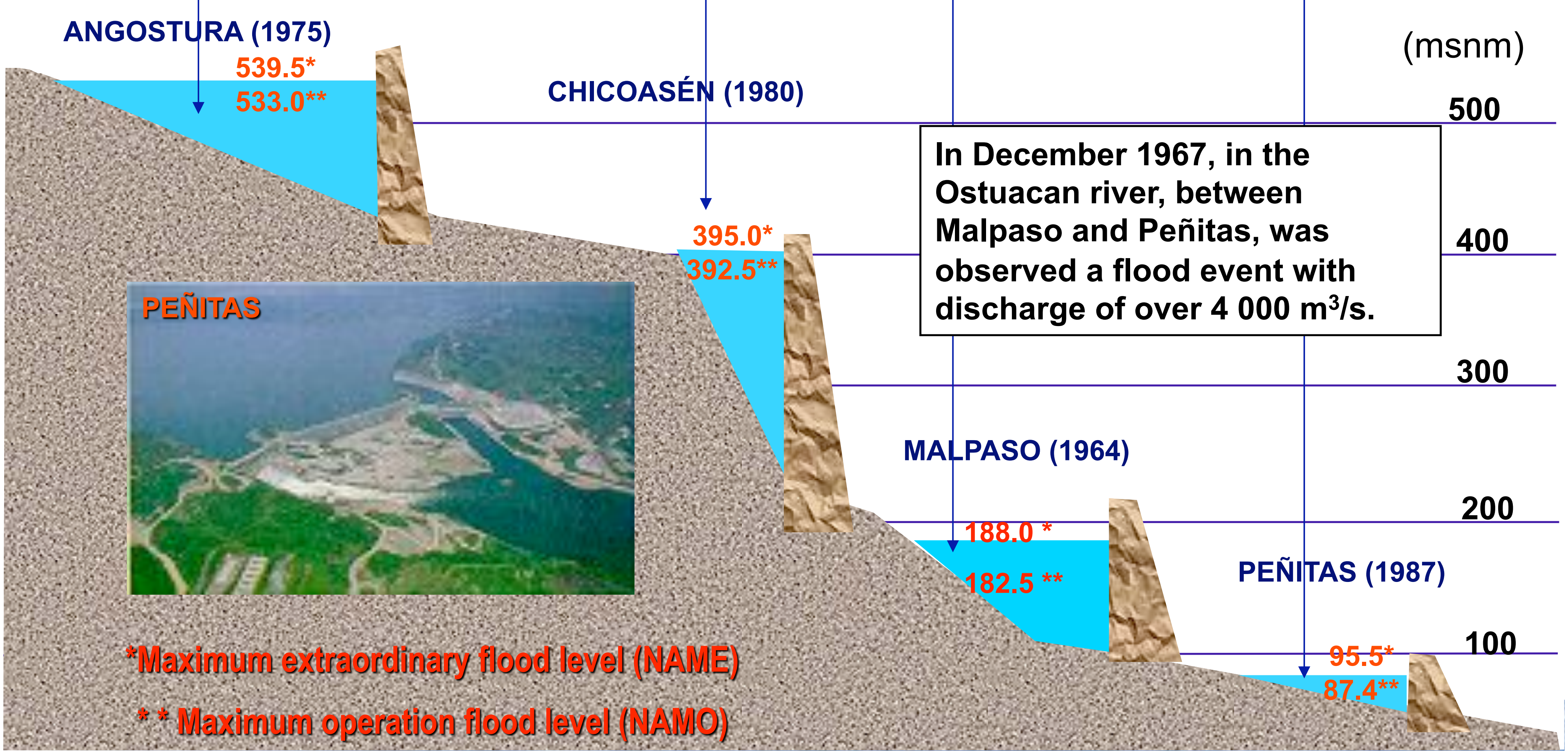
SCHEME OF DAMS ON THE RÍO GRIJALVA

CAPACITY
(In millions cubic meters)

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

(For flood regulation)

