# Combining multi source data to estimate a suspended sediment budget for a Mediterranean deltaic hydro-system (Rhone delta, France).


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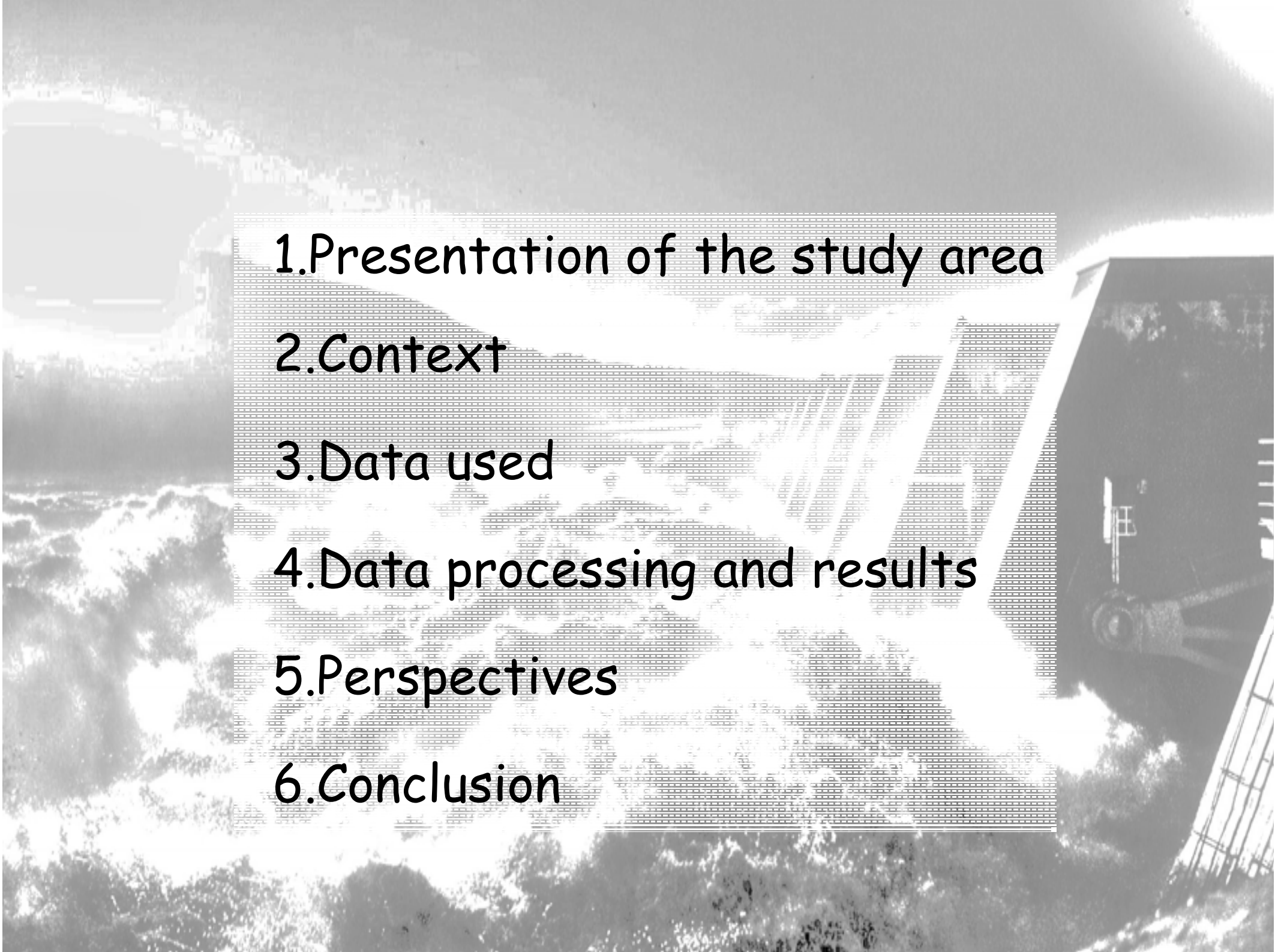


1.Presentation of the study area

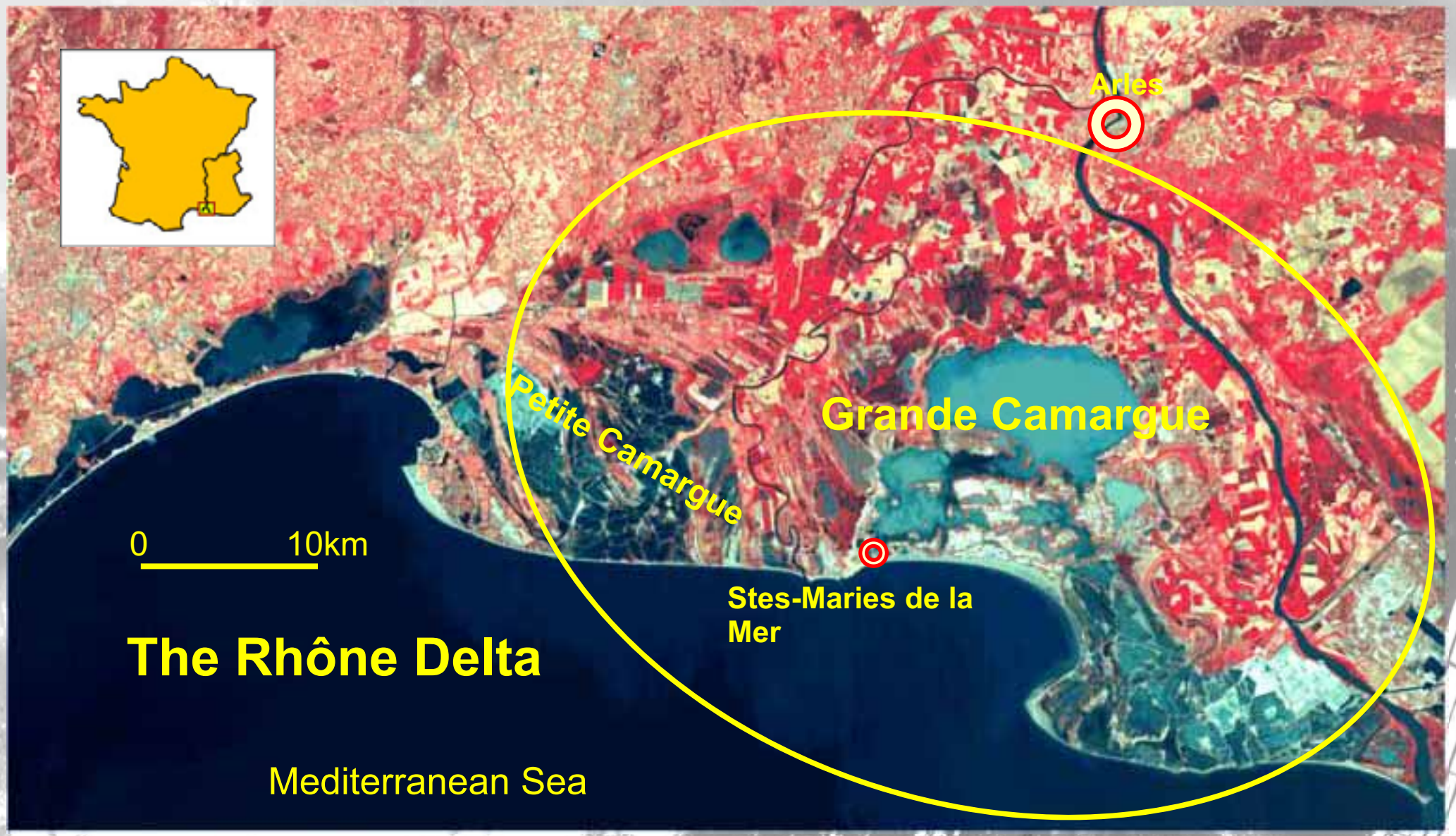
2.Context

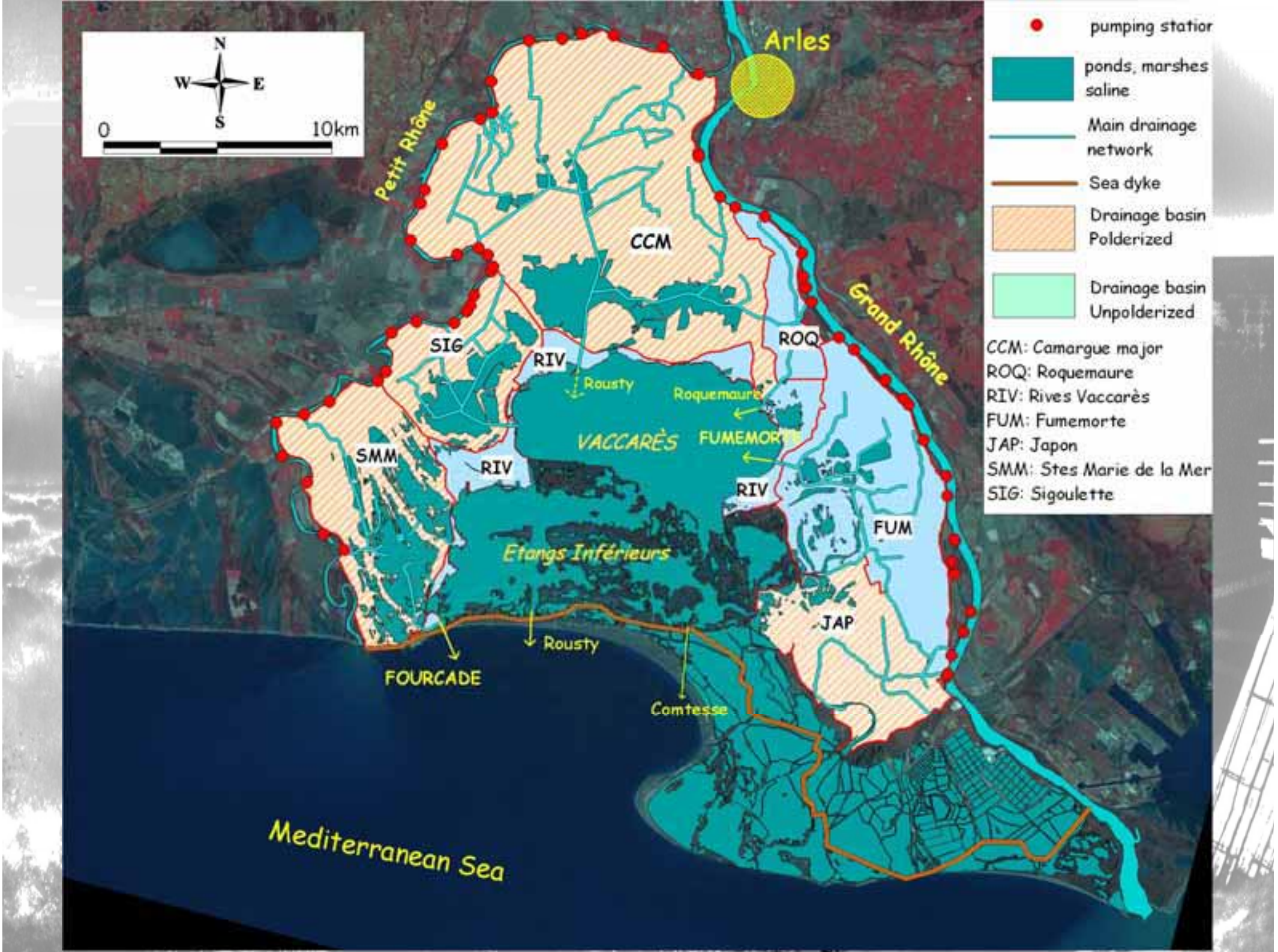
3.Data used

4.Data processing and results

5.Perspectives

6.Conclusion


Arles
Petite Camargue
Grande Camargue
0
10km
Stes-Maries de la Mer
The Rhône Delta
Mediterranean Sea


N
W
E
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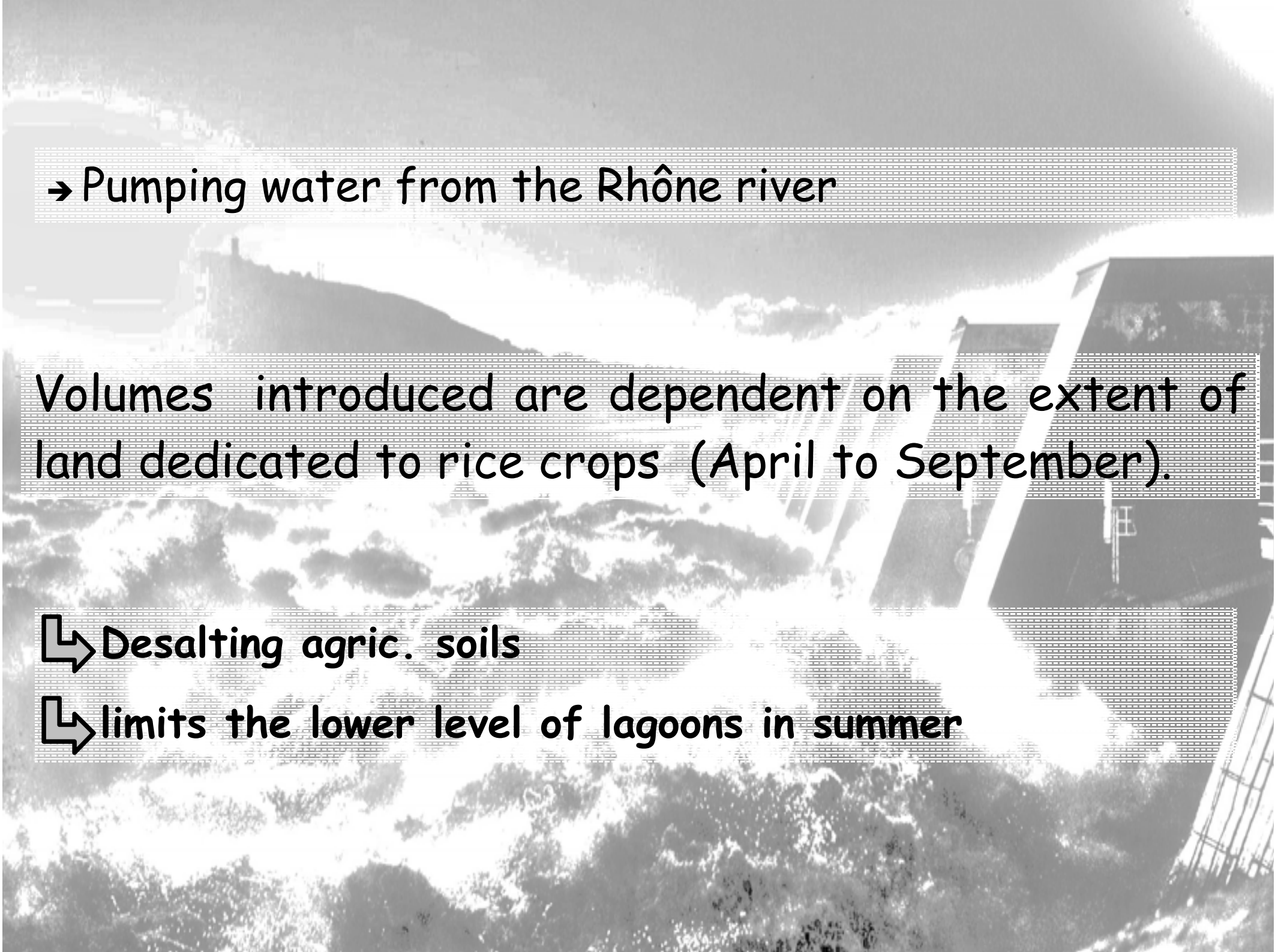
0
10km
Arles
Petit Rhône
Grand Rhône
CCM
ROQ
SIG
RIV
Rousty
Roquemaure
VACCARÈS
FUMEMORTE
SMM
RIV
RIV
FUM
Etangs Inférieurs
JAP
Rousty
FOURCADE
Comtesse
Mediterranean Sea
pumping station
ponds, marshes saline
Main drainage network
Sea dyke
Drainage basin Polderized
Drainage basin Unpolderized
CCM: Camargue major
ROQ: Roquemaure
RIV: Rives Vaccarès
FUM: Fumemorte
JAP: Japon
SMM: Stes Marie de la Mer
SIG: Sigoulette

