2nd Learning Workshop for GEF MENARID Project Managers

Amman, December 11-14, 2012

Opportunities for Managed Aquifer Recharge

MAR techniques and examples successfully applied in light of climate change adaptation: Case study in Morocco

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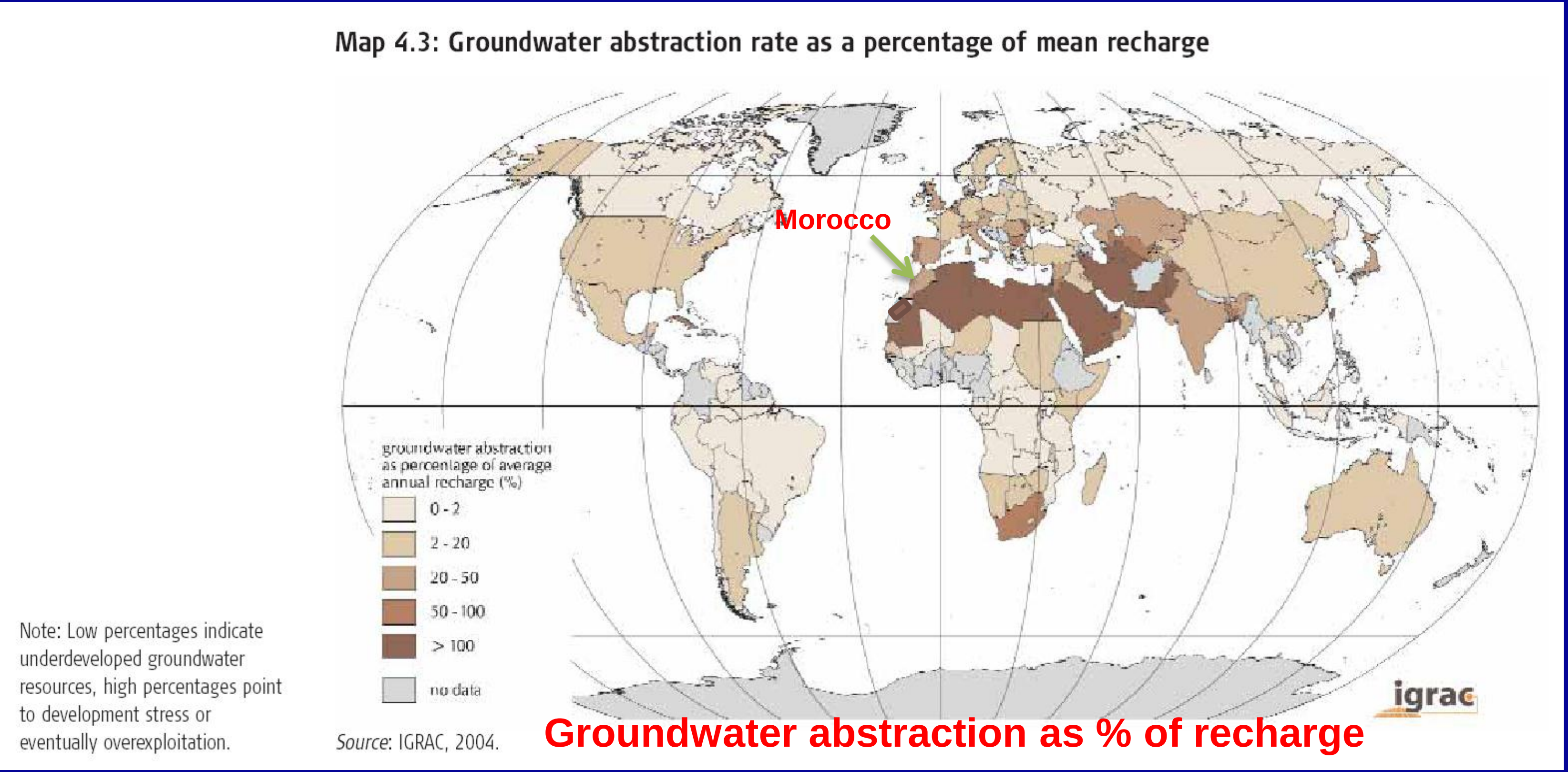
Outline of presentation

1. **Overview on water resources in Morocco**
2. **Recharge: Case of 2 overexploited aquifers in Morocco**

Work research is carried out within several projects and collaborations: IAEA, ABH, CNRS, UNESCO, NATO….

USE AND AVAILABILITY

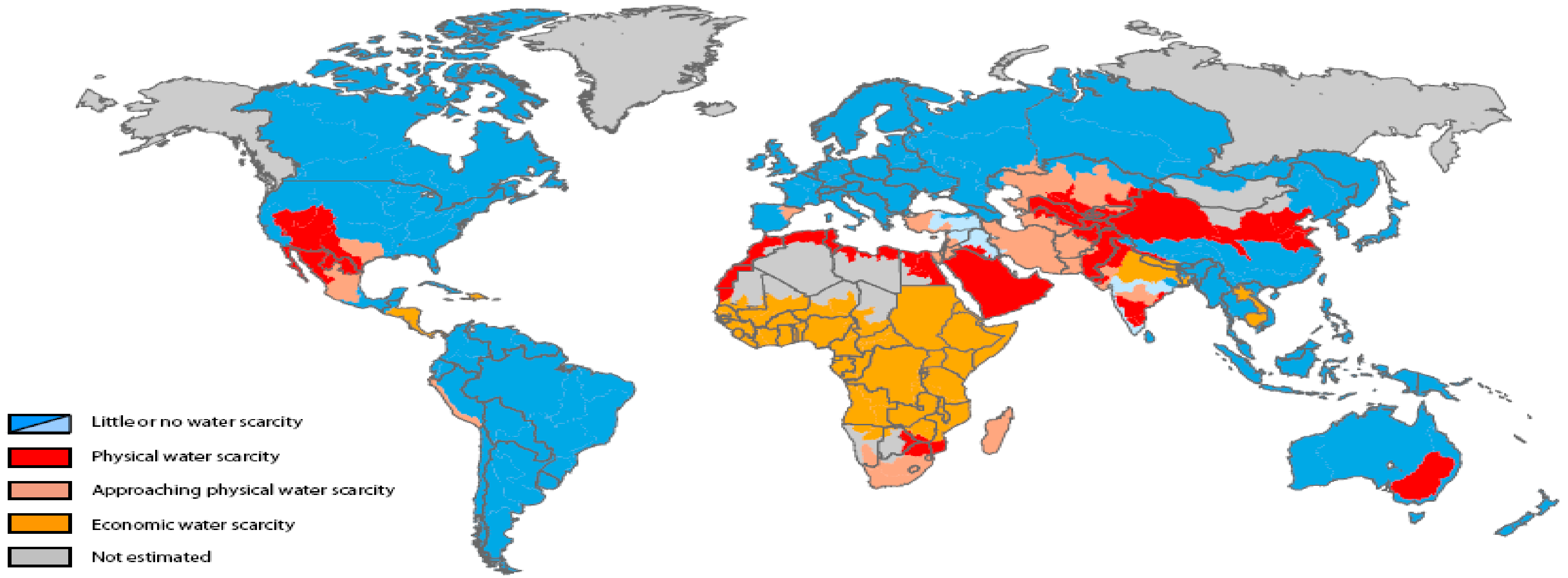


Constraints:

- **Unequal distribution (space and time)**
- **Geology: hard rock (low yields) and great depth (high cost)**

USE AND SCARCITY

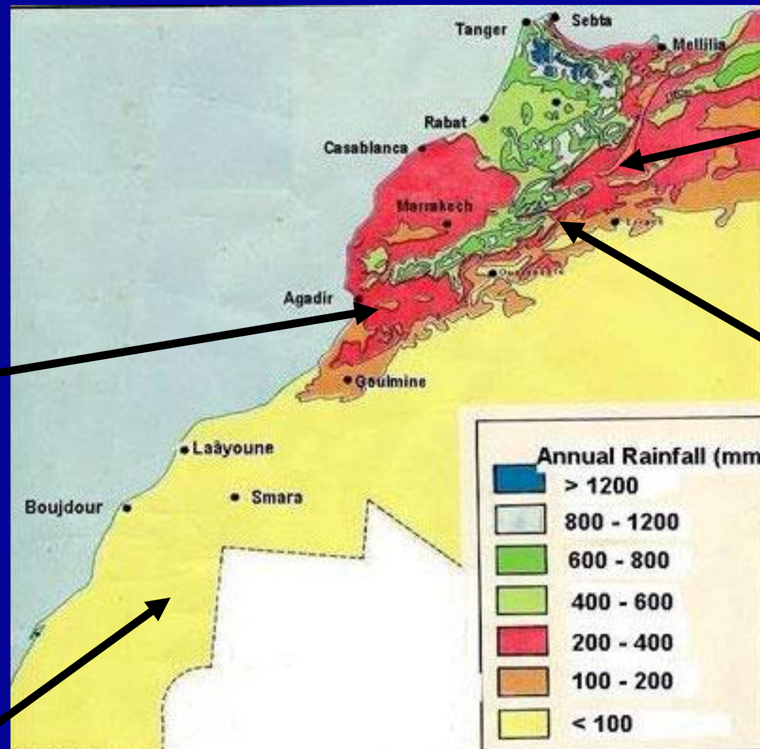
Map 2. Areas of physical and economic water scarcity



Red:	Physical Water Scarcity. More than 75% of the river flows are allocated to agriculture, industries or domestic purposes (accounting for recycling of return flows). This definition of scarcity—relating water availability to water demand—implies that dry areas are not necessarily water-scarce. For example, Mauritania is dry but not physically water-scarce because demand is low.
Light Red:	More than 60% of river flows are allocated. These basins will experience physical water scarcity in the near future.
Orange:	Economic Water Scarcity. Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exists. These areas could benefit by development of additional blue and green water, but human and financial capacity are limiting.
Blue:	Abundant water resources relative to use: less than 25% of water from rivers is withdrawn for human purposes.

GWMATE

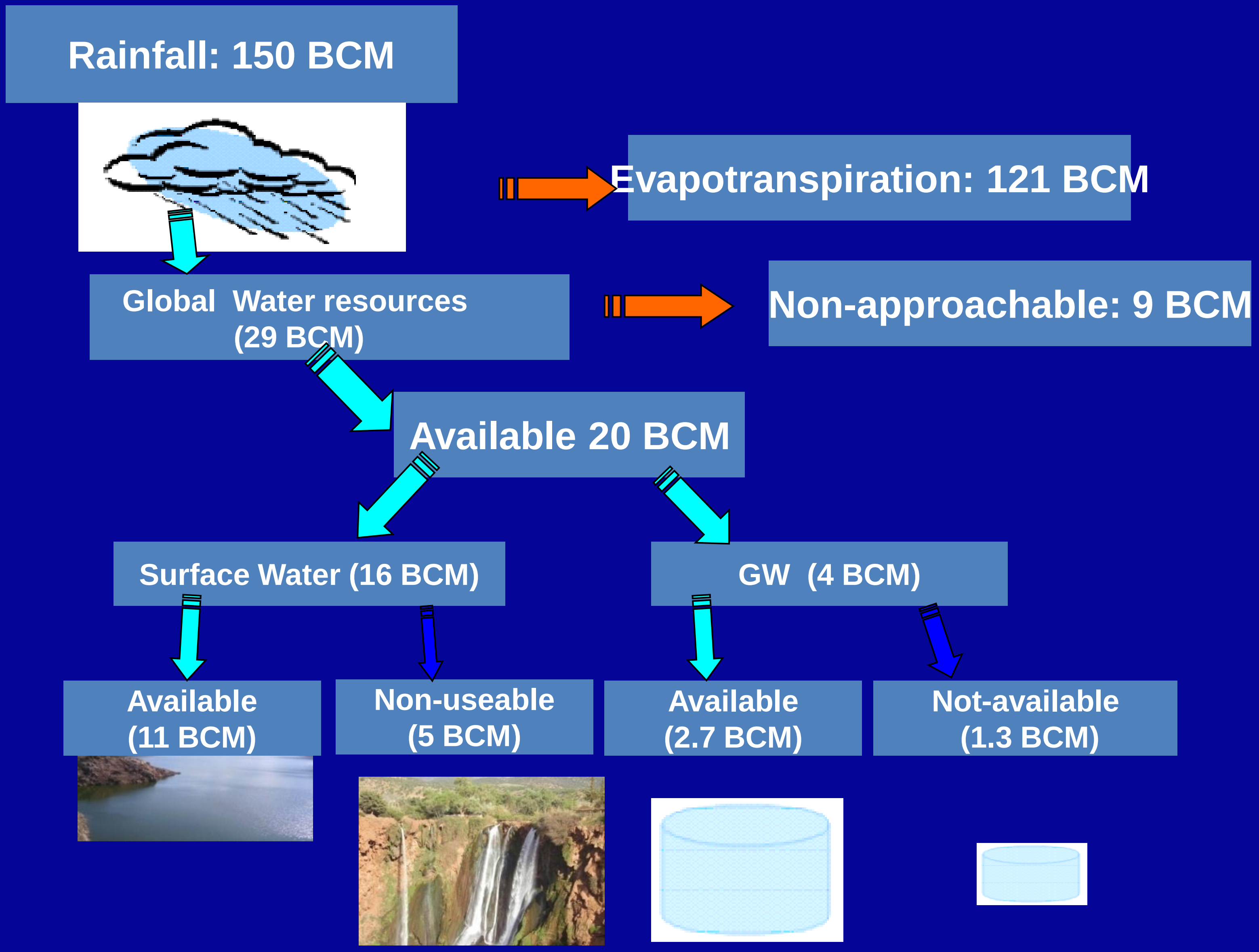
Water crisis in Morocco: low precipitation and overexploitation



Climate change models

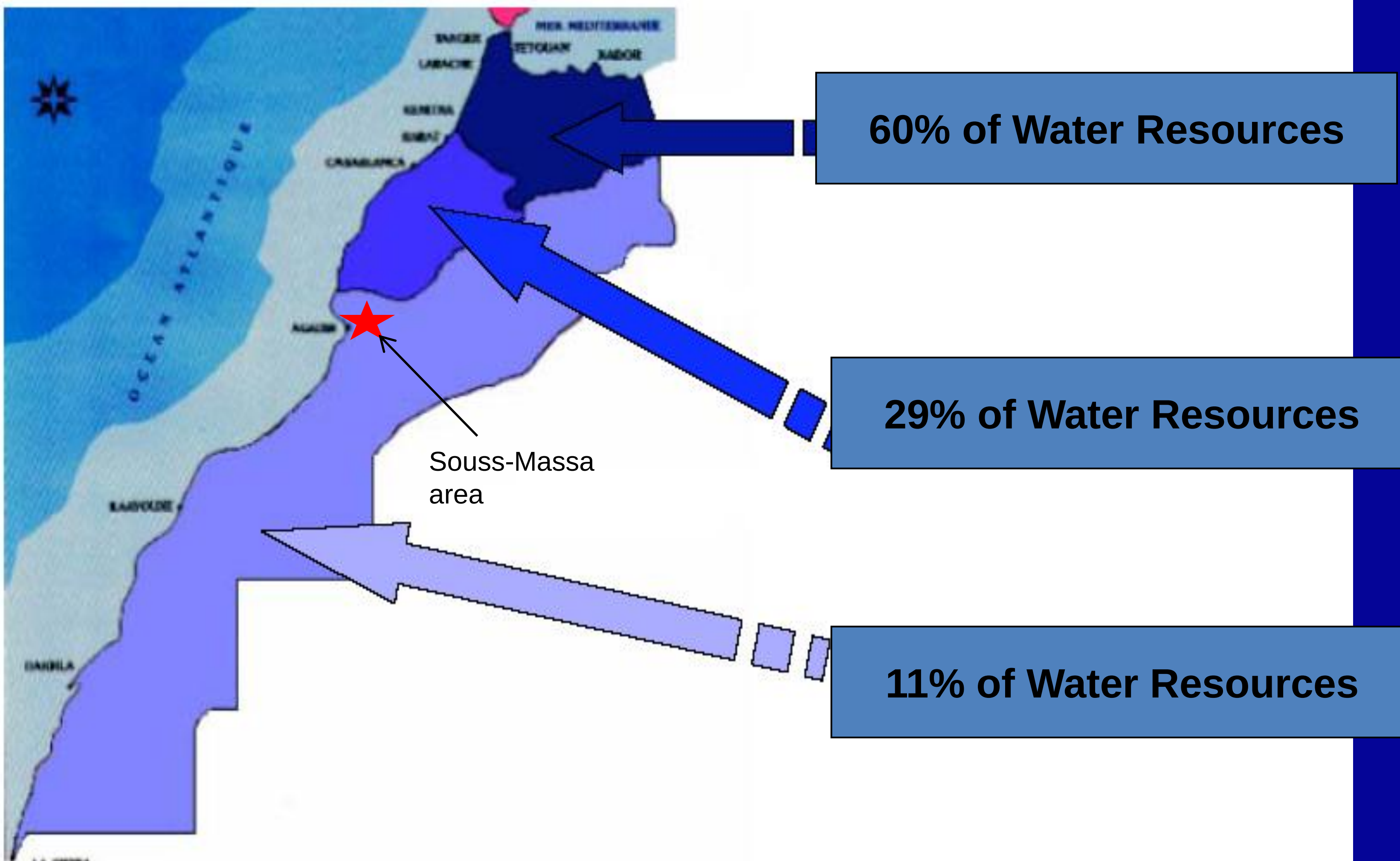
⇩

intensification of recurrences of droughts

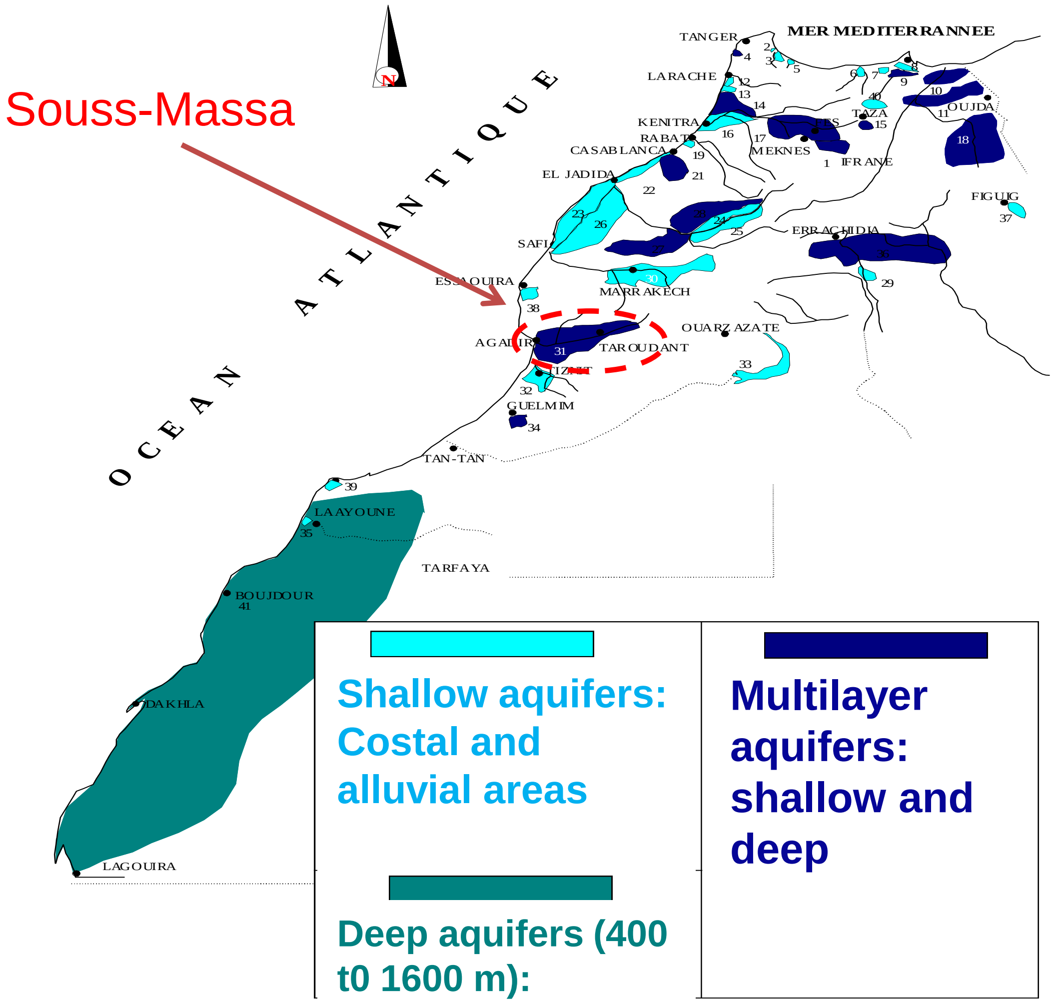


90 to 96 % are allocated to irrigation

Geographical distribution of water resources in Morocco



Main aquifers in Morocco



About 80 aquifers

- 48 unconfined
- 32 depth or confined

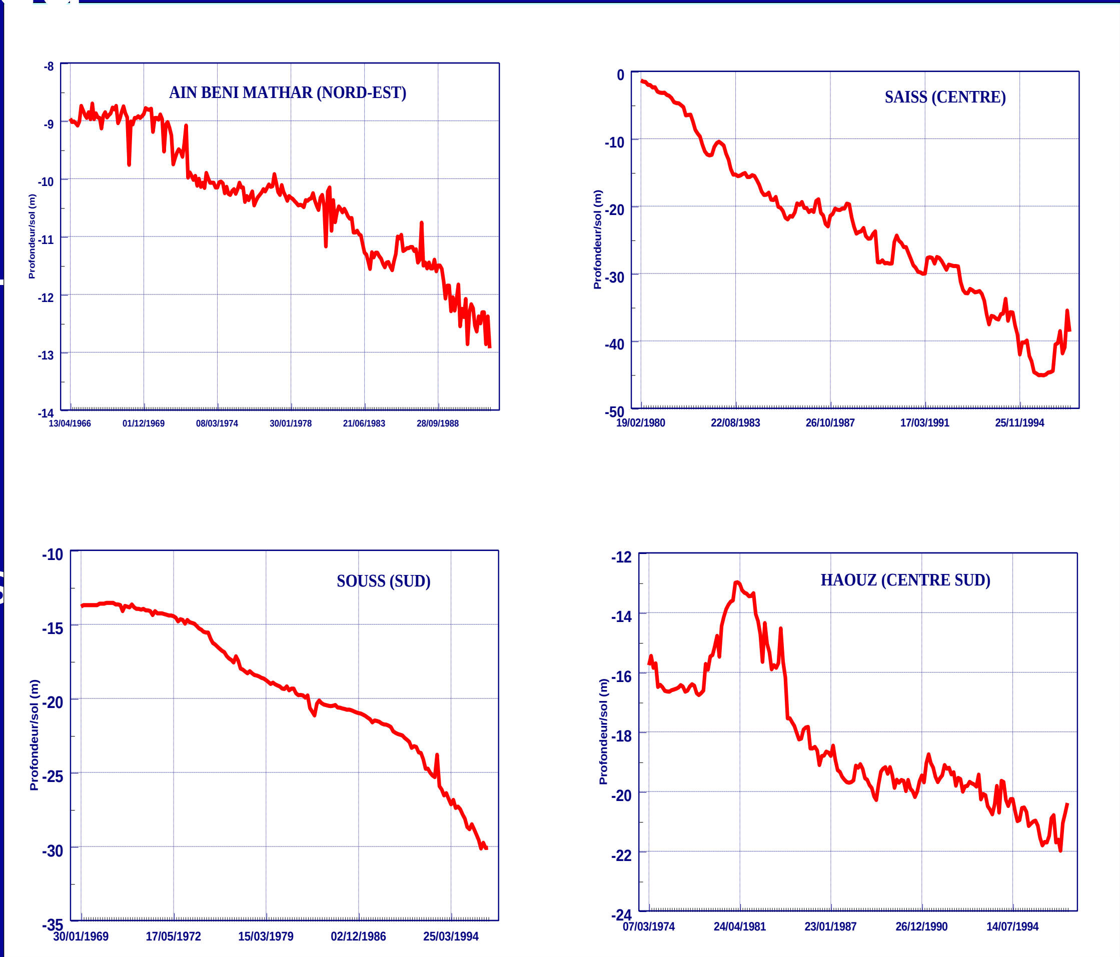
Potential limited

- 1960 : 2560 m3/capita./y
- Currently : 720 m3/capita./y
- 2020 : 520 m3/capita./an

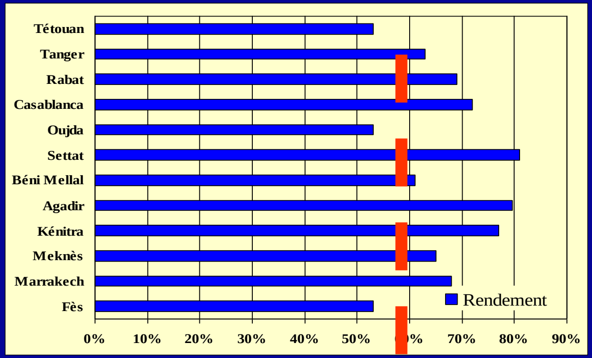
Potential highly stressed

Alarming decline in most aquifers: 40m in Souss-Massa-Souss, 30m in Haouz, 60m in Saïss et 40m in Aïn Béni Mathar

Depletion of some aquifers

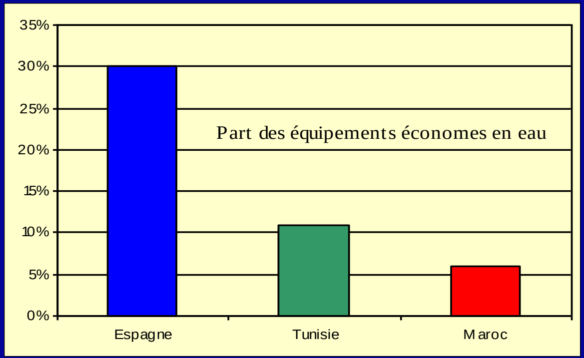


Potential undervalued



✓Inefficient use

- Most urban centers have a yield network less than 70%
- Performance of the irrigation network in the order of 80%
- loss of water on the irrigated parcel (40%)



✓ Pricing

- Does not take into account the cost of raising

✓Poor economic performance of projects

- Area of 119 000 ha dominated by dams and not yet equipped, low agricultural demand satisfaction (64%), hydroelectric power less than 50% of the objective.