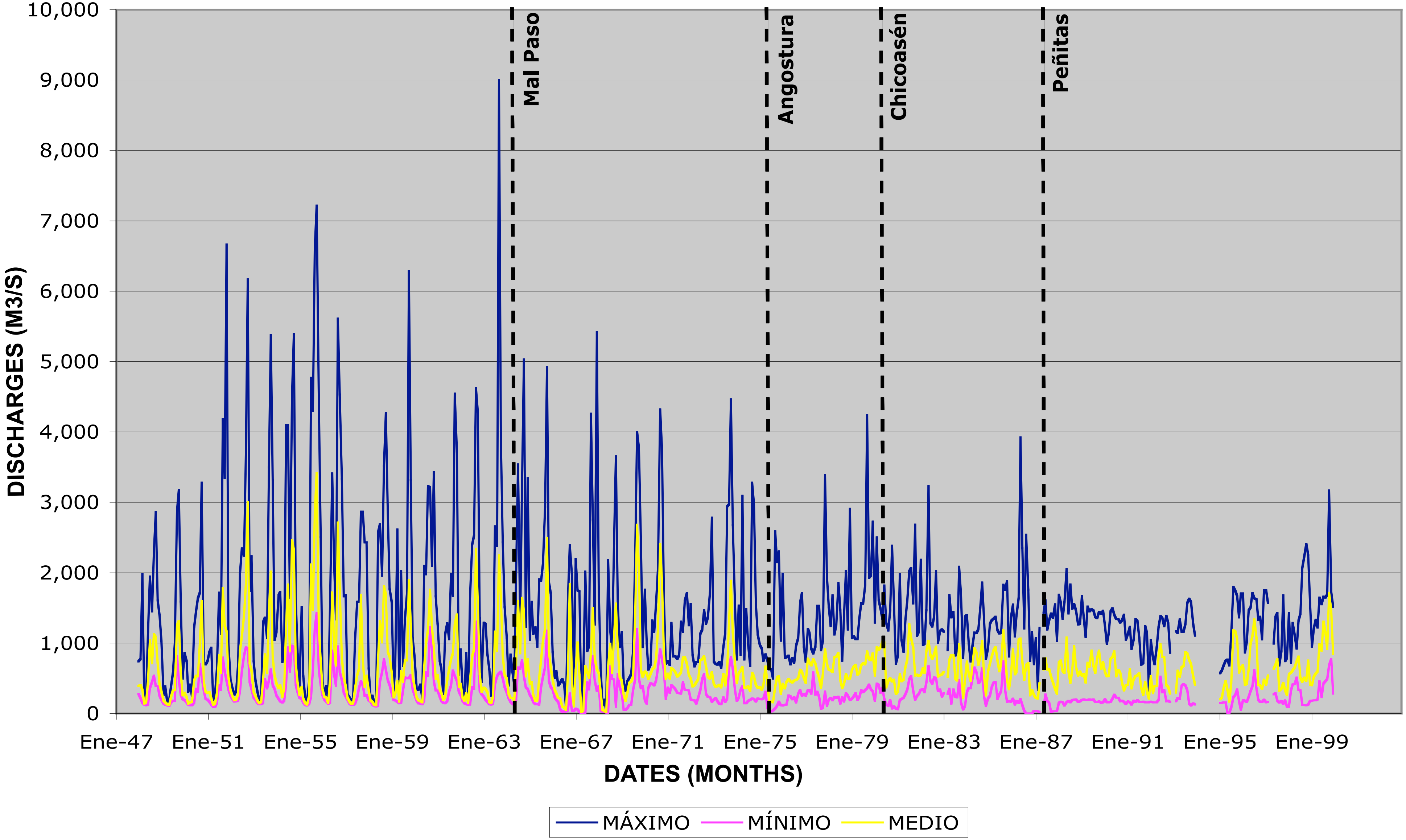
8,500	490	3,460	1,091

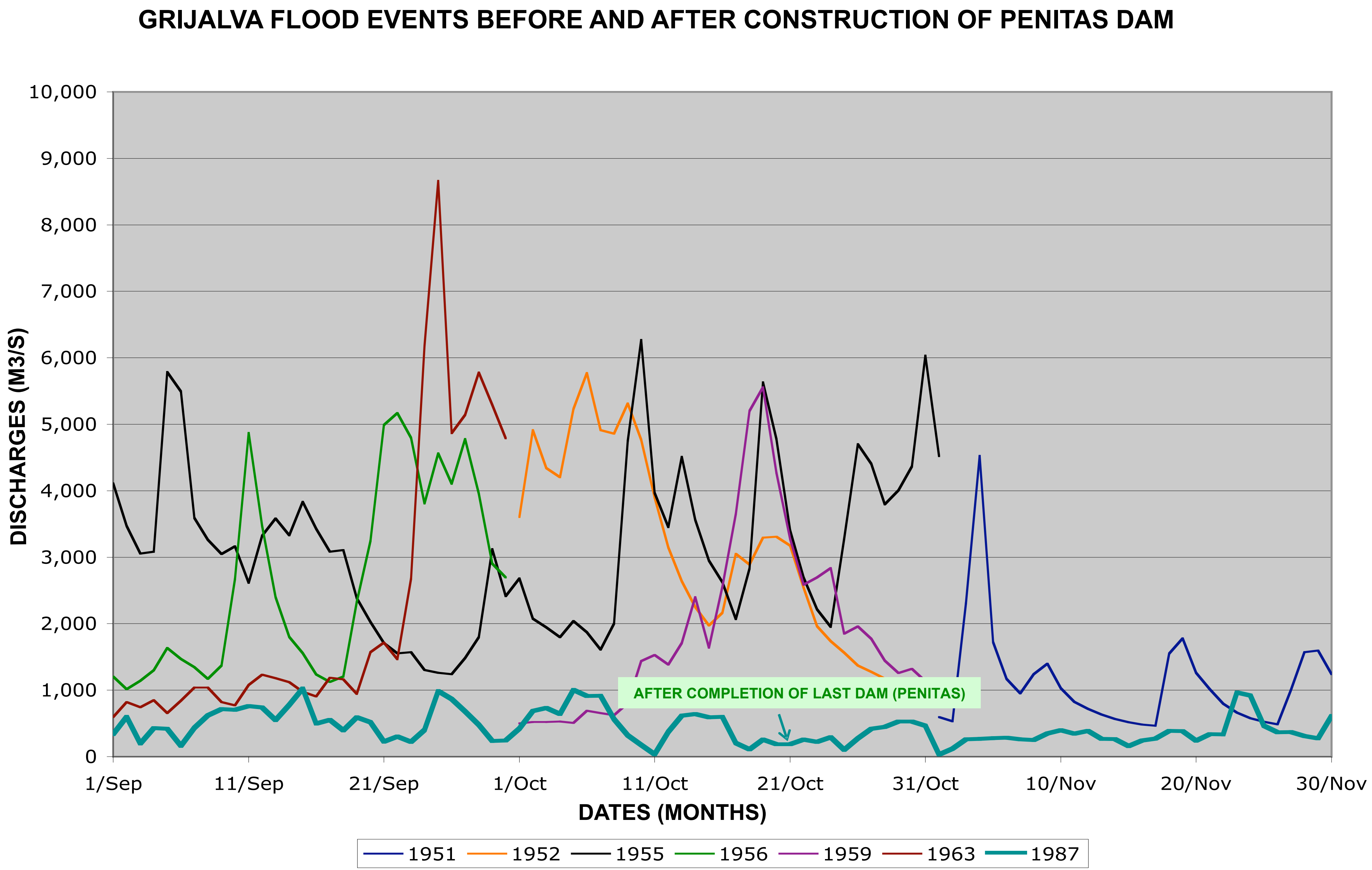


Impact of the dams

- The 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



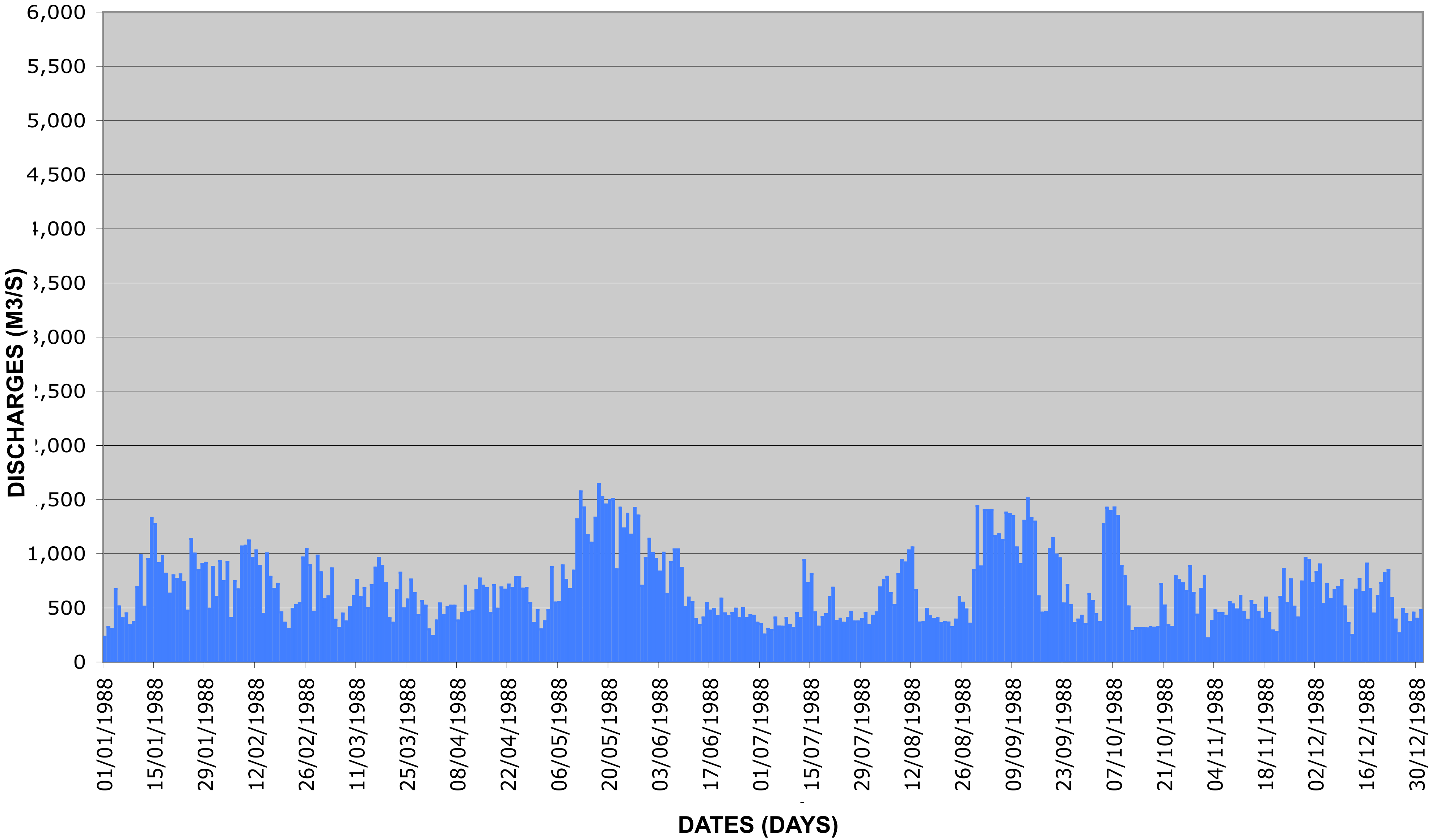

GRIJALVA FLOOD EVENTS BEFORE AND AFTER CONSTRUCTION OF PENITAS DAM
DISCHARGES (M3/S)
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1/Sep
11/Sep
21/Sep
1/Oct
11/Oct
21/Oct
31/Oct
10/Nov
20/Nov
30/Nov
DATES (MONTHS)
AFTER COMPLETION OF LAST DAM (PENITAS)
1951
1952
1955
1956
1959
1963
1987