# CLIMATE

- Precipitation: 600 mm on average (min 289-max 1050)
- Open water evaporation : 1400-1500 mm/yr

→ Significant water deficit

- Wind:
  - Mistral (NNW) can occur anytime throughout the year
  - S and SE winds (autumn)



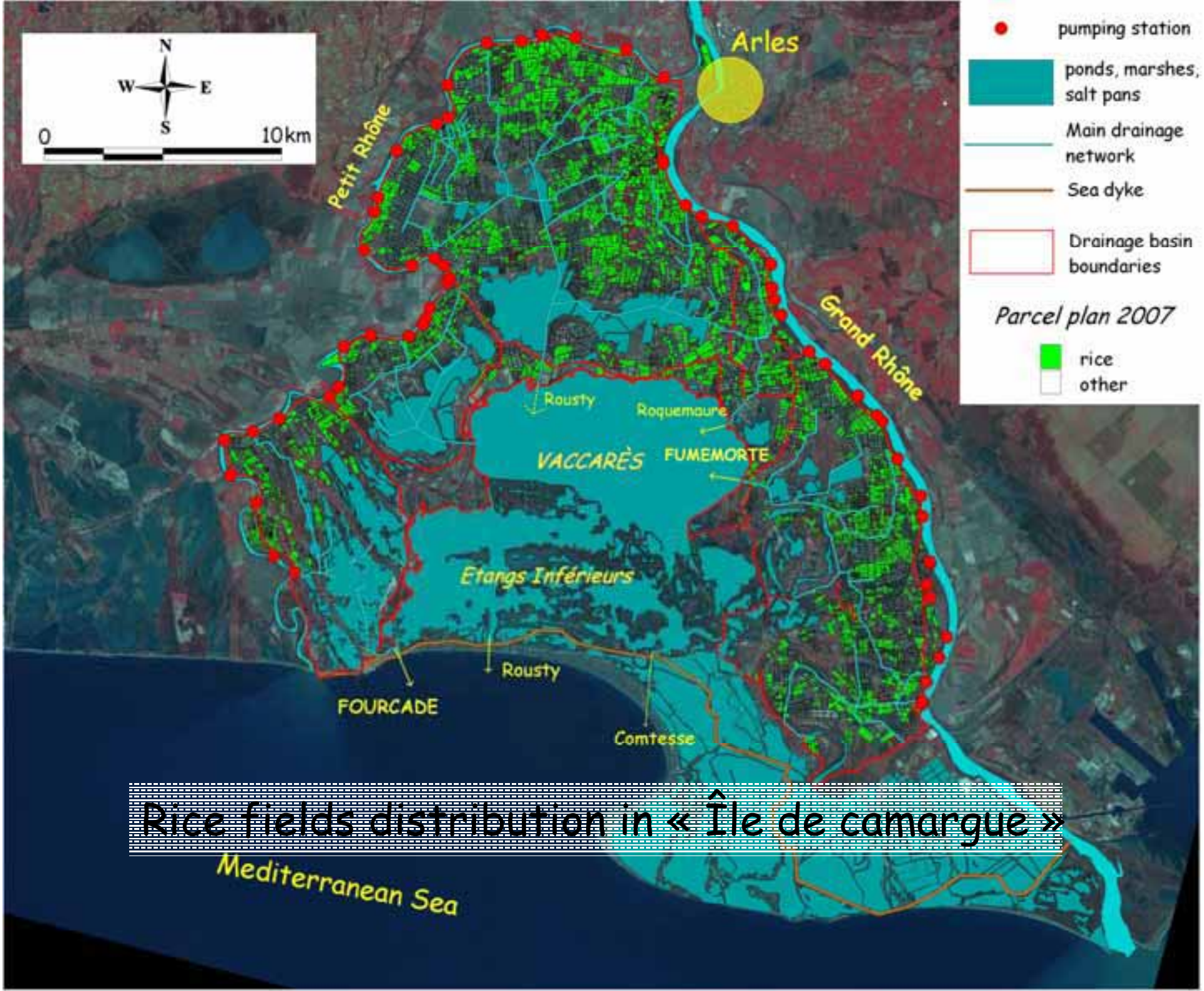
➔ Pumping water from the Rhône river

Volumes introduced are dependent on the extent of land dedicated to rice crops (April to September).

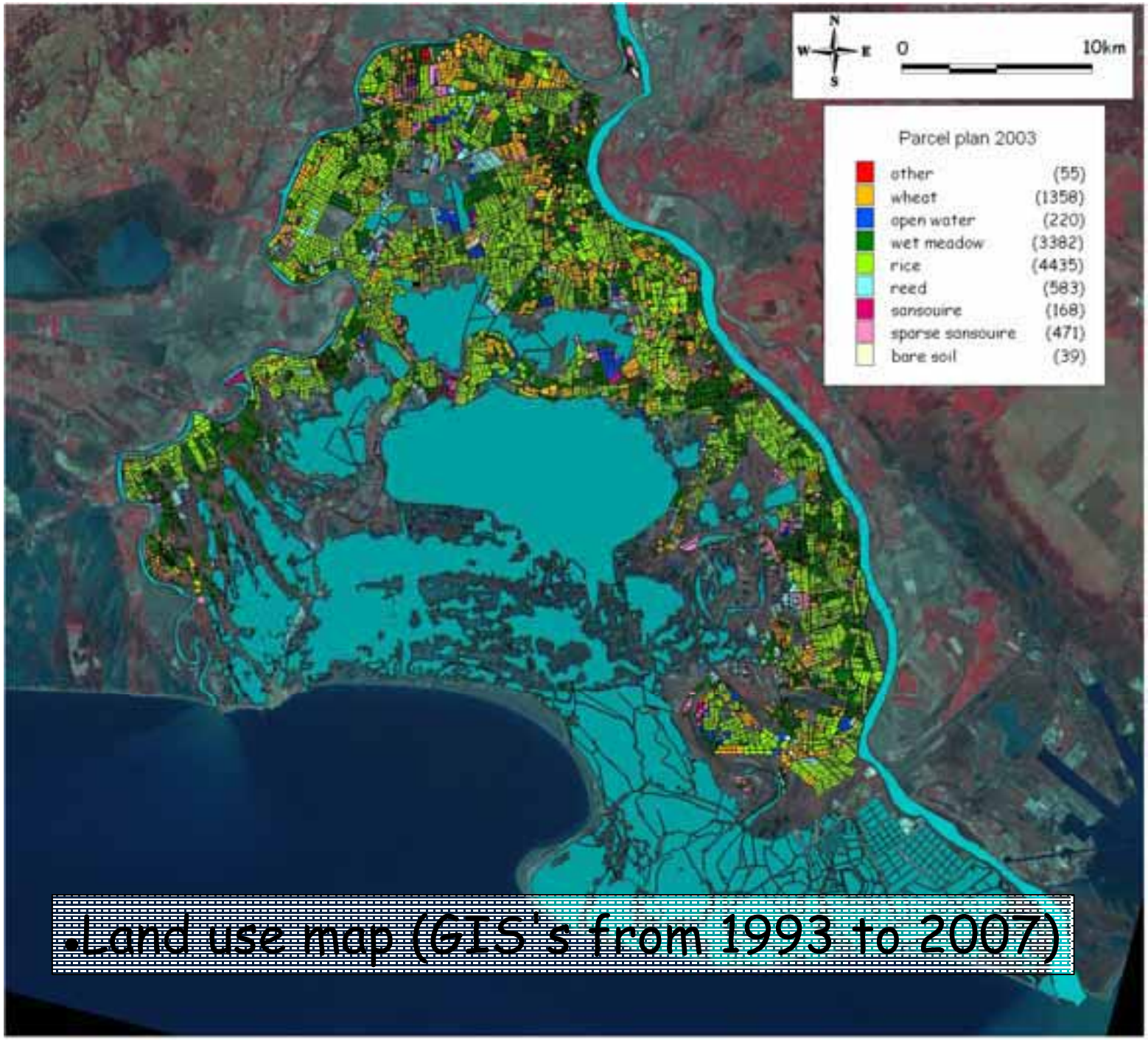
↳ **Desalting agric. soils**

↳ **limits the lower level of lagoons in summer**

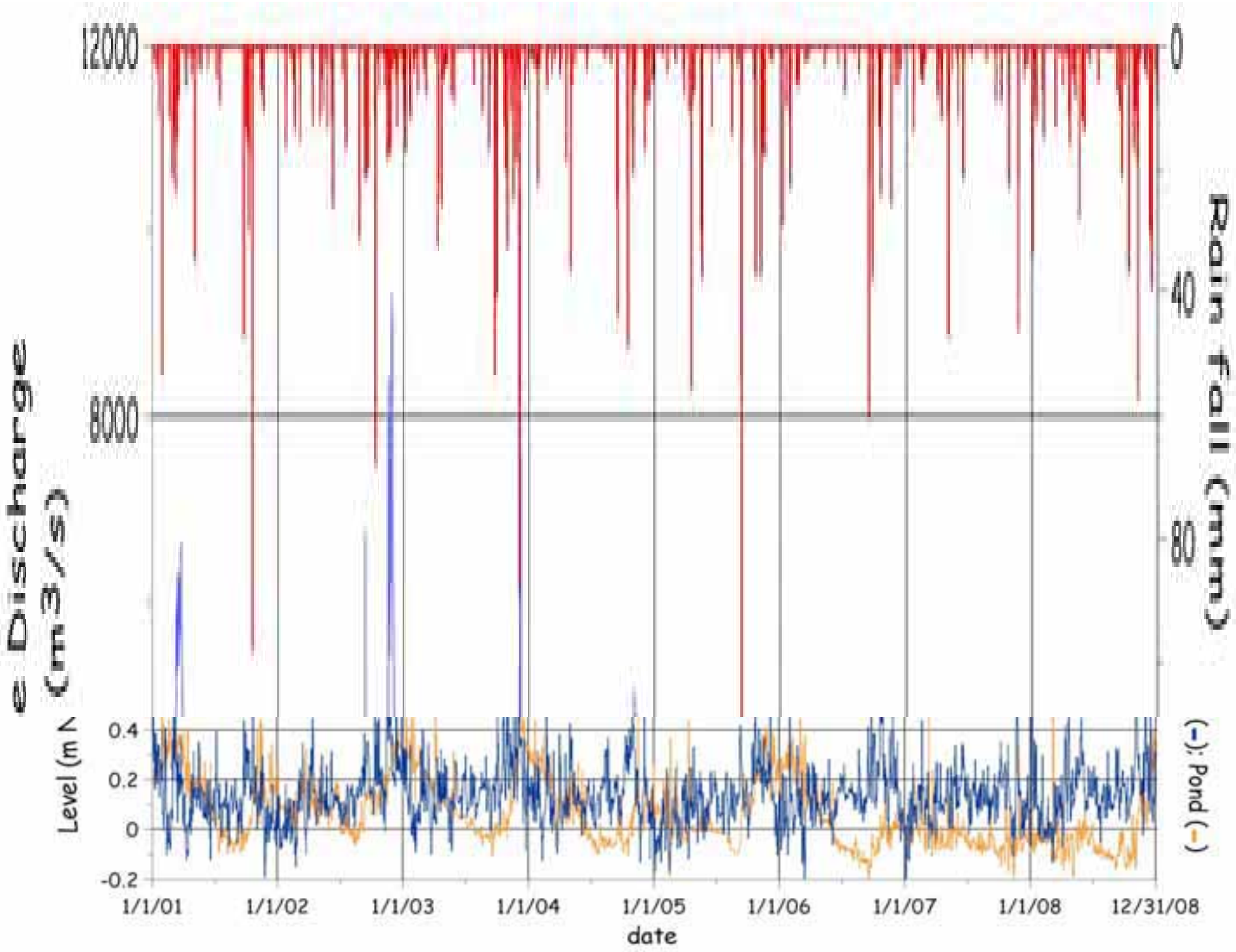
Rice fields under water

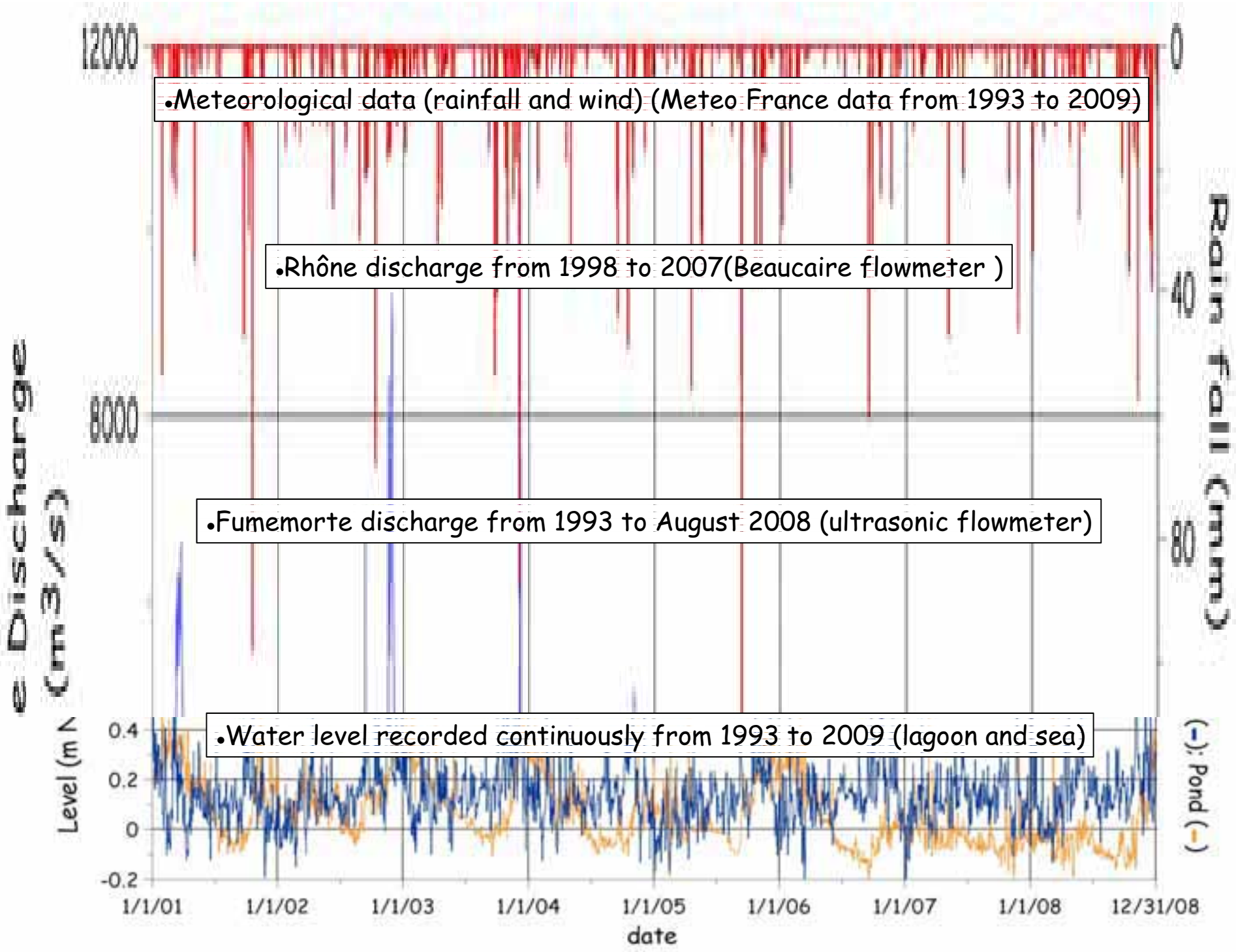



Rice fields distribution in « Île de camargue »