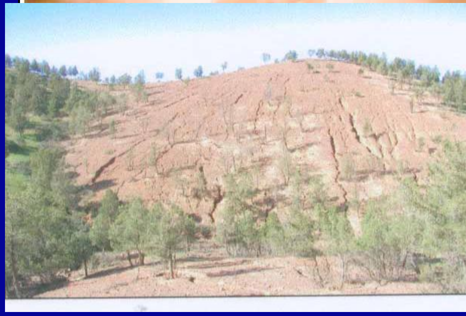
Potential threatened :

• **Salinization of groundwater in coastal and inland aquifers;**
• **Nitrate and Pesticide contamination;**
•**Waste water pollution**
•**Siltation:** Loss of storage capacity due to silting of 70 Mm3/year

AQUIFER DEGRADATION
the root causes

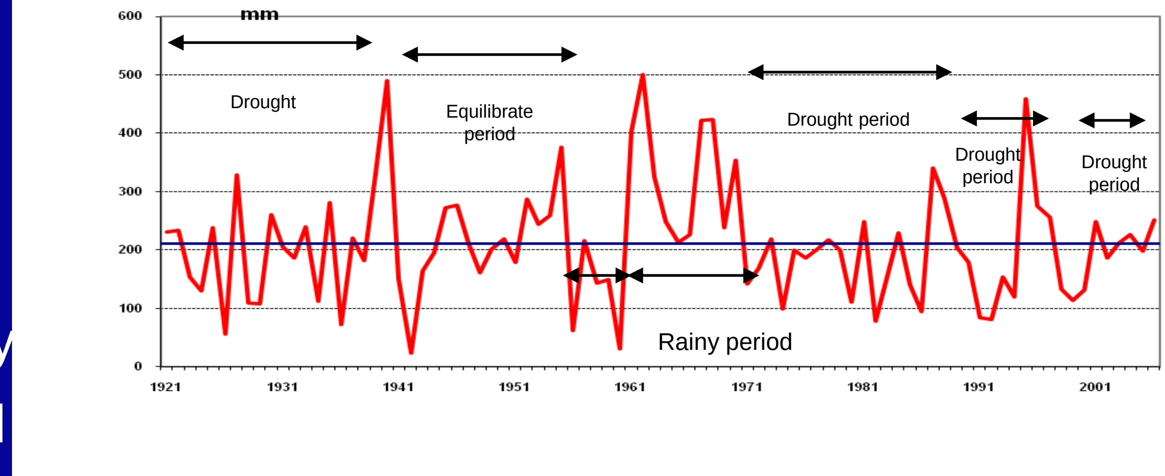
- ***resource governance*** **has not kept pace with** ***resource development*** **(government agencies have focused more on** ***development*** **than** ***management*****)**

- **low public and political awareness :**
  - **many still regard groundwater as an** ***unlimited*** **and** ***uncoupled*** **resource**
  - **lack of appreciation of critical linkages with 'surface environment' and land-use practices**



✓ Climate change:

➔ Frequent droughts



- Since 1950, more than forty drought periods were recorded
- Ten very dry periods generalized to the whole country (rainfall deficits sometimes exceeds 60%)

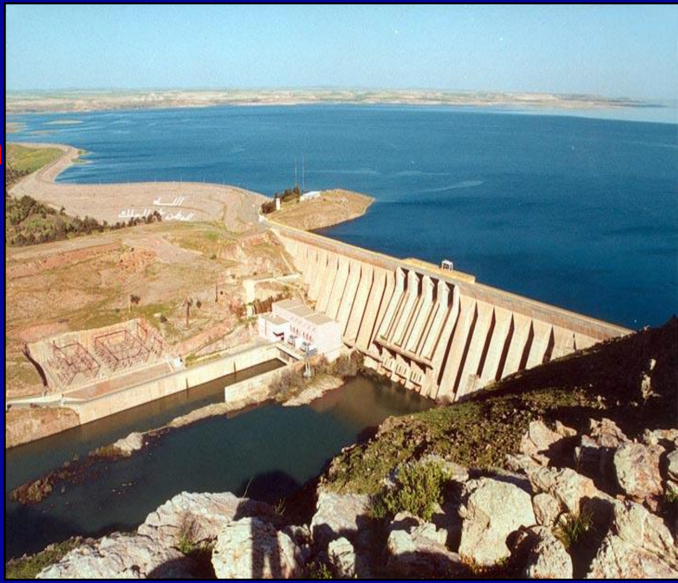
➔ Frequent flooding

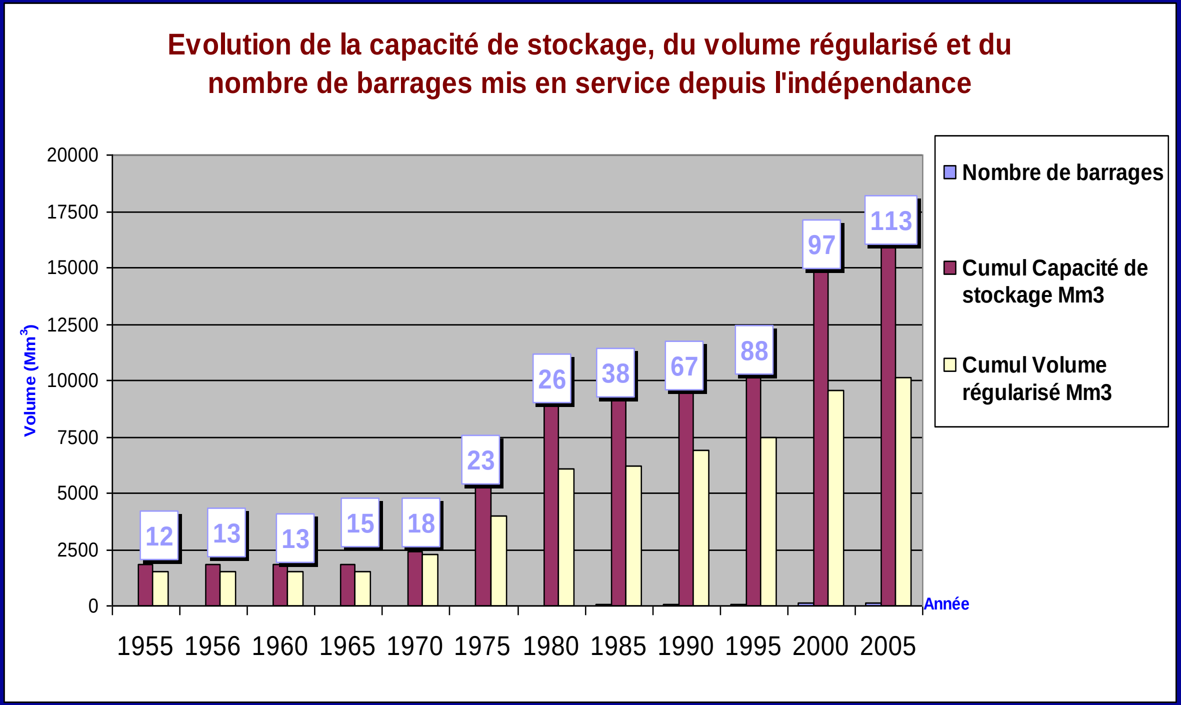
- Severe flooding in urban and rural with human and material damage

ACHIEVEMENTS

Mobilization Infrastructure

- 115 big dams with a total capacity of 16 billion m^3
- 13 water transfer systems: 1100 km with 210 m3/s
- Extensive network of wells and pumping





STRATEGY WATER RESOURCES DEVELOPMENT

- **Continued efforts to mobilize**
  - Continued mobilization of surface water
  - Examination of the transferability
  - Further research and mobilization of groundwater (deep aquifers)
  - **Development of artificial recharge of groundwater**
  - Mobilization of non-conventional water resources

- **Economy and Water Efficiency**
  - Conversion techniques and means of irrigation,
  - Reduction delay of hydro-agricultural equipment,
  - Adoption of a new rate.

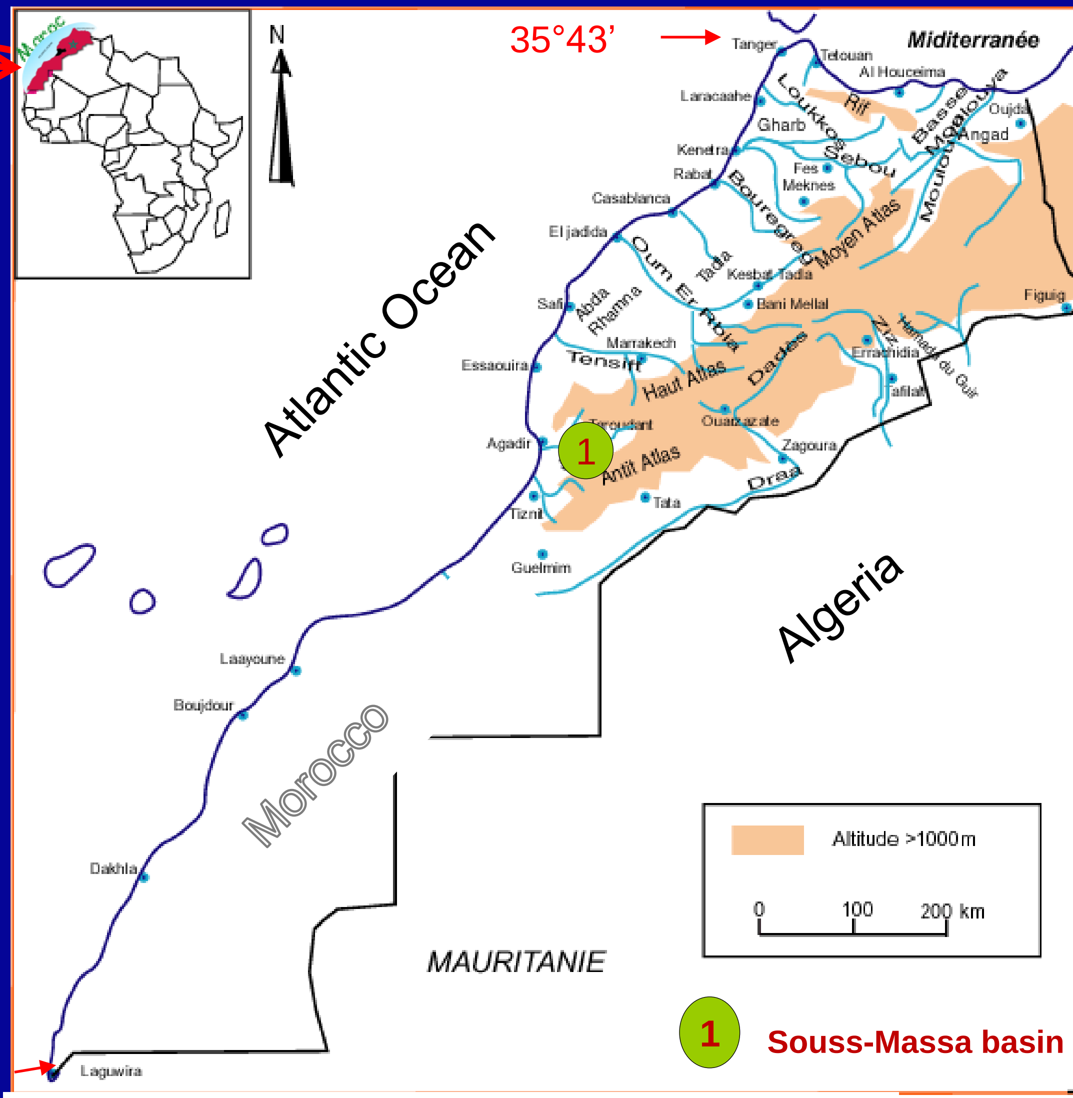
- **Sanitation and wastewater reuse**

- **Safeguard groundwater**
  - Contracts with groundwater users,
  - Strengthening of control: Police water

- **Protection against flooding**

Case of Souss-Massa aquifer

- **Climate:** Arid to semi arid , influenced by Mountains, Ocean and Sahara
- **Precipitations :**
  - ✓ 30 days/year;
  - ✓ 300 to 600 mm in High Atlas Mountains
  - ✓ 200 mm in Souss plain
  - ✓ 120 to150 mm in southern parts.
- **Snow in High and Anti-Atlas Mountains**
- **Evaporation : 2000 to 3000 mm/year**



21°56'

Geographical context of Morocco

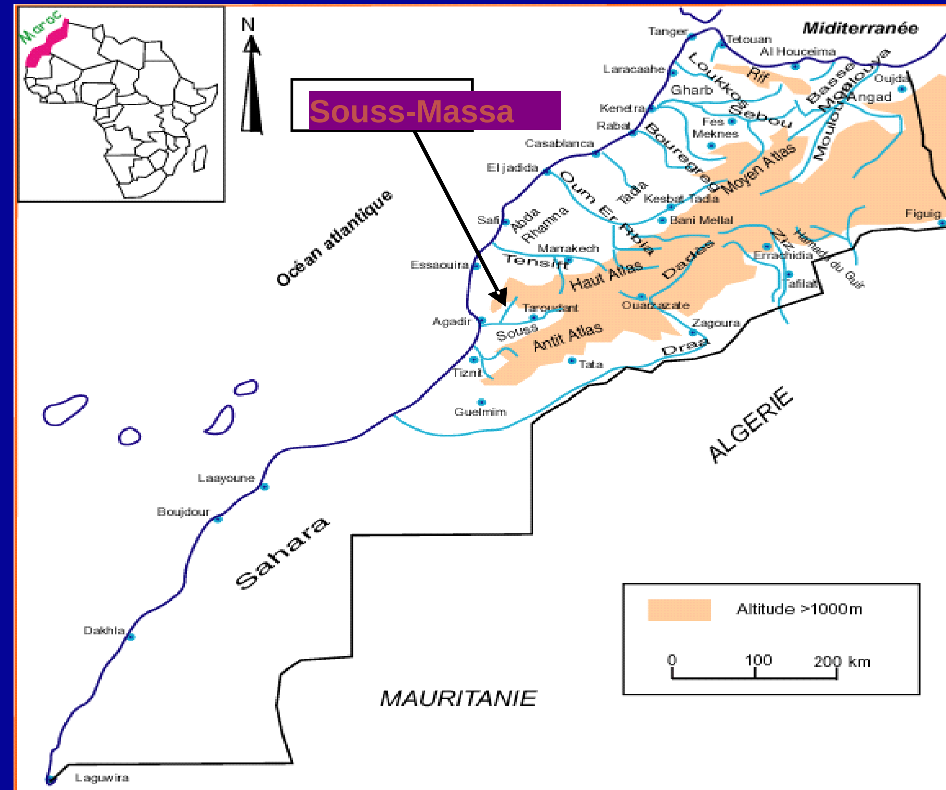
Souss-Massa

Important economic pole in Morocco.

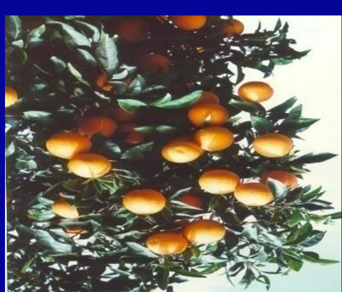
Agriculture, Tourism and Maritime fishing;

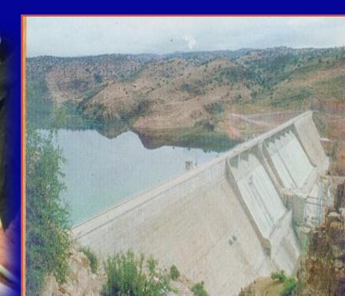
Approximately 94 % of water resources is used for irrigation;

variable water quality, high salinity exceeding 4 $g.l^{-1}$ in costal area

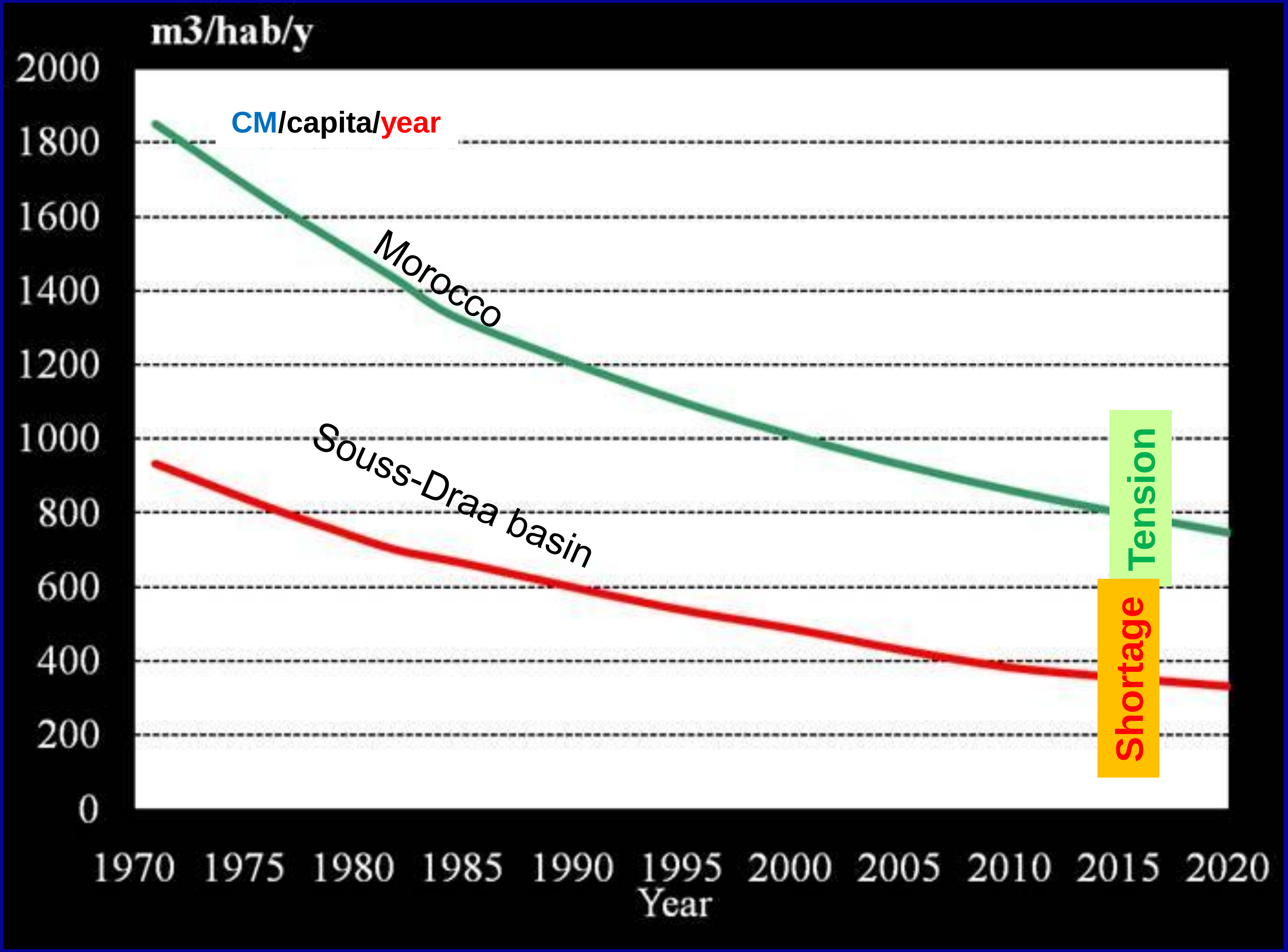


Studied area





Limited water potentiel



PROBLEMATIC

Decreasing level and Quality of groundwater (and soils) : Increasing problem, particularly in semi-arid and arid areas

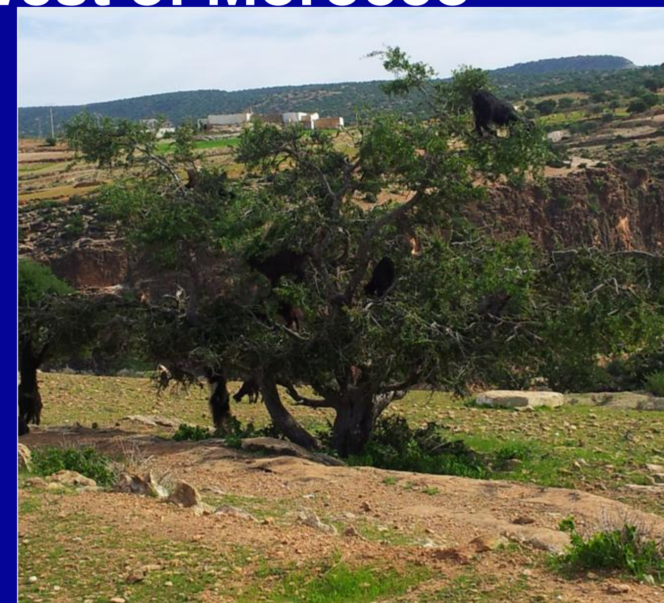
?

Recharge-outflow = deficit

- ☞ **Origin of water (recharge areas)**
- ☞ **Origins of Mineralization**
- ☞**Residence Mean Time (RMT) of water= water resources renewal**

Case of Souss-Massa aquifer

nvestigation of recharge, salinization, and residence time of water in the Souss-Massa aquifer, Southwest of Morocco



Geochemical tracers:
major and traces ions
isotopes : ^{18}O, ^{2}H, ^{13}C, ^{14}C, $^{87/86}Sr$, ^{11}B…

Journal of Hydrology (2008) 352, 267–287

available at www.sciencedirect.com

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JOURNAL OF HYDROLOGY

Application of multiple isotopic and geochemical tracers for investigation of recharge, salinization, and residence time of water in the Souss—Massa aquifer, southwest of Morocco

L. Bouchaou [a,*], J.L. Michelot [b], A. Vengosh [c], Y. Hsissou [a], M. Qurtobi [d], C.B. Gaye [e,1], T.D. Bullen [f], G.M. Zuppi [g]

Journal of Hydrology 438–439 (2012) 97–111

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Journal of Hydrology

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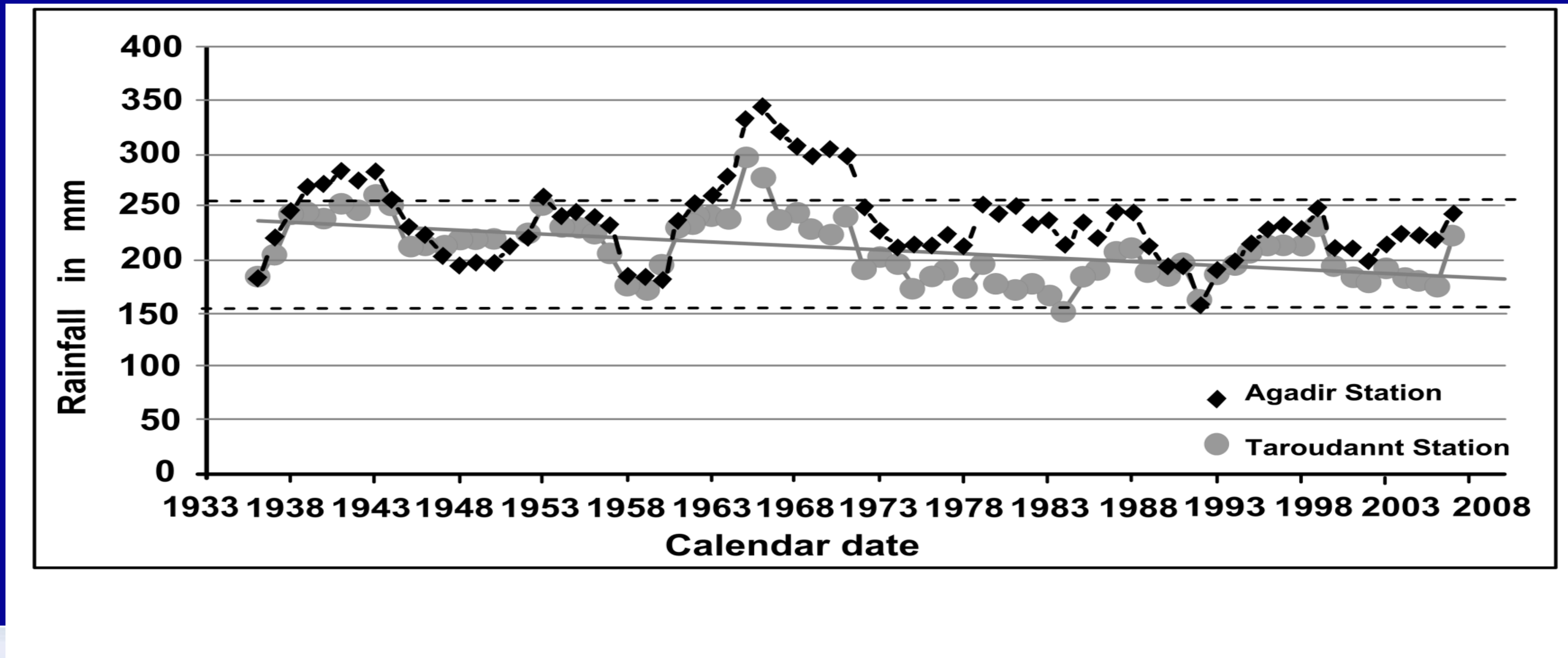
JOURNAL OF HYDROLOGY

Geochemical and isotopic (oxygen, hydrogen, carbon, strontium) constraints for the origin, salinity, and residence time of groundwater from a carbonate aquifer in the Western Anti-Atlas Mountains, Morocco

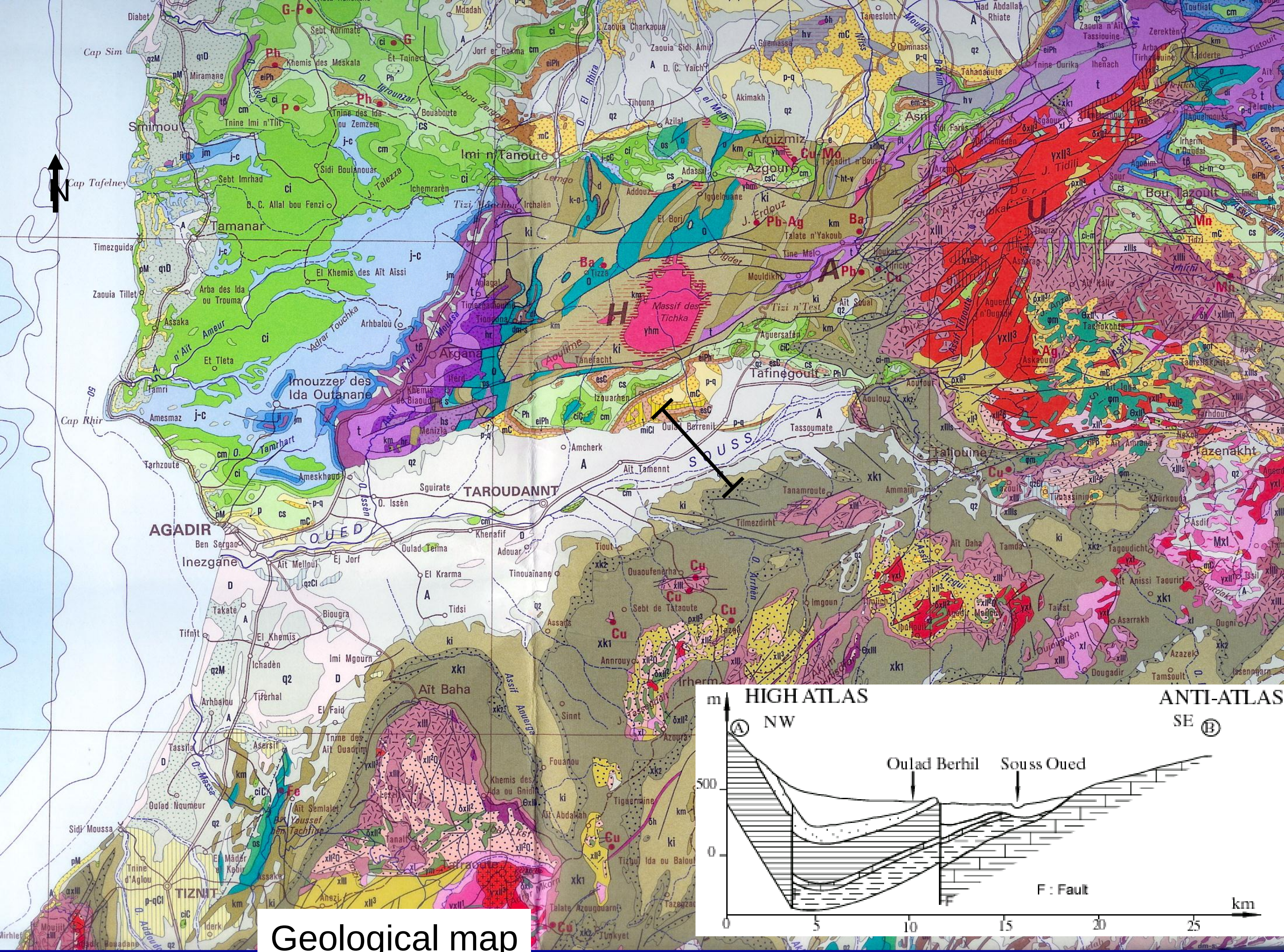
N. Ettayfi [a], L. Bouchaou [a,*], J.L. Michelot [b], T. Tagma [a], N. Warner [c], S. Boutaleb [a], M. Massault [b], Z. Lgourna [a], A. Vengosh [c]

[a] Applied Geology and Geo-Environment Laboratory, Ibn Zohr University, Agadir, Morocco