Hydrological impact of the dams

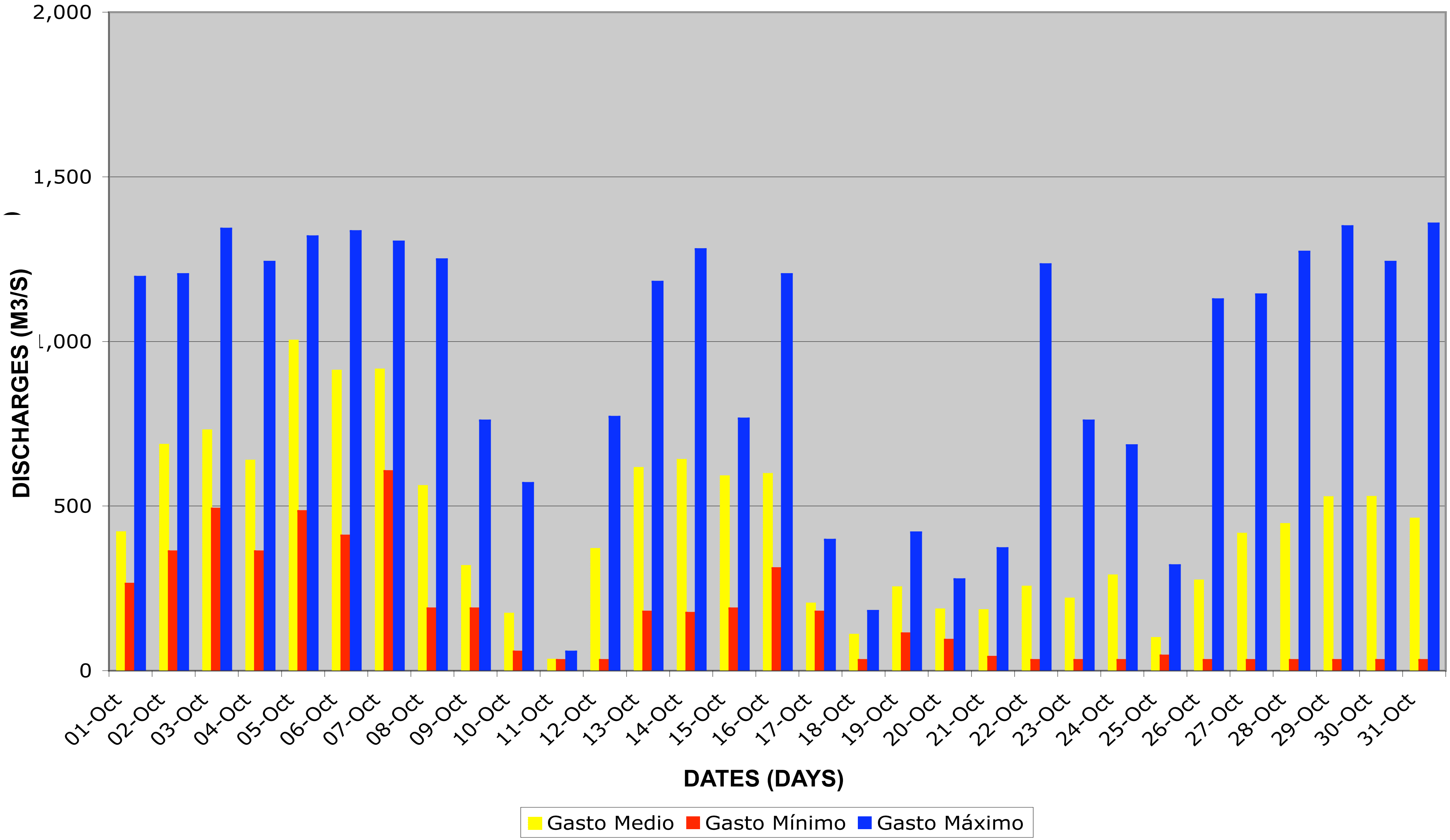
- Change in hydrological regimen, dry and flood seasons in *quite constant monthly discharges*, except in flood event periods

- 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 of the dams

- 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

The “river response” to the dams

- By **sediment deficit**, clear 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)