- Land use map (GIS's from 1993 to 2007)


12000
8000
0
40
80
e Discharge (m3/s)
Rain fall (mm)
Level (m
0.4
0.2
0
-0.2
(-): Pond (-)
1/1/01
1/1/02
1/1/03
1/1/04
1/1/05
1/1/06
1/1/07
1/1/08
12/31/08
date


•Meteorological data (rainfall and wind) (Meteo France data from 1993 to 2009)
•Rhône discharge from 1998 to 2007(Beaucaire flowmeter )
•Fumemorte discharge from 1993 to August 2008 (ultrasonic flowmeter)
•Water level recorded continuously from 1993 to 2009 (lagoon and sea)
12000
8000
0
40
80
Rain fall (mm)
e Discharge (m3/s)
Level (m N
0.4
0.2
0
-0.2
(-): Pond (-)
1/1/01
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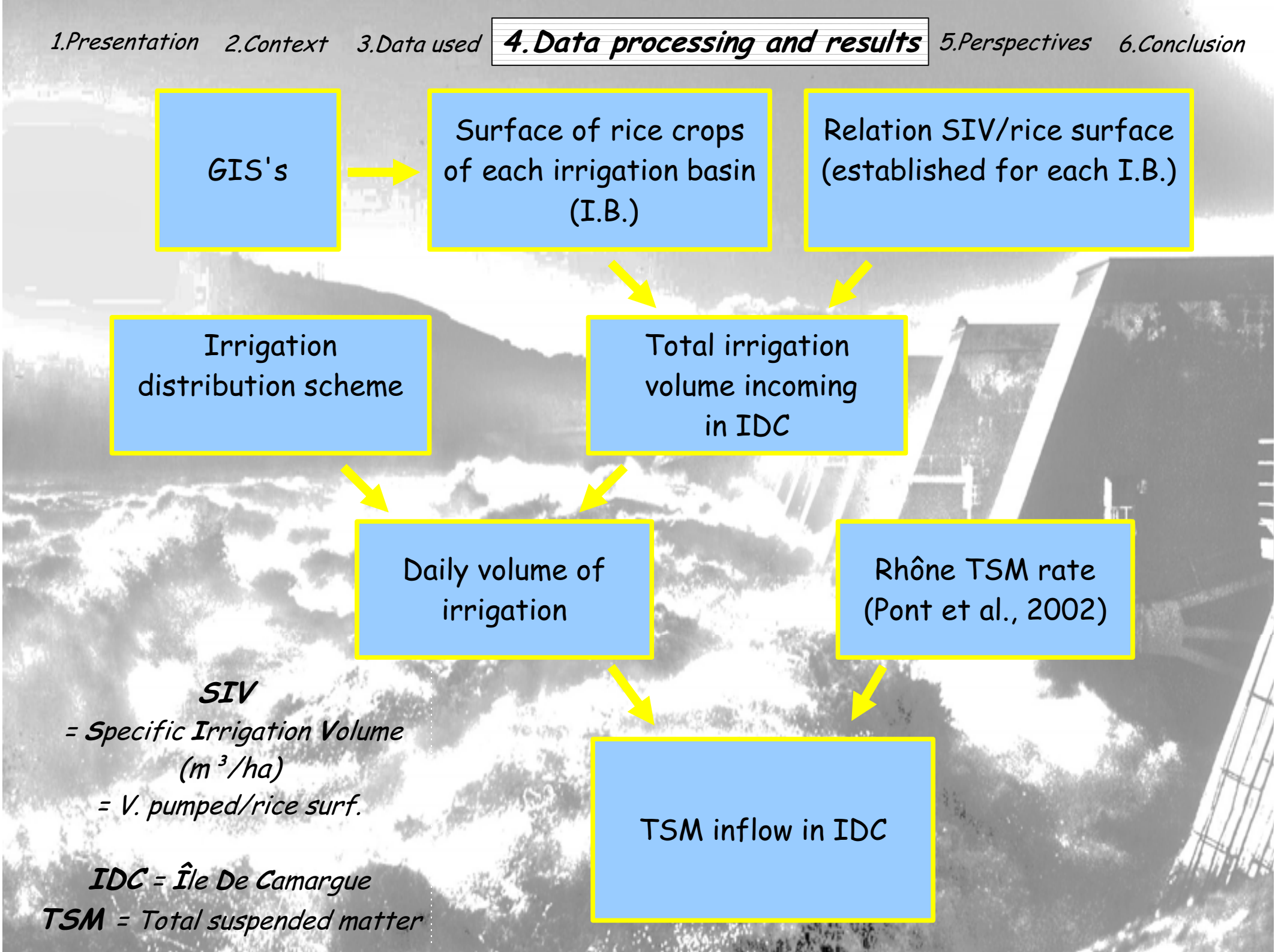


***SIV***
*= **S**pecific **I**rrigation **V**olume*
*($m^3/ha$)*
*= V. pumped/rice surf.*

***IDC** = **Î**le **D**e **C**amargue*
***TSM** = Total suspended matter*

G

surface
each I.B.)
000)

Ir
distrib
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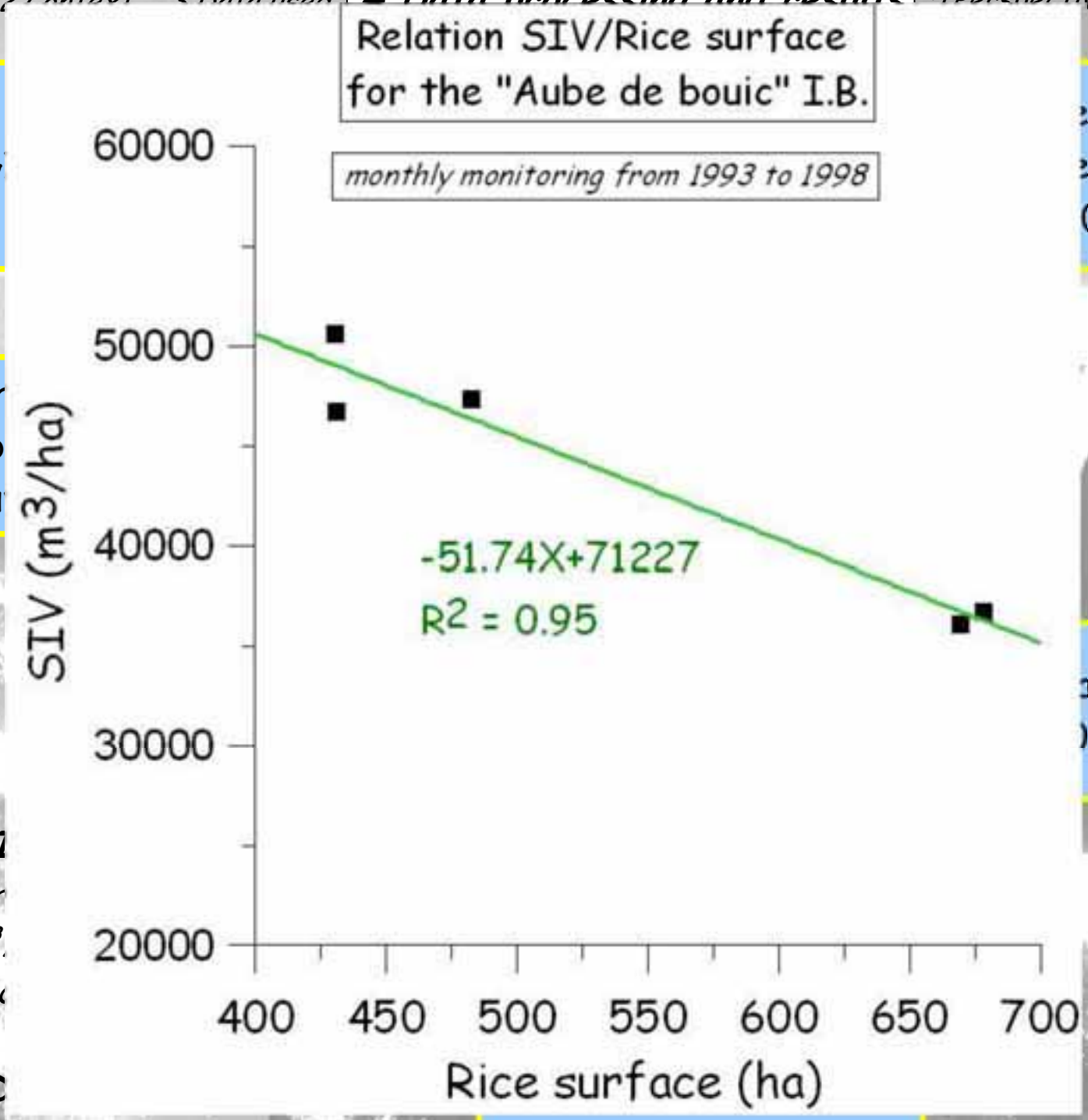
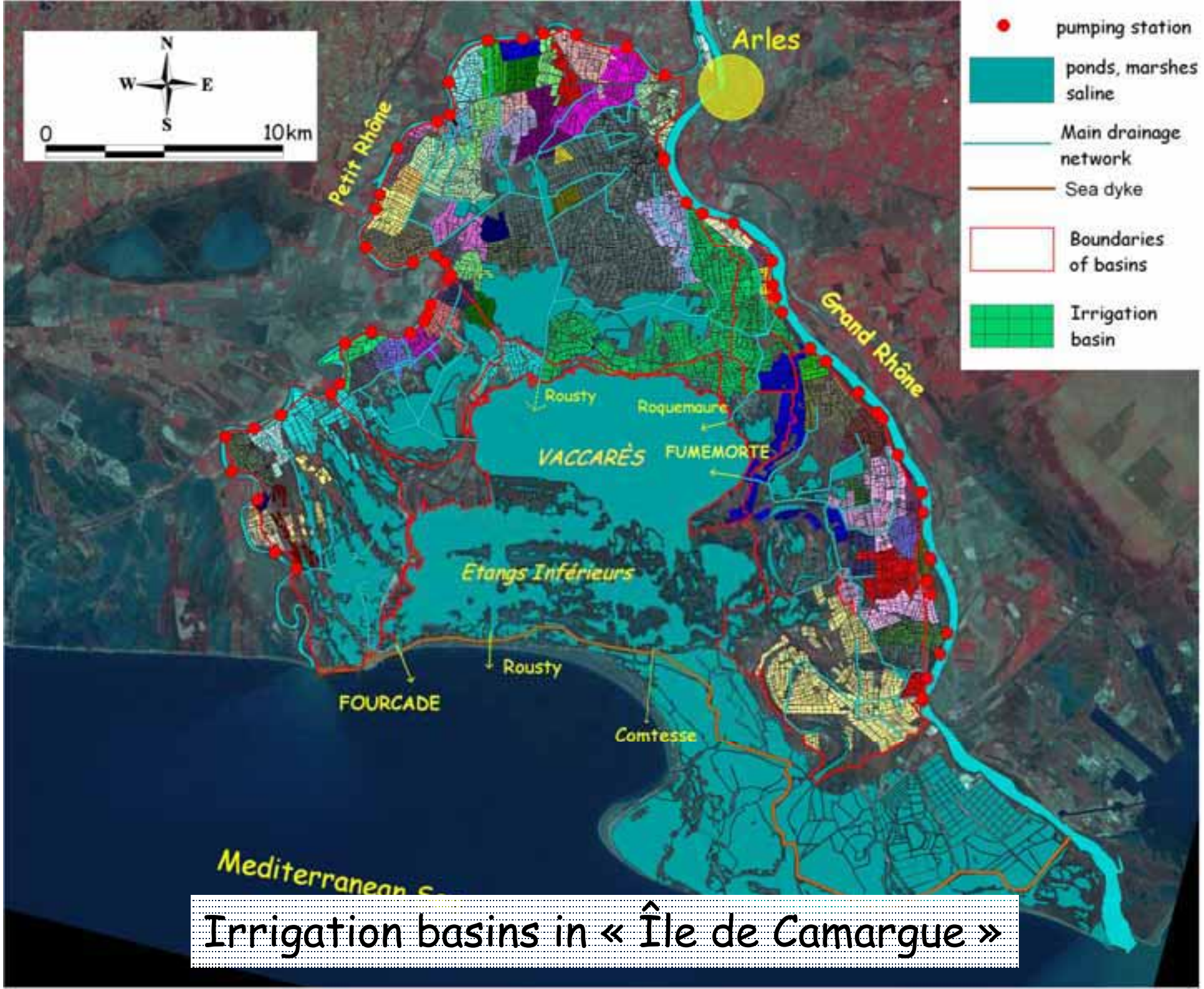
ate
02)