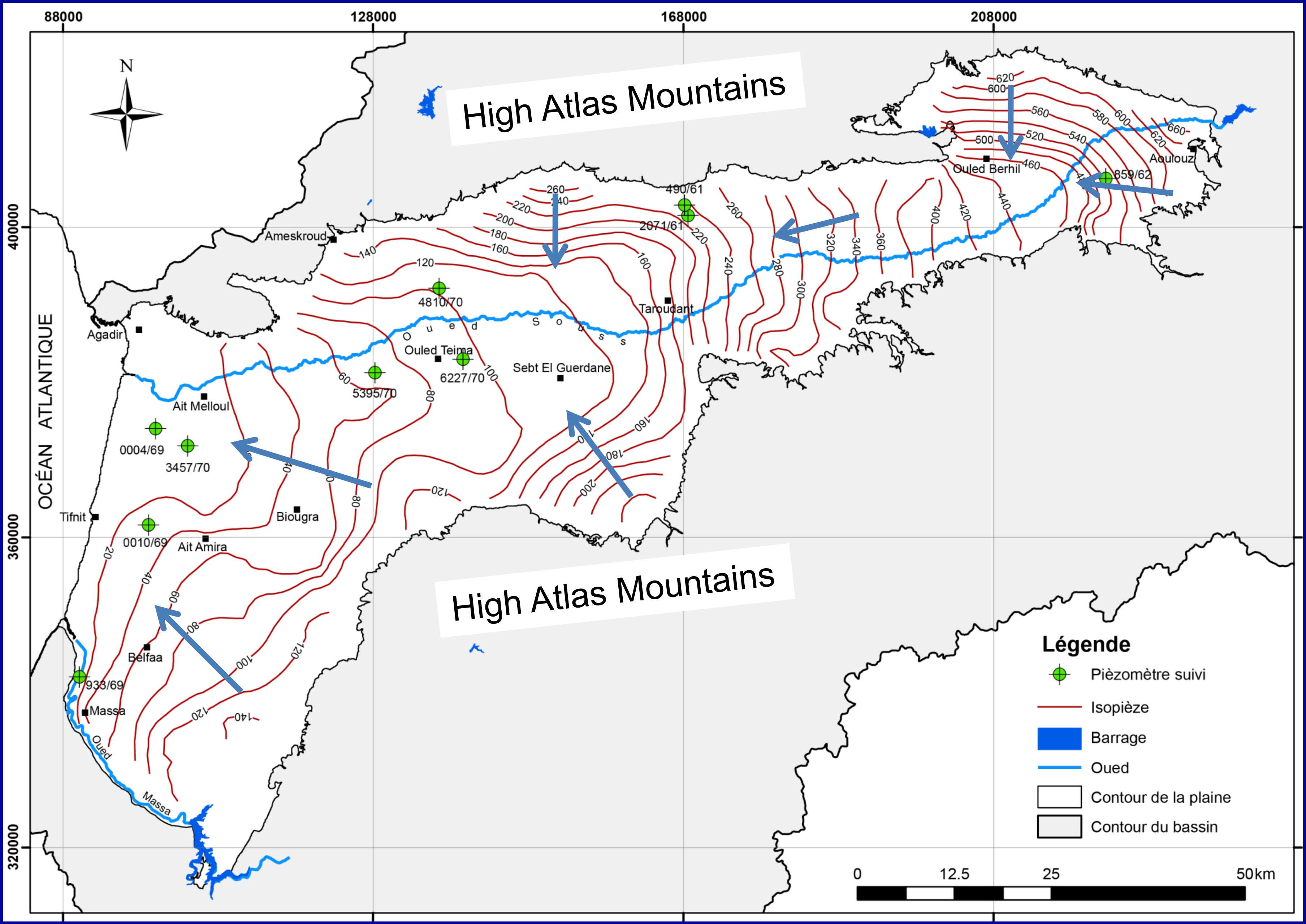
- Low and irregular rainfall
- Unequal repartition in time
- Long and frequent drought periods

Bouhaou et al., IAH series, 2012

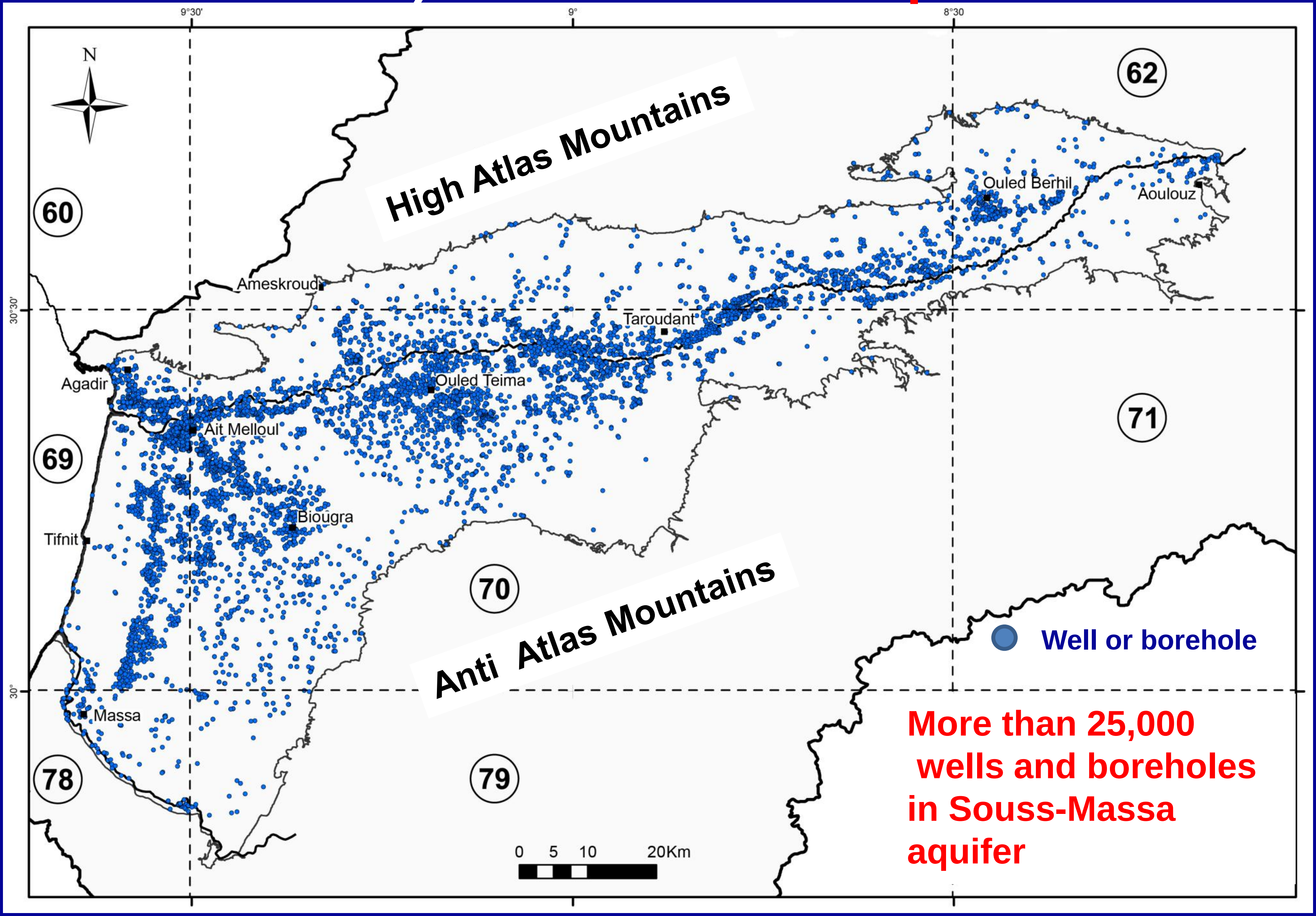


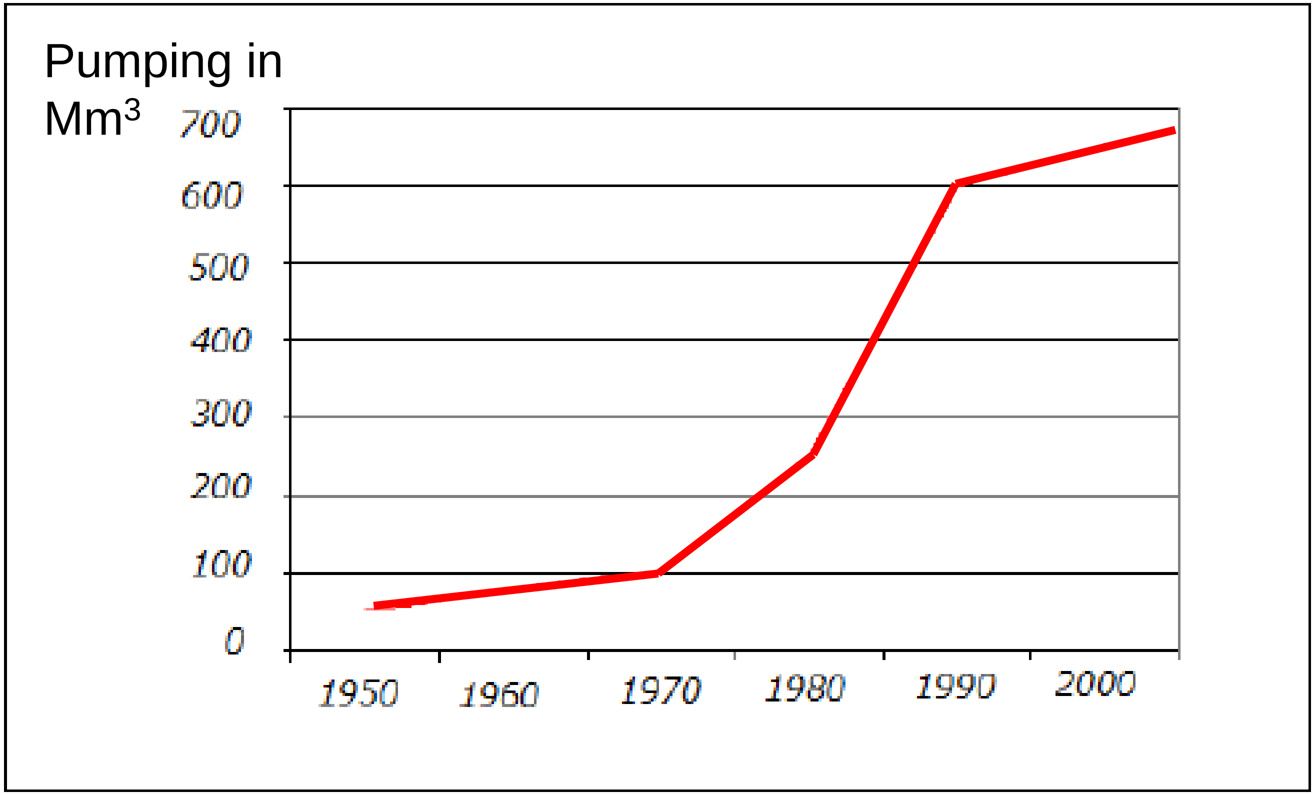
Geological map

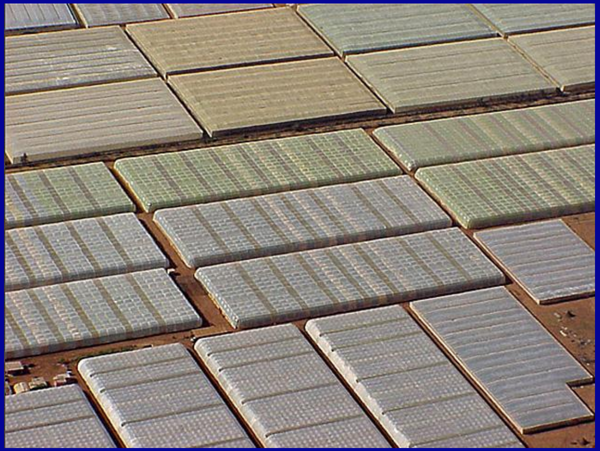
GW flow direction



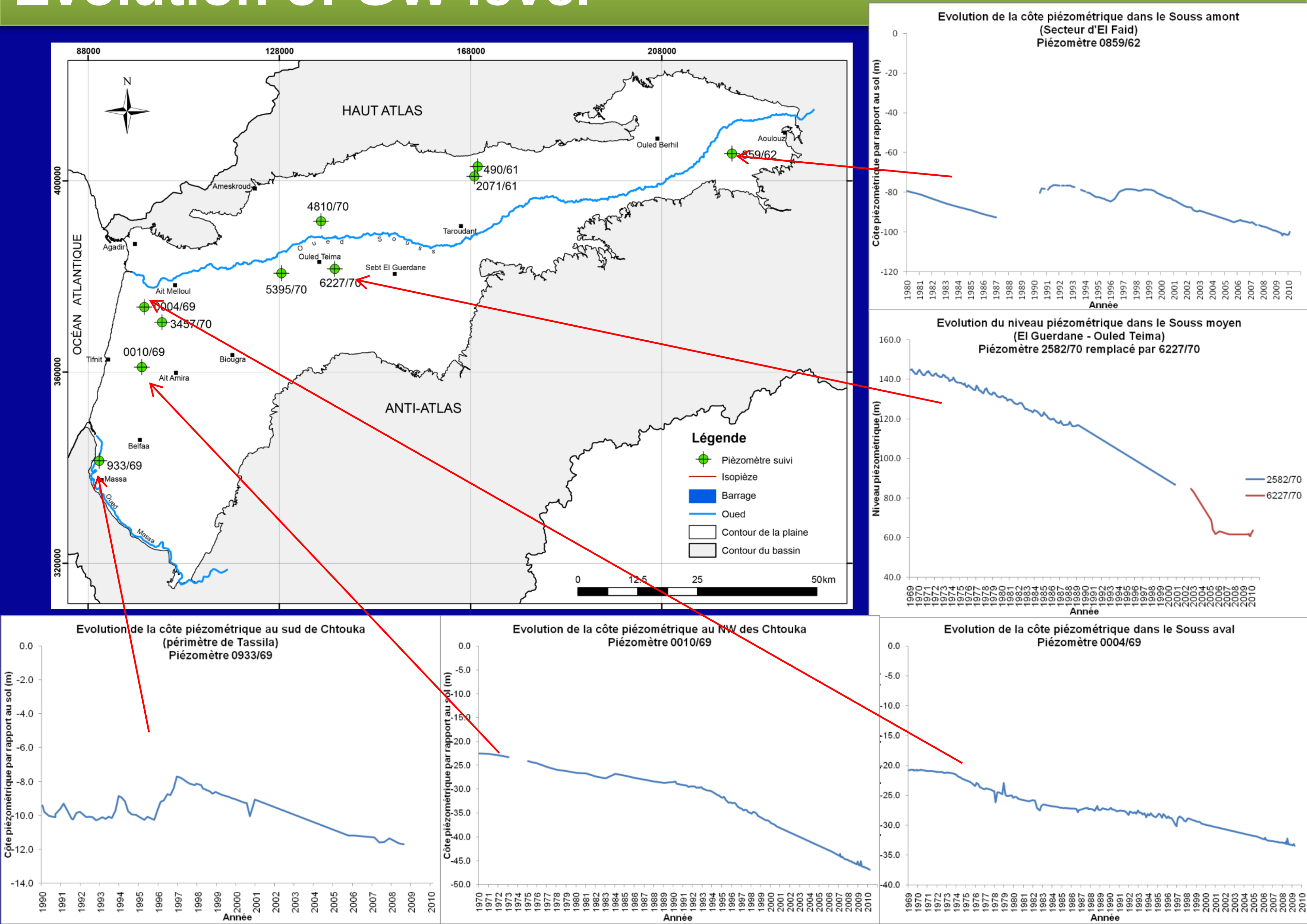
Souss-Massa aquifer (main one in southern part of Morocco) = an Intensive exploitation




Pumping in Mm³
700
600
500
400
300
200
100
0
1950
1960
1970
1980
1990
2000



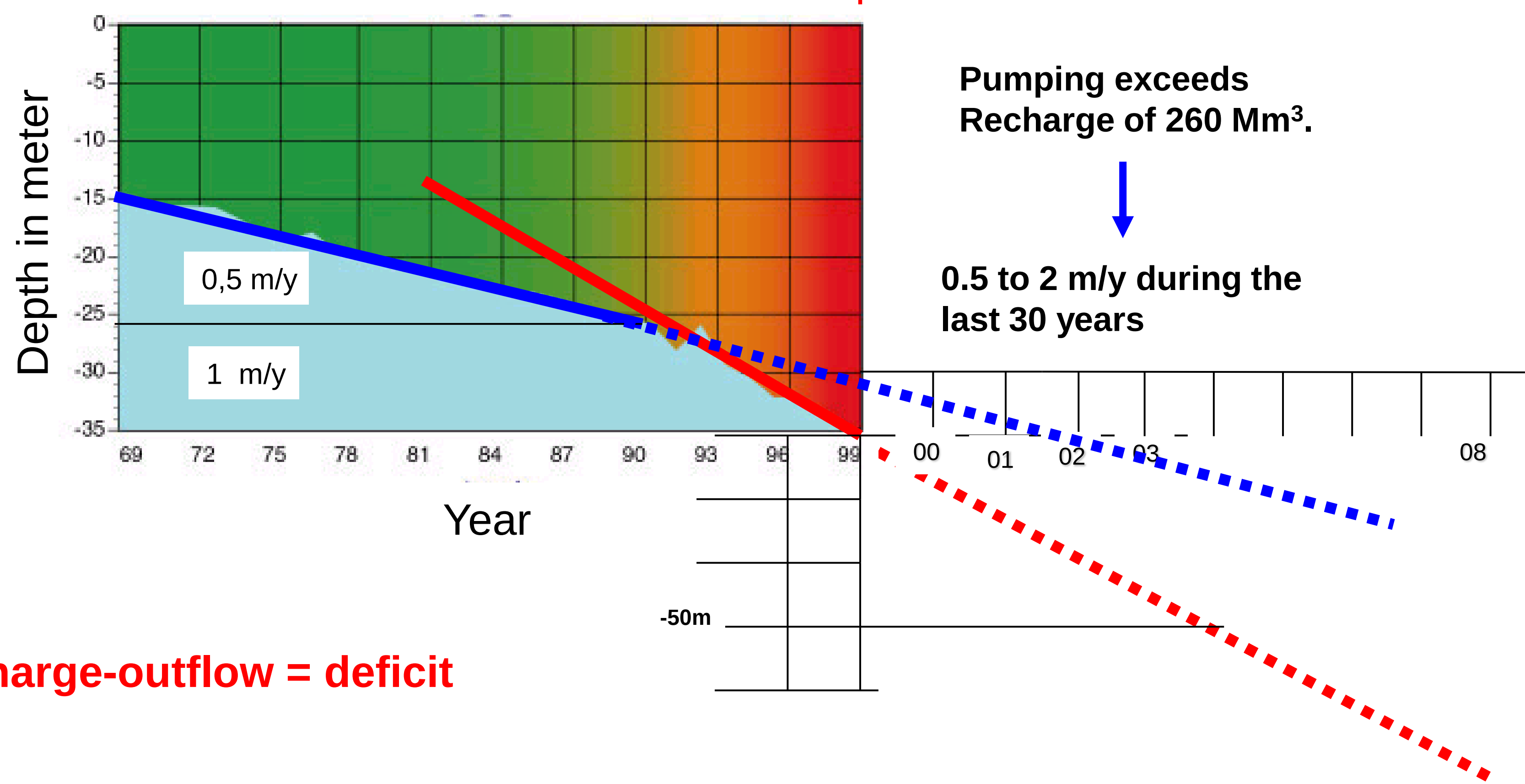
Evolution of GW level



Consequences:

- Water resources depleted
- Degradation of water quality

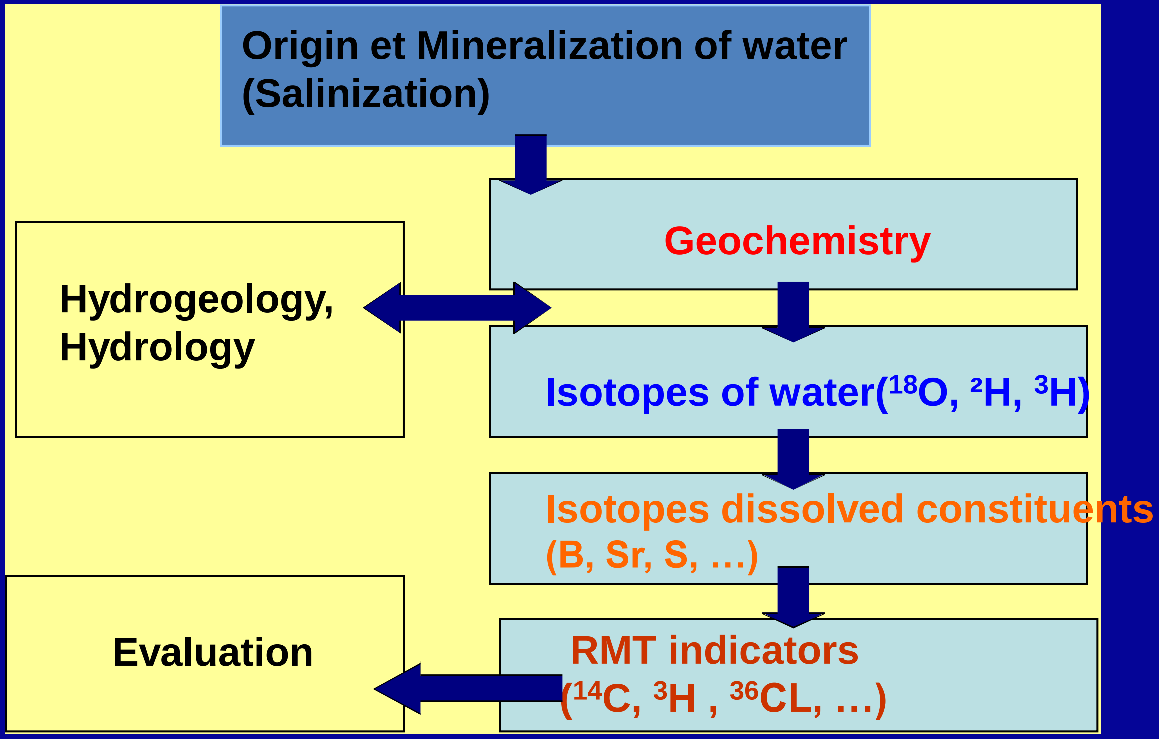
Evolution of water level in Souss-Massa aquifer



Recharge-outflow = deficit

The key for correct use tracer tools for evaluating the origin and the rate of water and salinization process

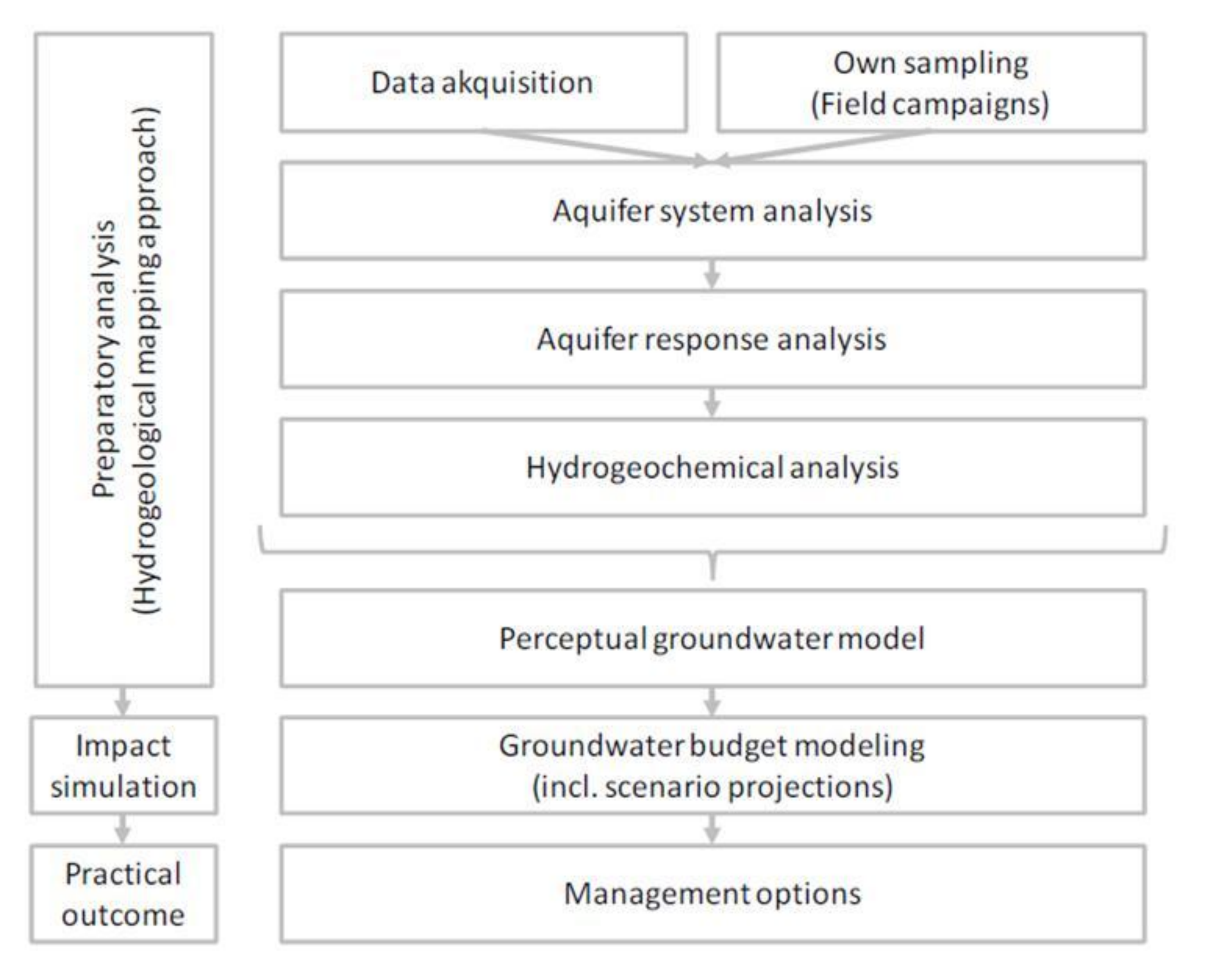
- **Chemical tracers;**
- **Isotopic tracers.**



<u>Resulting conceptual model</u>

Natural recharge (processes, distribution and timing , long/short term effects – long term recharge is depended on climatic conditions?!)