- 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

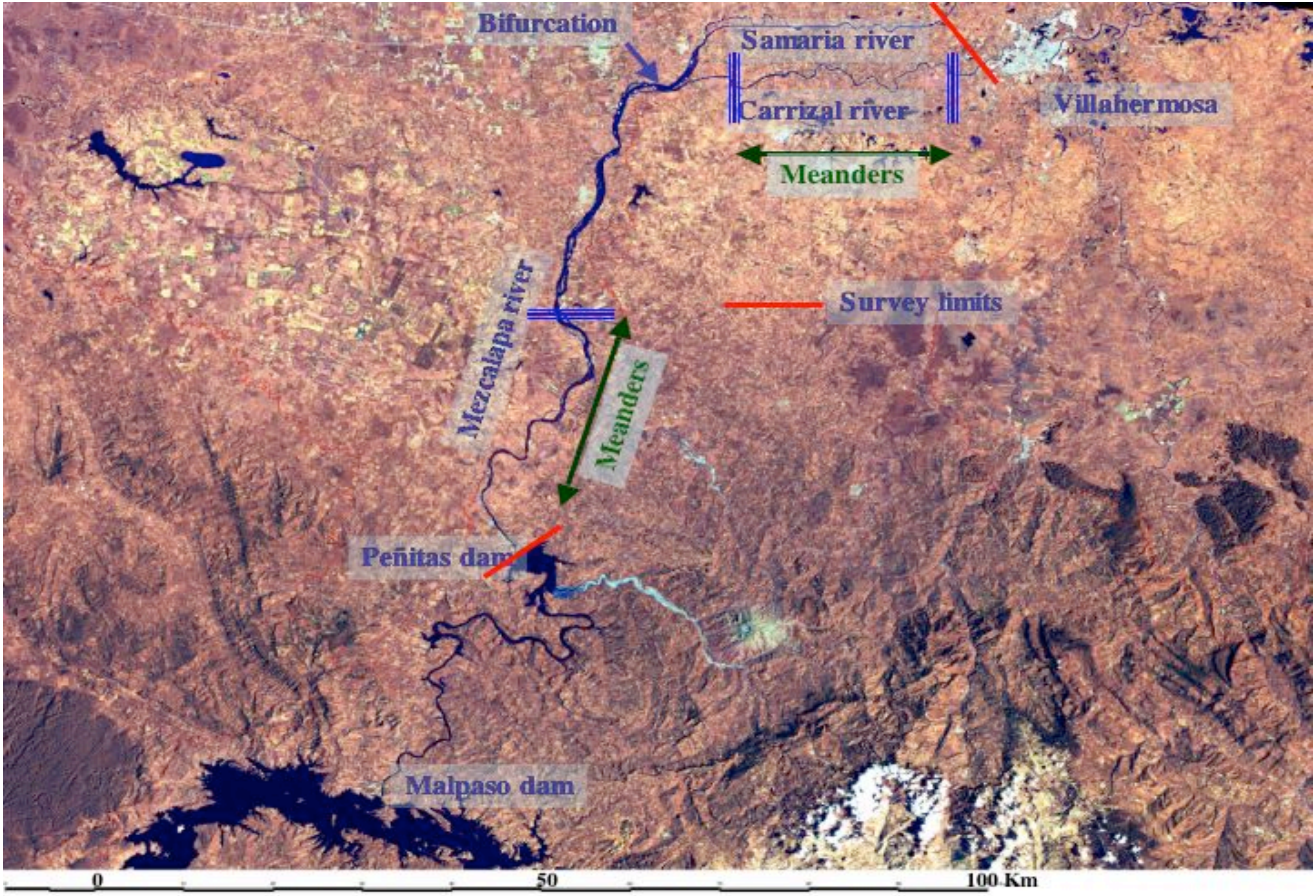
The “river response” to the dams

- 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,

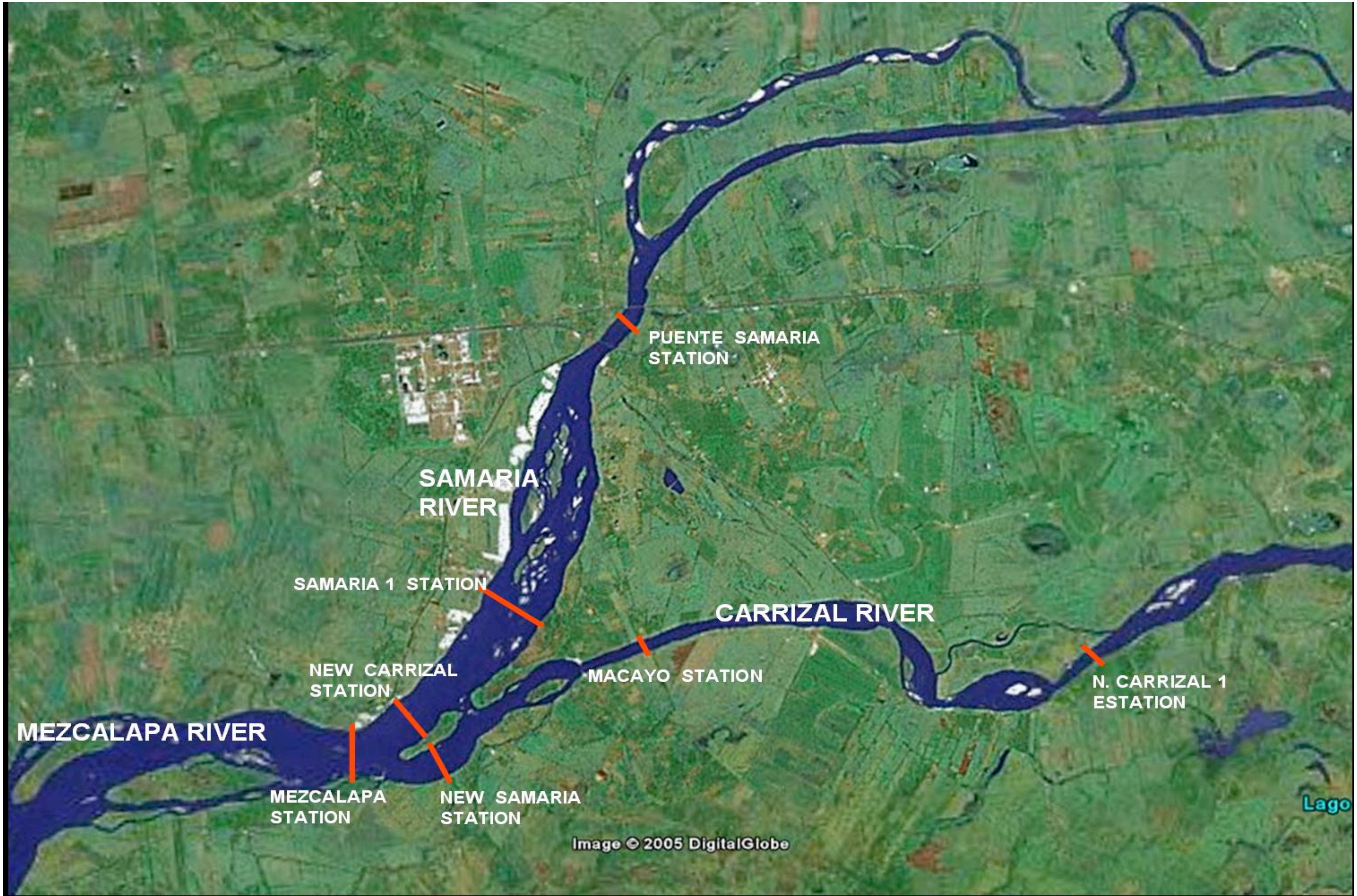
  …

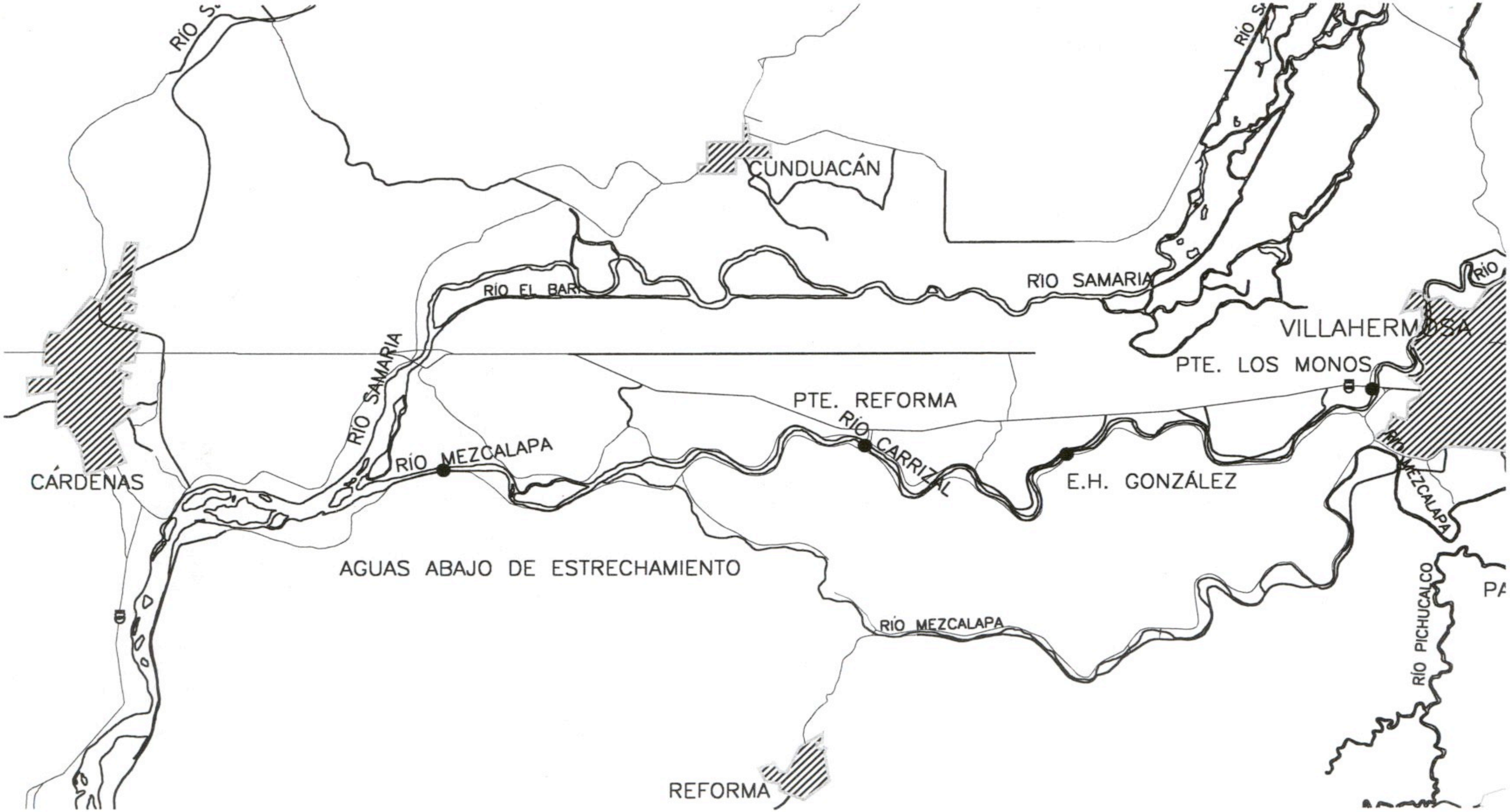
  what induced always more erosions, causing a **braided riverbed** in the lower part of the Mezcalapa


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

The bifurcation of the Mezcalapa river

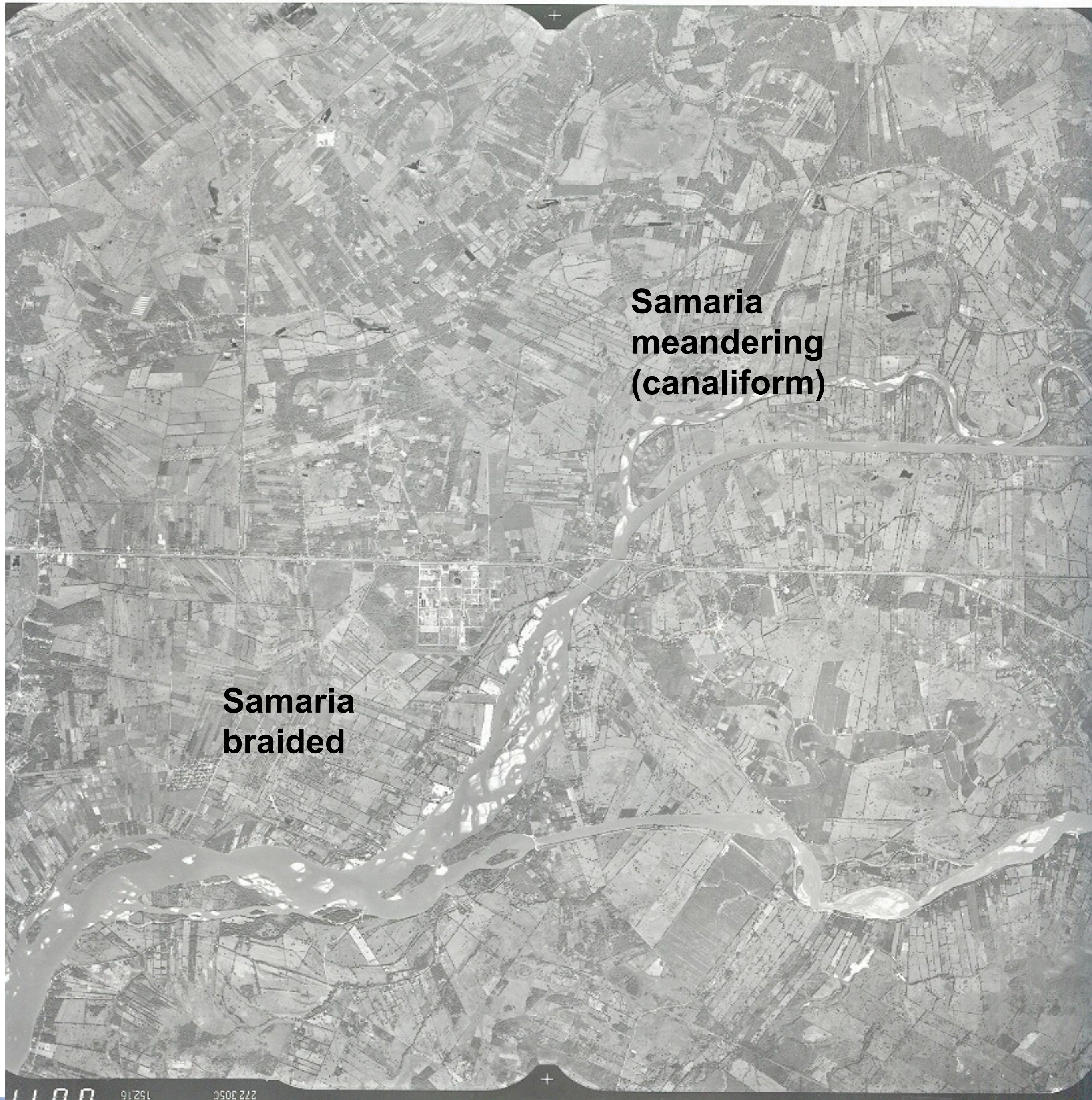
- The bifurcation of the Mezcalapa in Samaria and Carrizal rivers **exists since 1940**, when occurred the Cañas avulsion
- **Information is missing** on the development of the river **between 1940 and 1964**, when started construction of the dams
- However, aerial photographs reveal the **tendency** 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.
CUNDUACÁN
RÍO S.
RÍO EL BAR
RÍO SAMARIA
RÍO
VILLAHERMOSA
PTE. LOS MONOS
RÍO SAMARIA
PTE. REFORMA
RÍO CARRIZAL
CÁRDENAS
RÍO MEZCALAPA
E.H. GONZÁLEZ
RÍO MEZCALAPA
AGUAS ABAJO DE ESTRECHAMIENTO
RÍO PICHUCALCO
PA
RÍO MEZCALAPA
REFORMA