**SI**
= Specific Irr
(m ³
= V. pumpe

**IDC** = Île D

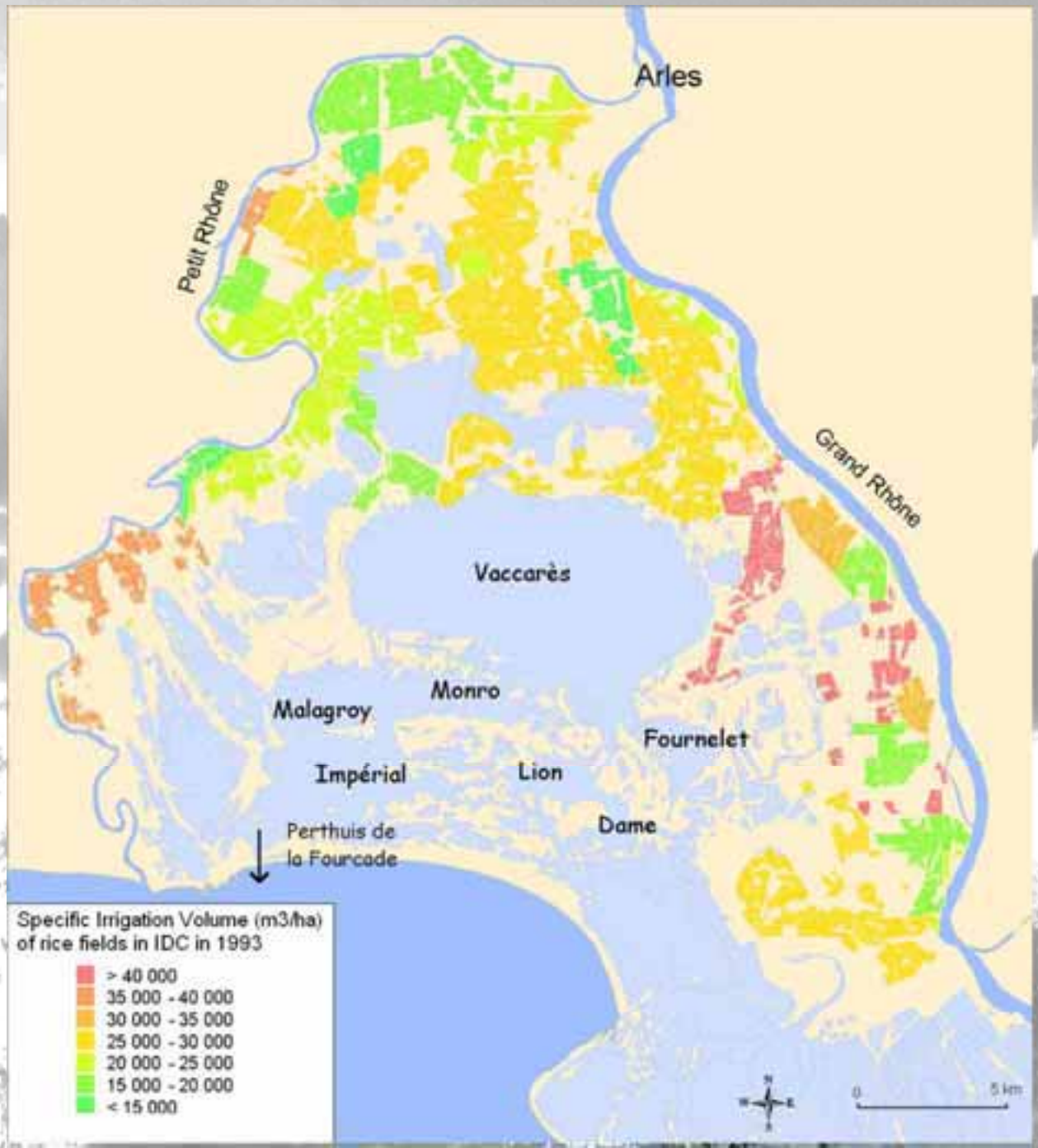
**TSM** = Total suspended matter





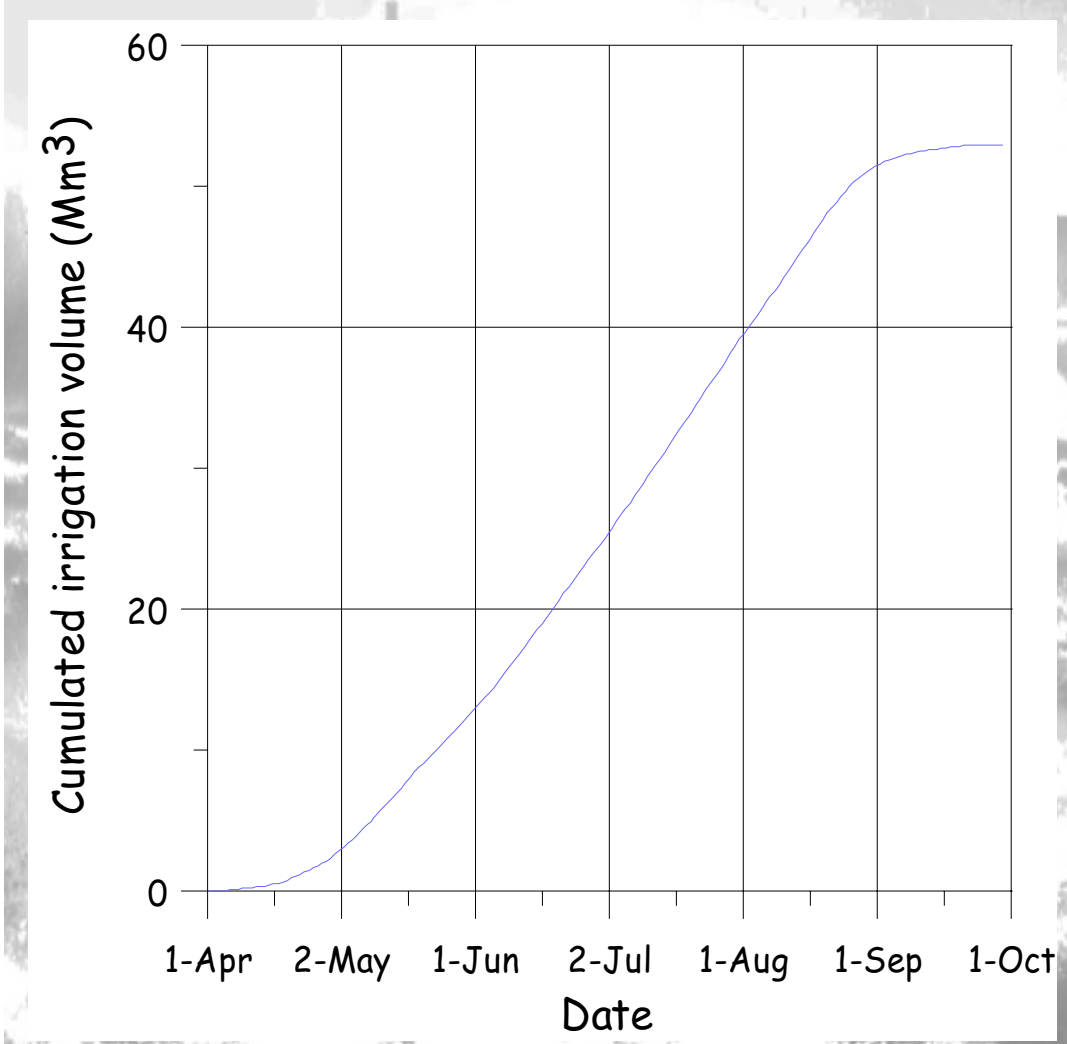

Irrigation basins in « Île de Camargue »

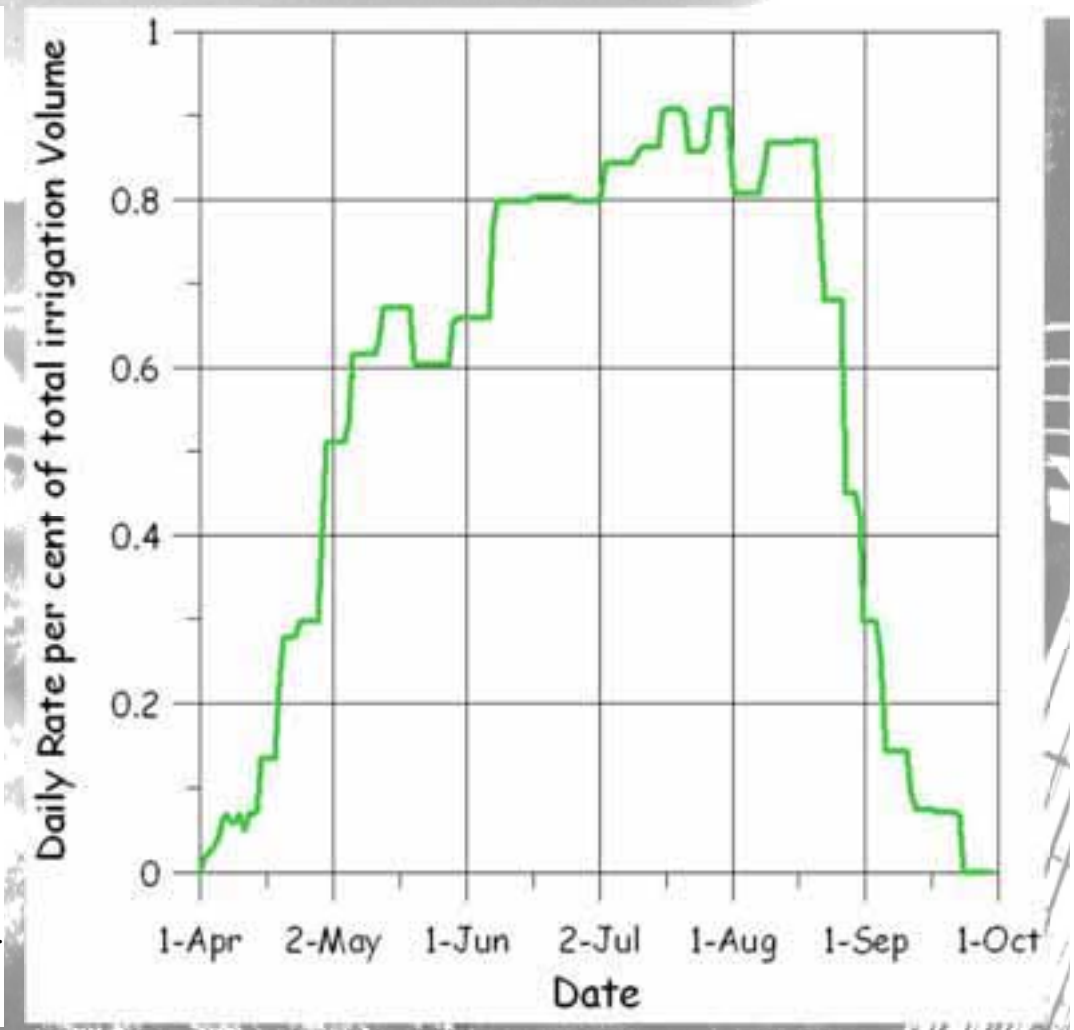
# Variability of SIV (Speficic irrigation Volume)



# Irrigation distribution scheme during season

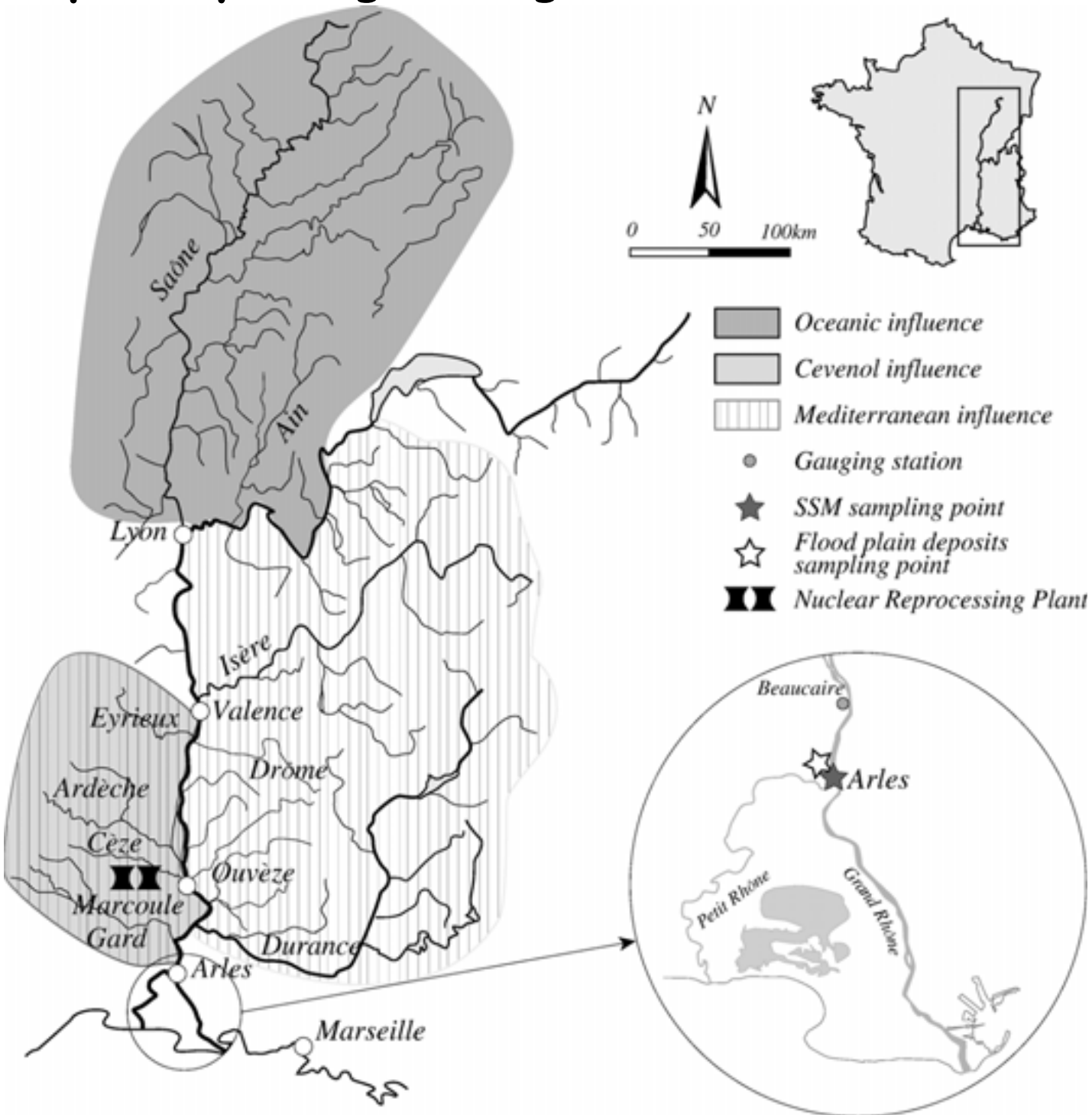
Established for the Fumemorte basin => iextrapolated toothers