Artificial recharge (Lâcher, irrigation return flow)

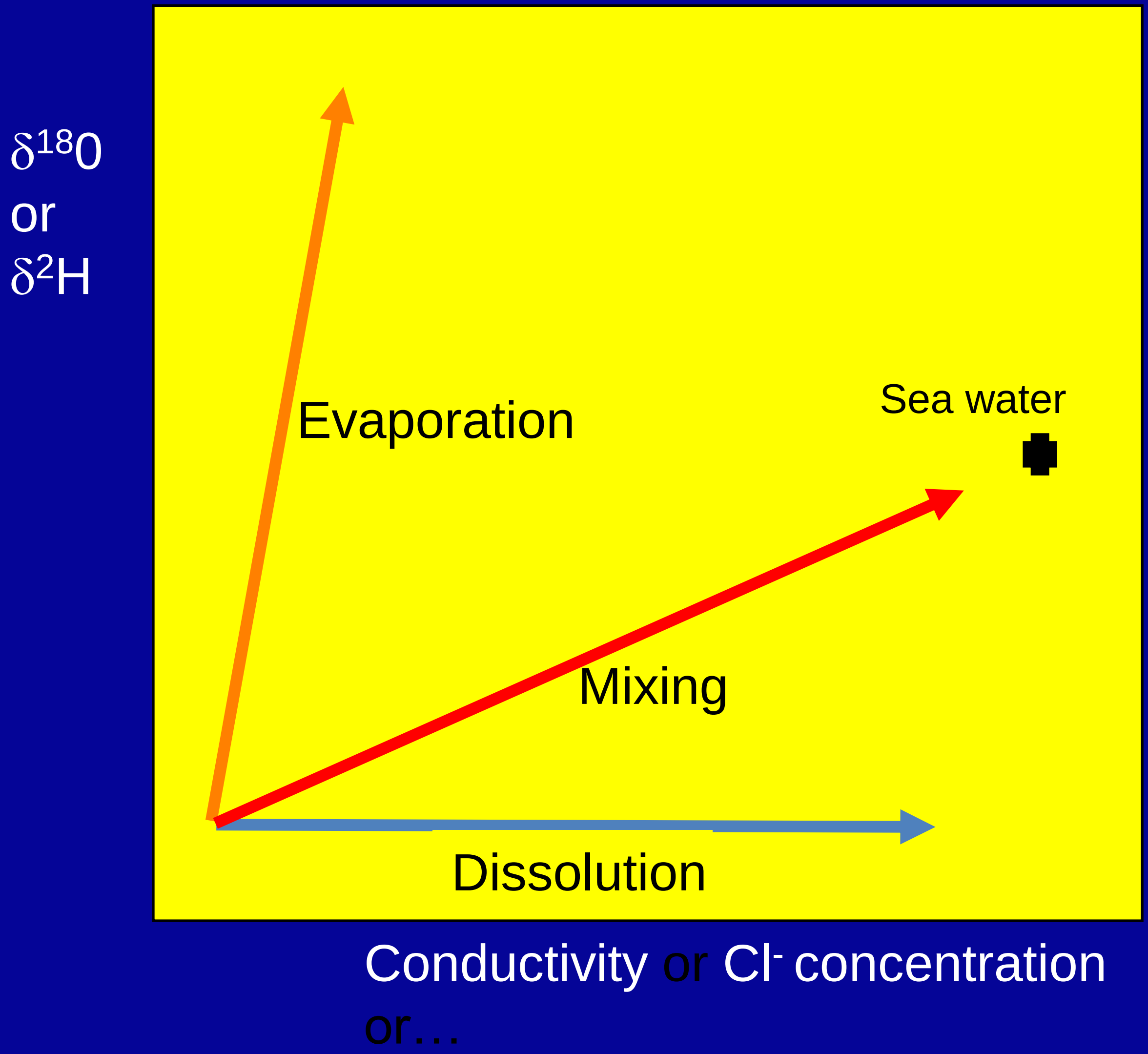


Abstract flow chart of the study approach.

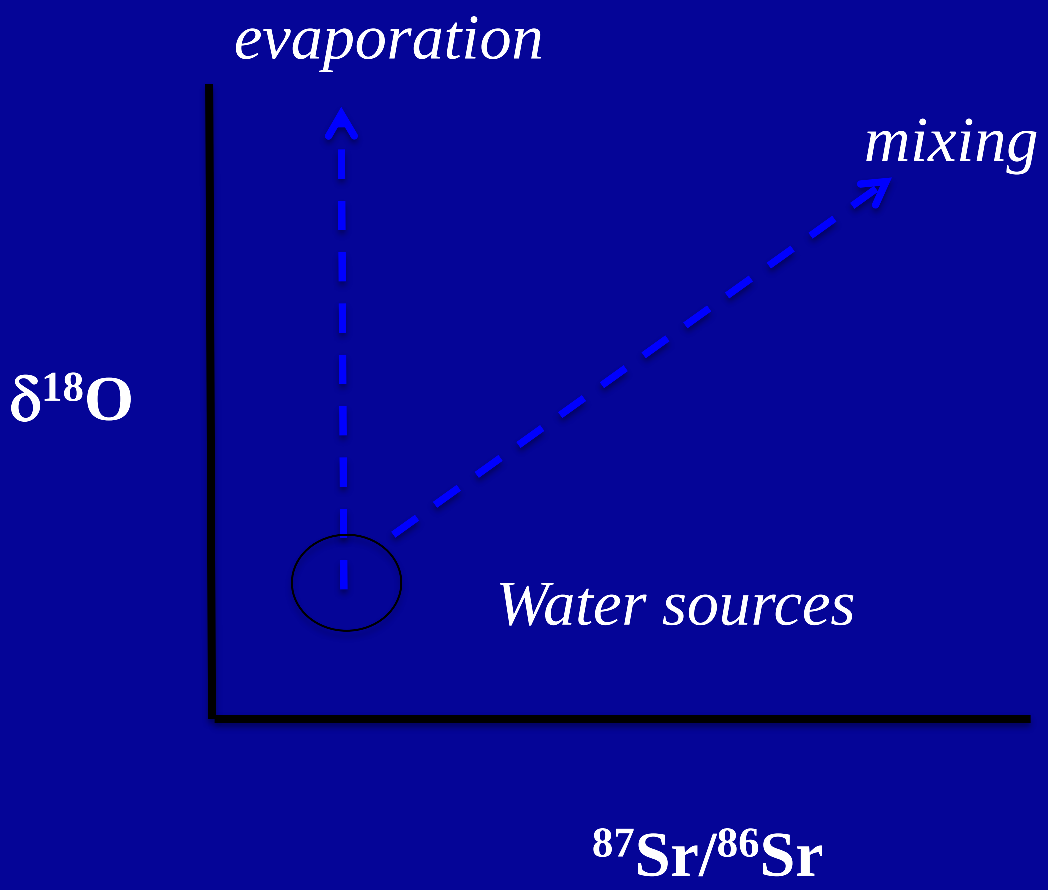
S. Klose, 2012

Salinity origins ?

A first simple approach based on environnemental tracers



New isotopic tracers for delineating salinization processes



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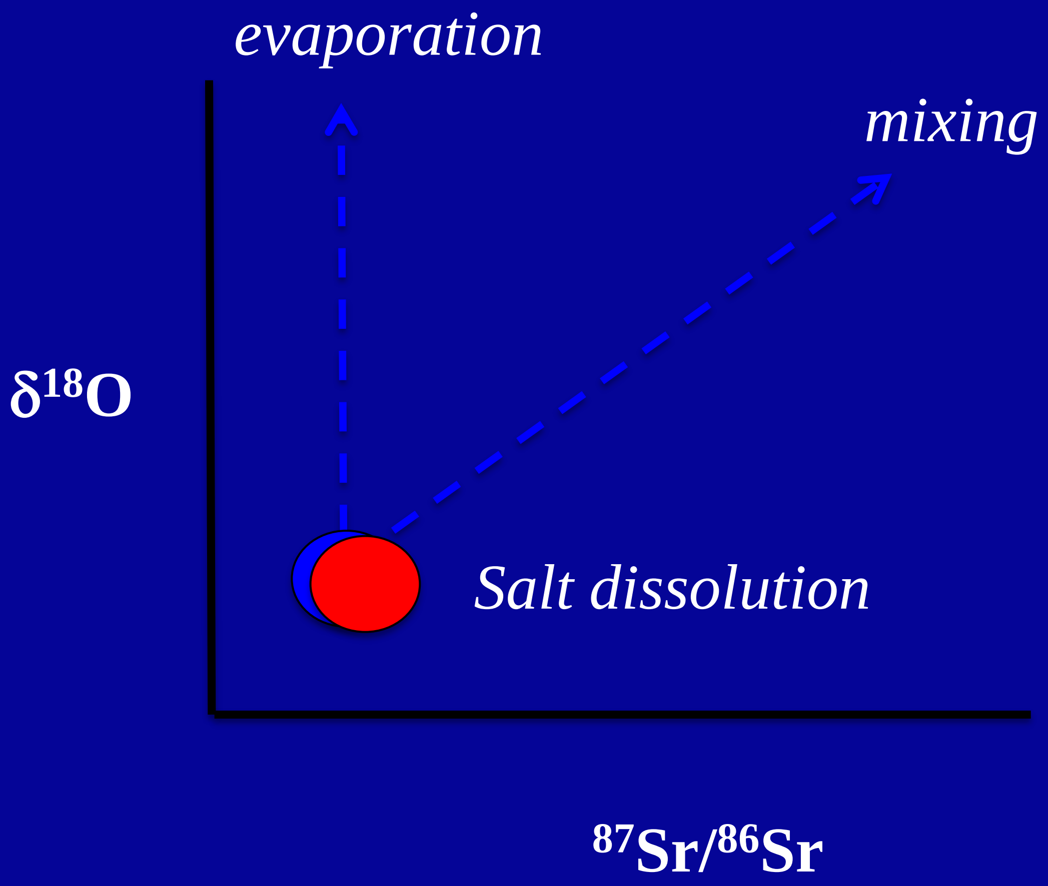
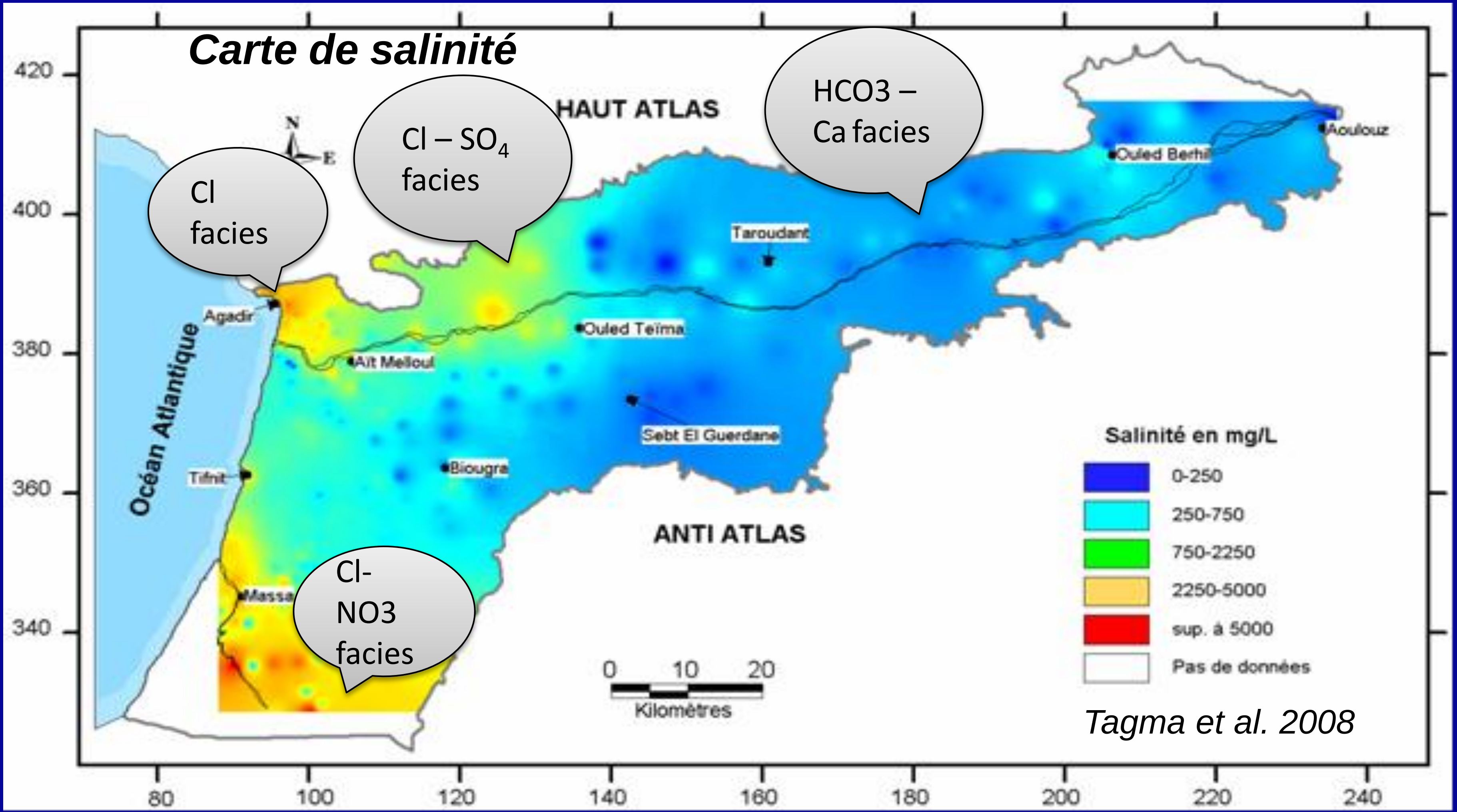




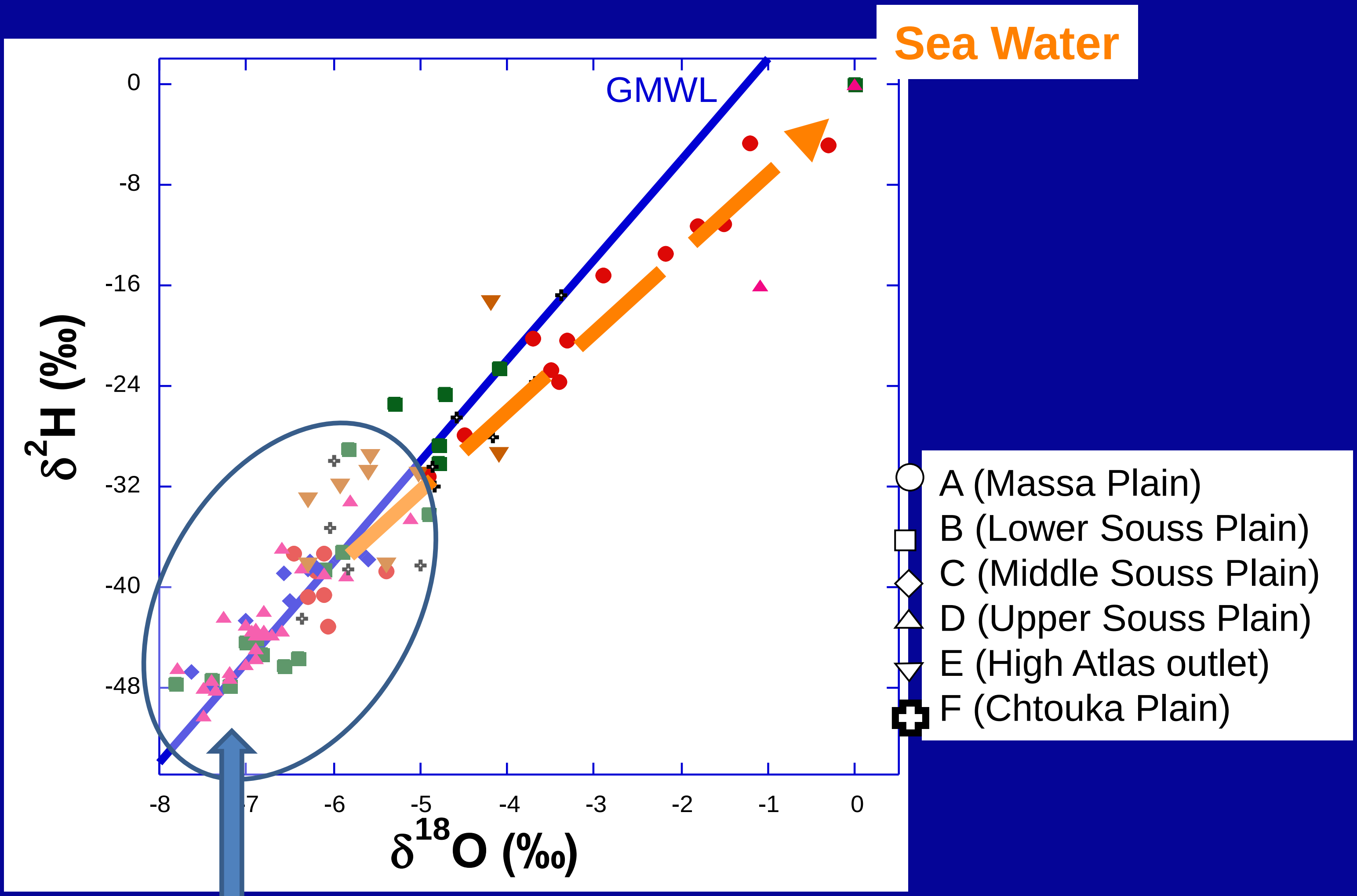
Sea water intrusion?

Salinity Origins??

Rock dissolution?
(Trias, gypsum, schists …)

Anthropogenic Activities ?

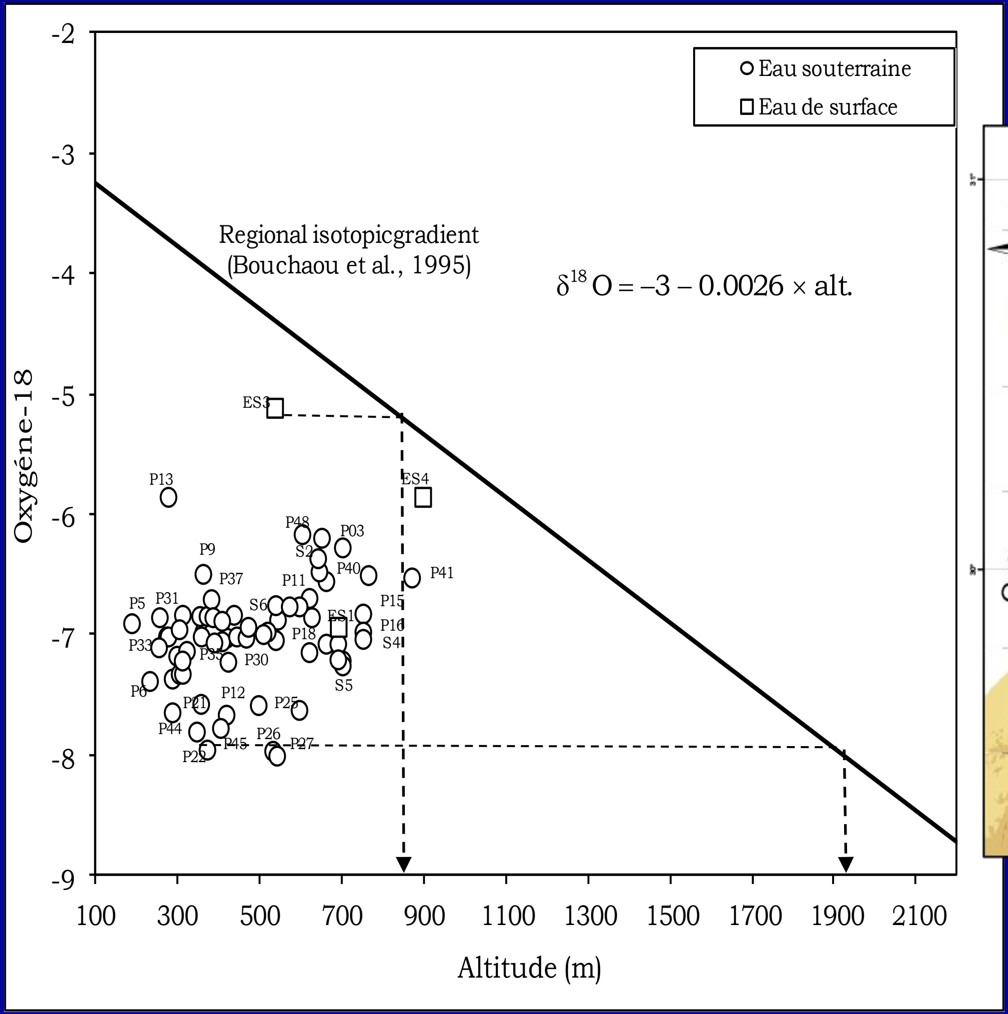
Origin of water

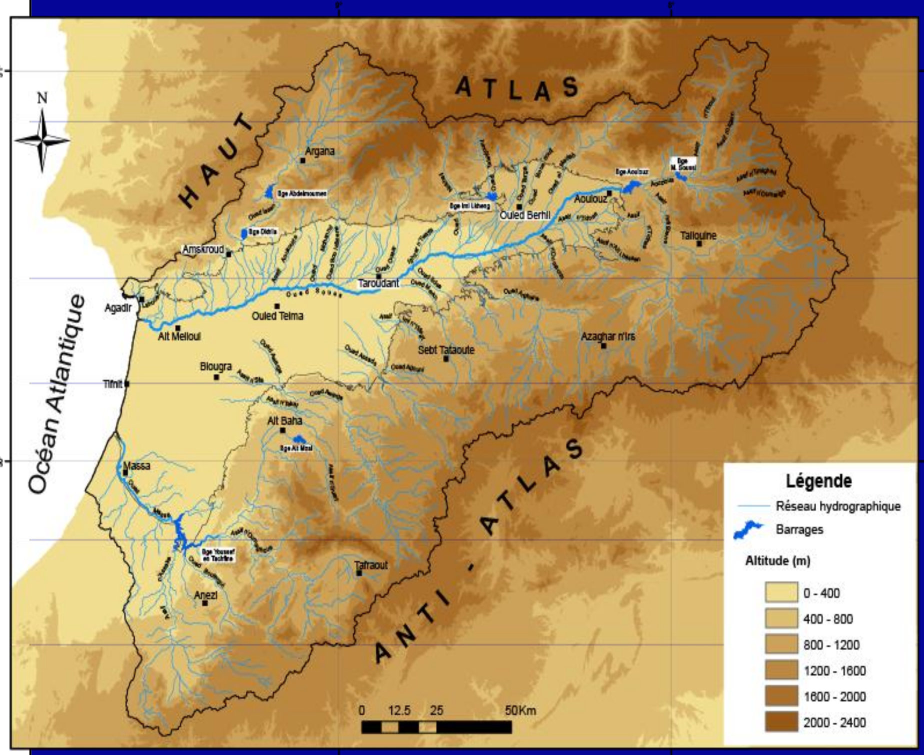


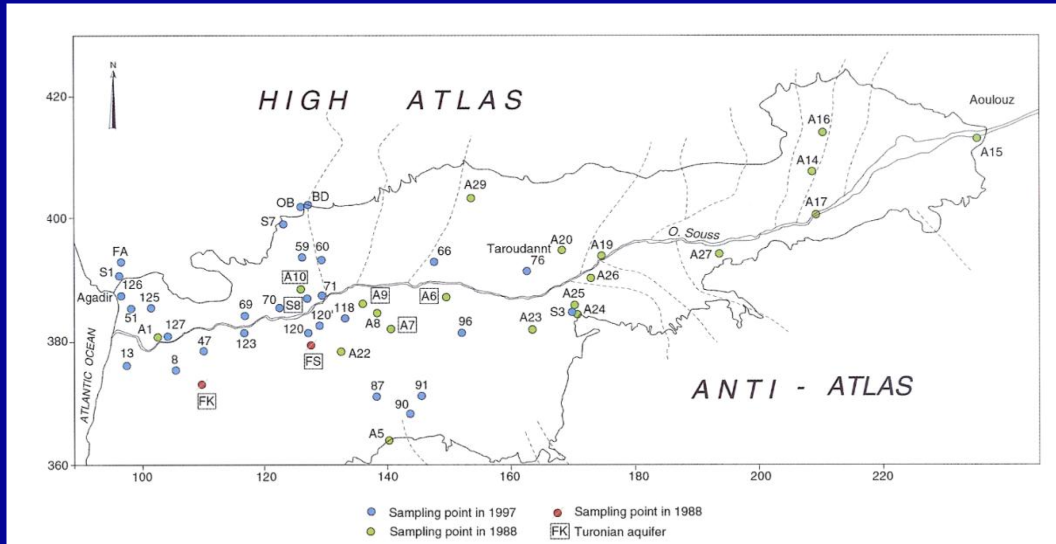
→ **Main recharge from High Atlas**

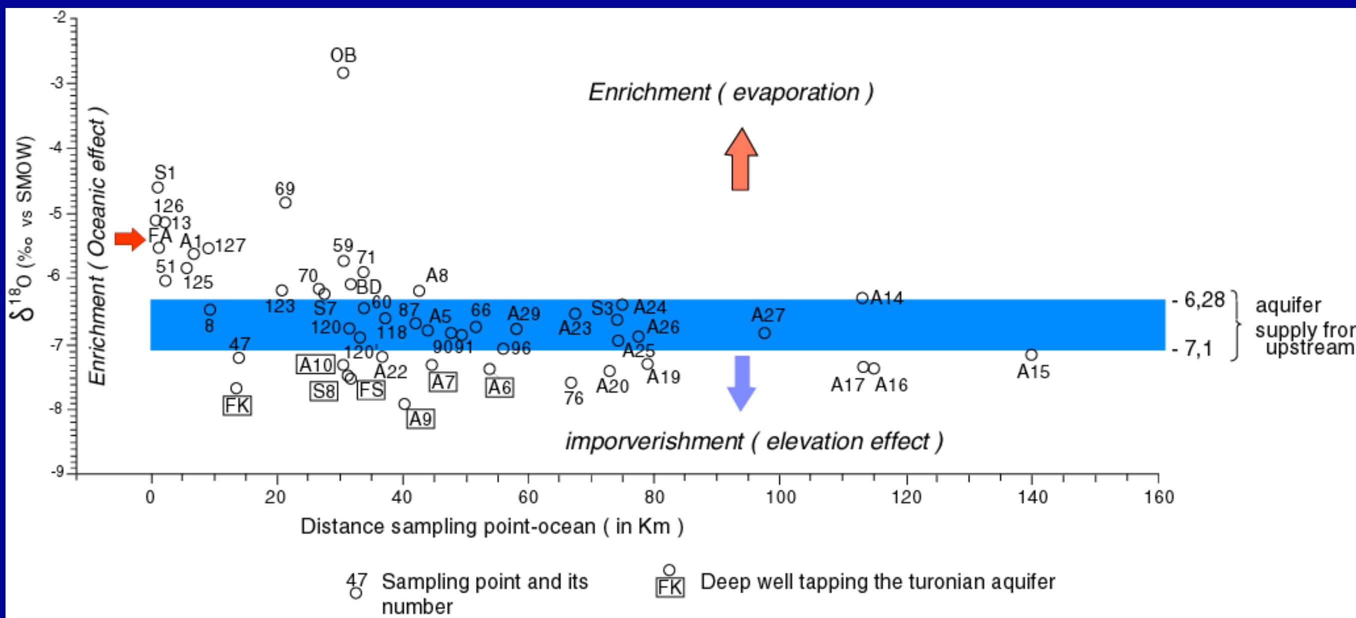
Bouchaou et al., 2008

Origin of water: Altitude of recharge between 850 to 2000 m.a.s.l = Atlas Mountains (mainly High Atlas with high rainfall).