1996

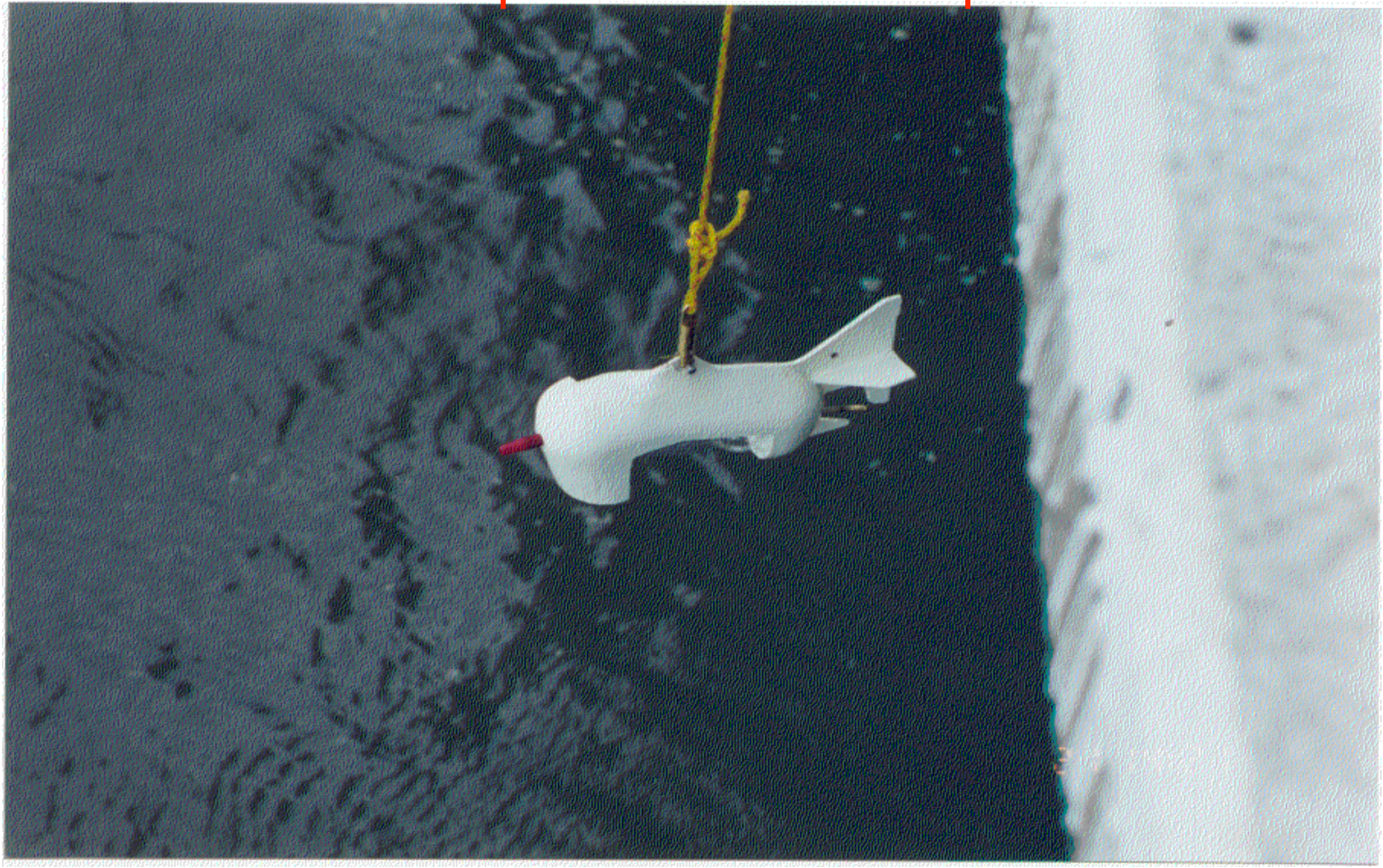
2000



The bifurcation of the Mezcalapa river

- Impact of Samaria bridges:
  - Produce backwater, with effect on **sedimentation** when flood retreats
  - Tendency to **outflank by bank erosion**
- The operation of the dams results in strong and rapid daily fluctuations of discharges
- The power of the flow is distributed in a too wide riverbed, **reducing the sediment transport capacity**
- A sediment gauging campaign was started with a WMO funded project

US DHS-59 for suspended load transport



US BL-84 for bedload transport

US BL-84 for bedload transport

Operated from a small unit

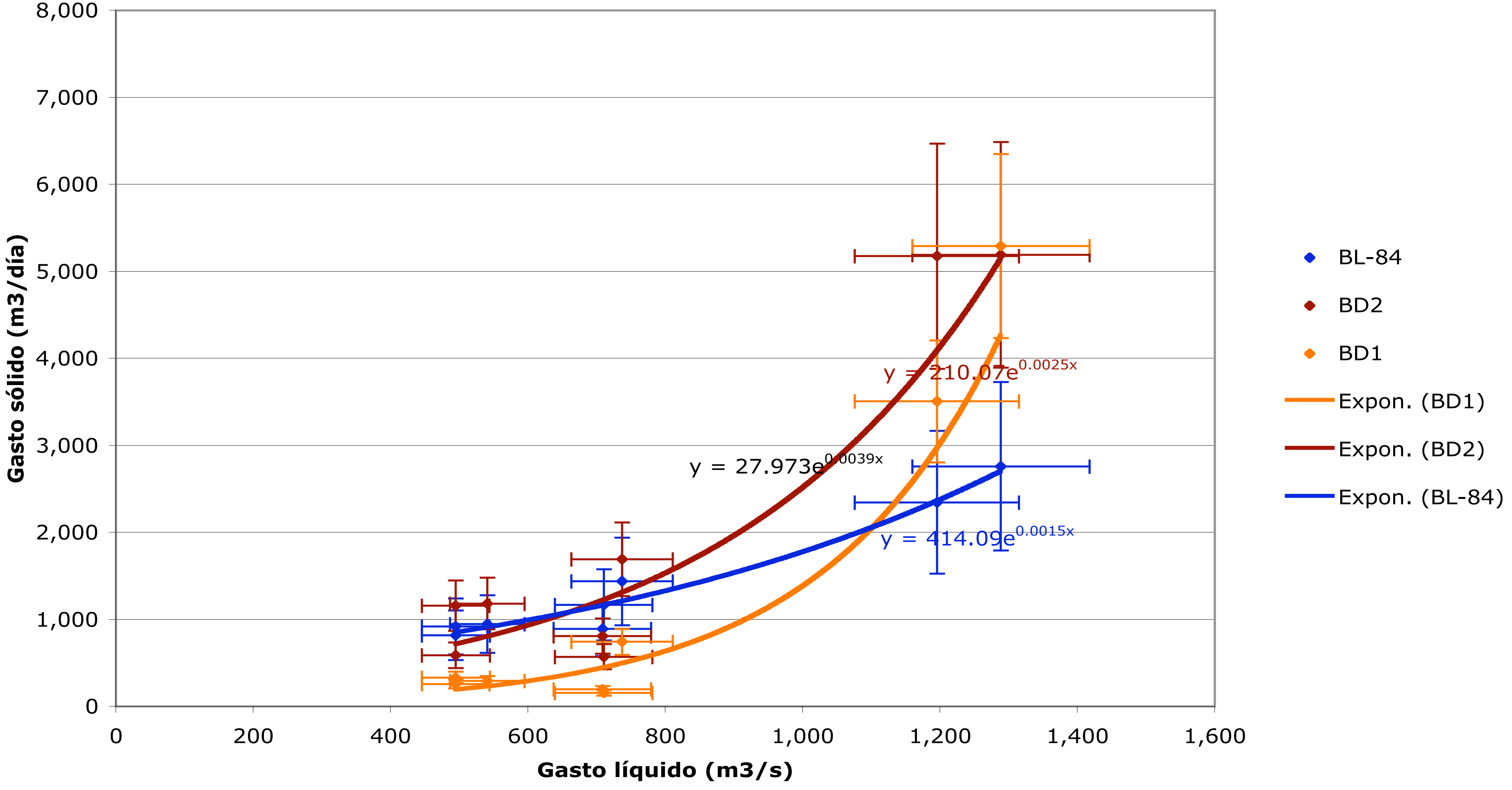
Delft Bottle BD2 for near-bed load transport