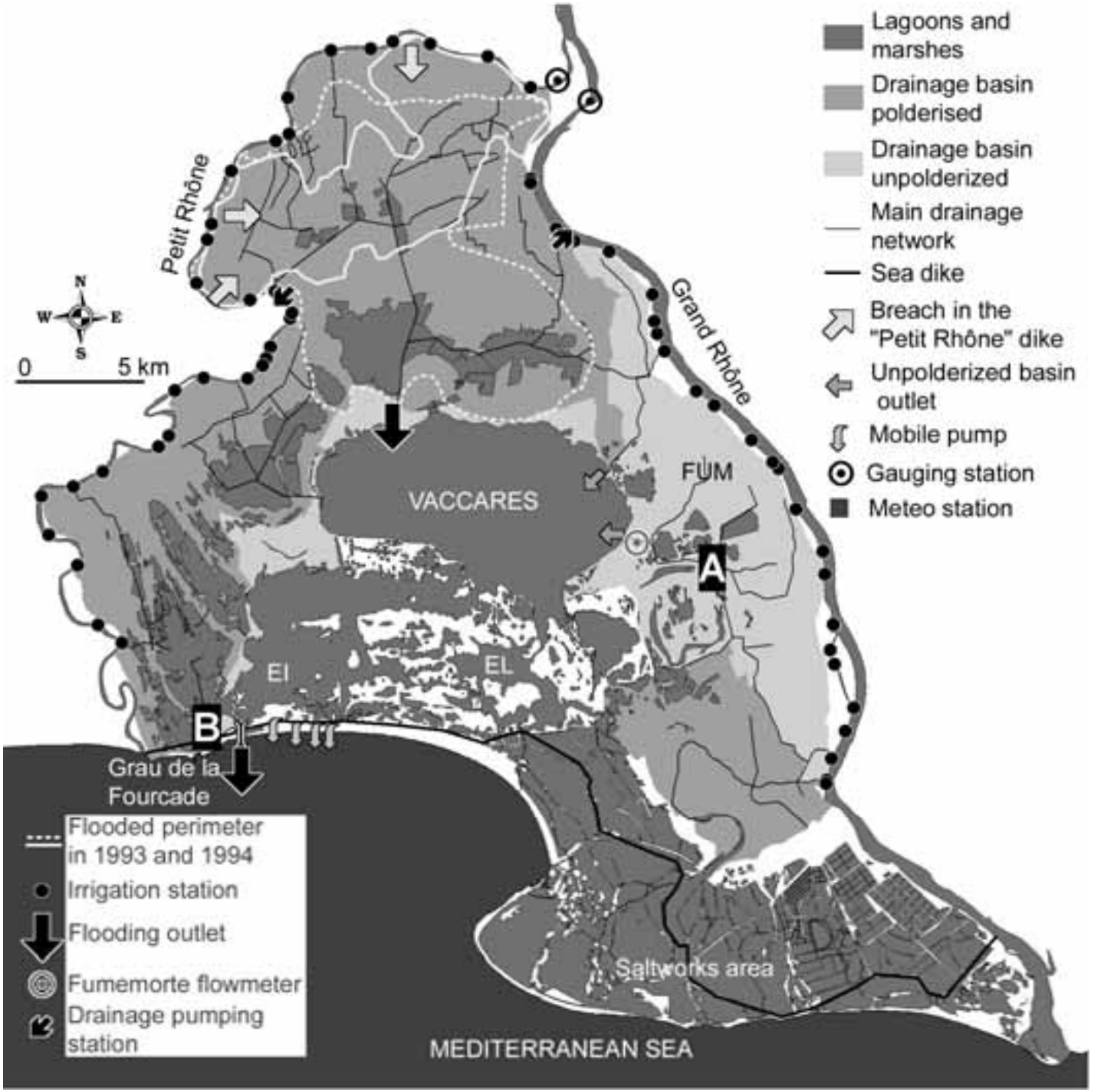


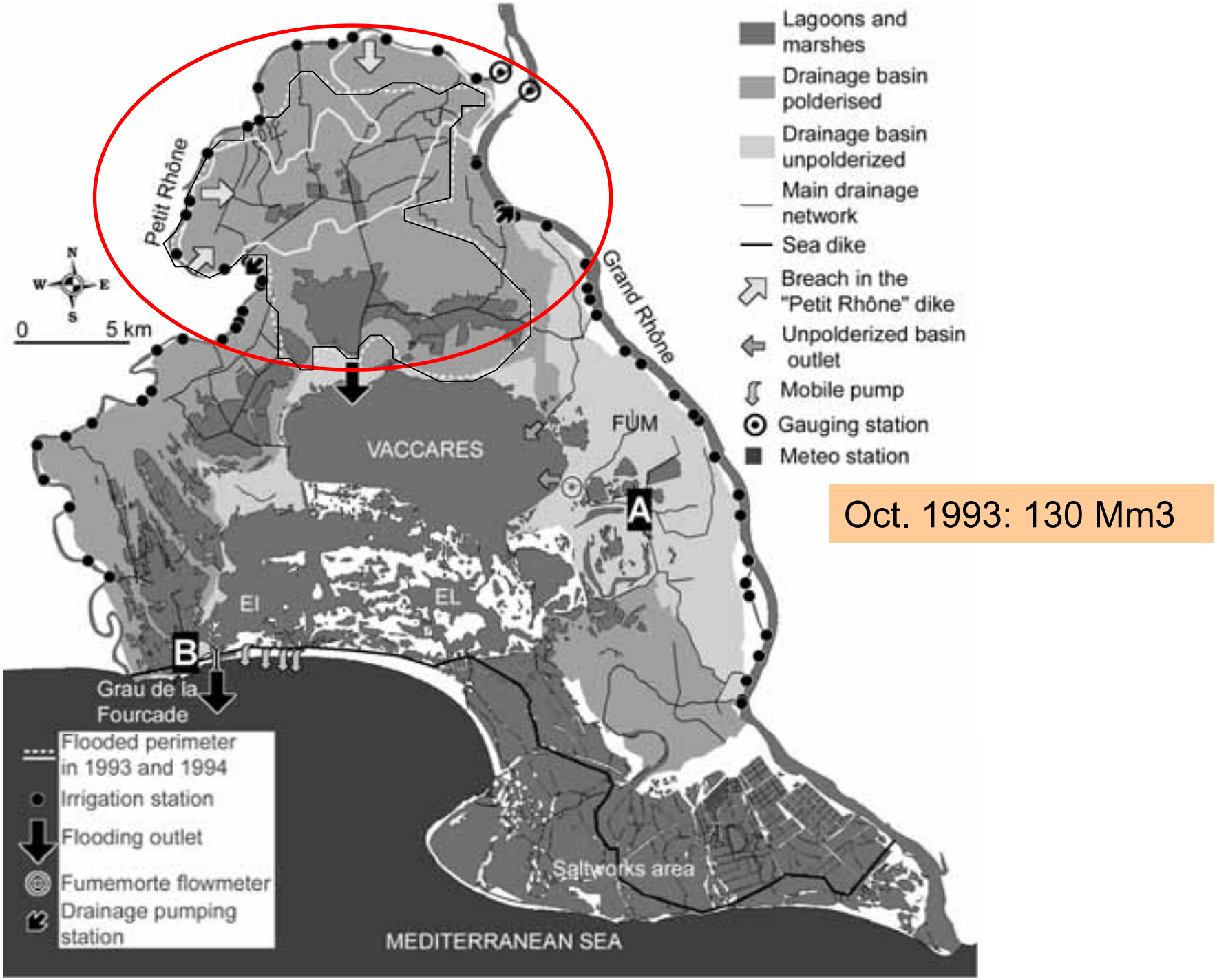

Study for the years 1993 and 1994 *(bi-weekly monitoring )*

# Complex hydrological regime of Rhone river basin






**Flooding conditions in 1993 and 1994**




Oct. 1993: 130 Mm3

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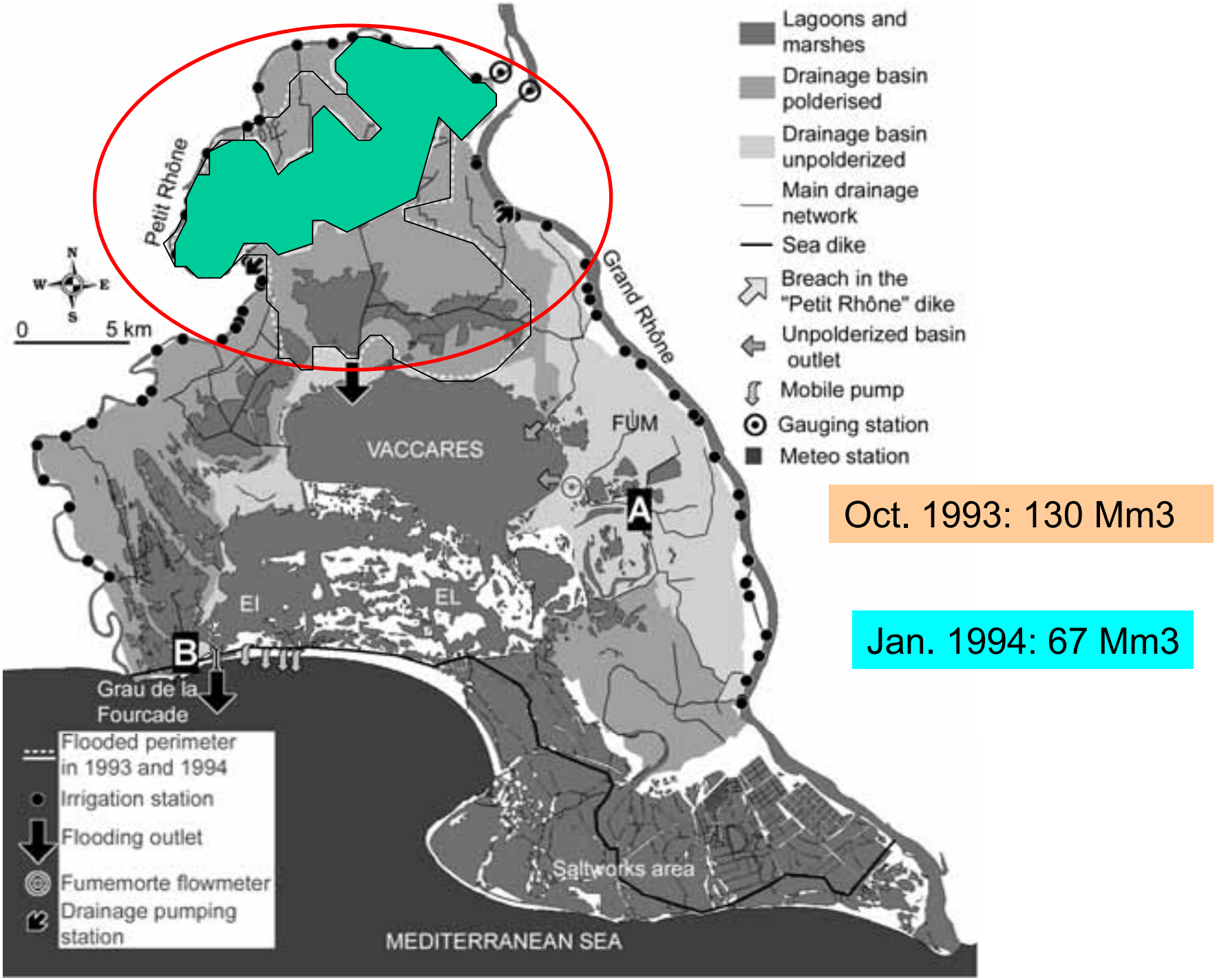


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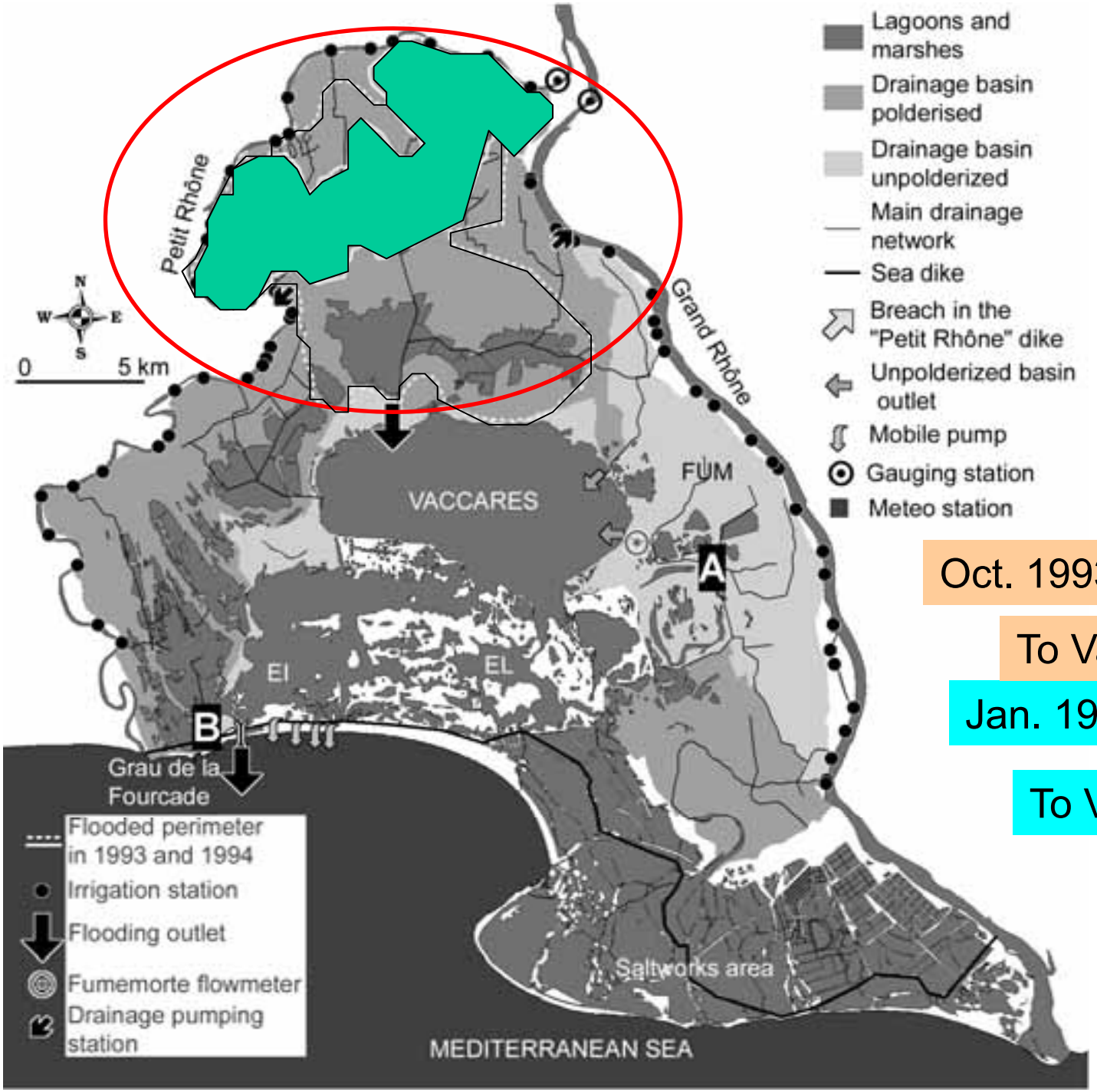



