# REGIONAL MODEL FOR SEAWATER INTRUSION IN THE CHAOUIA COASTAL AQUIFER (MOROCCO)

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# Aim of the Study

**DEVELOPMENT OF A MATHEMATICAL MODEL FOR SIMULATING SWI IN THE CHAOUIA COASTAL AQUIFER**

**USE OF THE MODEL AS A MANAGEMENT TOOL FOR PLANNING AND WATER RESOURCES MANAGEMENT IN THE AQUIFER**

# PROBLEMS ?

## Chaouia Coastal Aquifer

- Area : 1200 km2
- Important role in the irrigation Development
- Aquifer over exploited

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- Water table drop about 0.6m per year
- Salt water intrusion advances
- Water quality degradation
- Increase of the abundoned pumping wells

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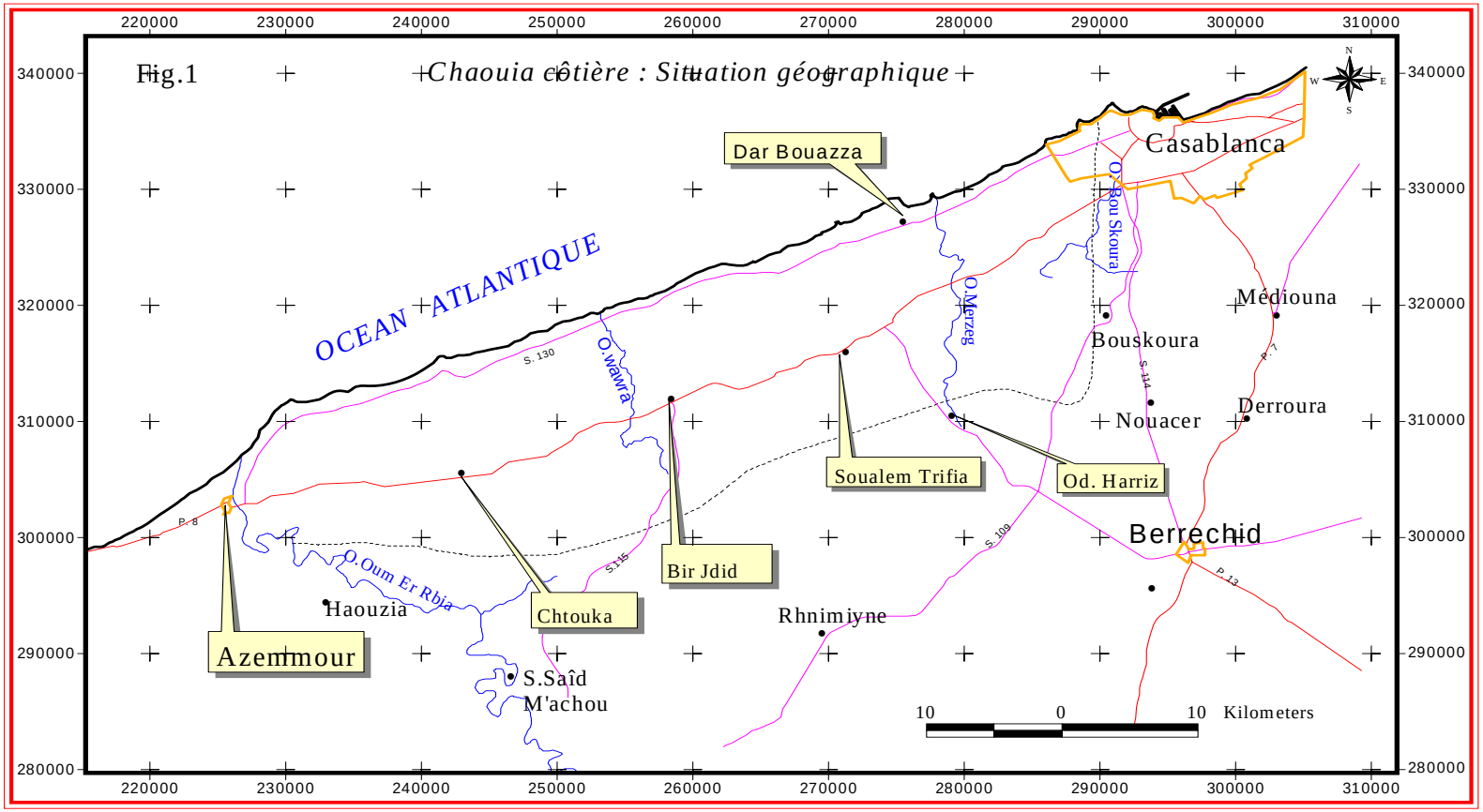
- Need of optimum management to protect the resource

# LOCATION



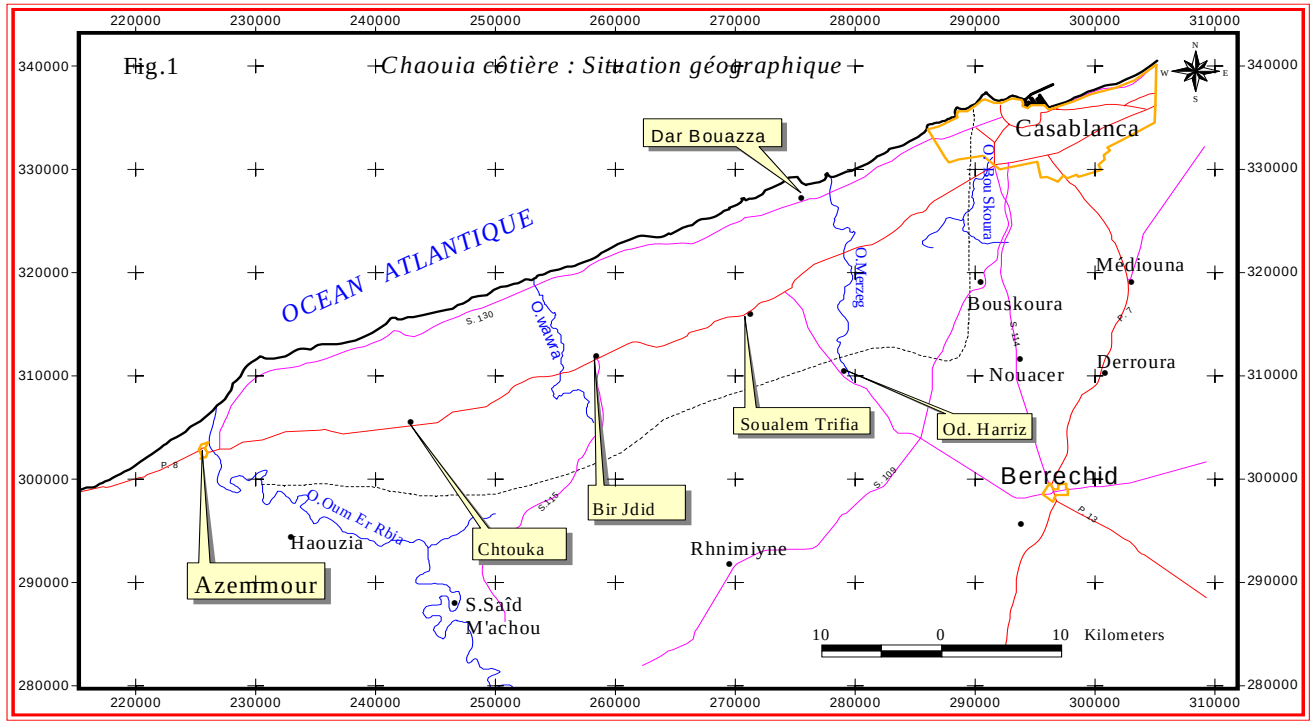

➡ MAIN CENTRES : TNINE CHTOUKA ; BIR JDID ; DAR BOUAZZA

➡ MAIN ACTIVITY : INTENSIVE AGRICULTURE

# CLIMATE

- **SEMI – ARID**
- Average yearly precipitation **400 mm**
- **Temperature 25° c**
- ETP **840 mm**