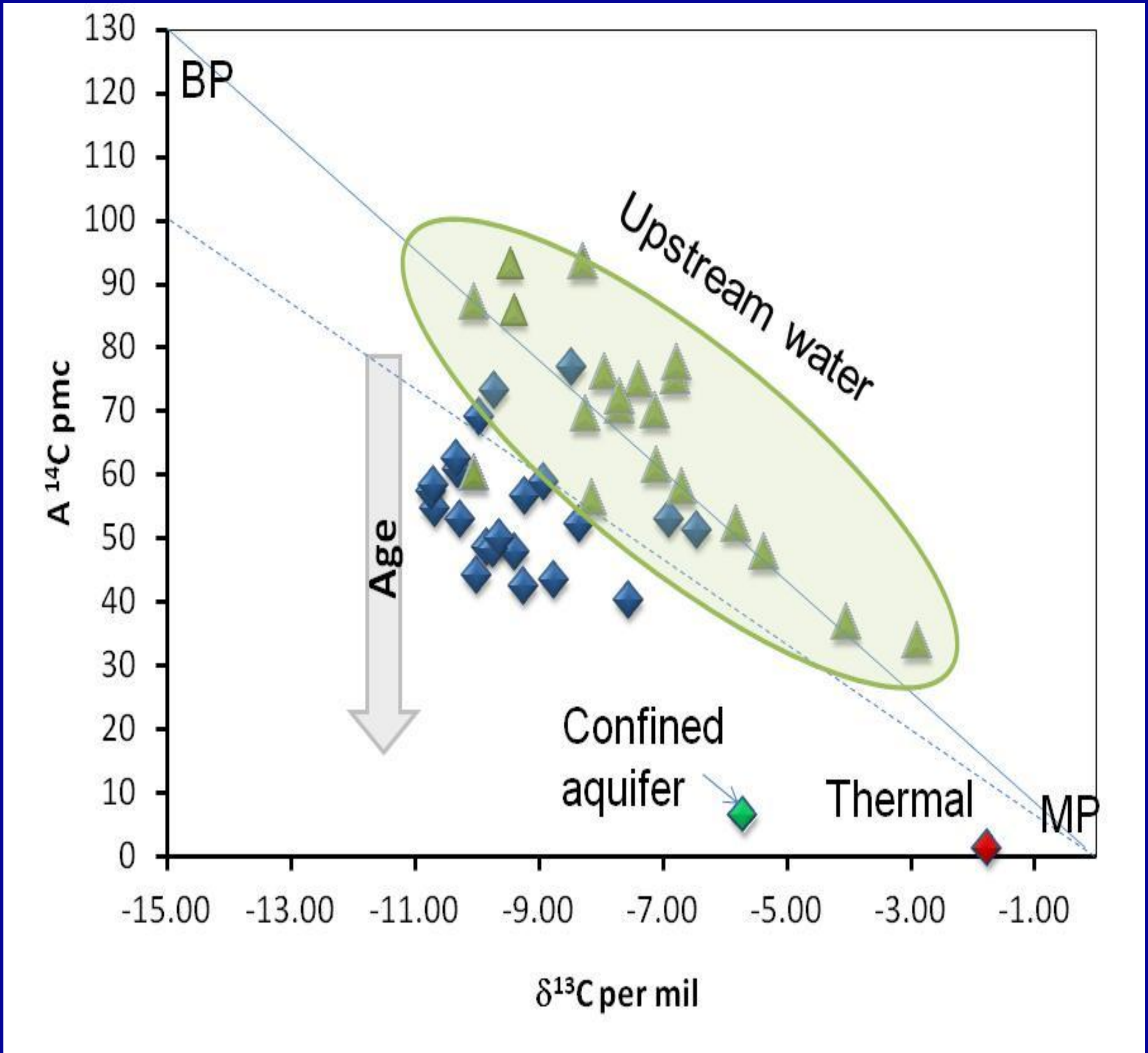


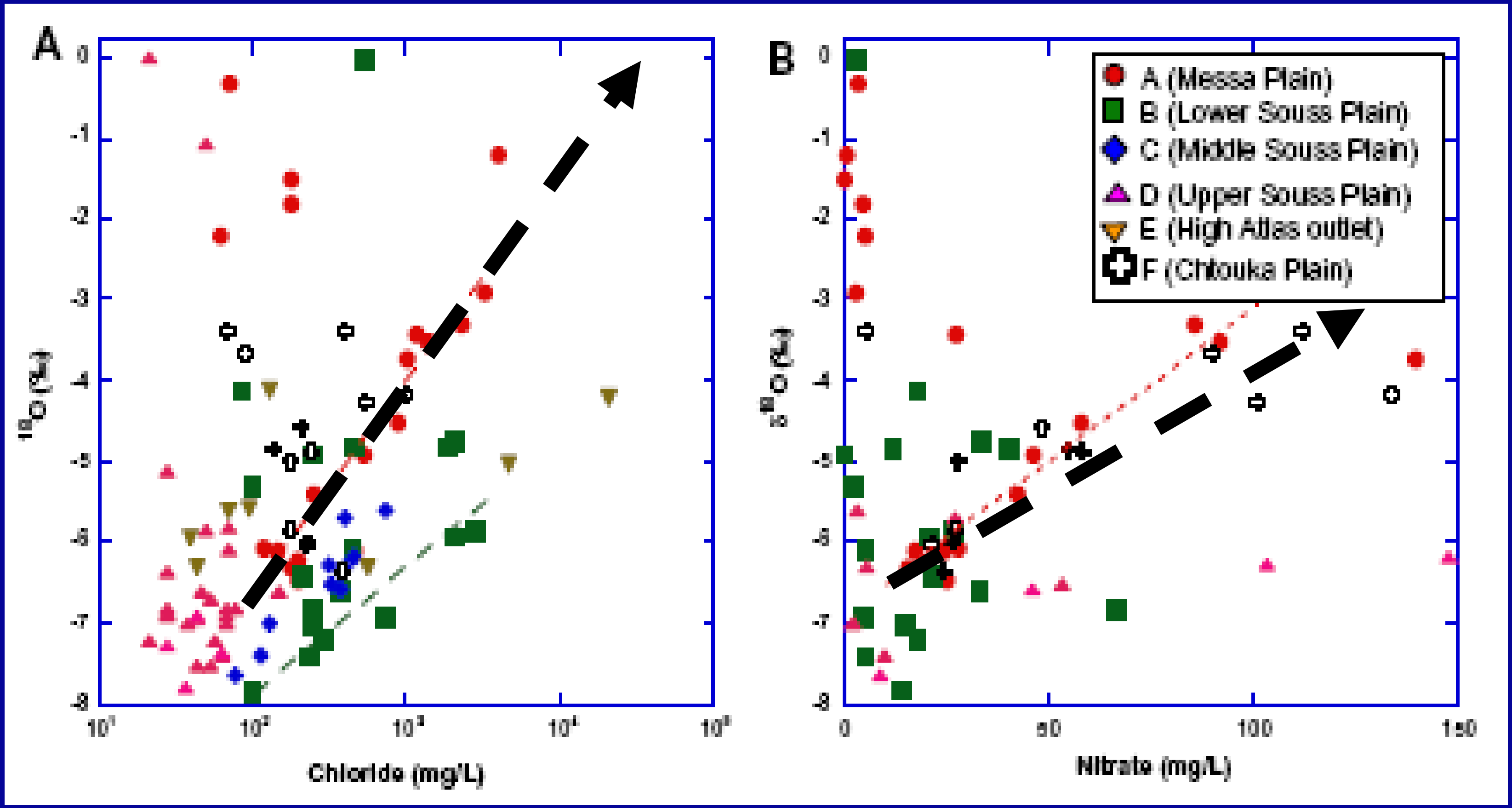




Hsissou et al. 2000

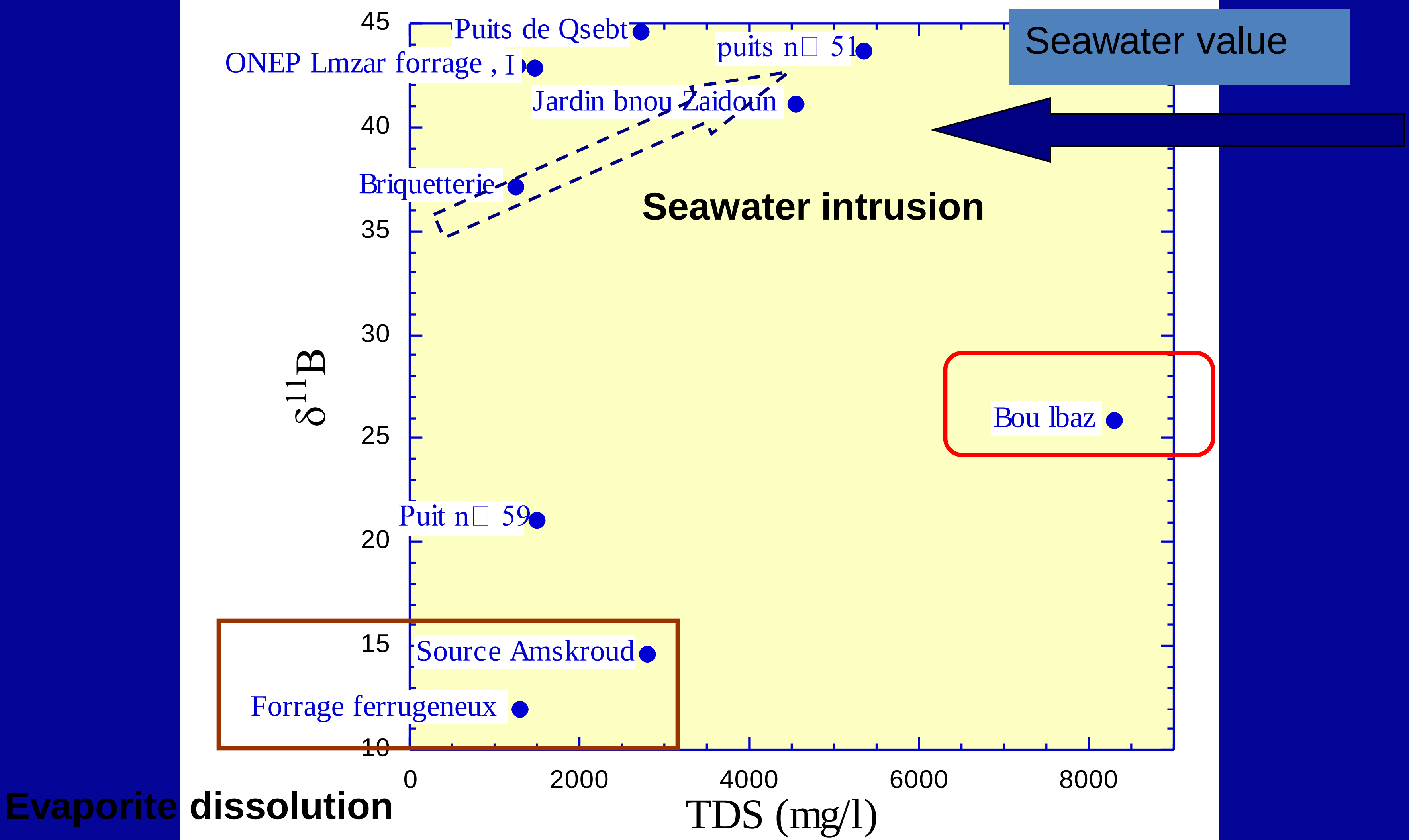
Age dating → Mixing of modern and old waters

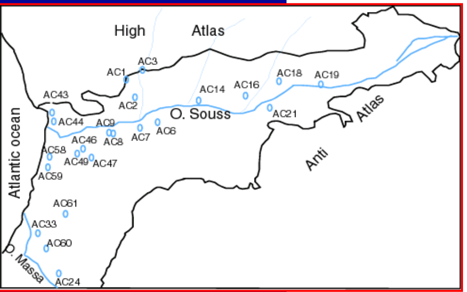


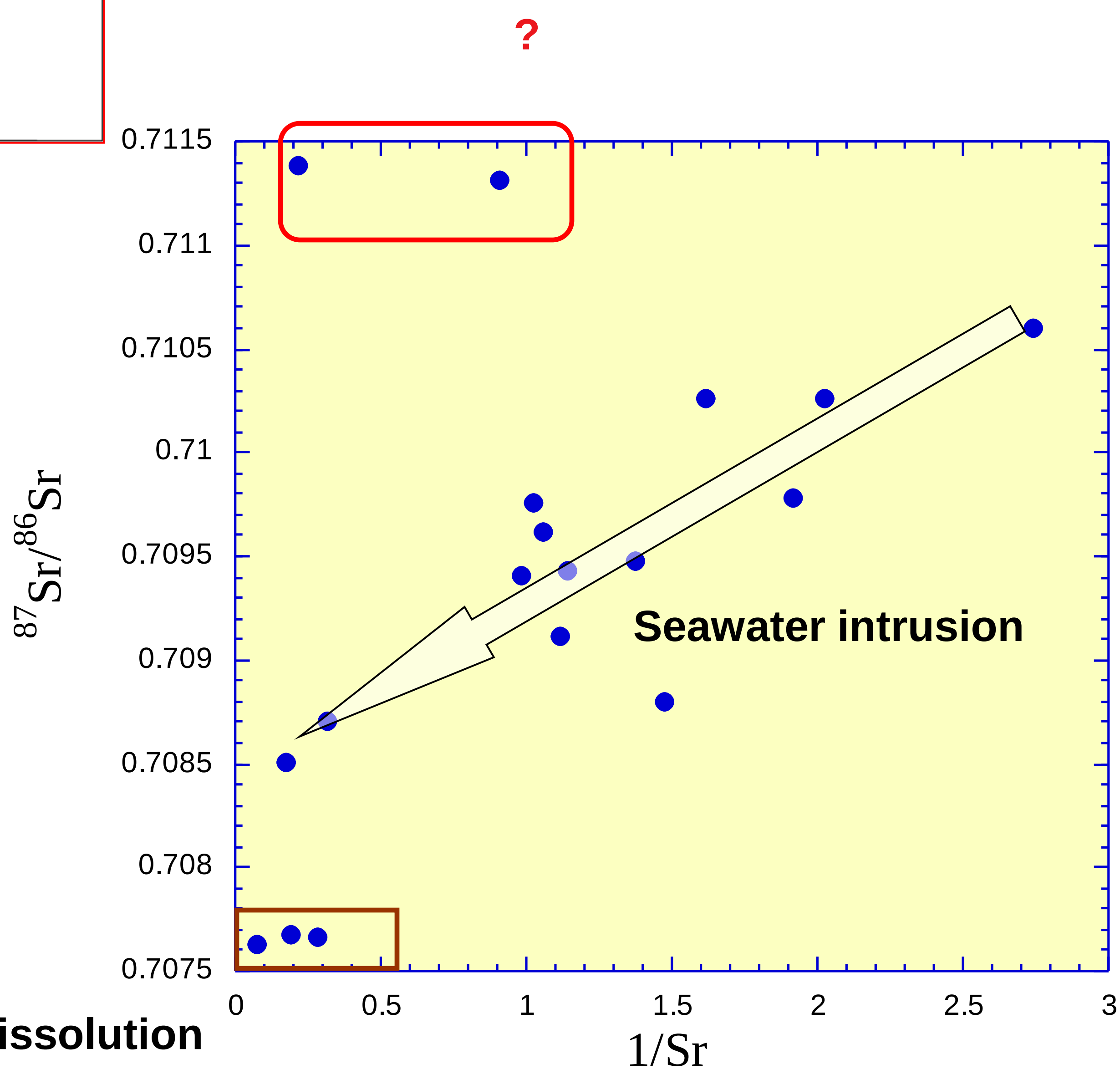


Evaporation : Recycling of agricultural return flows

Mixing with sea water

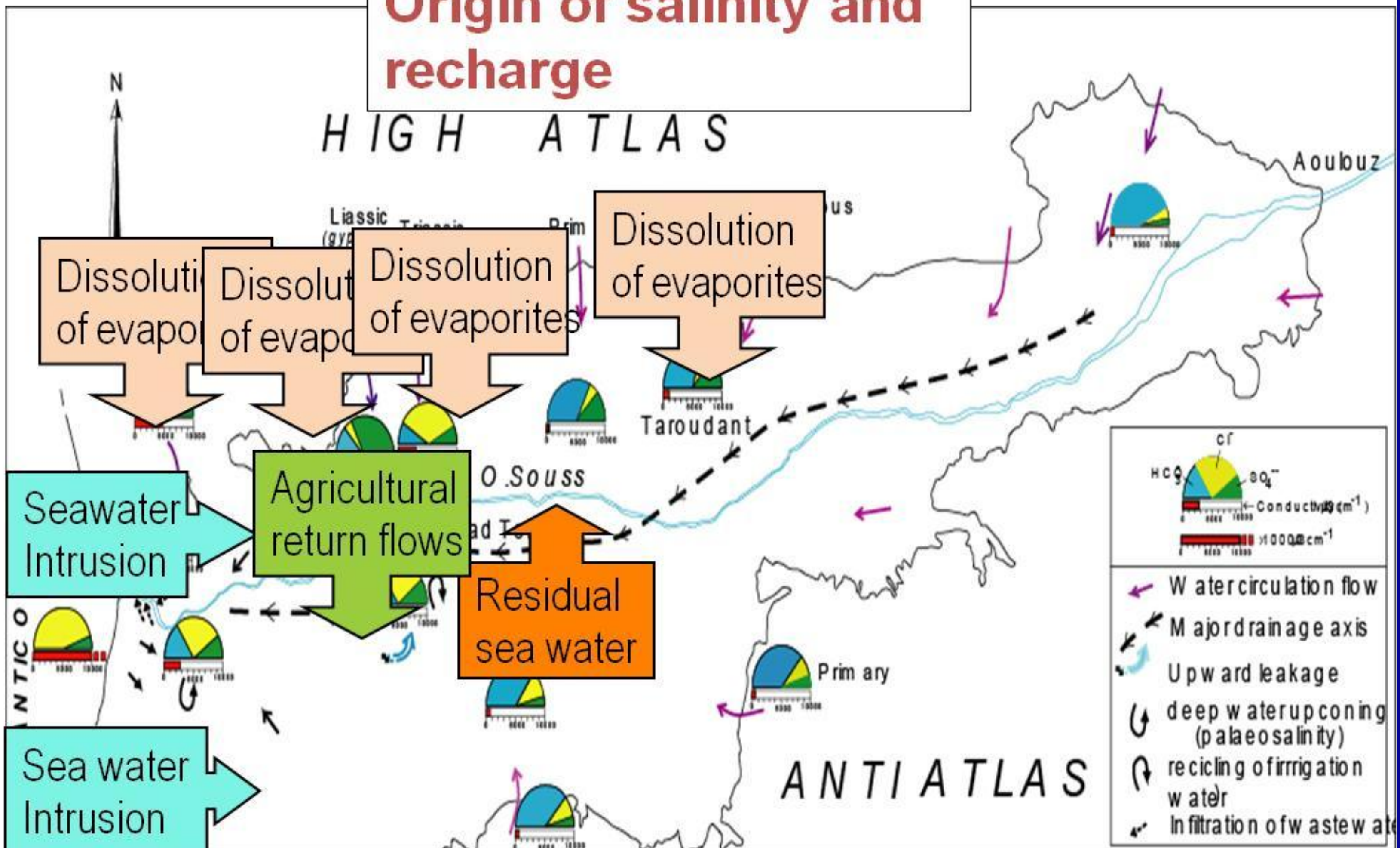

Seawater value
Seawater intrusion
Evaporite dissolution
Puits de Qsebt
ONEP Lmzar forrage , I
puits n° 51
Jardin bnou Zaidoun
Briquetterie
Bou lbaz
Puit n° 59
Source Amskroud
Forrage ferrugeneux
δ11B
TDS (mg/l)
45
40
35
30
25
20
15
10
0
2000
4000
6000
8000





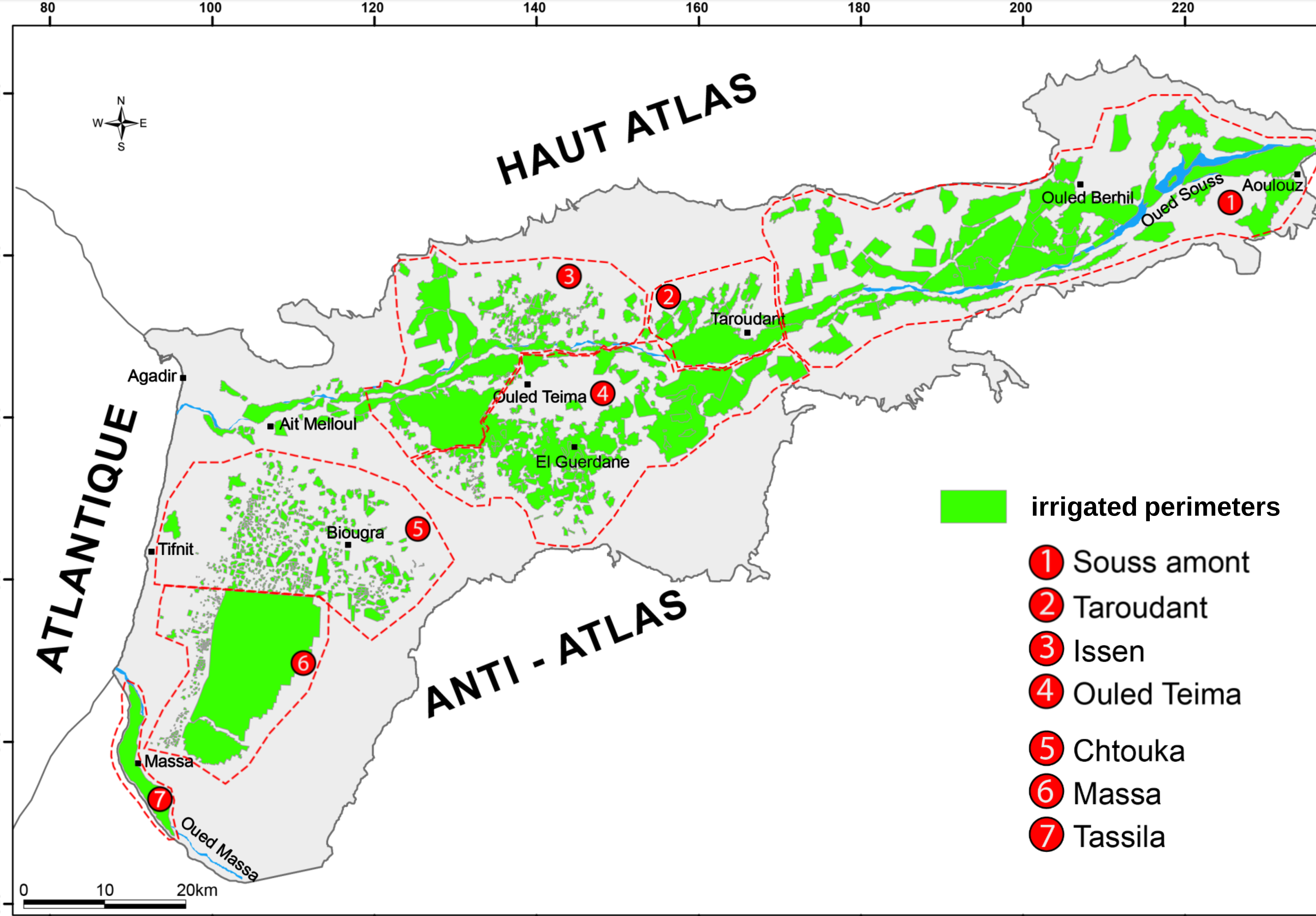
Evaporite dissolution

Origin of salinity and recharge

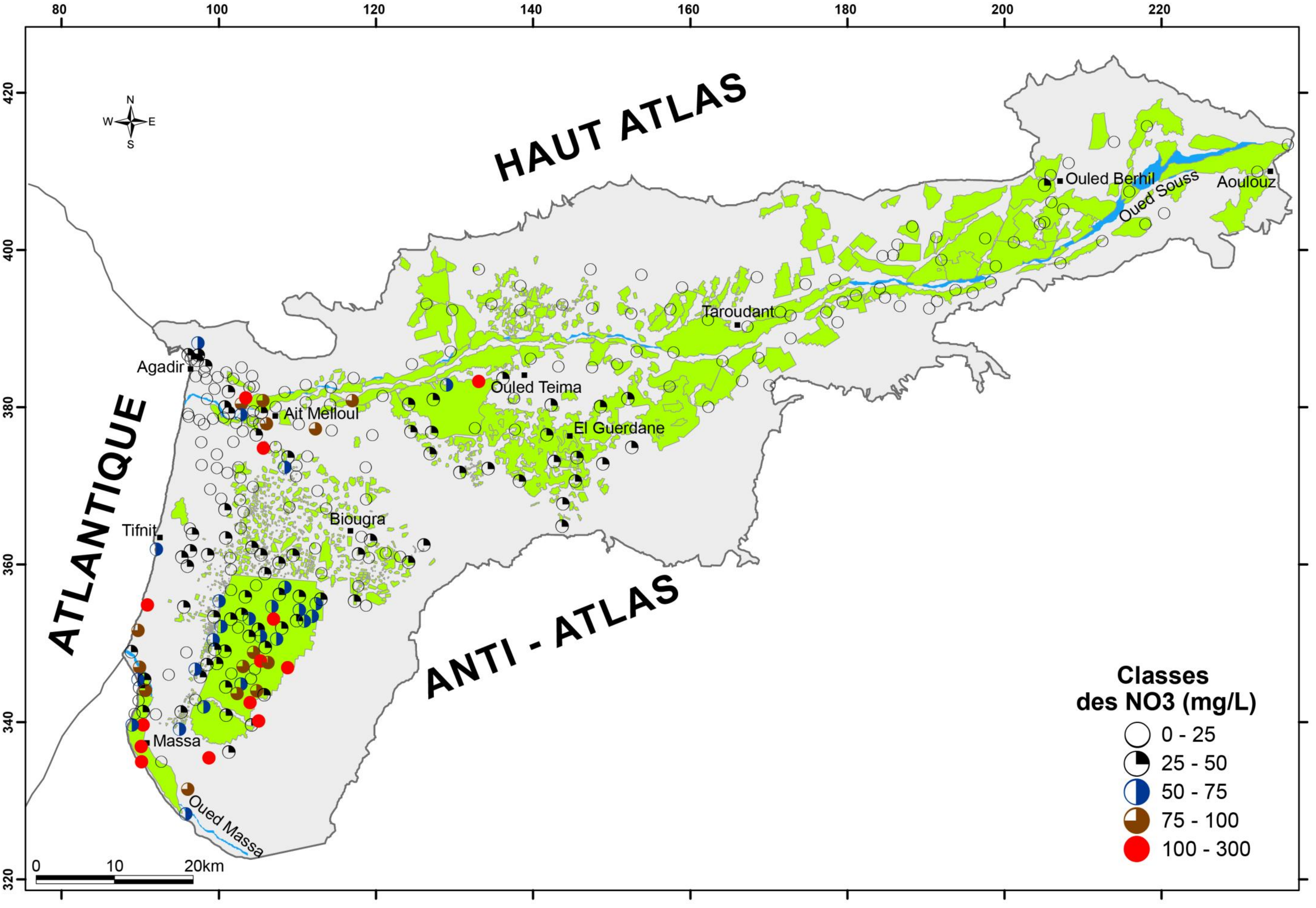


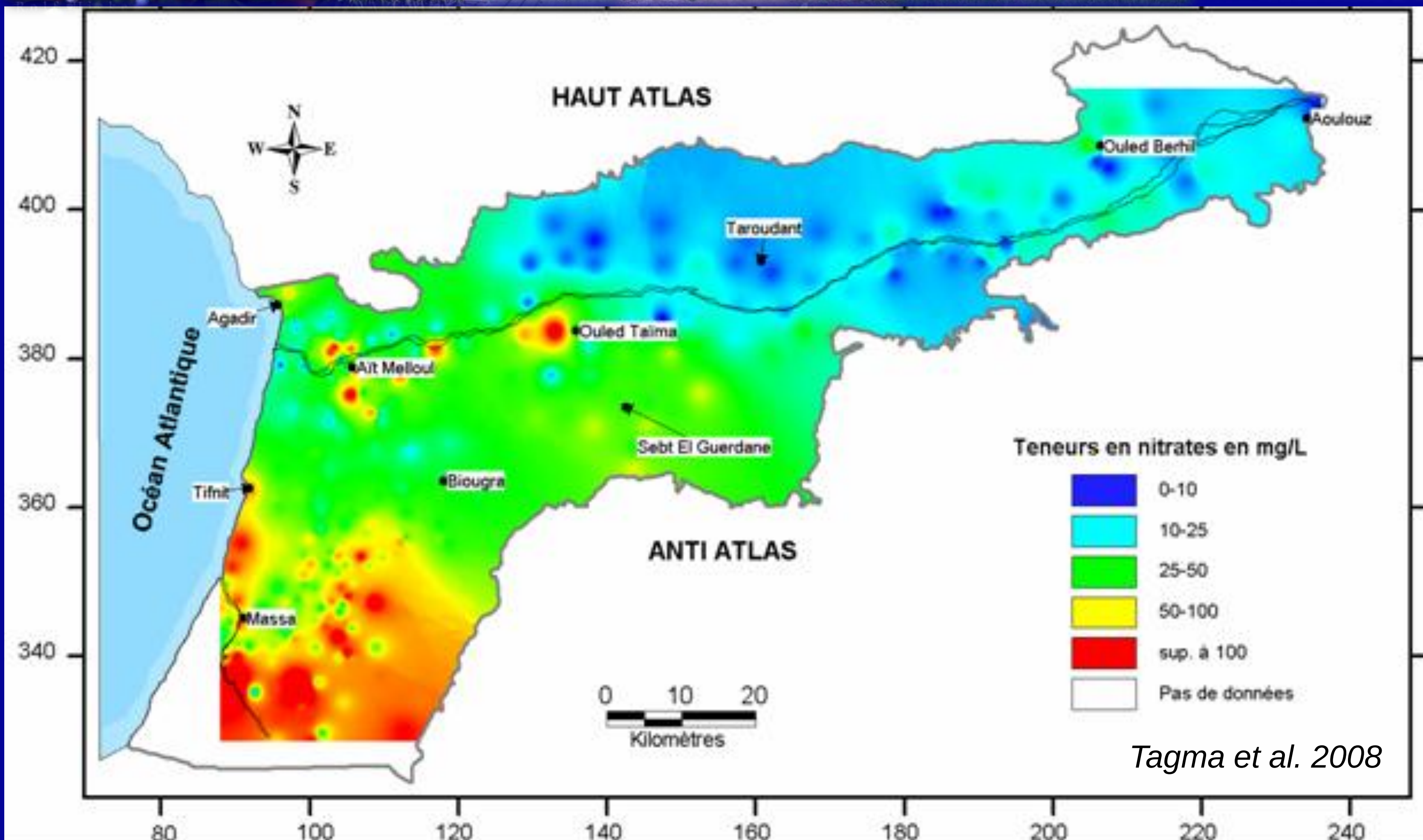
Hsissou et al. 2002, modified

Main irrigated perimeters and consequences



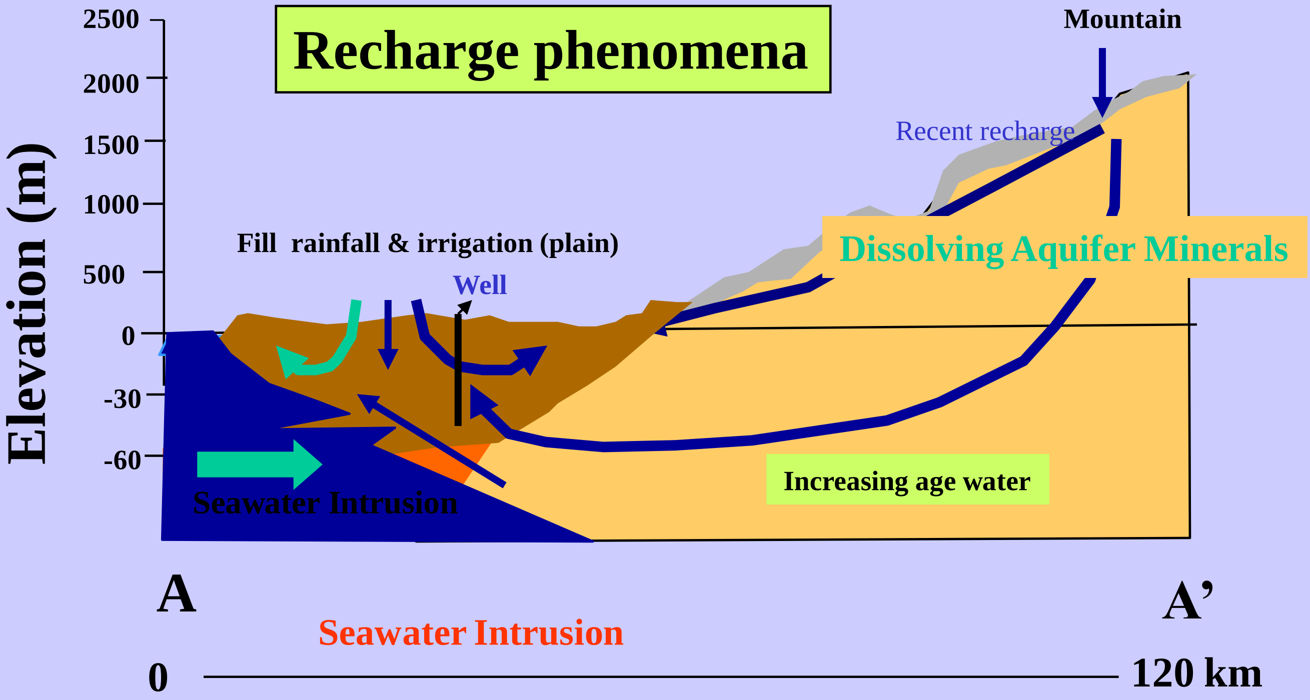
NO3 and irrigated perimeter





Spatial repartition of Nitrates anomlies in Souss-Massa costal plain (Tagma et al. 2009)