Oct. 1993: 130 Mm3

To Vacc : 90 Mm3

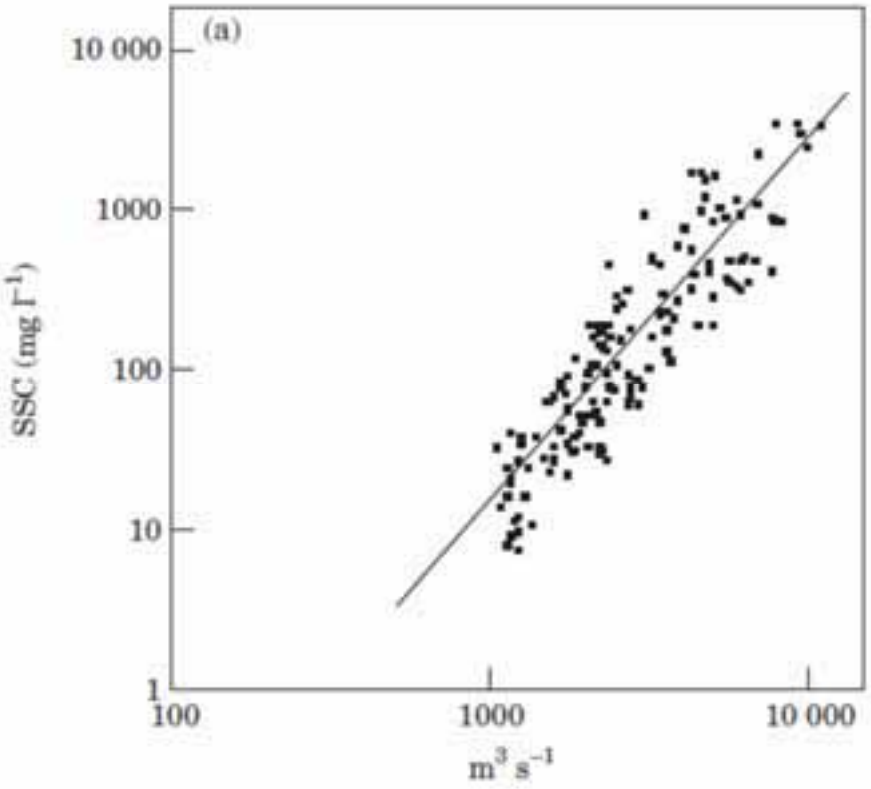
Jan. 1994: 67 Mm3

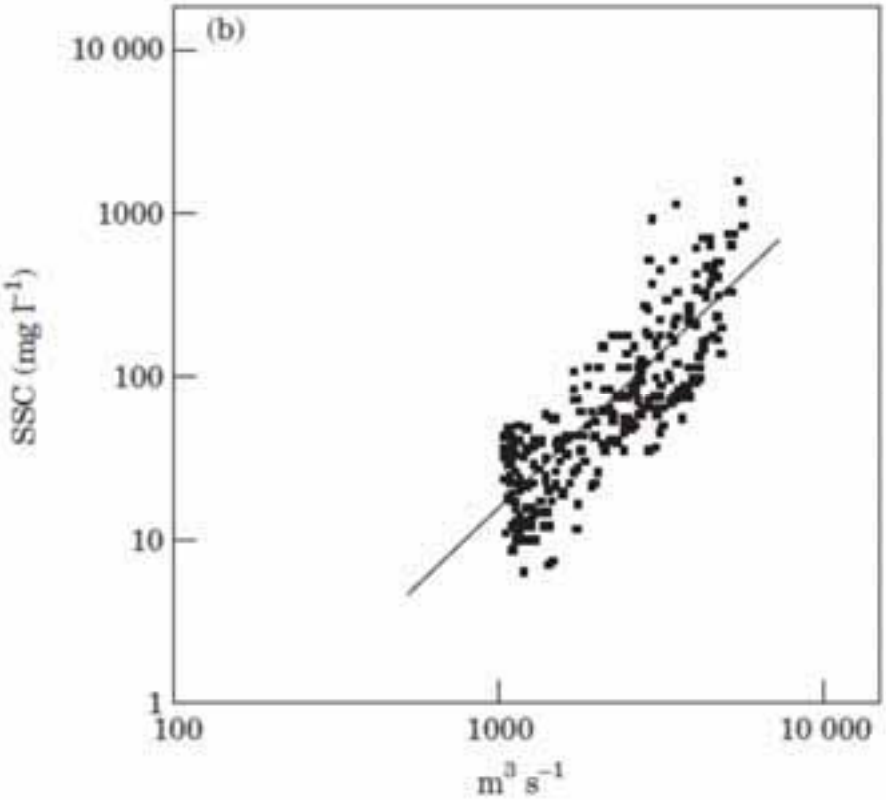
To Vacc: 16 Mm3

**Flooding conditions in 1993 and 1994**

# Rhône TSM/Q (Pont et al., 2002)

*Published in « Estuarine, Coastal and Shelf Science »*



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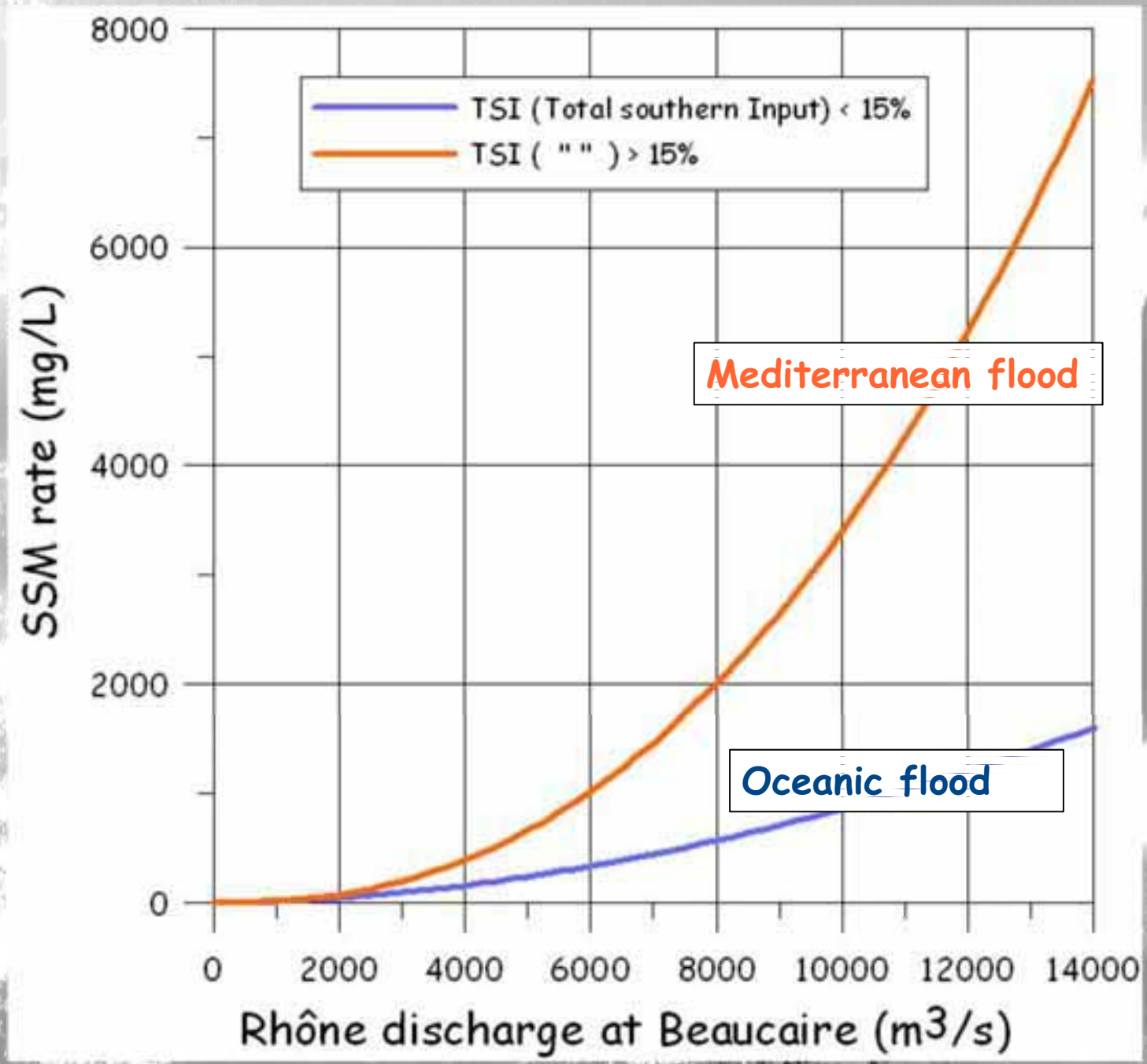
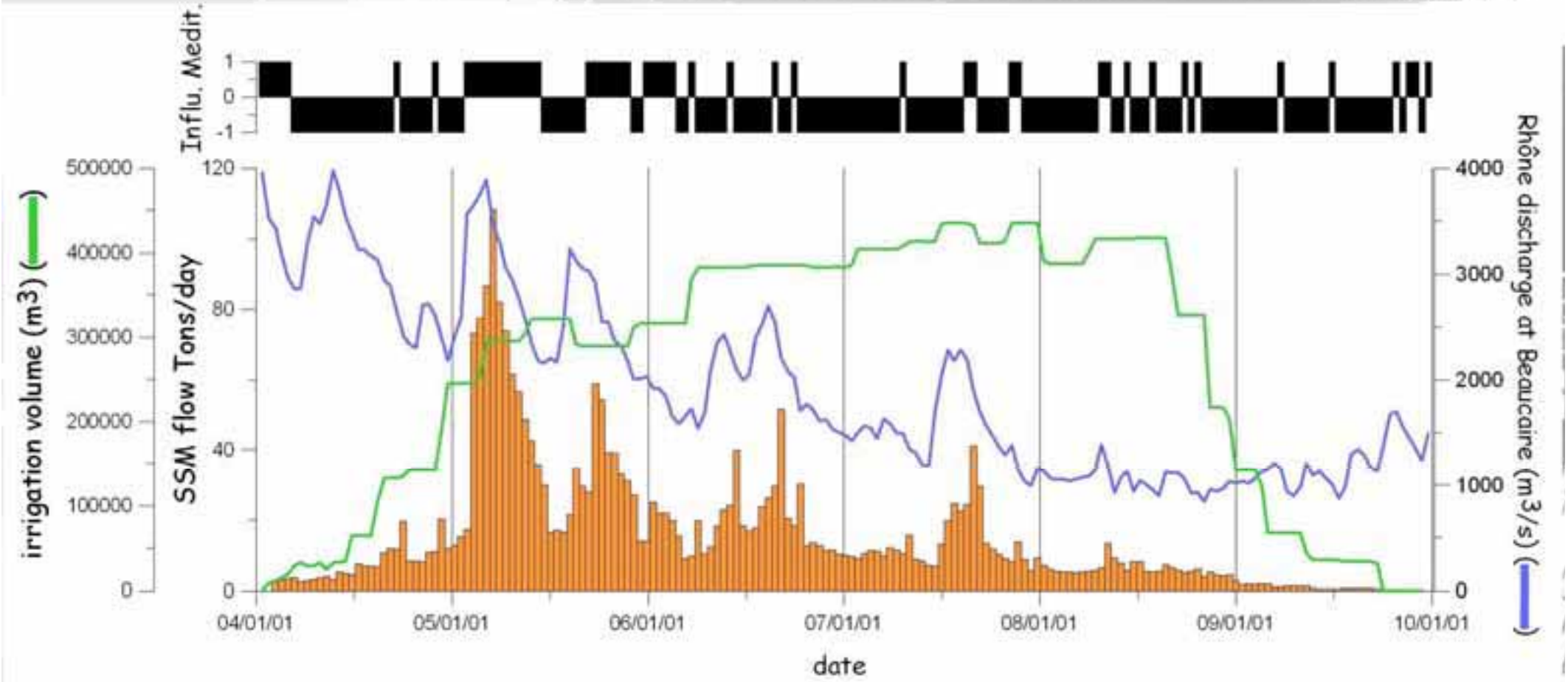


# Rhône TSM rate (Pont, 2002)

- mediterranean floods bring more sediment




TSM contribution of the irrigation water
in the Fumemorte basin during the rice period of 2001

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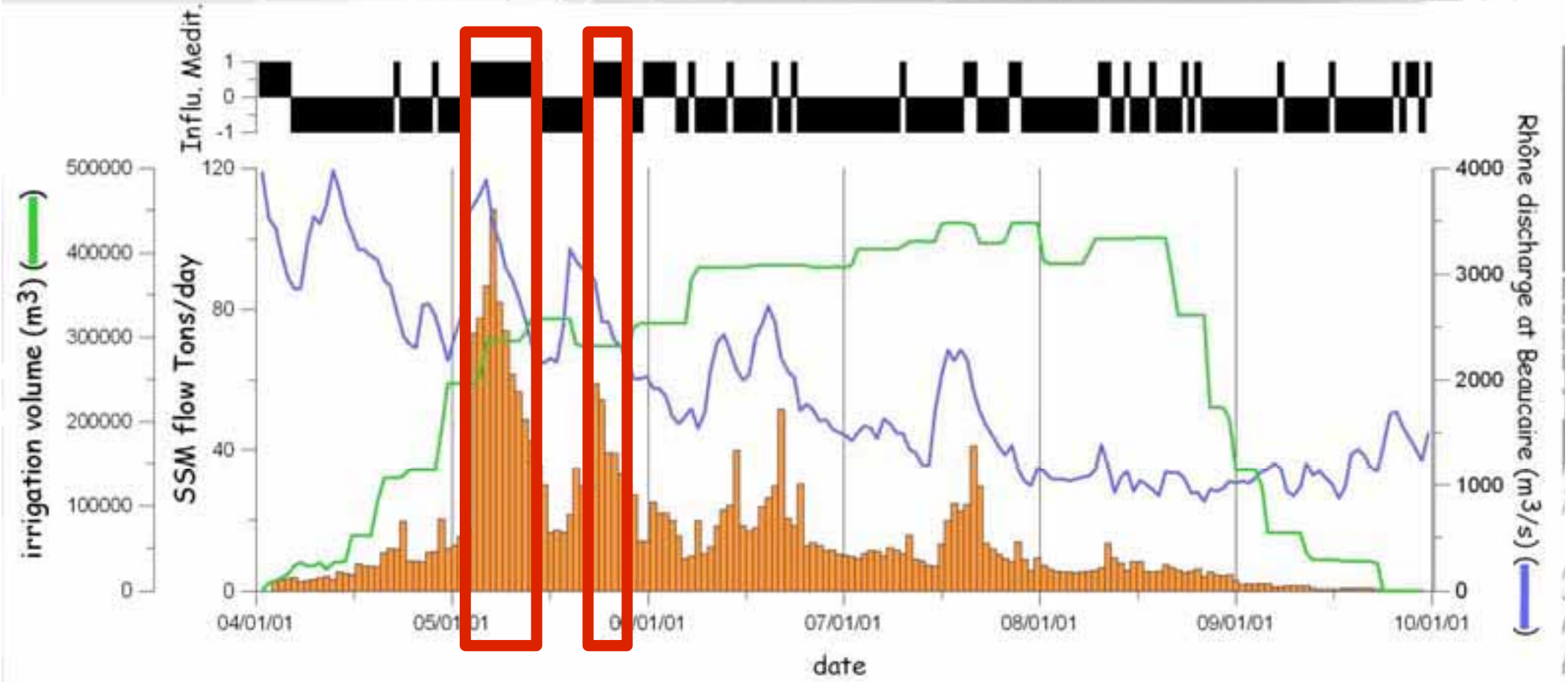