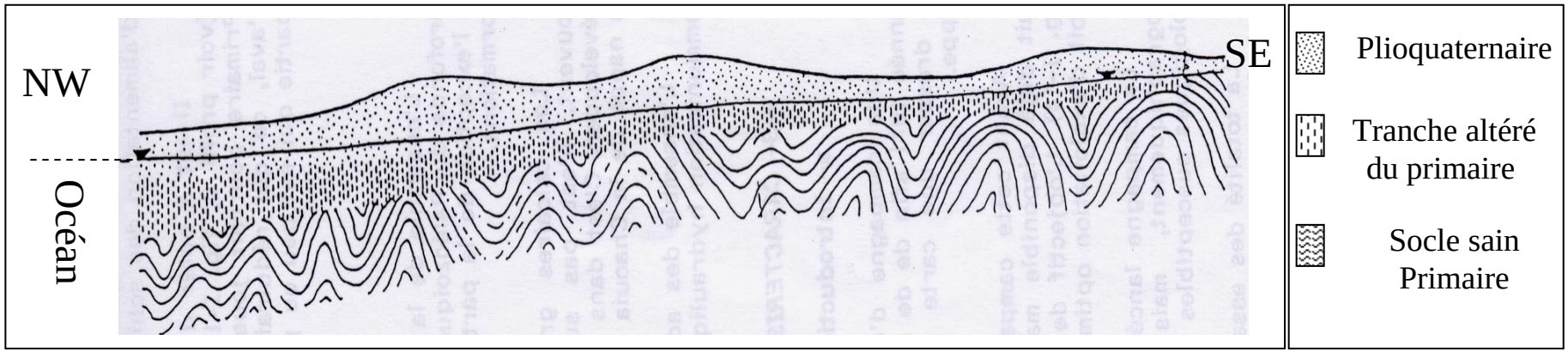
# HYDROLOGY




- The wadis **Merzeg** and **Houara** are of low importance
- Their flow is possible only for **short time during flooding**
- The **Oum ER Rbia river** and **Bouskoura Wadi are boundaries of the aquifer, but they don't hydraulically communicate with the system.**
- However, the **Oum er Rbia** river is draining the aquifer in the low areas.

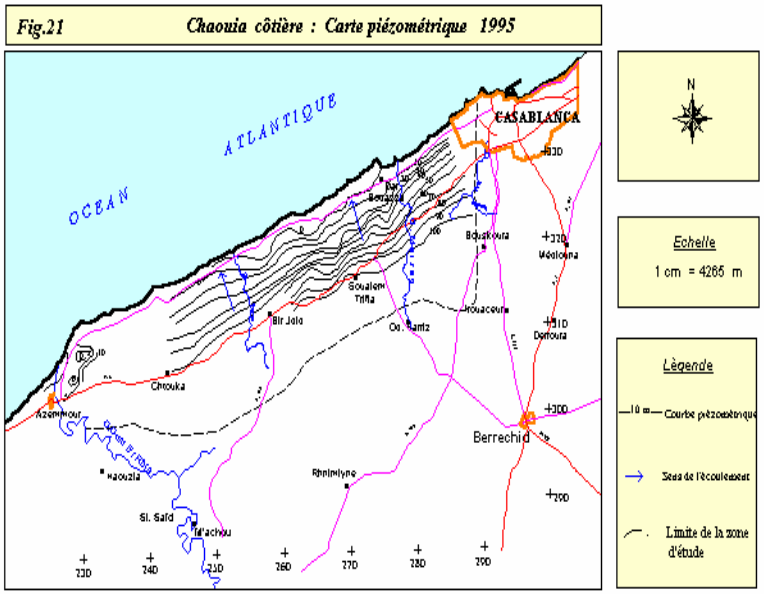
# HYDROGEOLOGICAL CONTEXT

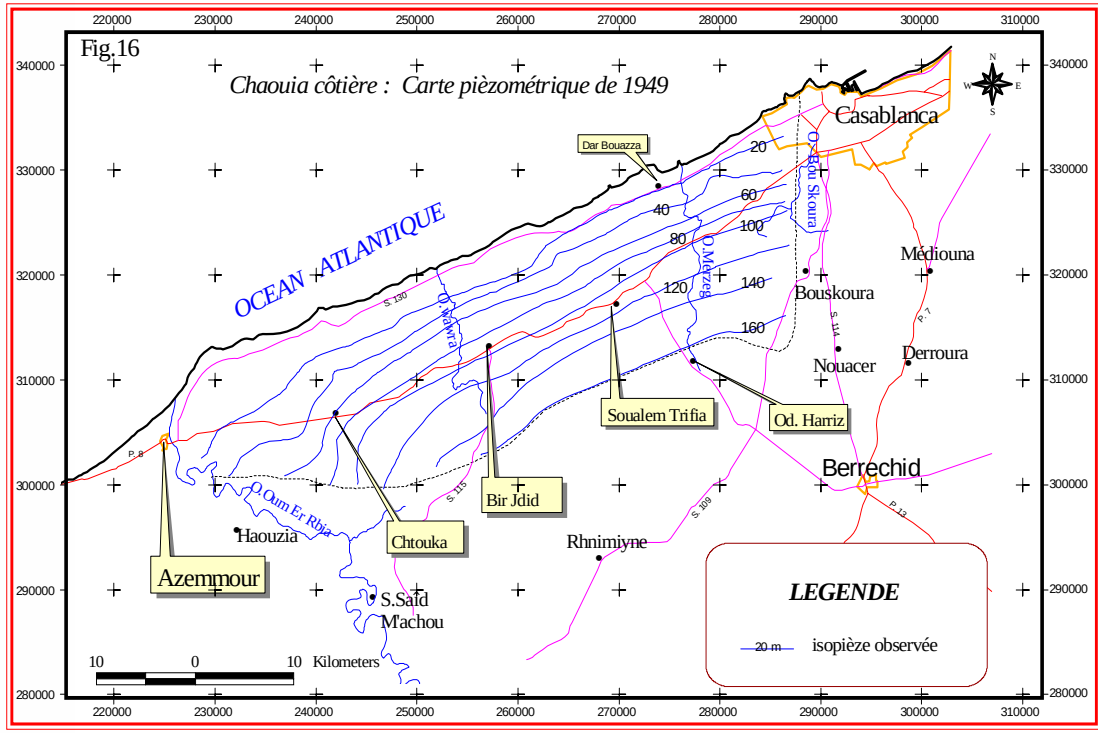
**hydrogeological scheme**




- *Substratum* : Bottom of the aquifer → schists
- *Aquifer formations :*
  - Altered schists
  - Calcareous and marls
  - Sandstone and calcareous
  - Consolidated dunes

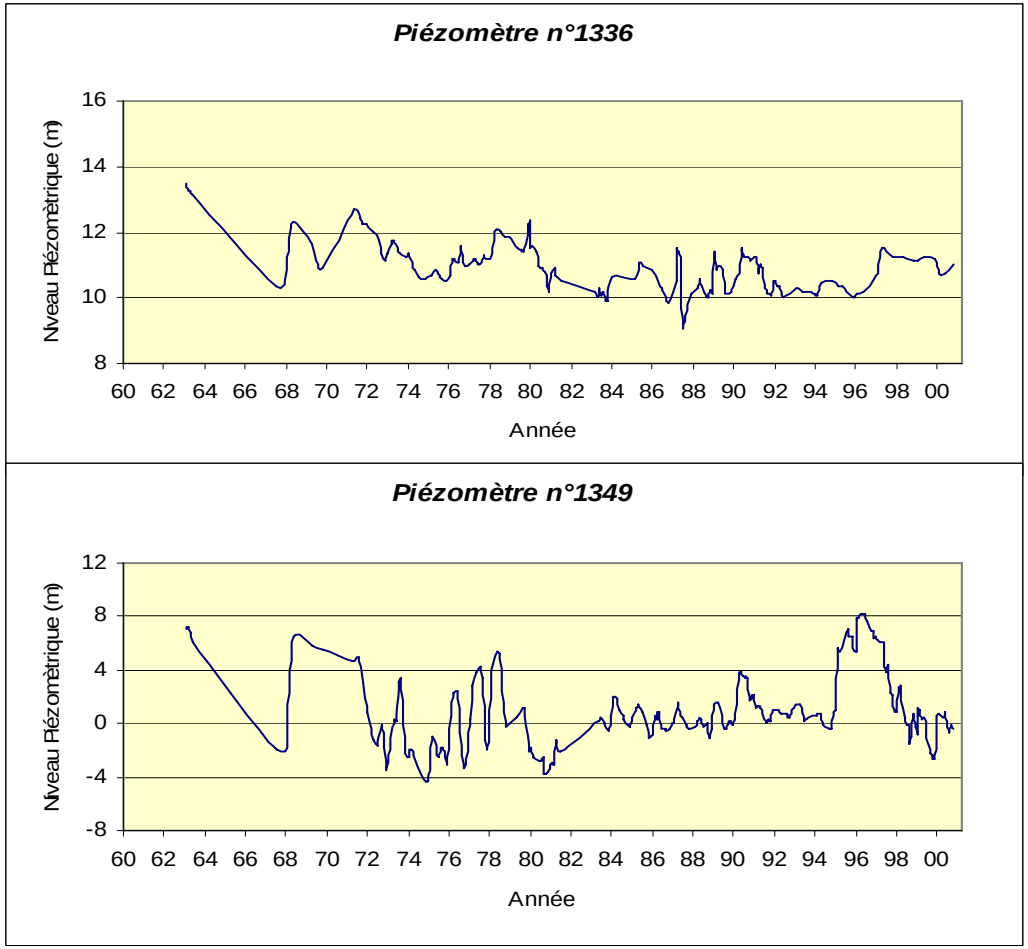
# Comparison of the piezometric maps 1949 and 1995