Functioning Souss-Massa aquifer



Bouchaou et al., 2009

Variable origins of water and salinity Using environmental tracers

Sea water intrusion :
High Cl TDS
High $\delta^{18}O$ and $\delta^{2}H$
Low Na/Cl
Marine Br/Cl
Marine $\delta^{11}B$
Variable $^{87/86}Sr$

Mixing with residual entrapped sea water :
High Br/Cl
High $\delta^{11}B$, High $^{87/86}Sr$

Agricultural return flows :
High $\delta^{18}O$ and $\delta^{2}H$
High NO_3 concentration

Dissolution of evaporites : Halite
High Cl TDS
Low Na/Cl, Low Br/Cl
Low $\delta^{11}B$, High $^{87/86}Sr$

Dissolution of evaporites : Gypsum
High SO_4
and Low Cl TDS
High Na/Cl
Low $\delta^{11}B$, Low $^{87/86}Sr$

Conclusion

- **Recharge : Mainly from the high Atlas mountains with high rainfall and snowmelt.**

- **Salinity origins are diverse:**
  - **Dissolution of evaporates;**
  - **Sea Intrusion;**
  - **Irrigation water return;**

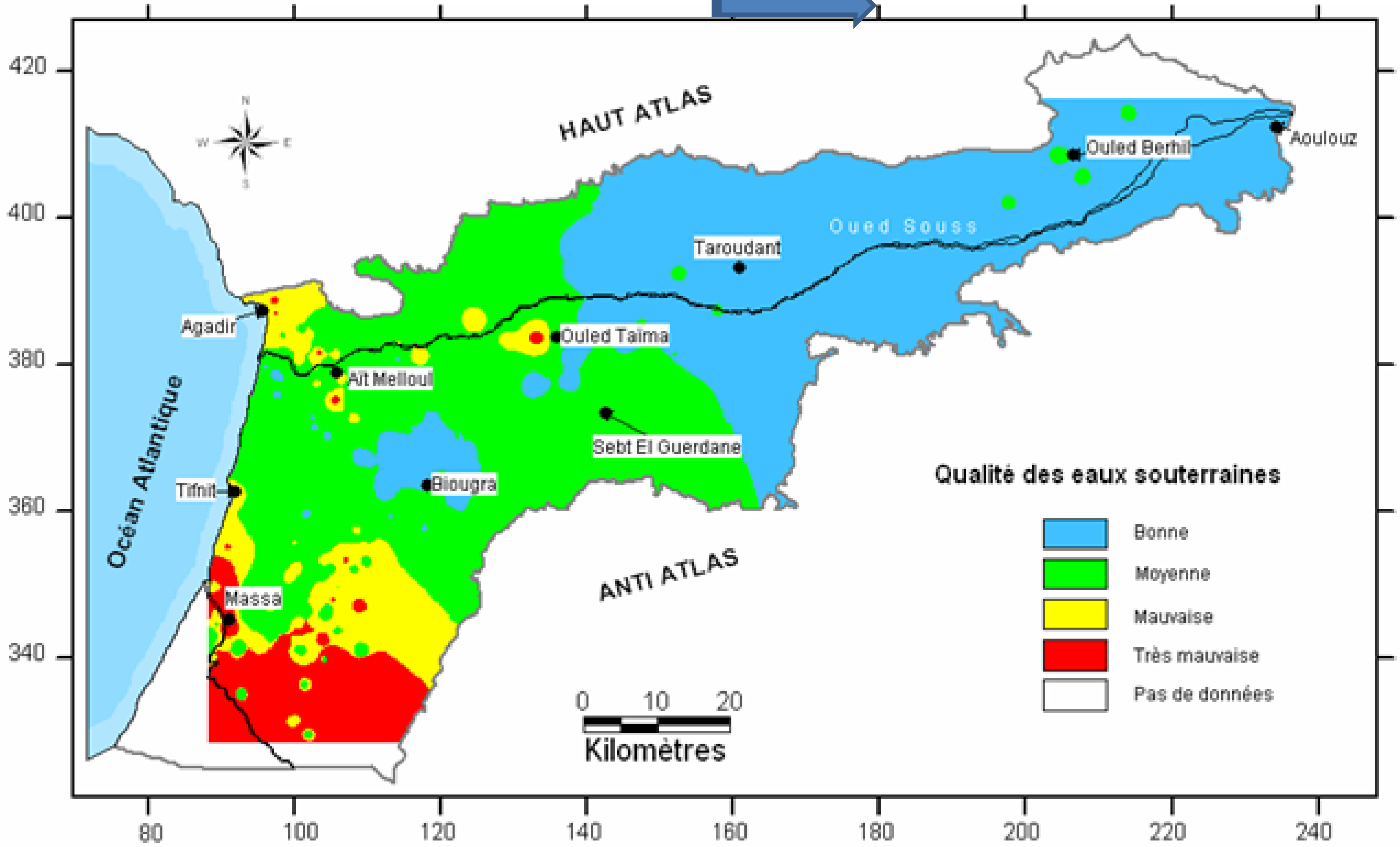
- ***Chemical and Isotopic tracers are the performing tool to study water resources particularly in:***

  - Arid areas;

  - Coastal aquifers

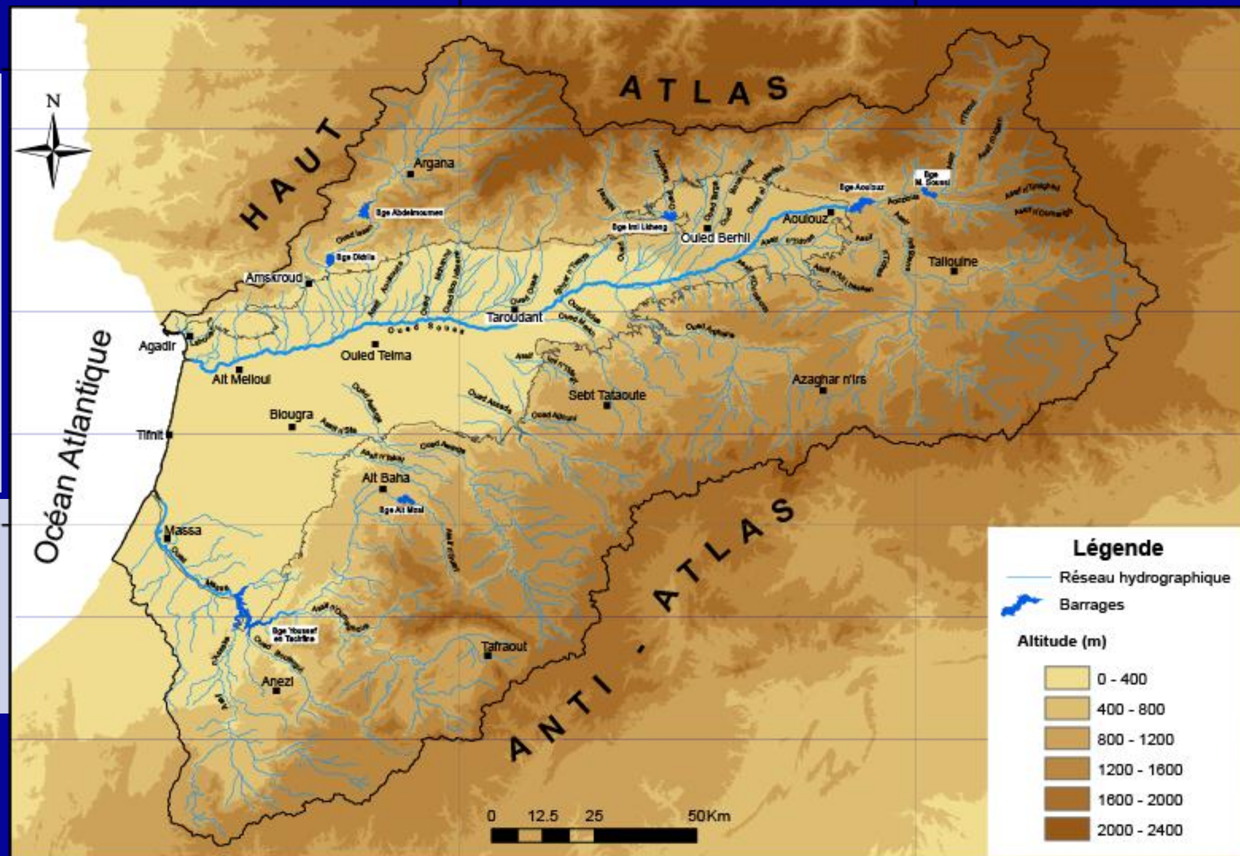
  - Non equipped zones;

Exploitation is shifting toward the upstream



Water quality distribution in Souss-Massa area

STATE WATER RESOURCE MOBILIZATION



Souss Massa Basin

- ✓Volume : 1.034 Mm³
  - 371 Mm³ from SW(36%)
  - 663 Mm³ from GW(64%)

- ✓Repartition use:
  - Drinking water: 5%
  - Irrigation : 95 %

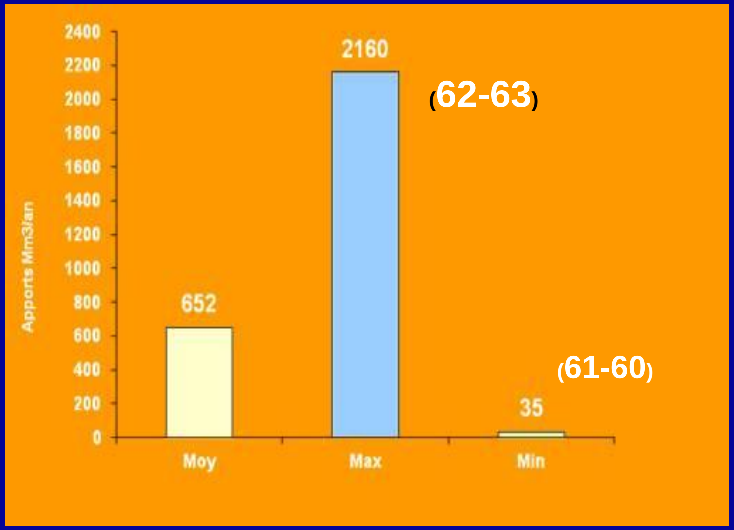
- ✓Dams realized: 8
- ✓Capacity : 797 Mm³
- ✓Volume regularized : 371 Mm³
- ✓Small dams: 9
- ✓Capacity: 15 Mm³
- ✓Number of Transfer channels : 6

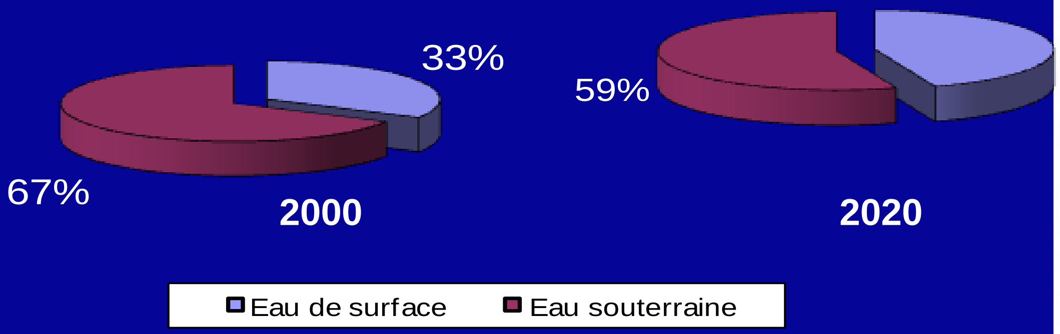
Souss aquifer balance

- **Souss plain : 4.150 Km²**
- **Renewable contribution: 414 Mm³**
- **Pumped volume : 650 Mm³**
- **Deficit : 260 Mm³**

Major problems

- High variability of surface water
- High and conflict water demand
- High use GW in irrigated areas
- Overexploitation of GW





Year	Drinking water(Mm³)	Irrigation (Mm³)
2000	50	942
2020	88	1102
increasing	+ 76%	+ 17%

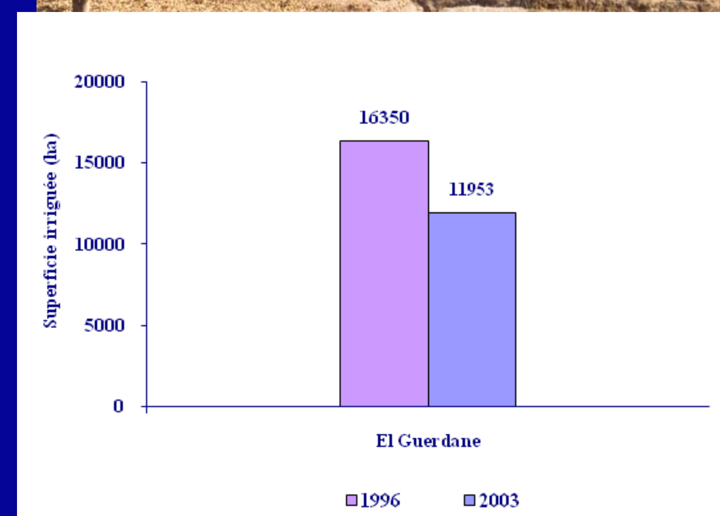
what Short-term Hazards?

Technical-economic hazard

- Decreasing of GW level ;
- Use the deepening of wells and the construction of new wells
- Lower aquifer levels – higher pumping costs
- Decrease farm profitability and product quality
- Abandonment of farmland,
- Rural exodus and loss of agricultural labor;;
- Impoverishment of small and medium farmers.

Environmental hazard

- Seawater intrusion in the coastal area;
- Increased salinity;
- Desertification and erosion of the area with negative impact on the environment and sustainable development.



Abandonment of framland

Which water resources management?

Mitigation

- **Enhancement of natural recharge of aquifers through infiltration of runoff**
- Mobilization of surface water: Dams
- Agricultural Return flow
- Economy and Integrated water resources management…….

How we can reduce the water lost to the ocean?

↓

Artificial recharge

↓

- Based on natural recharge phenomena
- Scientific results using new techniques:
  - Modeling?
  - Environmental Tracers (chemical, isotopic),

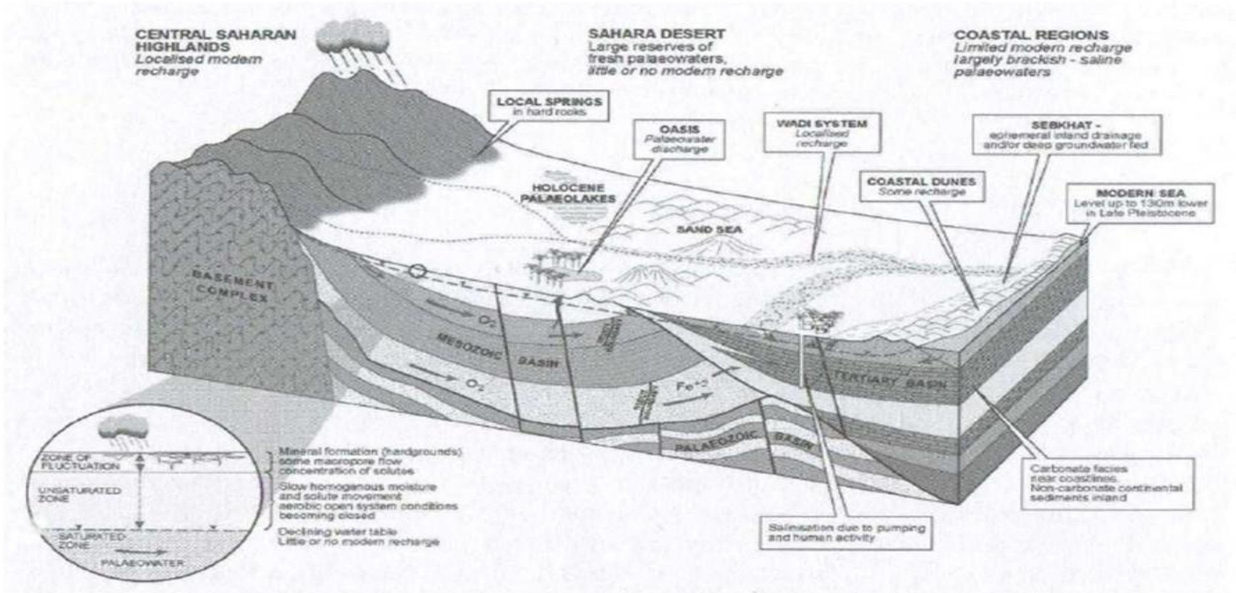


Figure 3-1: Landscape hydrogeology and hydrogeochemical processes in drylands reflecting the geological environment in North Africa (from Edmunds, 2003).

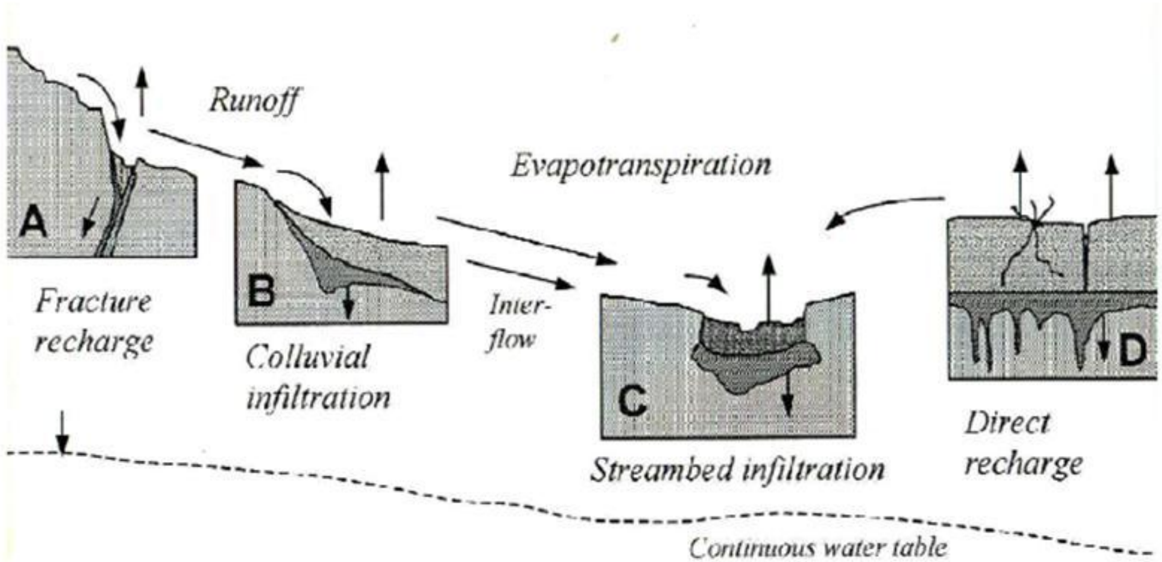


Figure3-3: Conceptual models of groundwater recharge (from Kuells, 2003).

Current system of the artificial recharge

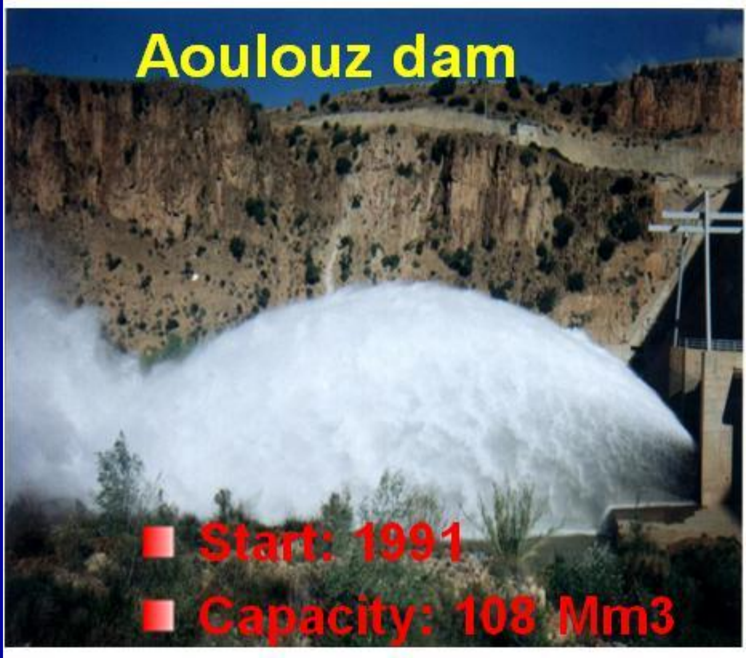
- **From dam:**

  - Aoulouz : 103 Mm^3

  - Imi El Kheng : 12 Mm^3

  - Release from dams to control discharge.