Operated from a small unit

Delft Bottle BD1 for suspended load transport

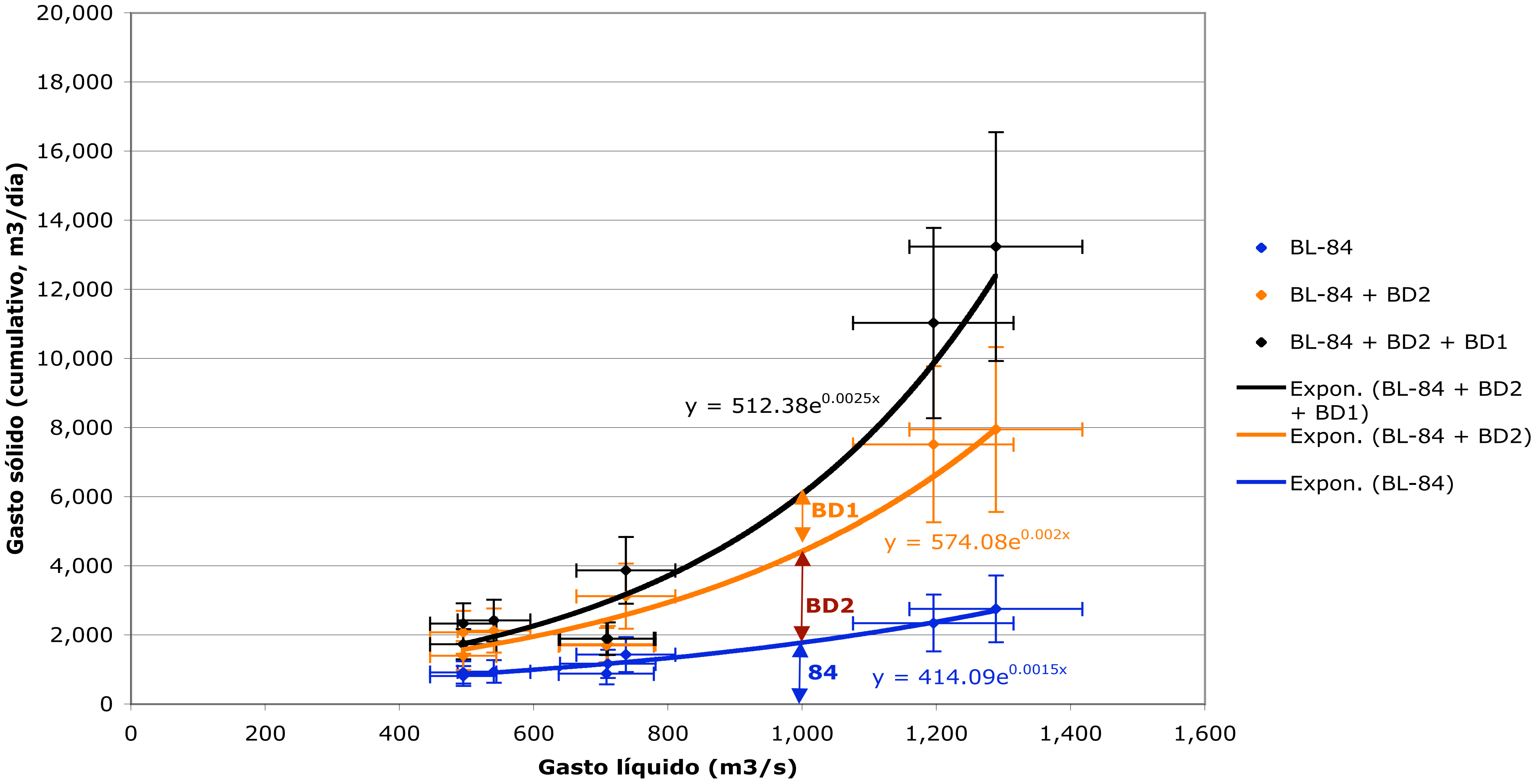
Fitting the tail; operated from a small unit

Flow and sediment transport relationship Mezcalapa



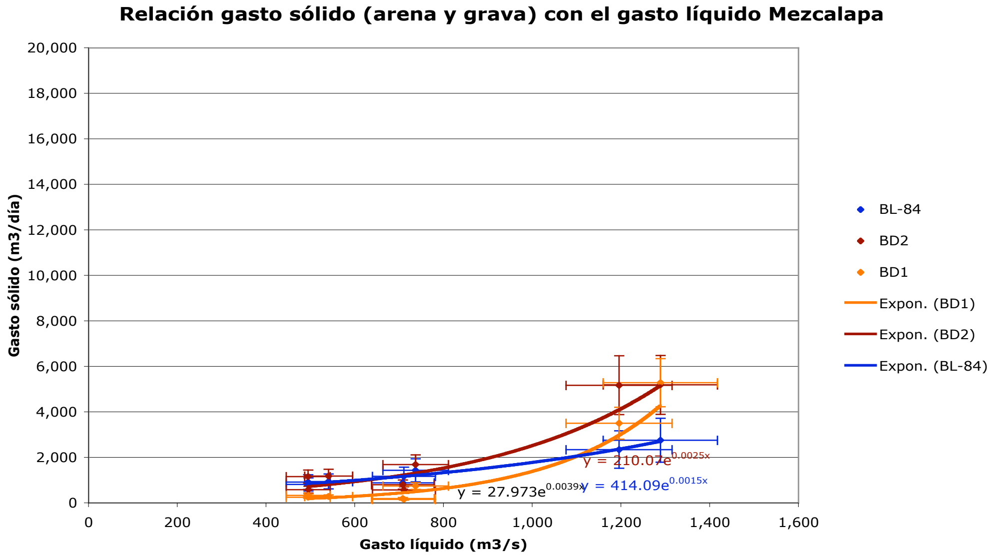
Sediment transport: BL-84 = bed-load; Delft bottle BD2= near-bed; Delft bottle BD1= suspension

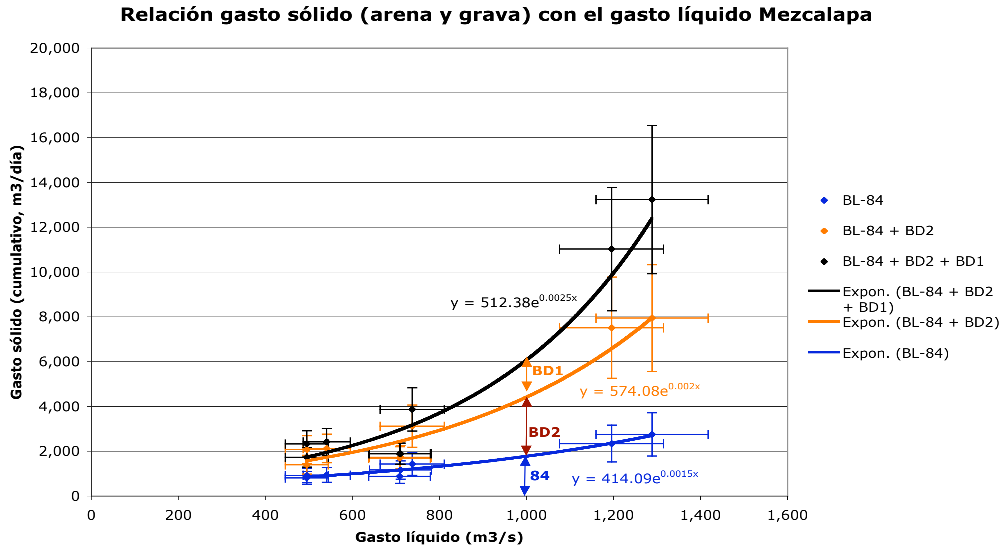
Flow and sediment transport relationship Mezcalapa