- **No deformed isolines** in the NE part (Tnine Chtouka et Azemmour) for 1949
- **New drainage axes** between Houara and Merzeg wadis in the coastal part in 1995 not visible in 1949
- **These axes are the results of permanent abstractions from the aquifer**

# Piezometric fluctuations :




- **Irregular evolution indicating piezometric fluctuations due to alternate sequences and rapid recharge/discharge such as pumping and irrigation.**

- **But, the general trend is decrease of the groundwater level.**

# THE MATHEMATICAL MODEL

# NUMERICAL CODE FOR MODELING SEWATER INTRUSION

## SEAWAT

**A Computer Program For Simulation of Three-Dimensional Variable-Density Ground-Water Flow (U.S.G.S.F)**

**MODFLOW**
**Hydrodynamic Model for variable density**

$$-\mathrm{div}(\rho V) + \rho q_s = \rho S_p \frac{\partial P}{\partial t} + n \frac{\partial \rho}{\partial C} \frac{\partial C}{\partial t}$$

$$\vec{V} = \frac{-k}{\mu} (\overrightarrow{\mathrm{grad}}\, P + \rho g \overrightarrow{\mathrm{grad}}\, z)$$

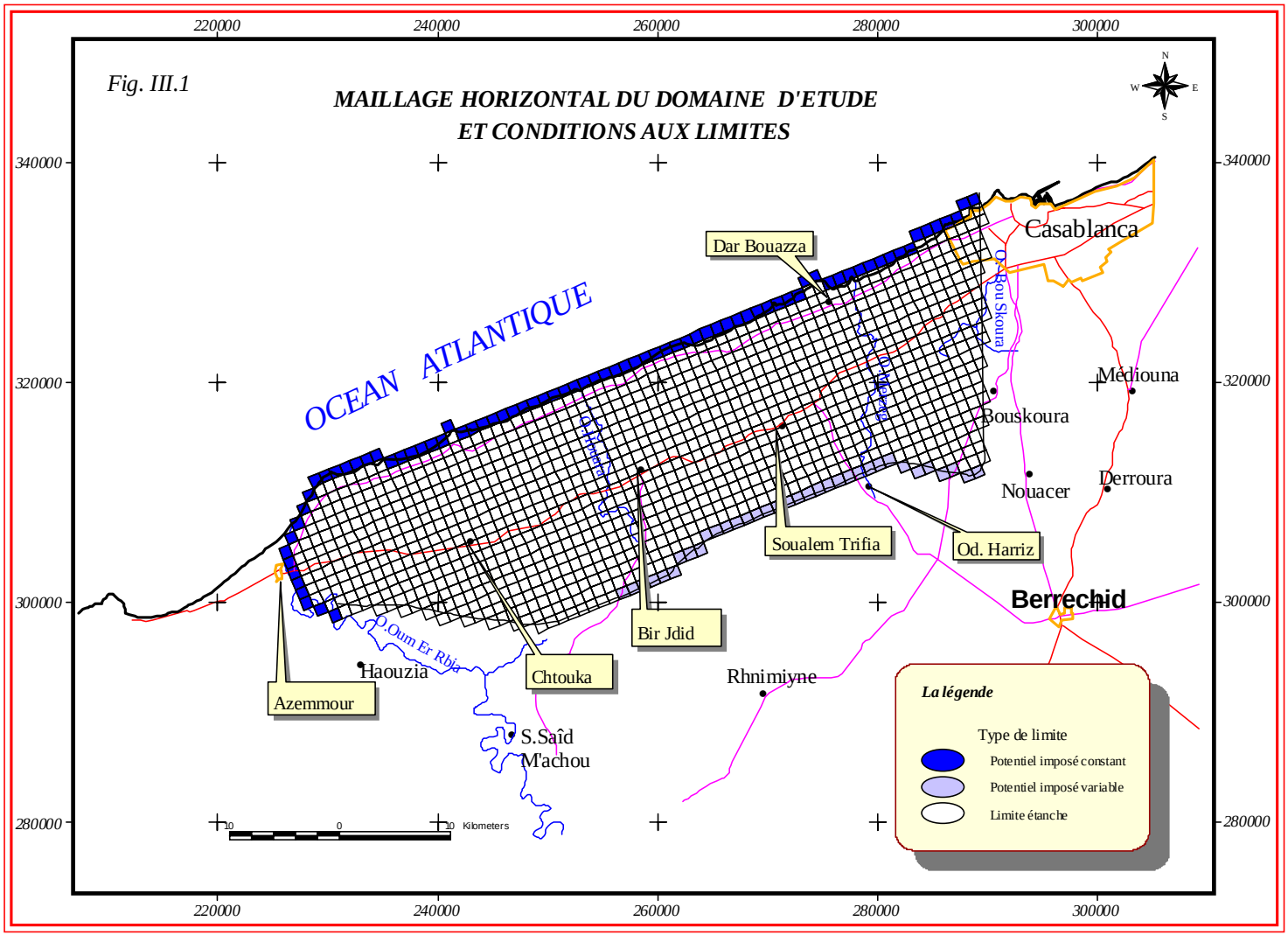
$$\rho = \rho_0 (1 + \delta)c$$

**MT3DMS**
**Solute Transport Model**

$$\frac{\partial C}{\partial t} = \underbrace{\frac{\partial}{\partial x_i}\left[D_{ij} \frac{\partial C}{\partial x_j}\right]}_{\text{Dispersion}} - \underbrace{\frac{\partial}{\partial x_i}(V_i C)}_{\text{Advection}} + \underbrace{\frac{q_s}{n} C_s}_{\text{Recharge/ Décharge}} + \underbrace{\sum_{k=1}^{N} R_k}_{\text{Réactions Chimiques}}$$