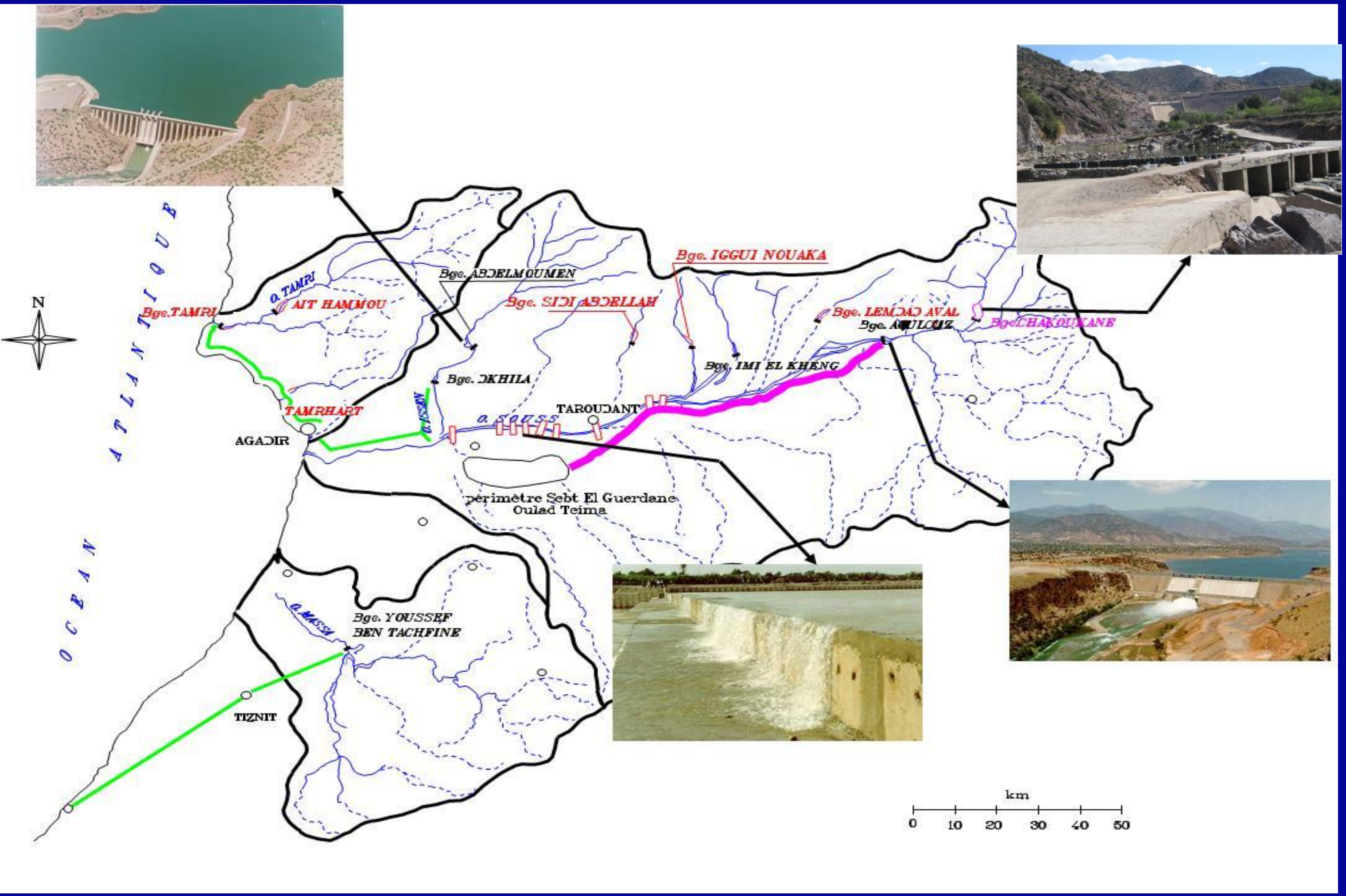
- **9 thresholds (barrier) in oued in order to spread the water released**

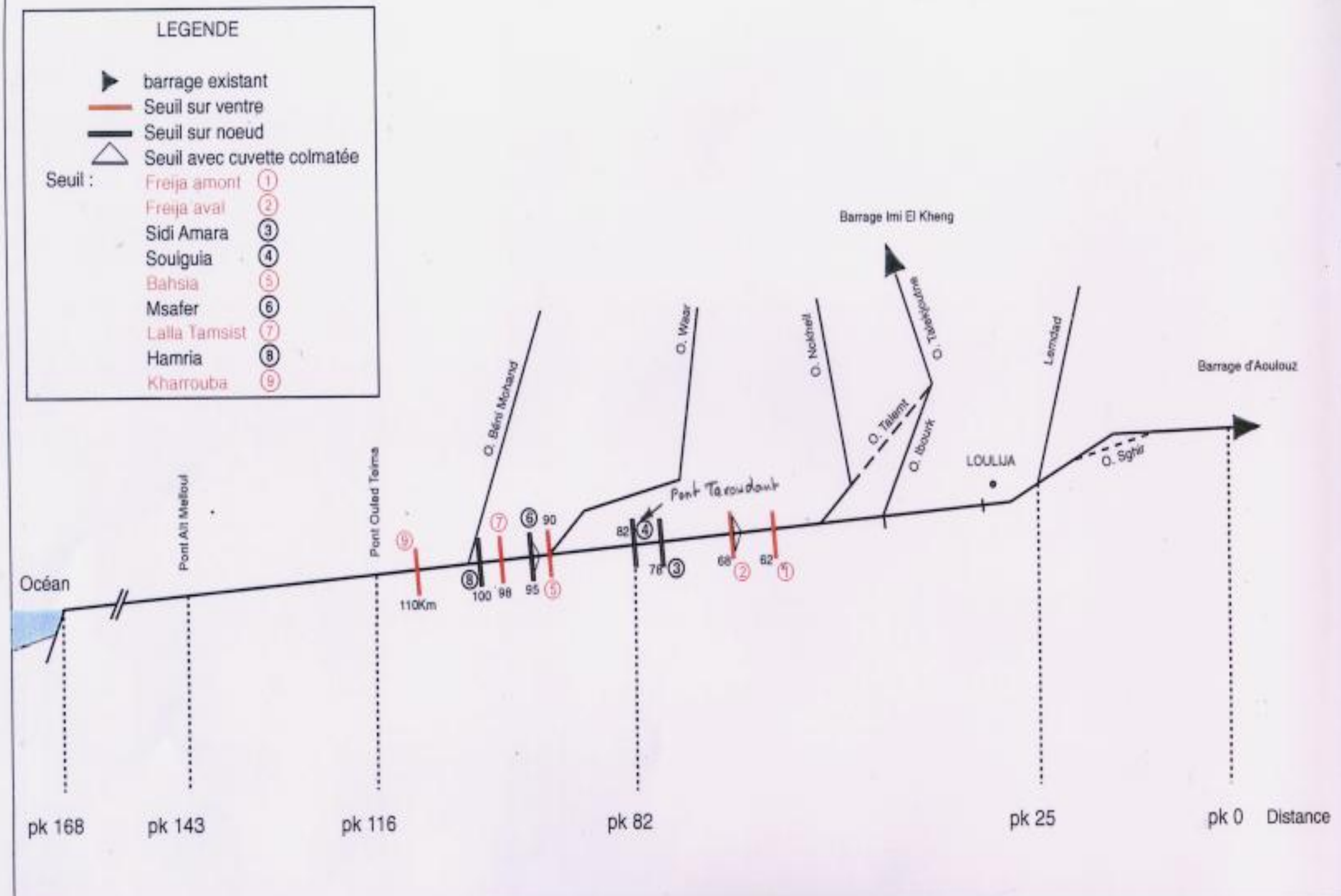


- **9 thresholds (barriers) made between Pk 62 and PK 110**
- **Heights 3 to 4 m (gabions and gravel).**

OBJECTIVE → **Increasing the infiltration** →

- **Stream flow storage**
- **Spreading water**





BURGEAP
INGEMA

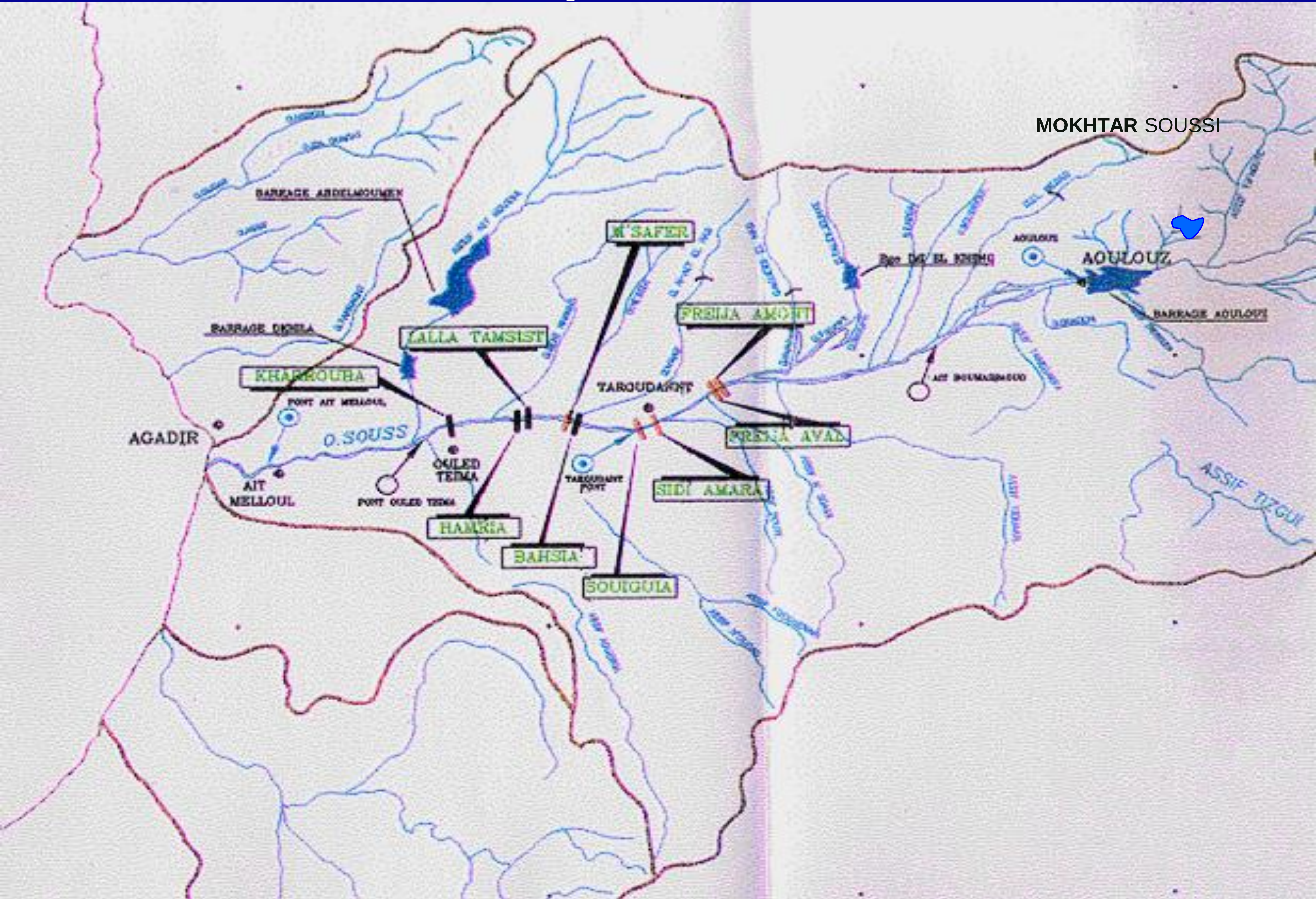
DIRECTION GÉNÉRALE DE L'HYDRAULIQUE / DRPE

LOCALISATION ET CARACTÉRISTIQUES DES SEUILS

R.3025
C.199275

Fig. 6

Position of hydraulic structures



Effective recharge after construction of dam

ABH/SM DGERE

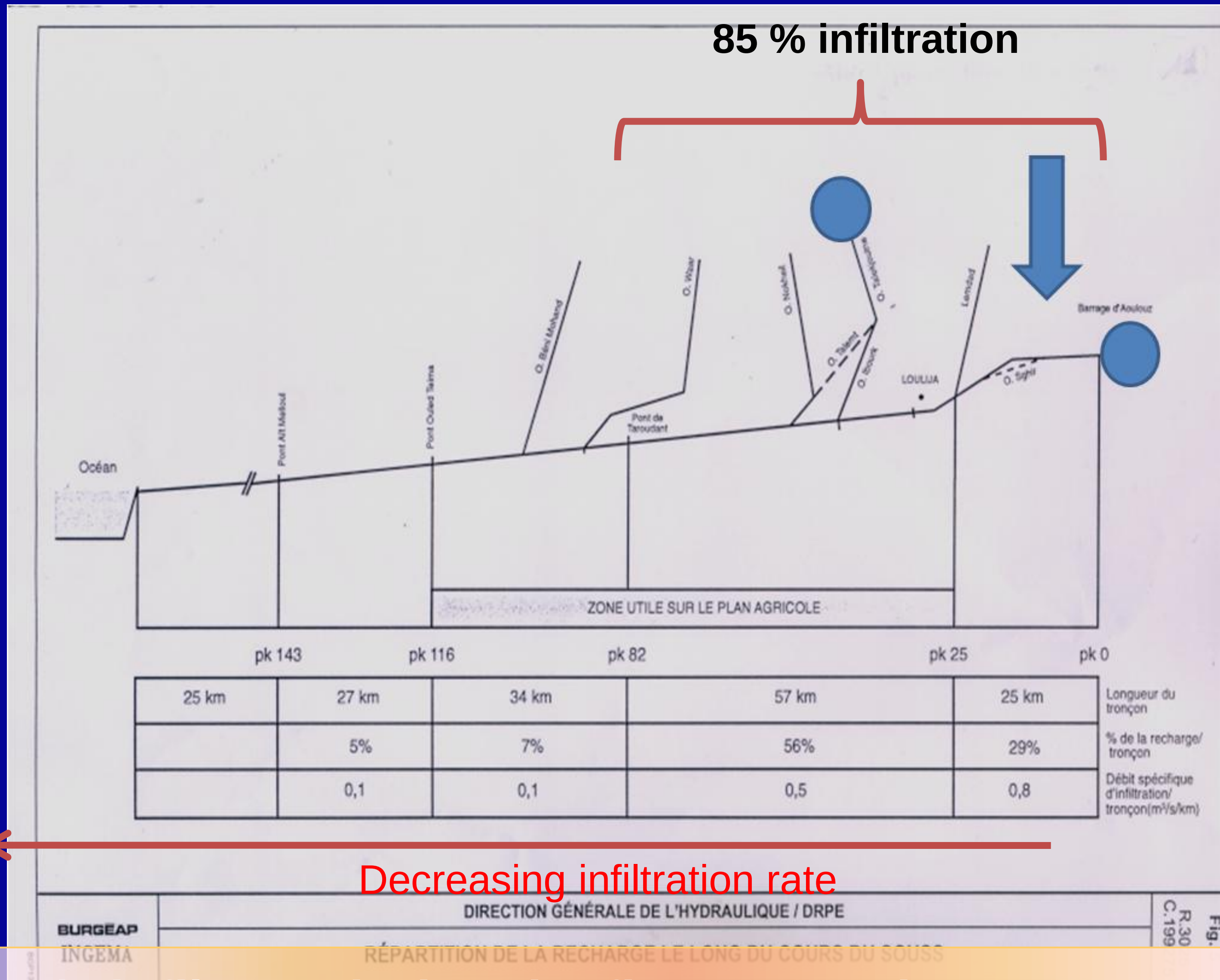
ANNEES	SEPT.	OCT.	NOV.	DEC.	JANV.	FEV.	MARS	AVRIL	MAI	JUIN	JUIL.	AOUT	TOTAL
1991-92	0,000	1,065	1,425	33,576	2,565	36,666	0,000	0,000	65,549	0,000	9,904	0,000	**150,750**
92-93	8,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	4,099	0,000	**12,099**
93-94	0,000	0,000	21,979	2,287	0,000	0,000	0,000	0,000	27,719	2,187	0,000	0,000	**54,172**
94-95	0,000	0,000	0,000	0,000	0,000	0,000	0,000	10,260	0,000	0,000	0,000	0,000	**10,260**
95-96	9,000	0,000	0,000	0,000	70,493	68,254	104,052	21,344	2,880	81,884	44,994	10,739	**413,640**
96-97	2,284	2,180	3,219	37,441	67,427	33,661	23,121	50,515	12,798	5,496	0,542	39,579	**278,263**
97-98	1,233	5,014	4,905	0,044	0,000	35,312	22,987	5,432	0,259	77,497	18,468	11,500	**182,651**
98-99	7,115	1,242	0	0	0	0	0	0	0	0	0	0	**8,357**
1999-2000	0	0	0	0	0	0	0	0	0	0	35,460	0	**35,460**
2000-2001	0	0	0	0	0	0	0	0	0	0	0	0	**0**
2001-2002	0	0	0	0	0	0	0	0	0	0	25,656	0	**25,656**
2002-2003	27,648	0	0	0	0	6,912	4,896	0	0	0	0	0	**39,456**
2003-2004	20,160	19,958	16,632	0,000	22,716			0	0	0	0	0	**79,466**
TOTAL	75,440	29,459	48,160	73,348	163,201	180,805	155,056	87,551	109,205	167,064	139,123	61,818	**1171,308**
MOYENNE	5,803	2,266	3,705	5,642	12,554	15,067	12,921	6,735	8,400	12,851	10,702	4,755	**106,483**

Les volumes sont en Mm3.

Evaluation of the recharge after the construction of the dam

- Discharge released from the dam: 50 to 80 m^3/s
- Discharge in 12 y : 1 200 Mm^3
- Repartition of the released flow:
  - infiltration : 86%
  - Direct irrigation : 14%
  - Lose to the ocean : 0 %
- Annual Recharge : 100 Mm^3/y

EVALUATION OF DISCHARGE FROM DAM



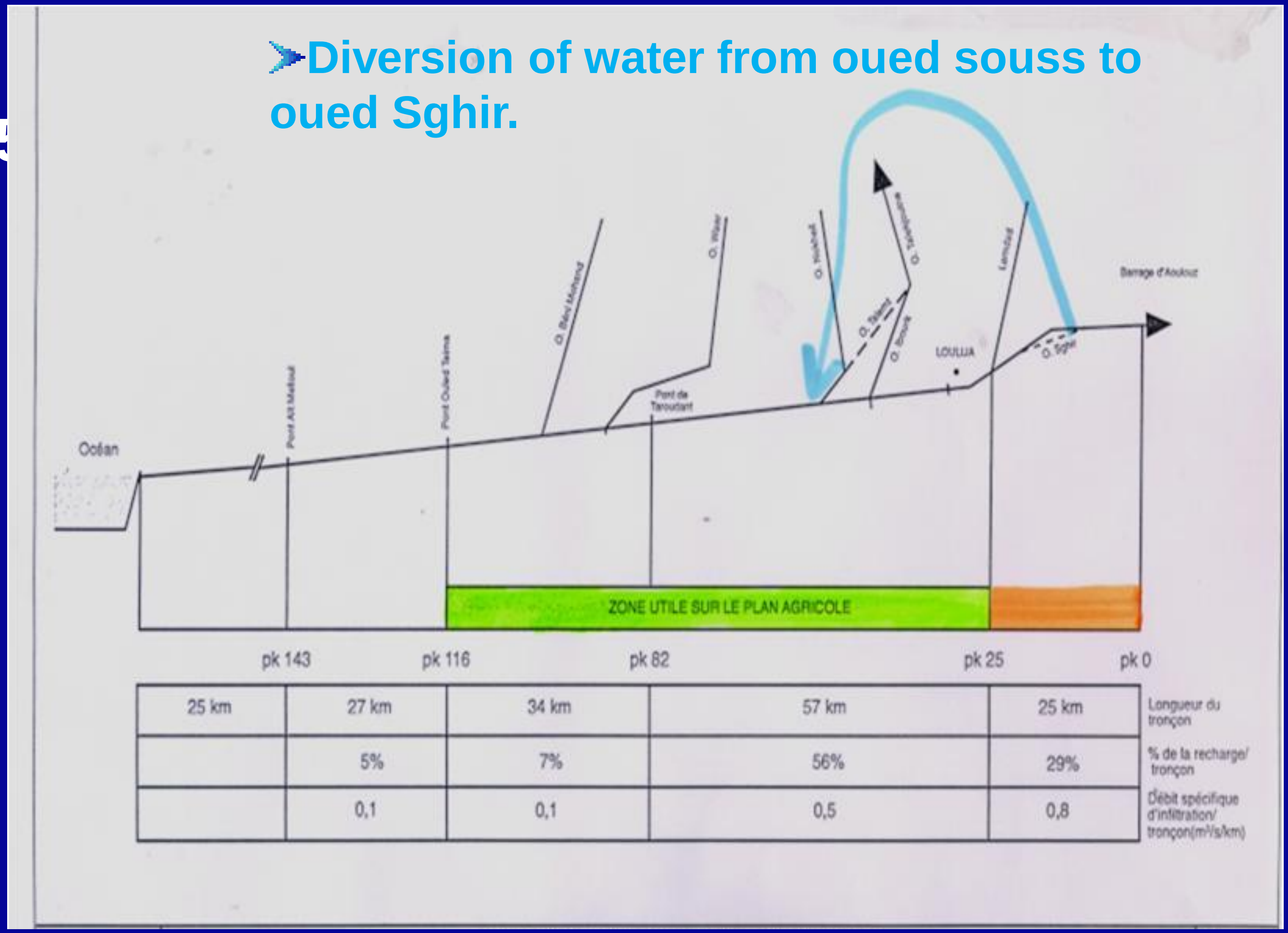
25 km	27 km	34 km	57 km	25 km	Longueur du tronçon
	5%	7%	56%	29%	% de la recharge/ tronçon
	0,1	0,1	0,5	0,8	Débit spécifique d'infiltration/ tronçon(m^3/s/km)

Q < 30 m3/s infiltrate during the first 30 Km (zone not useful for the agriculture)

Possible improvements for the recharge dispositive

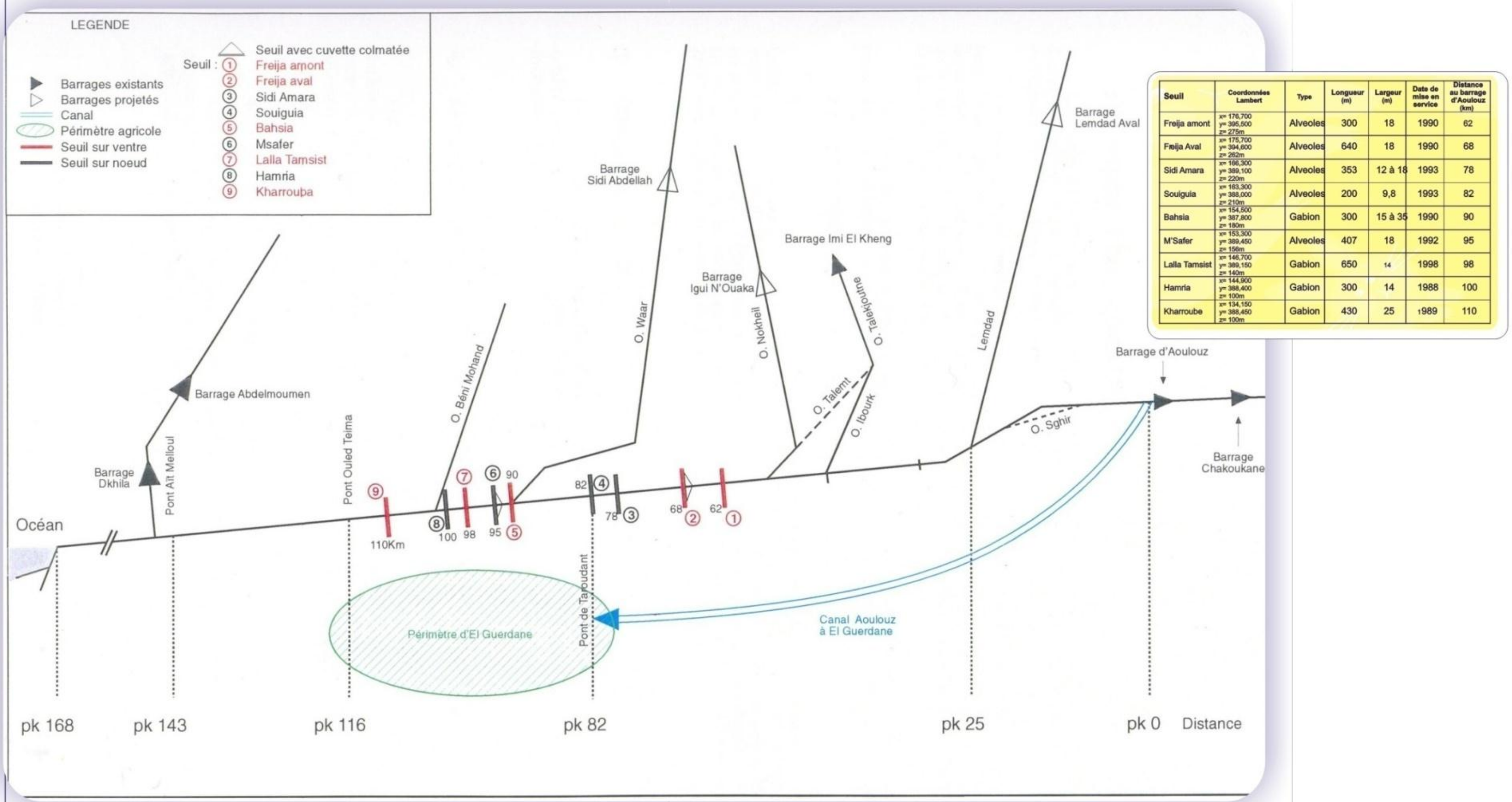
✓ **Recharge in the useful areas for the agriculture**

- **Reduce the infiltrated Q (25 km from dam)**
- **Increasing the Q infiltrated in useful areas(90km).**
- **Increasing the recharge from the tributaries**



✓Transfer from dam for irrigation

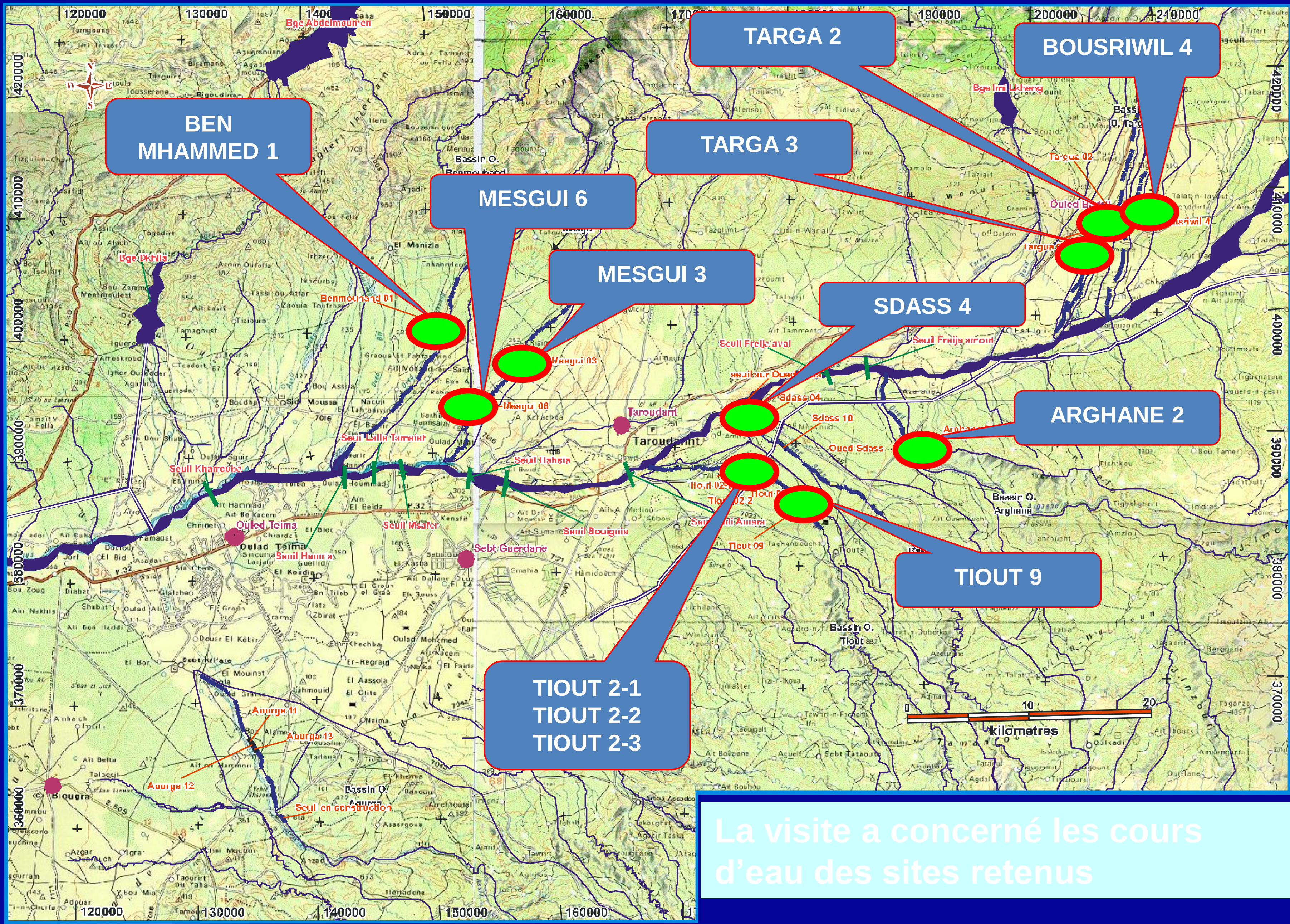
ETUDE D'EXECUTION DES SEUILS DE RECHARGE ARTIFICIELLE DE LA NAPPE DU SOUSS DANS LA PROVINCE DE TAROUDANT



Seuil	Coordonnées Lambert	Type	Longueur (m)	Largeur (m)	Date de mise en service	Distance au barrage d'Aoulouz (km)
Freija amont	x= 176,700 y= 395,500 z= 275m	Alveoles	300	18	1990	62
Freija Aval	x= 175,700 y= 394,600 z= 262m	Alveoles	640	18	1990	68
Sidi Amara	x= 166,300 y= 389,100 z= 220m	Alveoles	353	12 à 18	1993	78
Souiguia	x= 163,300 y= 388,000 z= 210m	Alveoles	200	9,8	1993	82
Bahsia	x= 154,500 y= 387,800 z= 180m	Gabion	300	15 à 35	1990	90
M'Safer	x= 153,300 y= 389,450 z= 156m	Alveoles	407	18	1992	95
Lalla Tamsist	x= 146,700 y= 389,150 z= 140m	Gabion	650	14	1998	98
Hamria	x= 144,900 y= 388,400 z= 100m	Gabion	300	14	1988	100
Kharroube	x= 134,150 y= 388,450 z= 100m	Gabion	430	25	1989	110