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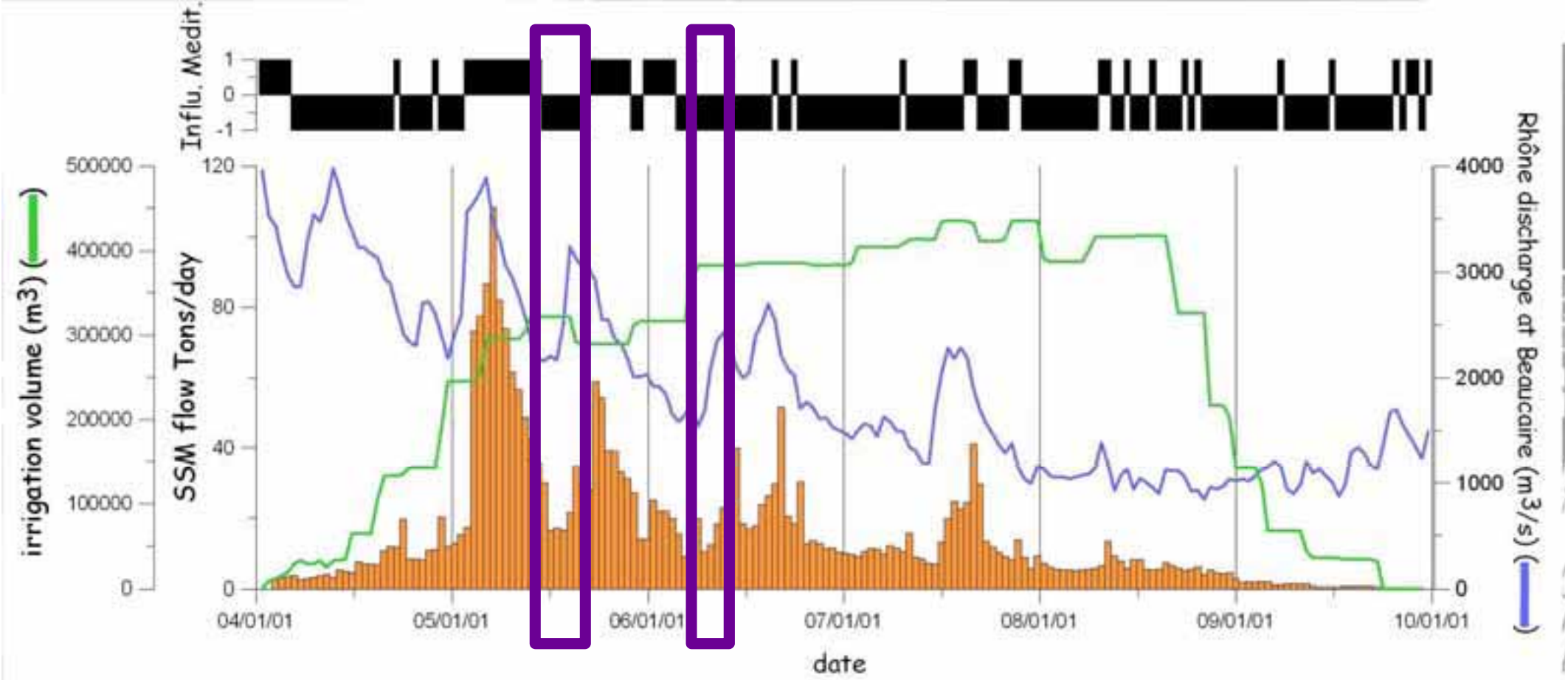


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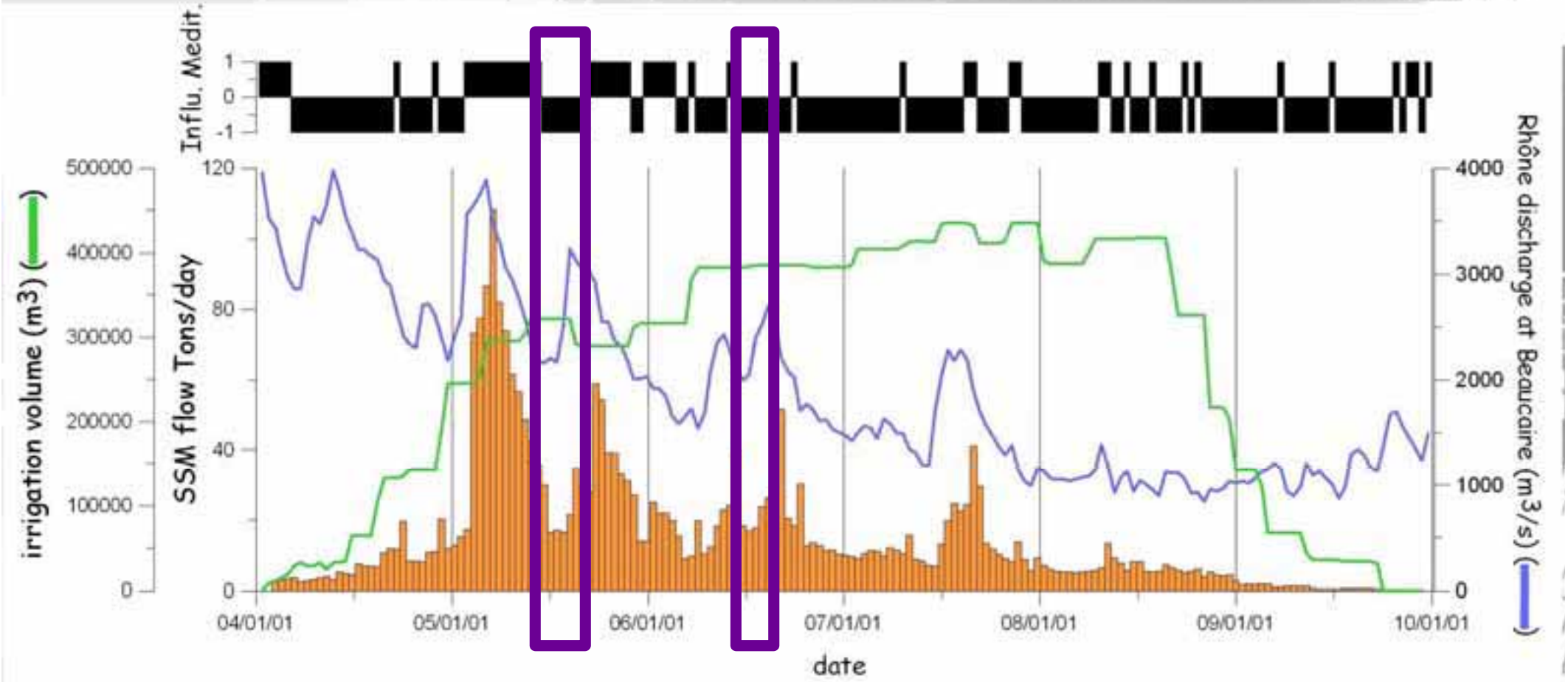



TSM contribution of the irrigation water
in the Fumemorte basin during the rice period of 2001

# TSM input due to irrigation of rice fields on the Roquemaure and Fumemorte non-polderized basins

| Years | | 2007 | 2006 | 2005 | 2004 | 2003 | 2002 | 2001 | 2000 | 1999 | 1998 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water inlet for irrigation (Million m3) | **ROQ** | 17,5 | 14,7 | 14,9 | 16,7 | 16,2 | 3,3 | 19,6 | - | 16,7 | 11,4 |
| | **FUM** | 41,5 | 39,1 | 45,9 | 40,9 | 45,7 | 45,4 | 47,9 | - | 37,7 | 39,6 |
| Mean daily discharge of the Rhône in Beaucaire ($m^3/s$) from the 1st April to the 30th Sept. | | 1437 | 1453 | 1196 | 1027 | 888 | 1210 | 1924 | - | 1789 | 1320 |
| Number of days of Mediterranean influence | | 10 | 0 | 0 | 0 | 0 | 90 | 52 | - | 68 | 68 |
| TSM input (tons) | **ROQ** | **611** | **336** | **335** | **295** | **223** | **88** | **1115** | | **976** | **334** |
| | **FUM** | **1445** | **895** | **1010** | **723** | **631** | **1205** | **2734** | **-** | **2197** | **1160** |

# Sedimentary Balance of the lagoon system

**Sediment input:**

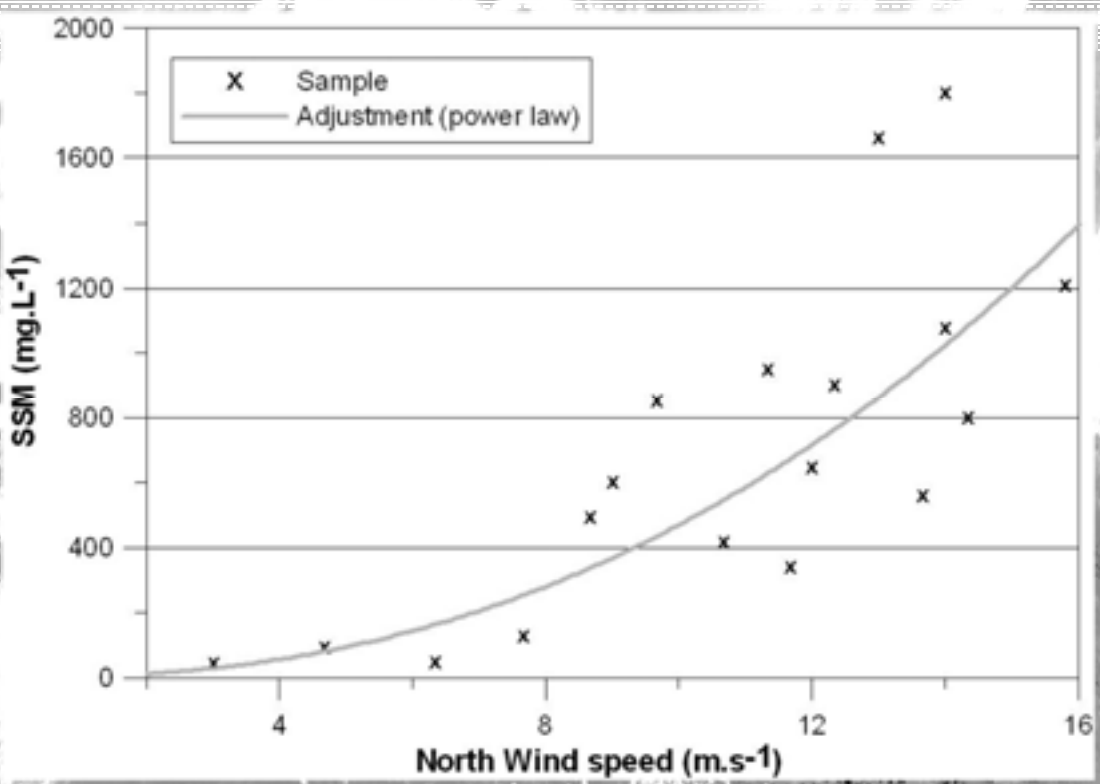
Two Relations used (for during and outside the rice growing period) between the discharge measured in the Fumemorte and the SSM rate.

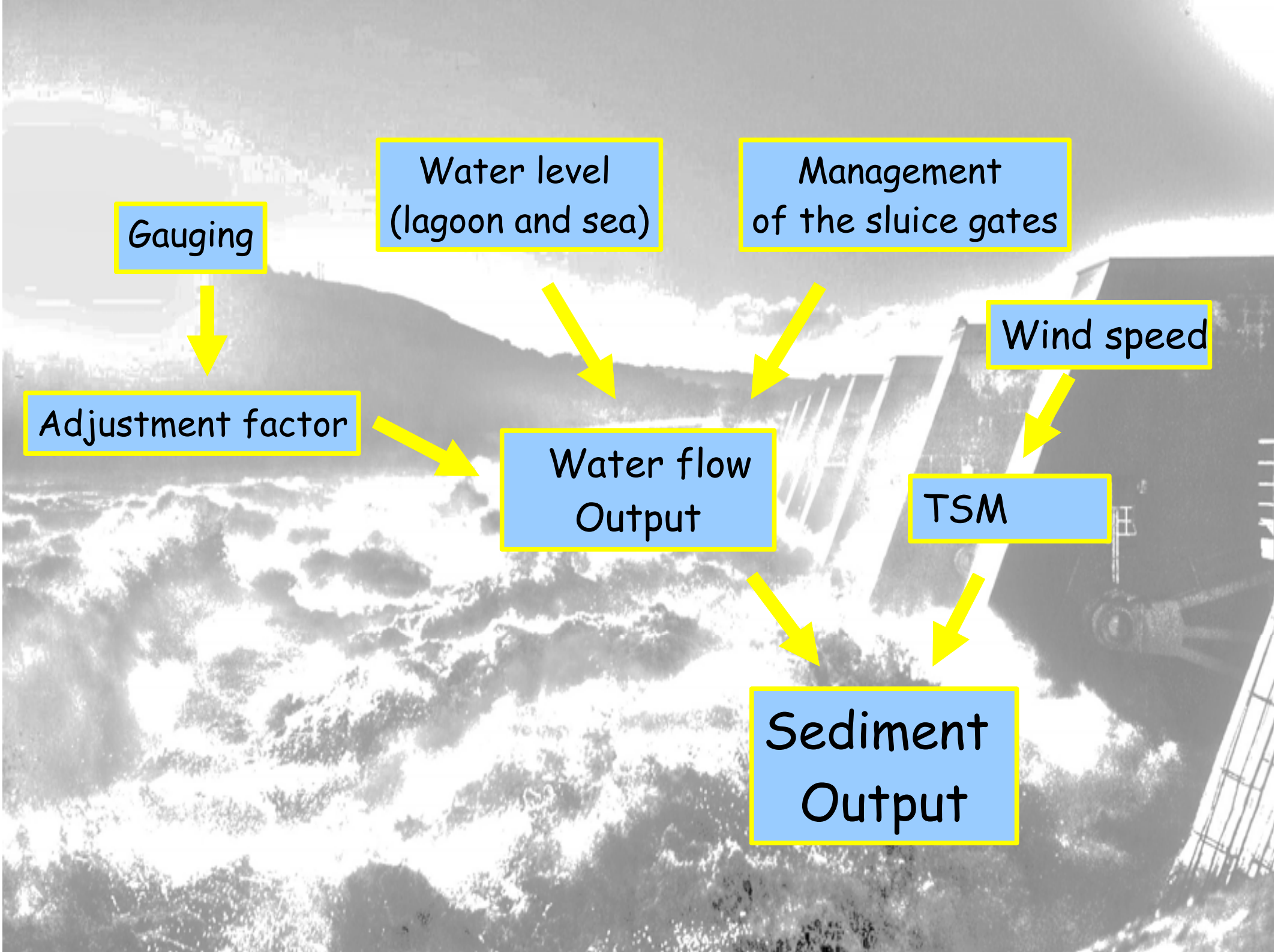
**Sediment output:**

Shallow lagoon => sediments lifted back into the water column by the wind

Water sampling at the Fourcade opening by north wind (with gates open)

=> Relation between the SSM rates of the samples and the average wind speed measured 3 hours before sampling.