# CONCEPTUAL MODEL

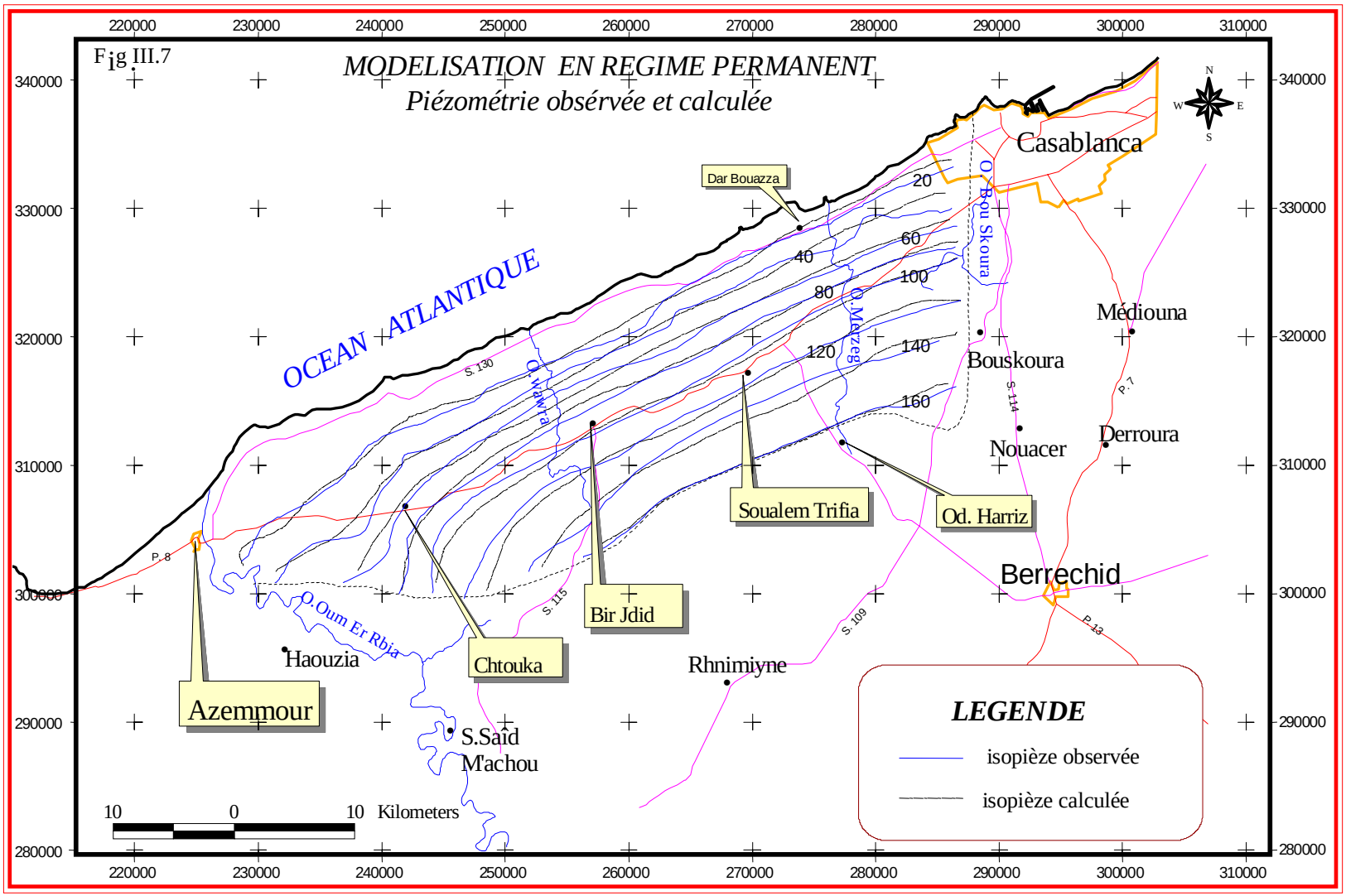
## Maillage et conditions aux limites




Mesh network : 71 COLUMNS, 24 ROWS and 8 LAYERS = 9680 SQUARE CELLS of 1000 m.

# MODELING RESULTS IN STEADY STATE

## CALCULATED PIEZOMETRY



# CALCULATED WATER BALANCE

| | TERMES DU BILAN | Volumes en $Mm^3$ /an |
|---|---|---|
| Entrées | Recharge par précipitation | 52.67 |
| | Alimentation par la nappe de Berrechid | 6.24 |
| | Total | 58.91 |
| Sorties | Perte en océan | 43.85 |
| | Sortie vers l'Oued Oum Er Rbia | 1.20 |
| | Evaporation | 13.34 |
| | Drainage par les sources | 0.53 |
| | Total | 58.91 |
| Erreur % | 7 E-6 | |

# FRESH – SALT WATER INTERFACE

# THE TRANSIENT MODEL

## OBJECTIVES

- Find out the starting period of Saltwater intrusion, and follow-up its evolution and its extent
- Identify the invaded zones by SWI and estimate the contamination degree
- Quantify the SWI inflow and the other balance terms

## Simulation period

- Transient period of simulation: 41 years from 1960 to 2001
- Consistant Data analysis has led to adopt 9 periods with a time step varying from 3 to 5 years

## Initial conditions

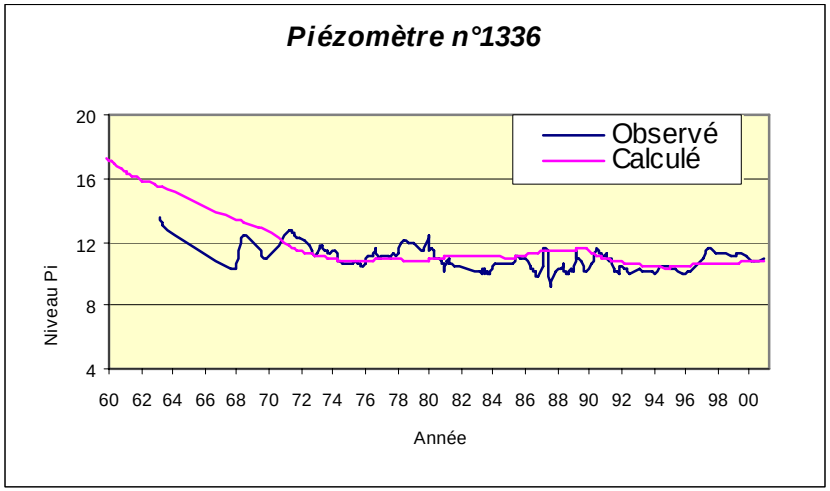
- Steady state results : distribution of the potential heads and the concentrations

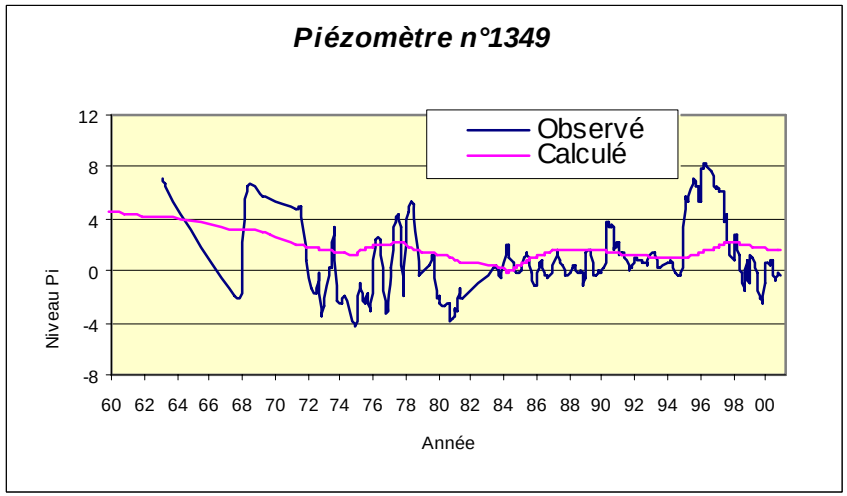
## Boundary conditions

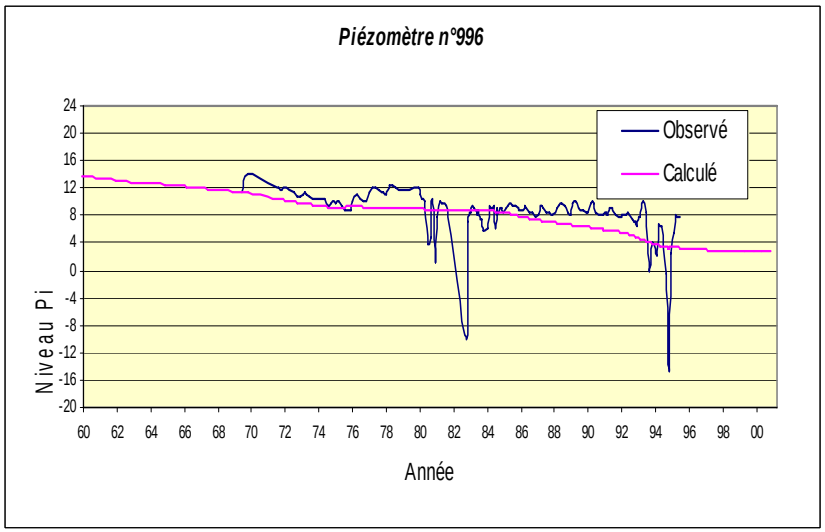
- South boundary :general variable head (GHB)
- Rest of the boundaries : same as in SS