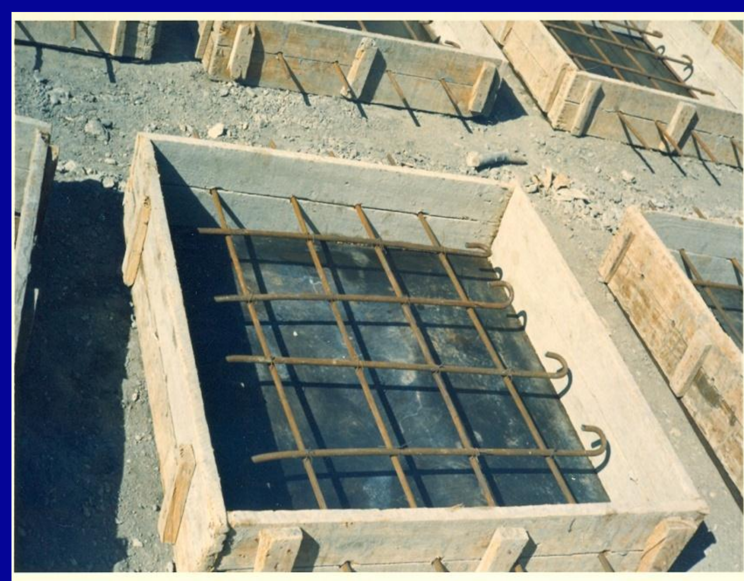
ABHSM	SCHEMA SYNOPTIQUE DES AMENAGEMENTS EXISTANTS ET BARRAGES PROJETES	SOMATEP

New sites on the tributaries of oued Souss



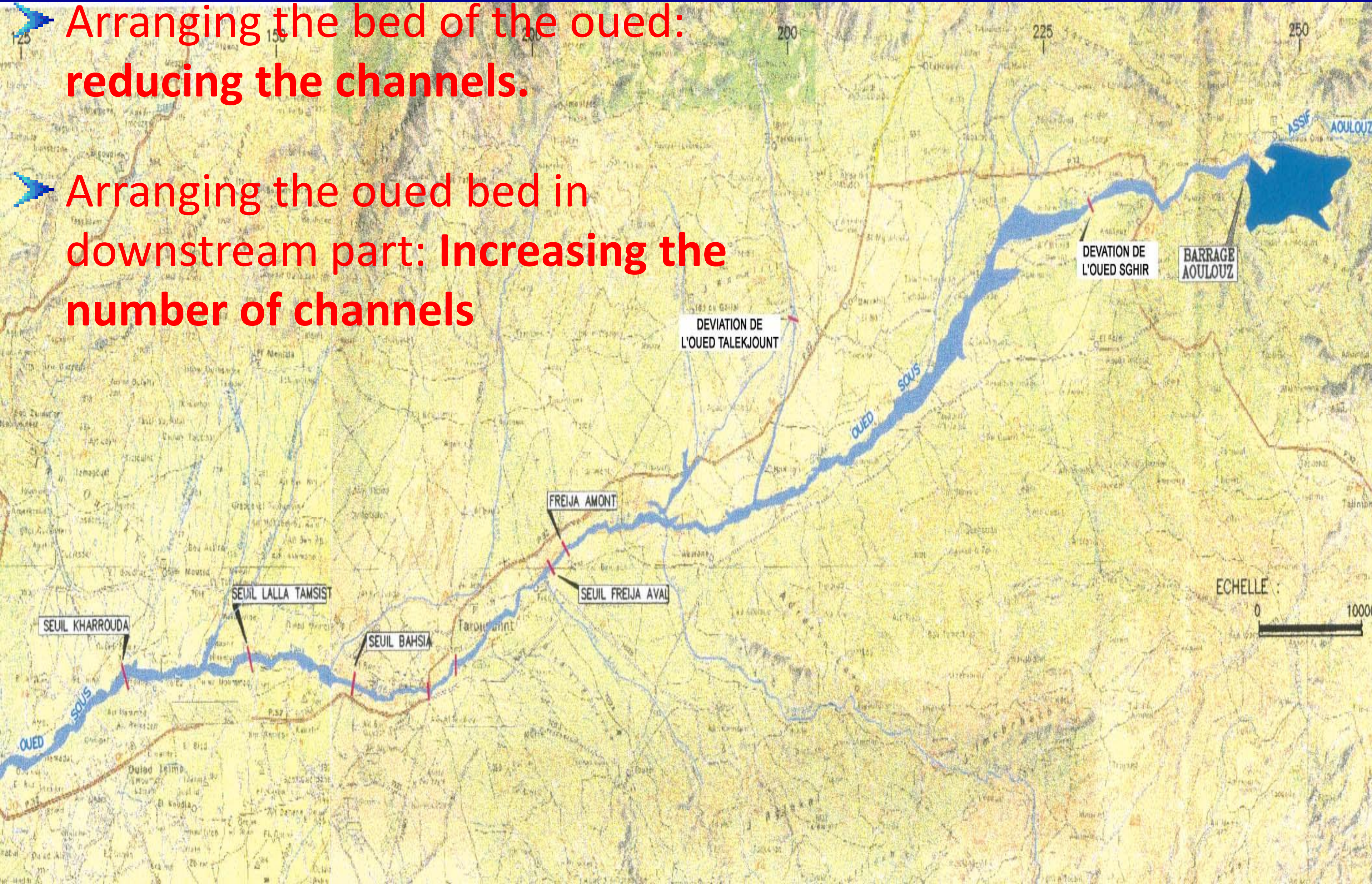
La visite a concerné les cours d'eau des sites retenus





Selected sites for artificial recharge improvement

- Arranging the bed of the oued: **reducing the channels.**
- Arranging the oued bed in downstream part: **Increasing the number of channels**



All areas arranged for the infiltration are filled by clays…

Degradations of thresholds by flooding

ABHSMD

Cost of cleaning

Description	Surface (m2)	Volume (m3)	Coût d'un curage (35 DH/m3)
FREIJA Amont	150 000	300 000	10 500 000
FREIJA Aval	400 000	350 000	12 250 000
SIDI AMARA	200 000	250 000	8 750 000
SOUIGUIA	150 000	20 000	700 000
BAHSIA	100 000	150 000	5 250 000
M'SAFER	320 000	200 000	7 000 000
LALLA TAMSIST	390 000	250 000	8 750 000
HAMRIA	150 000	300 000	10 500 000
KHARROUBA	200 000	300 000	10 500 000
TOTAL	**2 060 000**	**2 120 000**	**74 200 000**

Environmental Evaluation

- Positive socio-economic Impact
- Agro-economic improvement in downstream to balance the negative aspects

Case of Draa basin

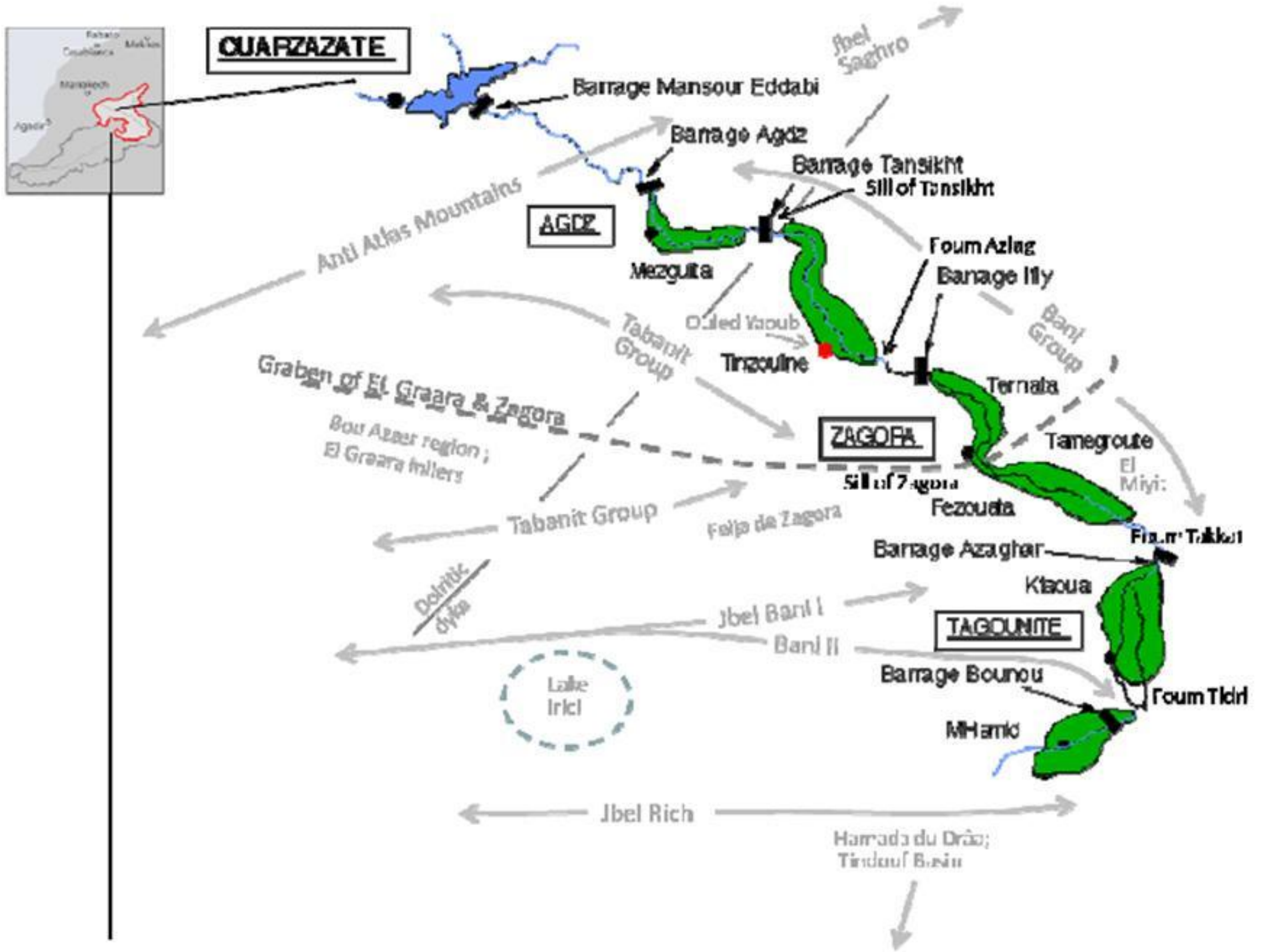
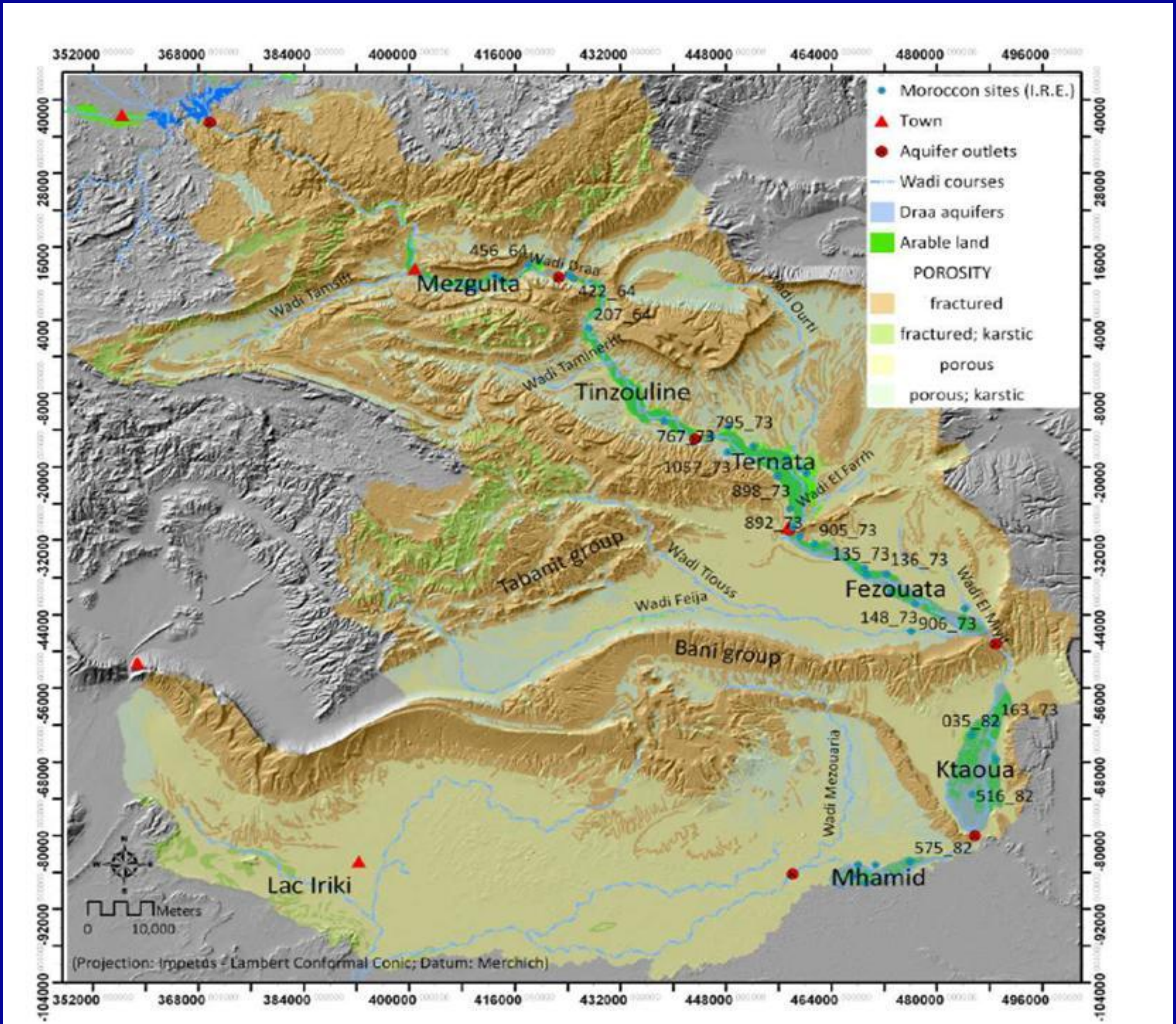
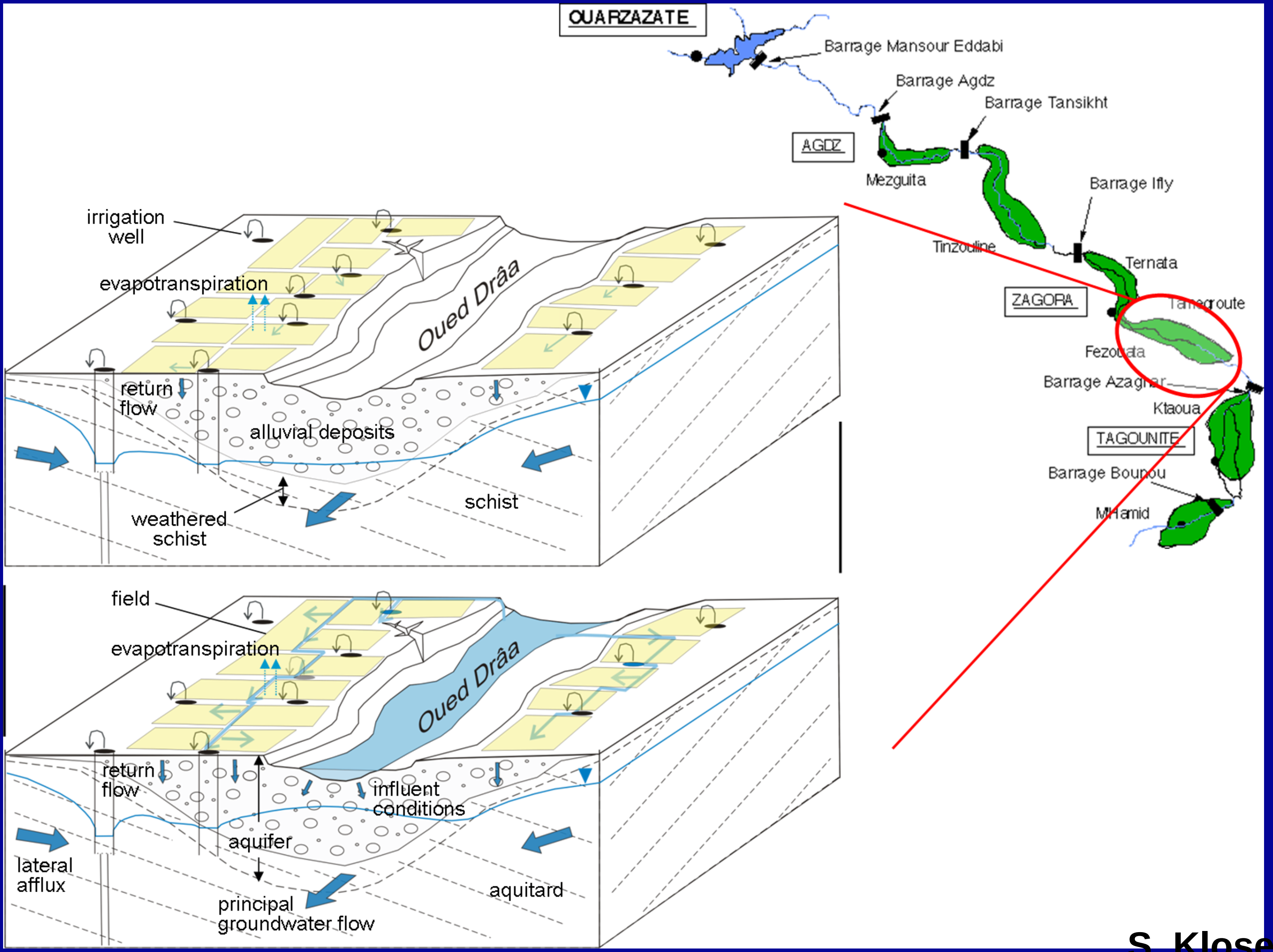


Figure 2-1: Scheme of the study area with the oases belt along the Wadi Drâa and the adjacent main features of landscape and geology.

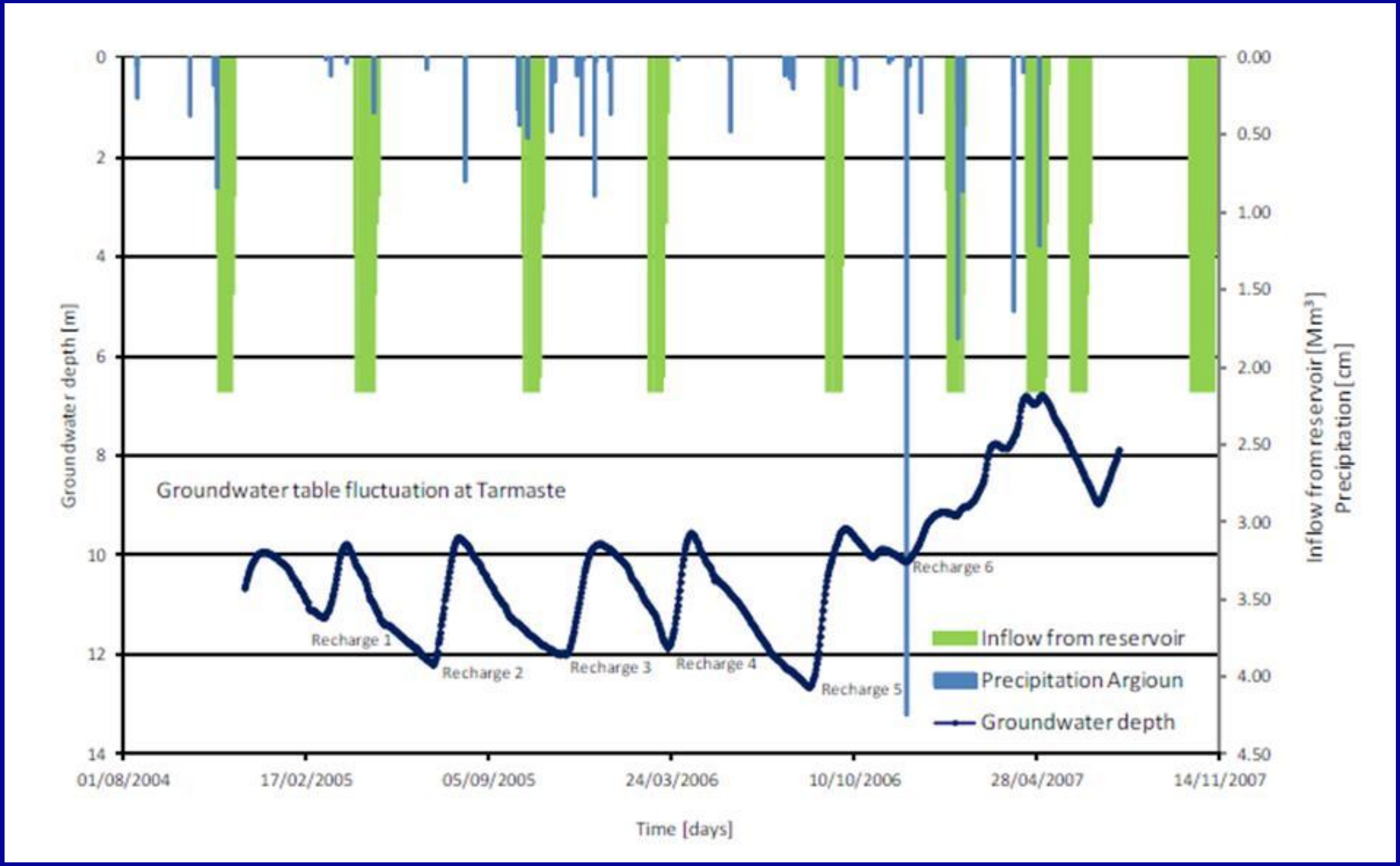

Moroccon sites (I.R.E.)
Town
Aquifer outlets
Wadi courses
Draa aquifers
Arable land
POROSITY
fractured
fractured; karstic
porous
porous; karstic
Mezguita
Tinzouline
Ternata
Fezouata
Ktaoua
Mhamid
Lac Iriki
Tabanit group
Bani group
Wadi Draa
Wadi Tamsift
Wadi Taminert
Wadi Ourti
Wadi El Farrh
Wadi Tiouss
Wadi Feija
Wadi Mezouaria
Meters
0 10,000
(Projection: Impetus - Lambert Conformal Conic; Datum: Merchich)

S. Klose, 2012

Conceptual model

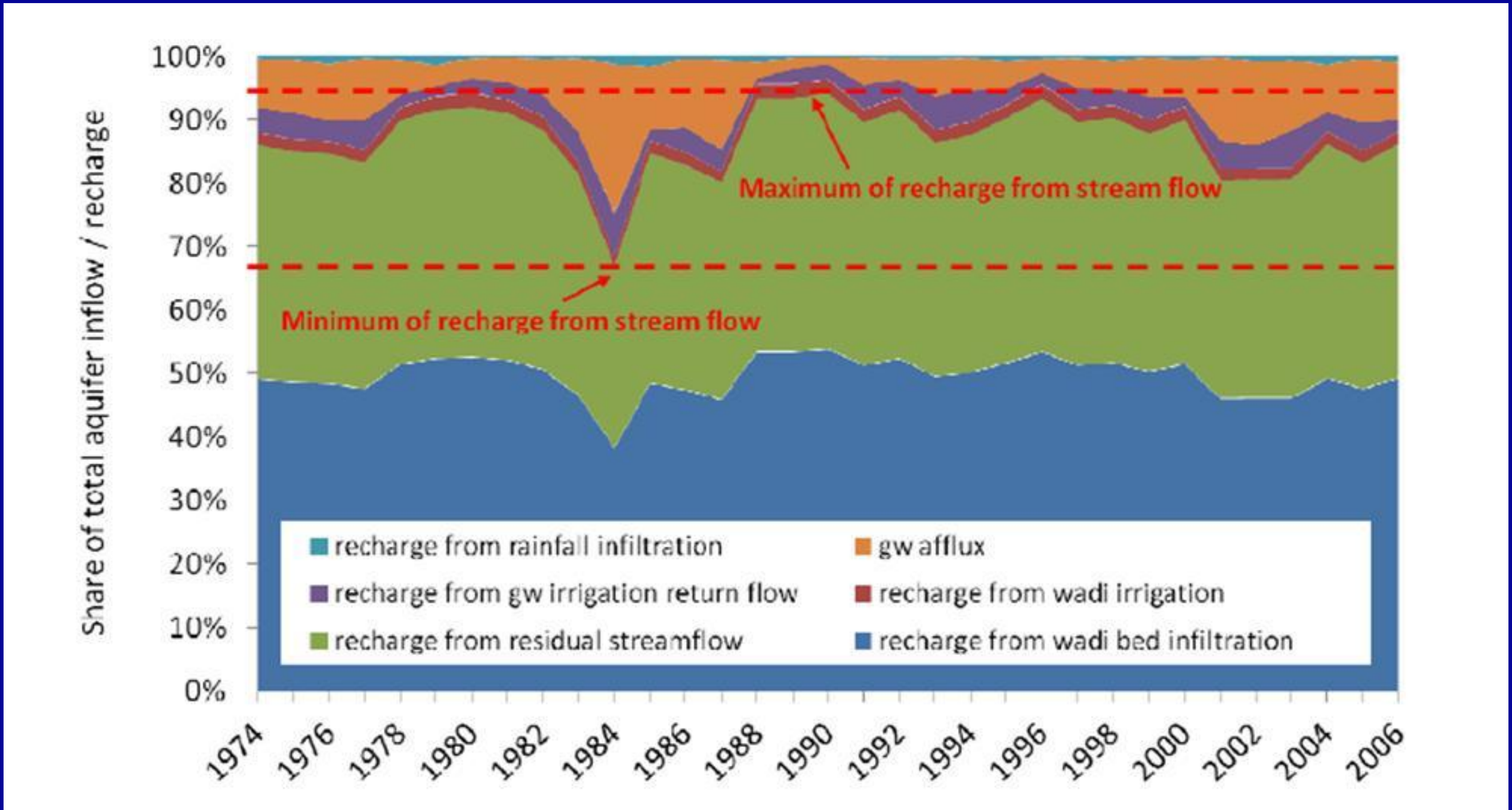


S. Klose, 2012



Groundwater table fluctuation at Tarmaste
Groundwater depth [m]
Inflow from reservoir [Mm³]
Precipitation [cm]
Recharge 1
Recharge 2
Recharge 3
Recharge 4
Recharge 5
Recharge 6
Inflow from reservoir
Precipitation Argioun
Groundwater depth
0
2
4
6
8
10
12
14
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
01/08/2004
17/02/2005
05/09/2005
24/03/2006
10/10/2006
28/04/2007
14/11/2007
Time [days]

S. Klose, 2012



Share of total aquifer inflow / recharge
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Maximum of recharge from stream flow
Minimum of recharge from stream flow
recharge from rainfall infiltration
gw afflux
recharge from gw irrigation return flow
recharge from wadi irrigation
recharge from residual streamflow
recharge from wadi bed infiltration
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006

S. Klose, 2012







Perspectives:

The water resources sustainability, The agricultural production and the domestic use of water in ecosystem under semi-arid climate are subjected to various constraints

- **Domestic water use**
- **Availability of surface water (GW recharge)**
- **Requirements out of water for the cultures (crops)**
- **Availability of GW water**
- **Salinity of the soil**

Objective: **to develop a fully integrated water resources management and land management approach, replicable to the sensitive ecosystems**

Activities: **Improve knowledge on GW resources, socioecon. dev. of the area and related GW needs, analysis of irrigated agricultural production systems…**

INTEGRATED WATER MANAGEMENT
the general wisdom

- **multi-disciplinary approach** *(managing people)*
  - **socio-economic, legal and institutional**
  - **(as well as) technical and environmental**

- **cross-sectorial vision** *(macro and micro level)*
  - **urban infrastructure design and operation**
  - **agriculture cropping policy and practice**

Adaptation to the impacts climate Changes

To discuss with you

- Which indicators can we use for sustainability, vulnerability, renewability….??
- Is MRT useful indicator in an assessment of groundwater that supplementing the knowledge from other measurements?
- Artificial recharge…….?? Other cases

Thank you for your attention

Average Precipitation:

High-Atlas Mountains	Souss-Massa Basin	Anti-Atlas Mountains
350-800 mm yr-1	240 mm yr-1	250-350 mm yr-1

Recharge - outflow = deficit

Drinking Well AC25 in the South part of the Basin

Cl^-	1136 mg/L
Na^+	740 mg/L
$\delta^{18}O$	-3.34 ‰
δD	-26 ‰
$^{36}Cl/Cl$	12×10^{-15}