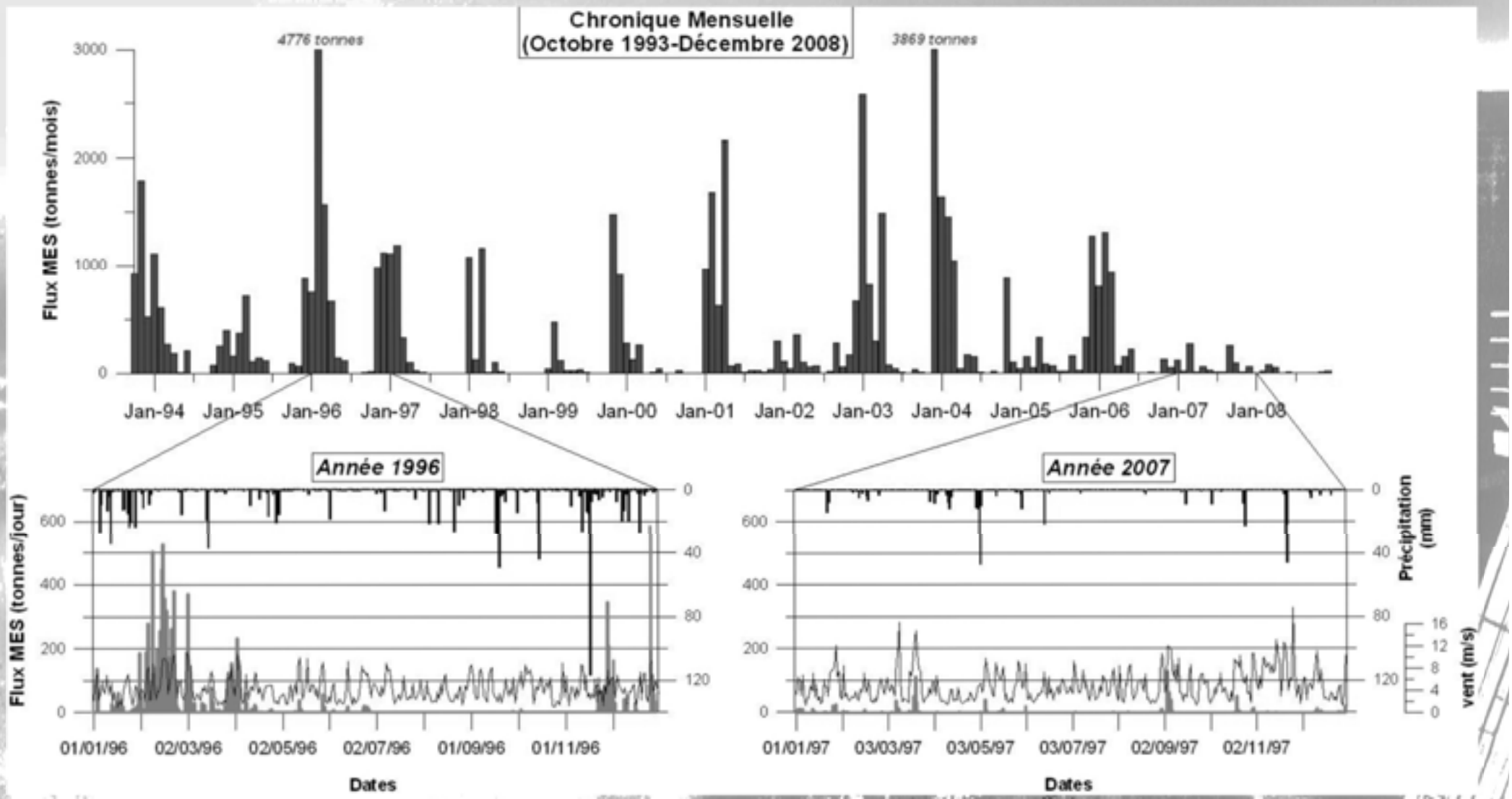

Water level
(lagoon and sea)
Management
of the sluice gates
Gauging
Wind speed
Adjustment factor
Water flow
Output
TSM
Sediment
Output

# Sedimentary Balance of the lagoon system

| Years | precipitation | North wind distance | Gate Day | Input | Entry by flood | Output | BALANCE |
|---|---|---|---|---|---|---|---|
| | *mm* | *(*10³ km)* | *Nb G./d* Nb d open* | *tons* | | | |
| 1993 | 569 | 105 | 734 | 2792 | **14500** | **7400** | **9892** |
| 1994 | 787 | 99 | 789 | 3332 | **2700** | 3108 | **2924** |
| 1995 | 772 | 64 | 513 | 3219 | - | 2623 | 597 |
| 1996 | ***1016*** | 105 | ***1192*** | 3931 | - | ***10151*** | -6220 |
| 1997 | 415 | 98 | 1034 | 2356 | - | 2735 | -379 |
| 1998 | ***464*** | 101 | 365 | 1872 | - | 2474 | -602 |
| 1999 | 595 | 101 | 629 | 2383 | - | 3165 | -782 |
| 2000 | ***509*** | 98 | ***214*** | 2289 | - | ***709*** | 1581 |
| 2001 | 542 | 110 | 474 | 2346 | - | ***5933*** | -3587 |
| 2002 | 622 | 95 | 492 | 2390 | - | 1910 | 480 |
| 2003 | 731 | 92 | 765 | 4186 | - | ***9213*** | -5027 |
| 2004 | ***473*** | 108 | ***1013*** | 2239 | - | ***5473*** | -3234 |
| 2005 | 613 | 112 | 661 | 3023 | - | 2512 | 511 |
| 2006 | 421 | 96 | 920 | 2533 | - | 3654 | -1120 |
| 2007 | ***370*** | 111 | 680 | 2725 | - | ***875*** | 1850 |
| 2008 | 603 | 94 | 356 | 3028 | - | ***145*** | 2883 |

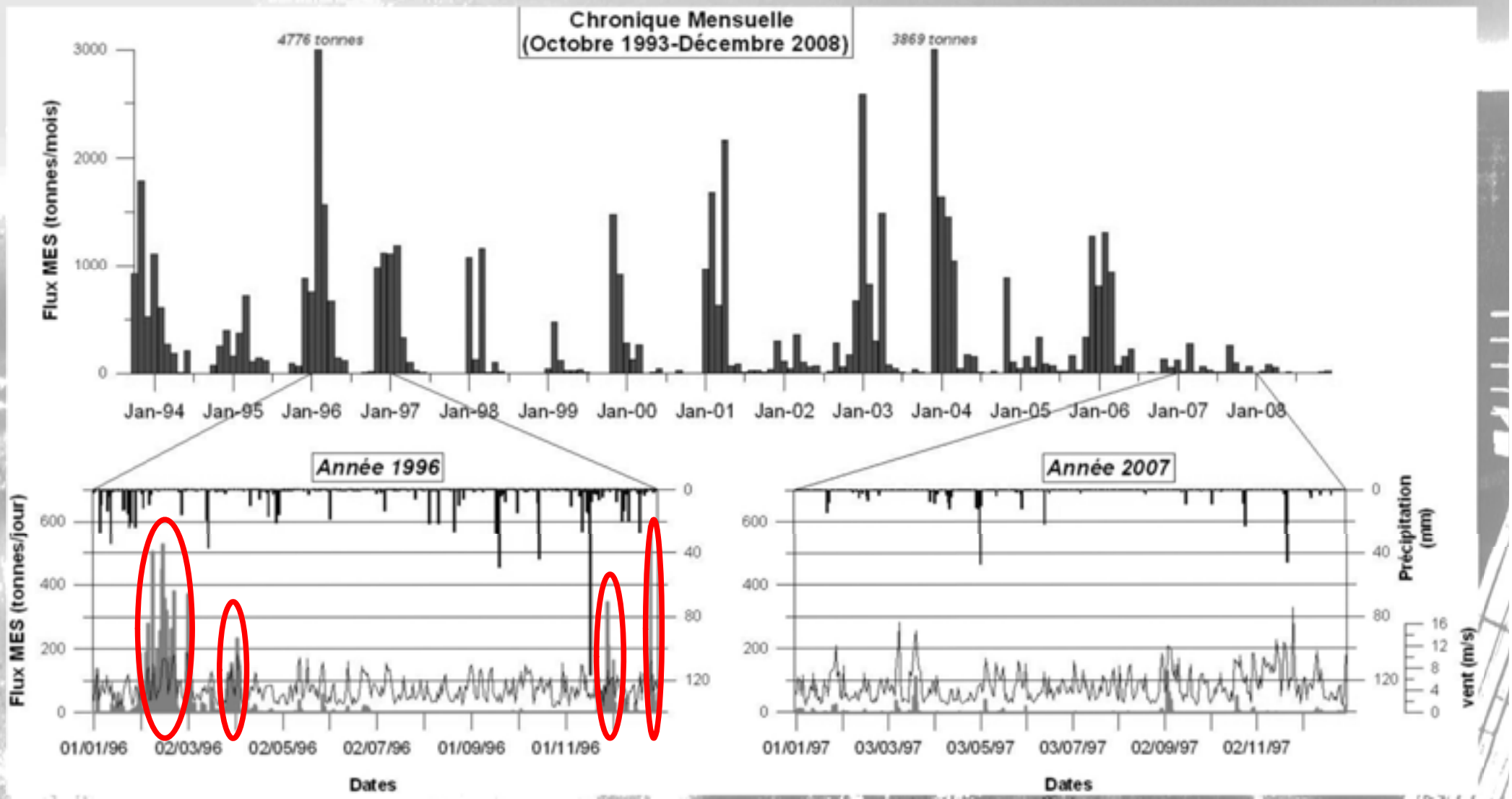
| TOTAL BALANCE | | |
|---|---|---|
| | *Without flood* | **-13049** |
| | *With flood* | **-233** |

# SSM flow towards the sea through the Fourcade opening




Impulse Character of the SSM flow

# SSM flow towards the sea through the Fourcade opening




Impulse Character of the SSM flow

# TSM flow towards the sea

- The sediment export to the Fourcade opening depends on the rainfall and on the mistral (strength and number of windy days)

- Some years inherit high water levels from the previous years (specially the winter)

- => which explains the high output even when there is an important rainfall deficit

- Large sediment deficit outside a flood => these events appear to provide a better sedimentary balance for the system

- Impulsive character of the SSM flow through the sea opening

- => reflects the preventive and reactive management (floods, salinity for ecological needs and human activities (essentially fisheries))

# What future in a context of global change?

- ***Current observations***

➔Climate change, sea level rise

➔Subsidence (compression of unconsolidated sediments of the delta)

➔Major floods of the Rhône have been more frequent since 90'S

➔Water deficit increase

➔What about Camargue rice crops in the new Common Agricultural Policy?

- ***Consequences***

➔Increased differential altitude Sea / Delta

➔Soil salinization

➔Larger and more frequent flooding

# a story of water, salt, sediment…

**What is essentially a delta, physically speaking?**

**A coastal dynamic environment where freshwater from a river with its sediments and solutes… encounter seawater**

**In a living delta… Accretion, erosion, flooding, sea intrusion are natural processes.**

**water deficit (Precip-Evap) of more than 600 mm, soil salinity: agricultural water management.**

**Endykement caused a chronical sediment deficit for the delta**

**A complex hydraulic management scheme**

**We intend not only to manage water levels and fluxes..**

**But also salt, other solutes (pollutants), fish migrations…**

**Ecosystem protection!**

**What about sediment (suspended particulate matter) management?**

# Towards new rules for Camargue hydraulic management?

Limits for present hydro saline management:

- Constraints of CC consequences: continuous sea level rise (uncertainty on amplitude and speed of this phenomenon for next decades) combined to delta subsidence.

-Increase of frequency or intensity of hydro climatic extremes (ex. : floods, droughts…),

- Uncertainty on future agricultural water input (Rice cultivation and EU CAP?..)

>>> it is impossible to manage efficiently water levels and salinity with present available tools

>> Within the framework of the “Plan Rhone”: for strong floods (>10500 m3/s) overtapping with weirs on the dykes: water volume to evacuate from Ile de Camargue (river, lagoon, sea)

Short term objectives for a better hydraulic management:

- Increase flow capacity of drainage stations on catchment

- Increase flow capacity of outlets to/from the sea

- Introduce directly (and gravitally) water from the river to the lagoons

->>>>> and modified water governance (Water commissions of PNRC…)

On the longer term :

- Adaptation of dyke management: lower second rank dykes around settlements
- What about the sea wall?

-Re initiate partially a more natural deltaic functionning:

**->>> river floods should also be considered as a mean for sediment management that need the delta!**

- We should be able to input flood water with sediments on the North of the endyked delta …

But it is on the South delta that they are most necessary!

Sedimentation may reduce the lagoon storage capacity… And contribute, together with salinity variations, to modify the ecosystem.

**No easy solutions… Compromises, compensation mesures and adaptative management are required.**

**Many debates to come, scientific information to contribute directly.**

**We need to increase our understanding and modelling capabilities of the hydro system functionning through inter disciplinary research (socio-economy, geomorphology).**

# Thank you for your attention...


THANKS

This study received financial support:

-from MEEDDAT through the project IMPLIT, program GICC 2;

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