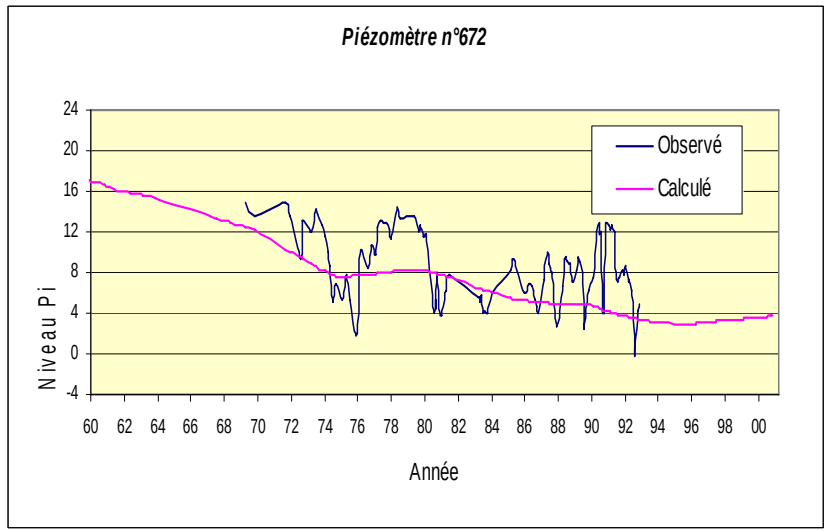
# RESULTS OF THE UNSTEADY MODEL

## CALCULATED PIEZOMETRY



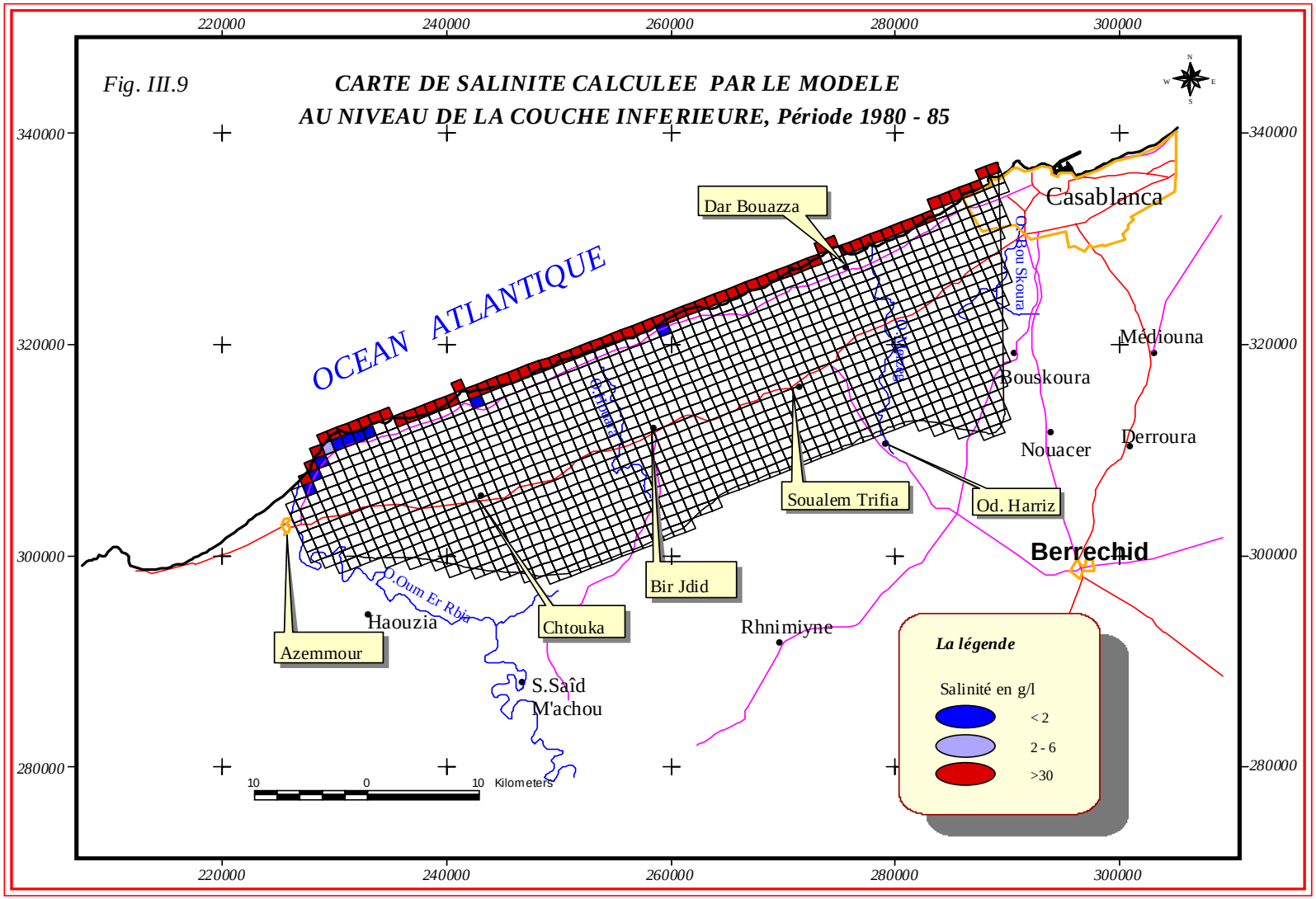



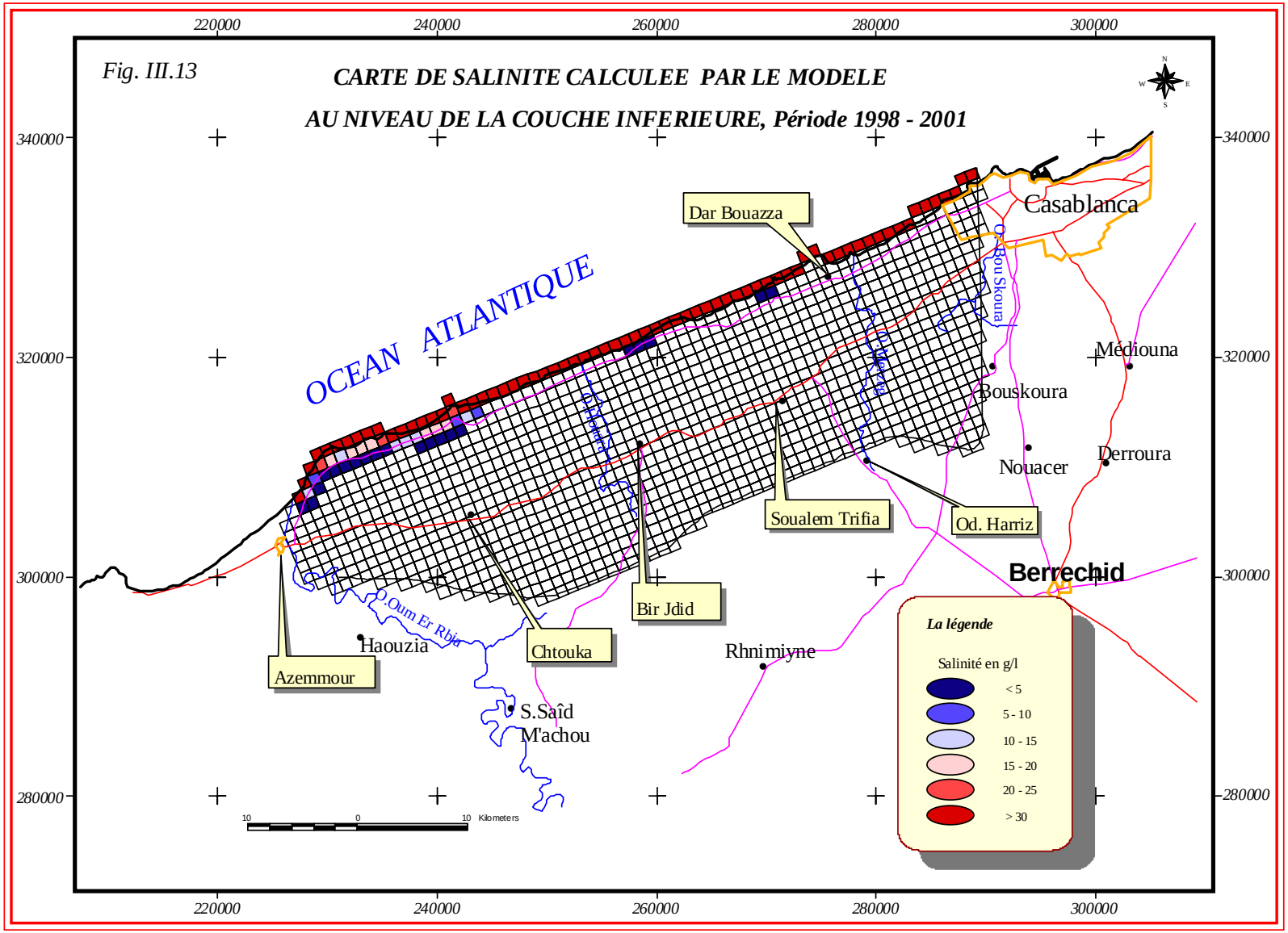
# CALCULATED WATER BALANCE

| Termes du bilan en $Mm^3/an$ | 1965 | 1970 | 1975 | 1980 | 1985 | 1990 | 1995 | 2001 |
|---|---|---|---|---|---|---|---|---|
| Entrées | | | | | | | | |
| Intrusion marine | 0 | 0 | 0 | 0 | 0.40 | 2.13 | 4.05 | 1.10 |
| Recharge par précipitations | 64.17 | 56.37 | 55.92 | 53.59 | 33.95 | 43.48 | 40.23 | 48.16 |
| Alimentation par la nappe de Berrechid | 5.86 | 5.53 | 4.56 | 3.72 | 3.08 | 2.81 | 2.67 | 2.37 |
| Entrées par l'Oued Oum Rbia | 0 | 0 | 0 | 0 | 0 | 0.06 | 0.15 | 0.14 |
| **Total des entrées** | **70.03** | **61.90** | **60.48** | **57.31** | **37.43** | **48.47** | **47.10** | **51.77** |
| Sorties | | | | | | | | |
| Déversement vers l'océan | 41.90 | 34.05 | 23.71 | 23.23 | 13.60 | 10.12 | 8.18 | 10.30 |
| Prélevement par pompage | 16.36 | 32.79 | 51.93 | 41.71 | 42.43 | 31.12 | 34.65 | 30.62 |
| Sources | 1.11 | 0.77 | 0.60 | 0.45 | 0.28 | 0.47 | 0.47 | 0.64 |
| Evaporation | 13.09 | 8.95 | 6.46 | 5.96 | 4.57 | 5.11 | 5.01 | 5.6 |
| Sorties vers l'Oued Oum R'bia | 1.08 | 0.98 | 0.92 | 0.87 | 0.50 | 0.40 | 0.37 | 0.38 |
| **Total des sorties** | **73.55** | **77.54** | **83.62** | **72.22** | **61.39** | **47.23** | **48.69** | **47.55** |
| Variation des réserves (destockage net) | 3.51 | 15.64 | 23.13 | 14.90 | 23.96 | -1.25 | 1.59 | -4.22 |