Sediment transport: BL-84 = bed-load; Delft bottle BD2= near-bed; Delft bottle BD1= suspension

Flow - sediment transport relationship

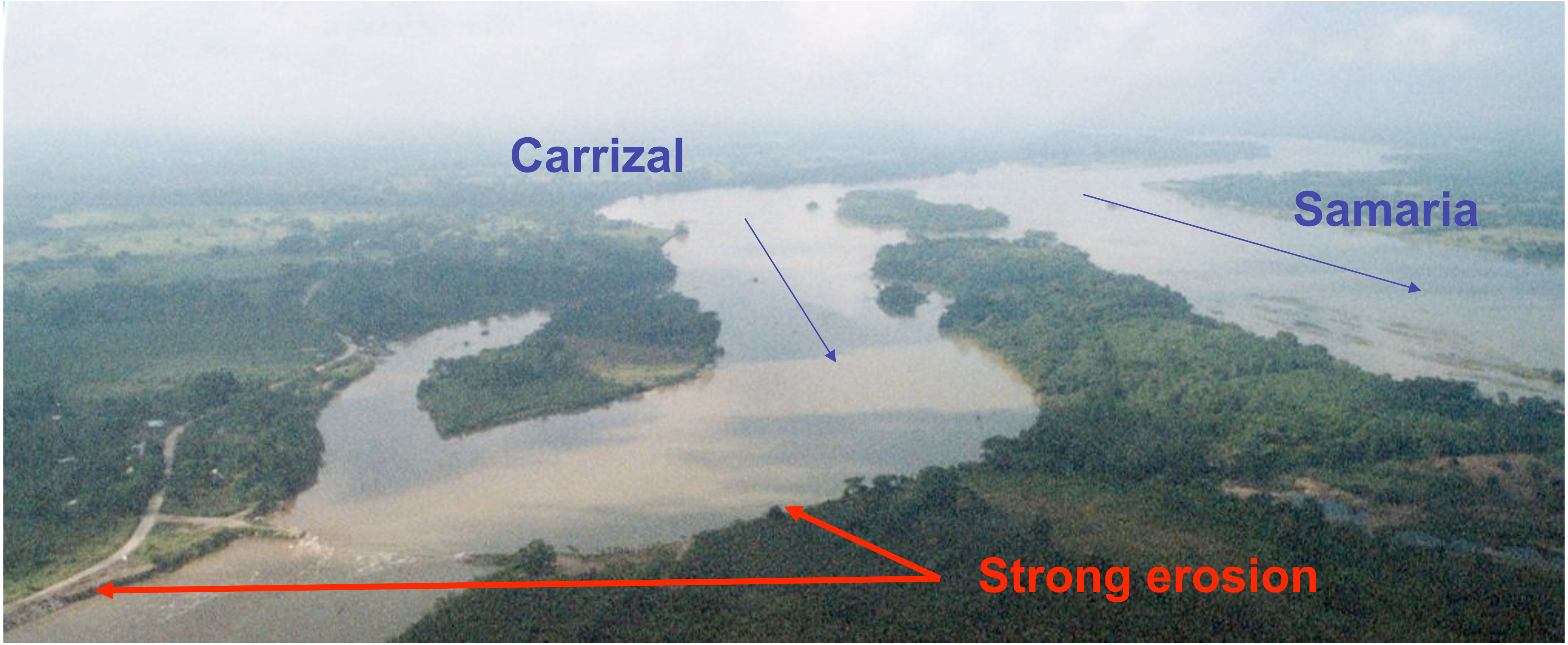




- At low discharges, bottom transport is significant but increases slowly with discharge
- Transport close to the bottom increases more rapidly, because of the increase in turbulence
- Transport in suspension, very low at mild discharges, augments more rapidly with discharges than transport close to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

A weir to control the flow, a "weird" idea …

- The studies of the weir (numerical and scale models) did not properly contemplate "sediment" issue
- The weir induced formation of an ample sand bar in the centre of the river, upstream of this weir
- 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 again strong erosion etc., etc.



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

WEIR STRUCTURE TO CONTROL FLOW IN CARRIZAL

Impact of the 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 of the Samaria bridges

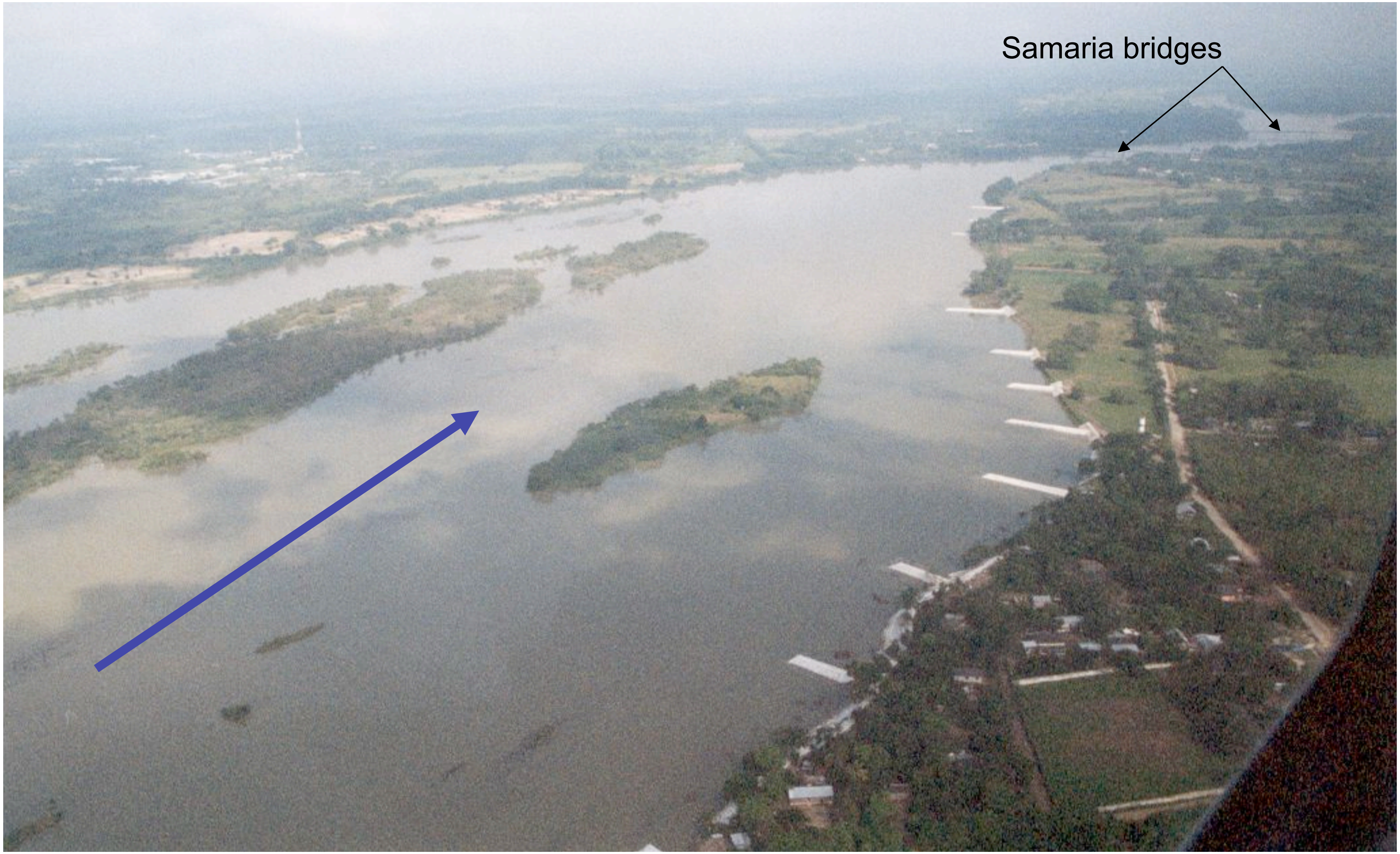
- The Samaria bridges have a long-lasting effect on sediment retention of sediments, riverbed aggradation and formation of bars and canals (remember the case discussed by Jean Cunge, although only about flow)
- These bars deflect the flow towards the banks, creating an ever more complex riverbed morphology
- This riverbed morphology causes always more bank erosion, resulting as usual with ever more protection (at least, contractors are happy to build the bank protections …)