- **Negative variation of the reserves from beginning of 60, due to abstractions and successsive droughts.**
- **Reduced variation of the reserves after 1985**
- **Seawater intrusion starts**

# SEAWATER INTRUSION

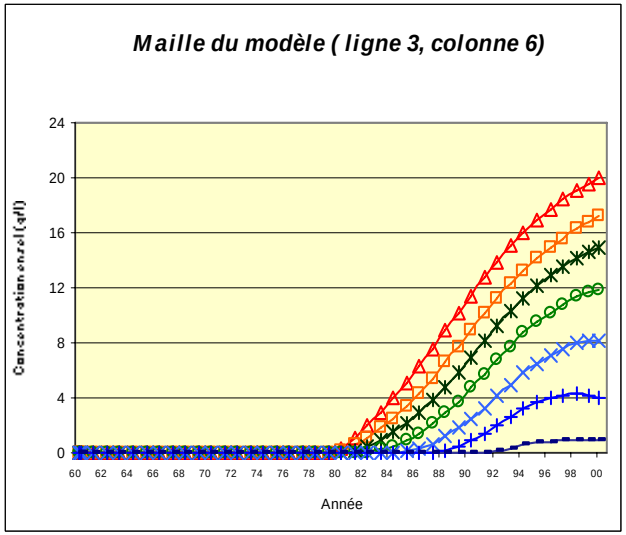


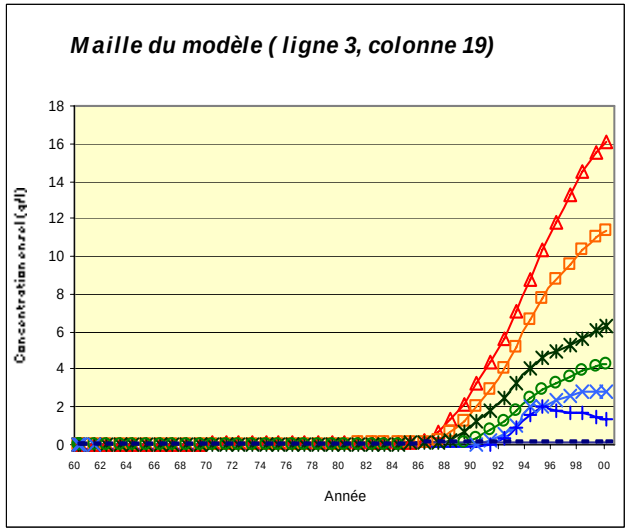


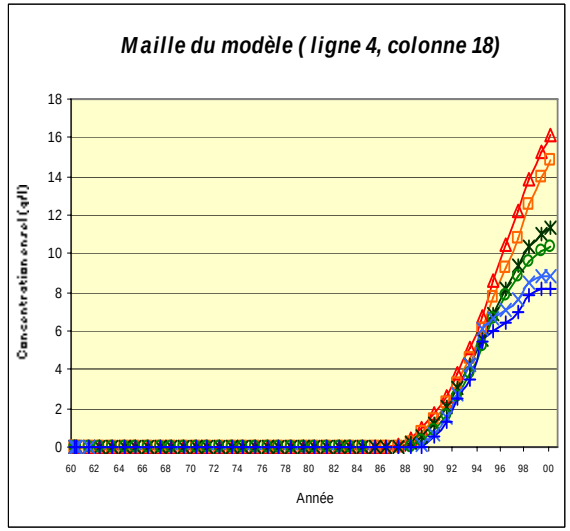

**South West part is more vulnerable to SWI due to :**

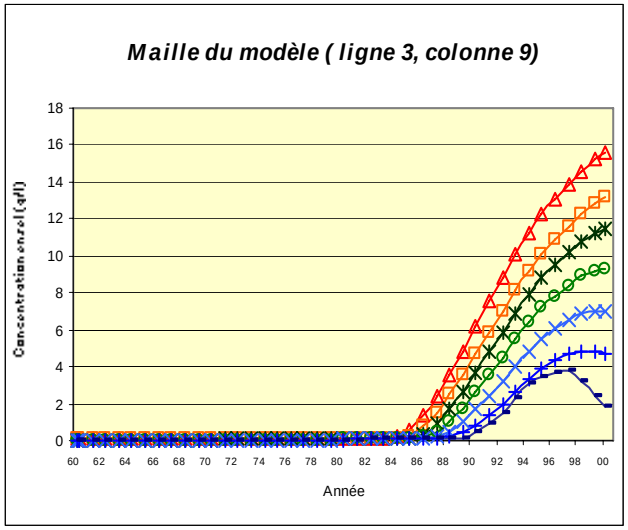
- **High values of local K**
- **Deeper aquifer bottom**
- **Concentration of the abstractions**

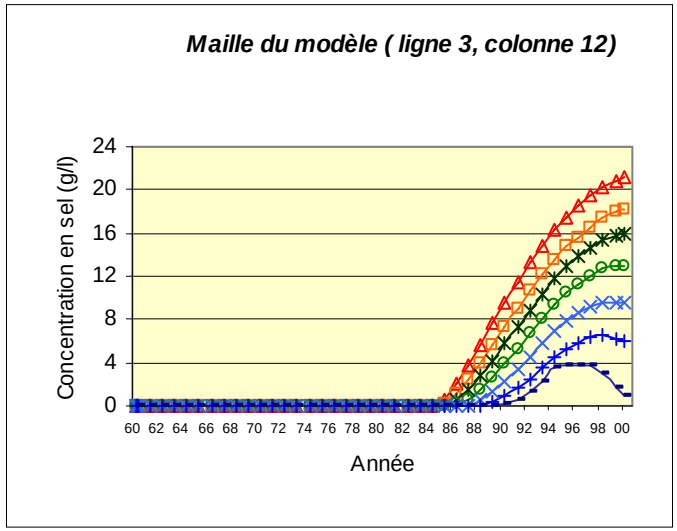
# SALINITY EVOLUTION

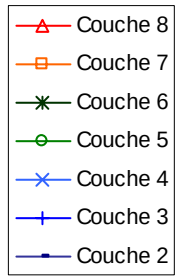


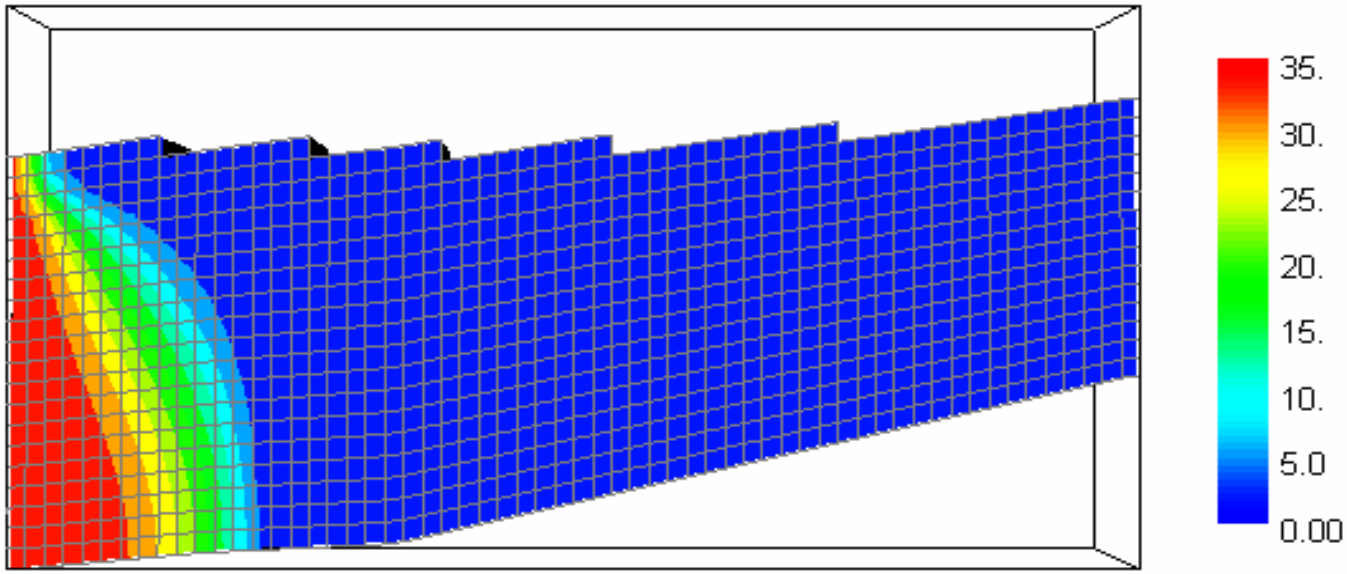




**Salinity exceeds 10g/l in deeper levels and is lower than 2g/l in the upper levels of the aquifer**

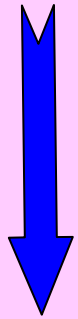
# DISTRIBUTION OF THE SALINITY in 2001




SWI starts in 1985 over some 100 m from the coast. The SWI front progressed until 1300 m in 2001

Time = 1.292e+009 (41-1-20)

**Satisfactory Model Results**



**Support Tool for Water Resources Planning and Management in the area**

# SIMULATION OF PREVISIONAL APPLIED SCENARIOS FOR WR MANAGEMENT

## SCENARIO 1 and 2

- Implementation of irrigation project from surface water in 2005 :
  - Water supply of 12Mm3/yr from the Oum Er Rbia river
  - Irrigated area : 2500 ha (346 farmers)
- Reduction of the abstractions in the SW coastal part over 3 km from the coast, just after the implementation of the irrigation project in 2005
- quasi-stabilisation pumping until the end of simulation to 22 $Mm^3/yr$.
- Scénario 1 : Normal recharge conditions
  Scénario 2 : Conditions less than the normal ones

## SCENARIO 3 and 4

- Keeping the present exploitation : 30,5 $Mm^3$/an
- Scénario 3 : Normal conditions of recharge
- Scénario 4 : Minimum conditions of recharge

## SCENARIO 5 and 6

- Keeping the present exploitation
- Artificial recharge of the aquifer through a serie of injection wells upstream of the highly contaminated zone (300 l/s)
- Scénario 5 : Normal conditions of recharge
  Scénario 6 : Minimum conditions of recharge

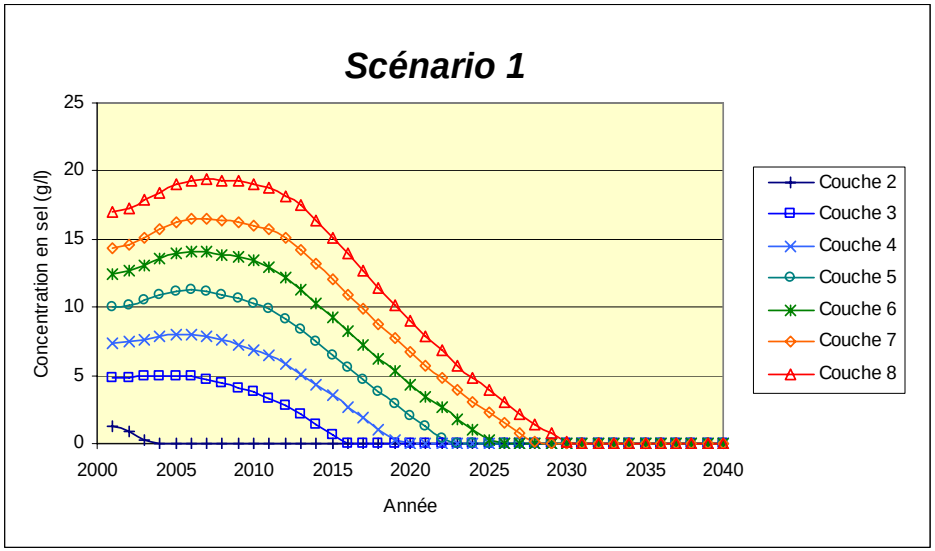
## Simulation period : **2001 à 2040**

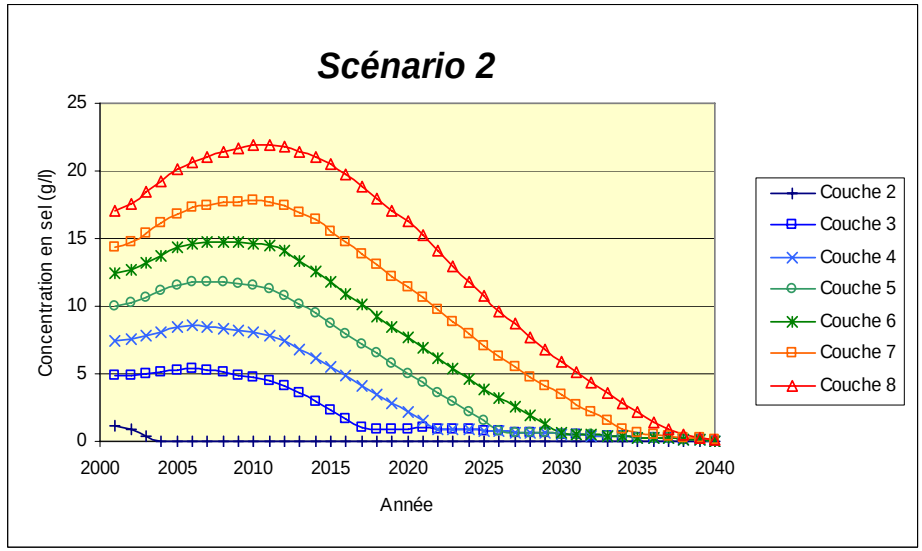
# SIMULATION RESULTS OF APPLIED SCENARIOS

## SCENARIO 1 and 2

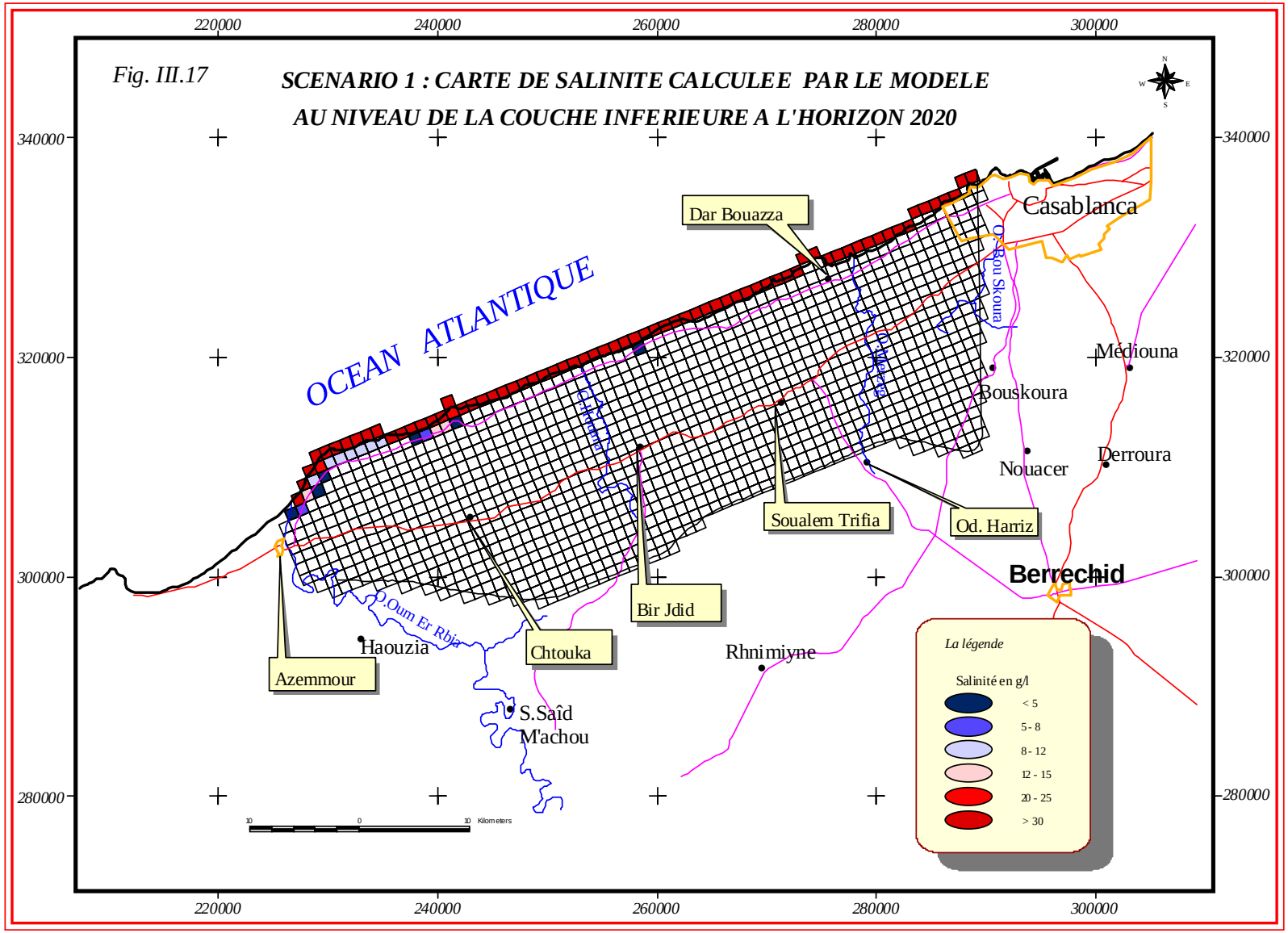
**Previsional seawater intrusion volumes ($Mm^3/yr$)**

| Année | 2005 | 2010 | 2015 | 2020 | 2030 | 2040 |
|---|---|---|---|---|---|---|
| Scénario 1 | 1.45 | 0.2 | 0 | 0 | 0 | 0 |
| Scénario 2 | 2 | 0.42 | 0.27 | 0.26 | 0.31 | 0.5 |