Impact of the Samaria bridges

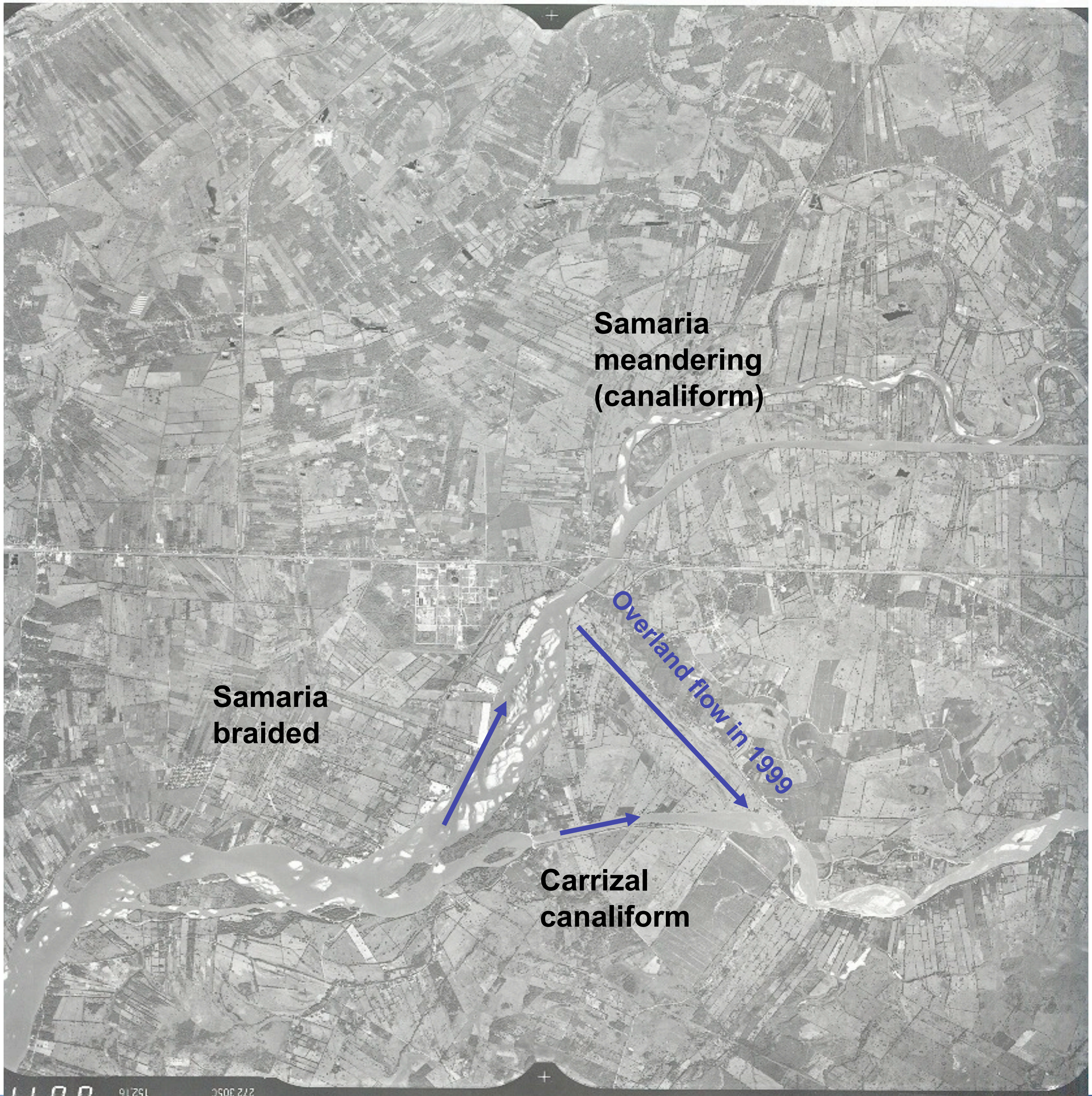
- A groyne field has been constructed to protect the right bank of the Samaria upstream of the bridges

- However, these protection works are not very effective, as the river flow attacks the bank with an oblique orientation

Impact of the Samaria bridges



2000



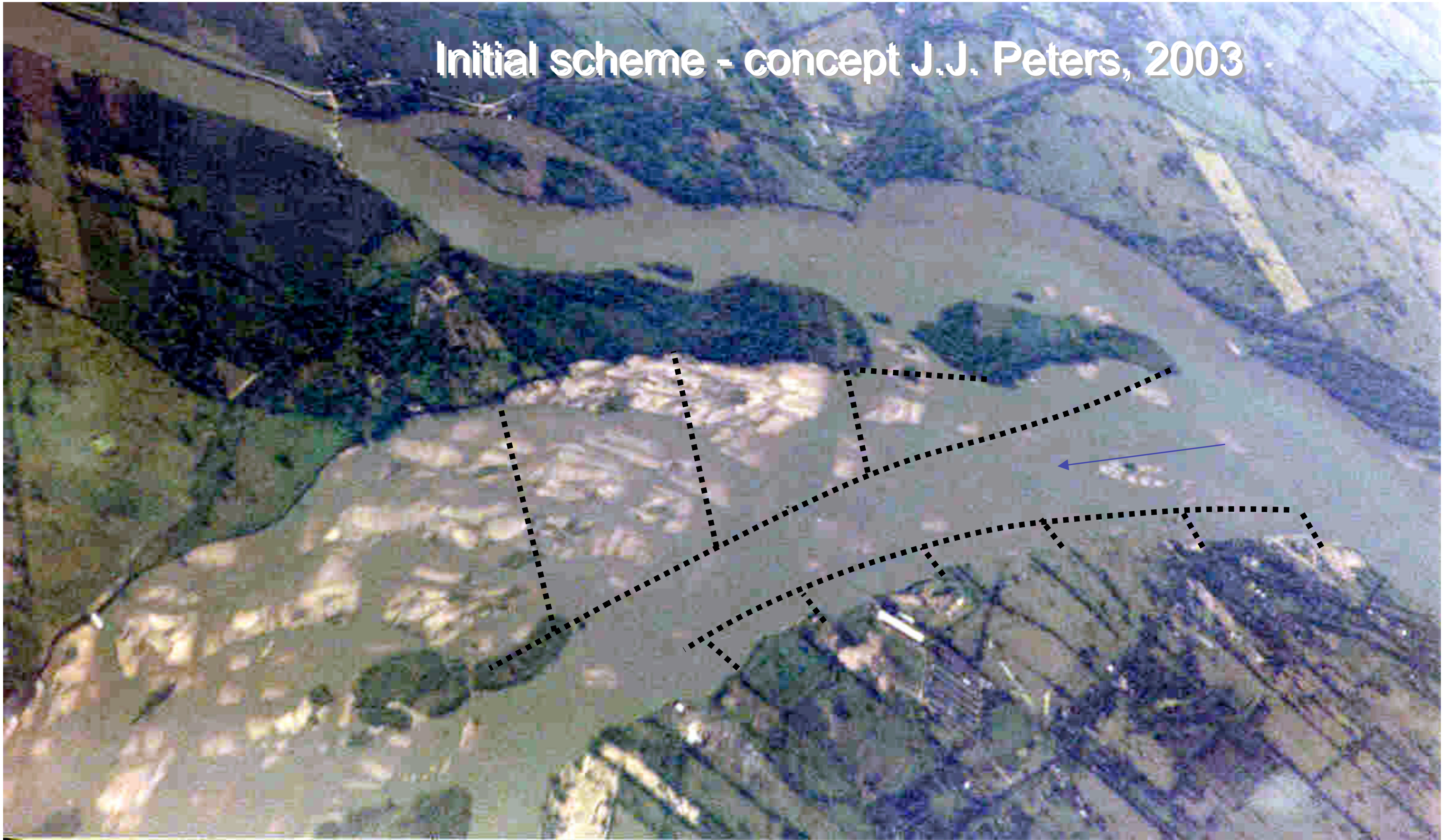
Samaria
meandering
(canaliform)
Overland flow in 1999
Samaria
braided
Carrizal
canaliform

What are possible solutions?

1. Avoid rapid fluctuations of the flow discharge en Peñitas (new compensation dam?)

3. Training the Samaria river between the bifurcation and Samaria bridges (proposal with three types 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)

A river training project (now planned …)



What does this case study learn us?

- The **impact of dam construction and operation** on the hydrological and sedimentological regime and on the morphological behaviour of rivers has to be recognized properly
- **Management of rivers in deltaïc systems** must take into account sediment transport and morphology, but numerical models can not presently cope with sediment and morphology, so field *investigations* (more than field *surveys*) and mobile-bed scale modelling is required in addition (as well as expertise)

What does this case study learn us?

- For some rivers, **design of bridges and culverts** may not be based on hydraulic solely, sediment transport and morphological analysis must also be accounted for (I refer to Jean Cunge’s presentation)
- There is a problem with **river engineering**, as most of it is made by applying (blindly) kitchen recipes, without understanding the functioning of the river (especially morphology and sediment transport)
- River engineering should take into account the past, present and future changes in the river system

Thank you for your attention

QUESTIONS AND/OR REMARKS?