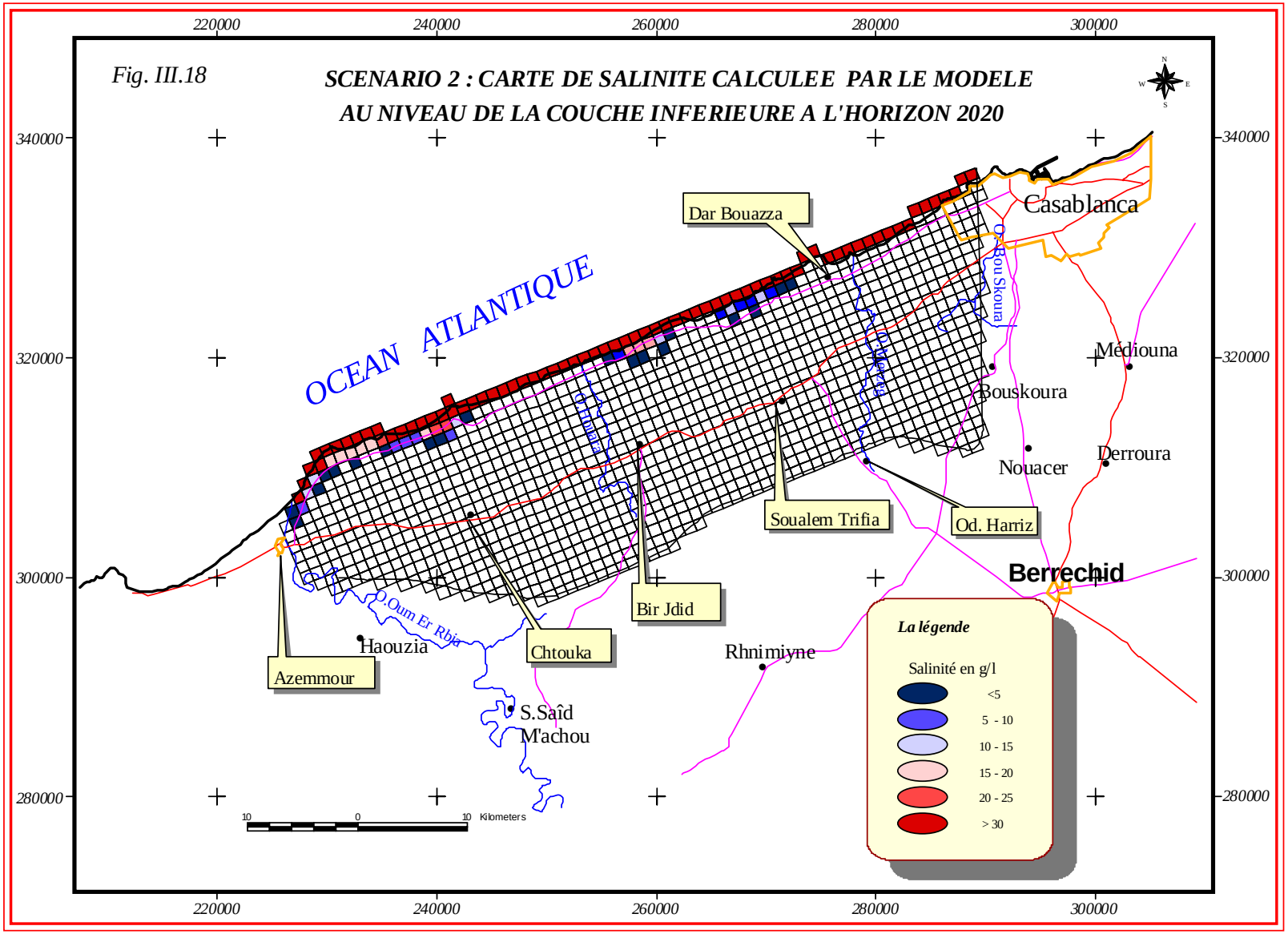



- **Restoration of the normal conditions after 2010**
- **Less improvement of water quality before 2020**
- **No good improvement of water quality before 2020**




- **Extent lenght of seawater intrusion :1km**
- **Significant Reduction of the salt concentrations**

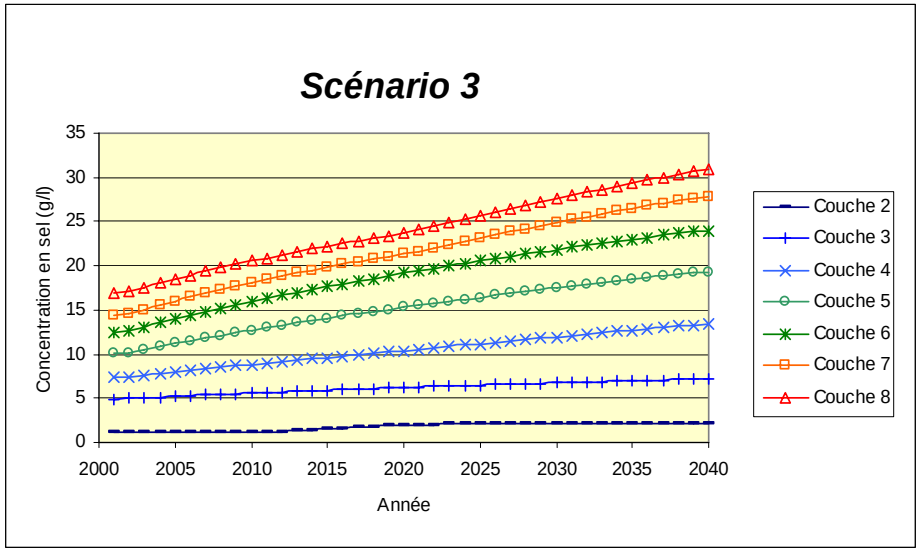


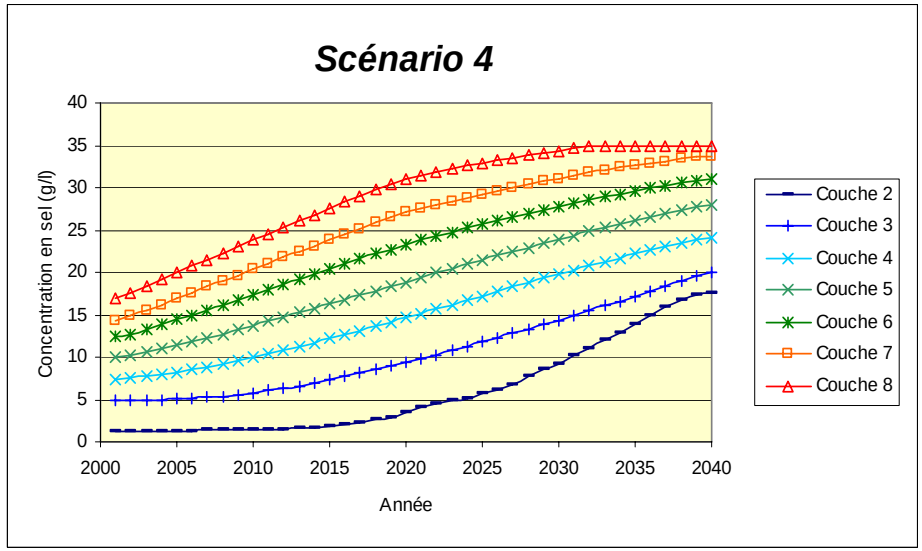

- **The quality improvement is still very low before 2020 (less outflow to the sea)**
- **The North-East sector of the coastal zone will be intruded too**

# SCENARIO 3 and 4

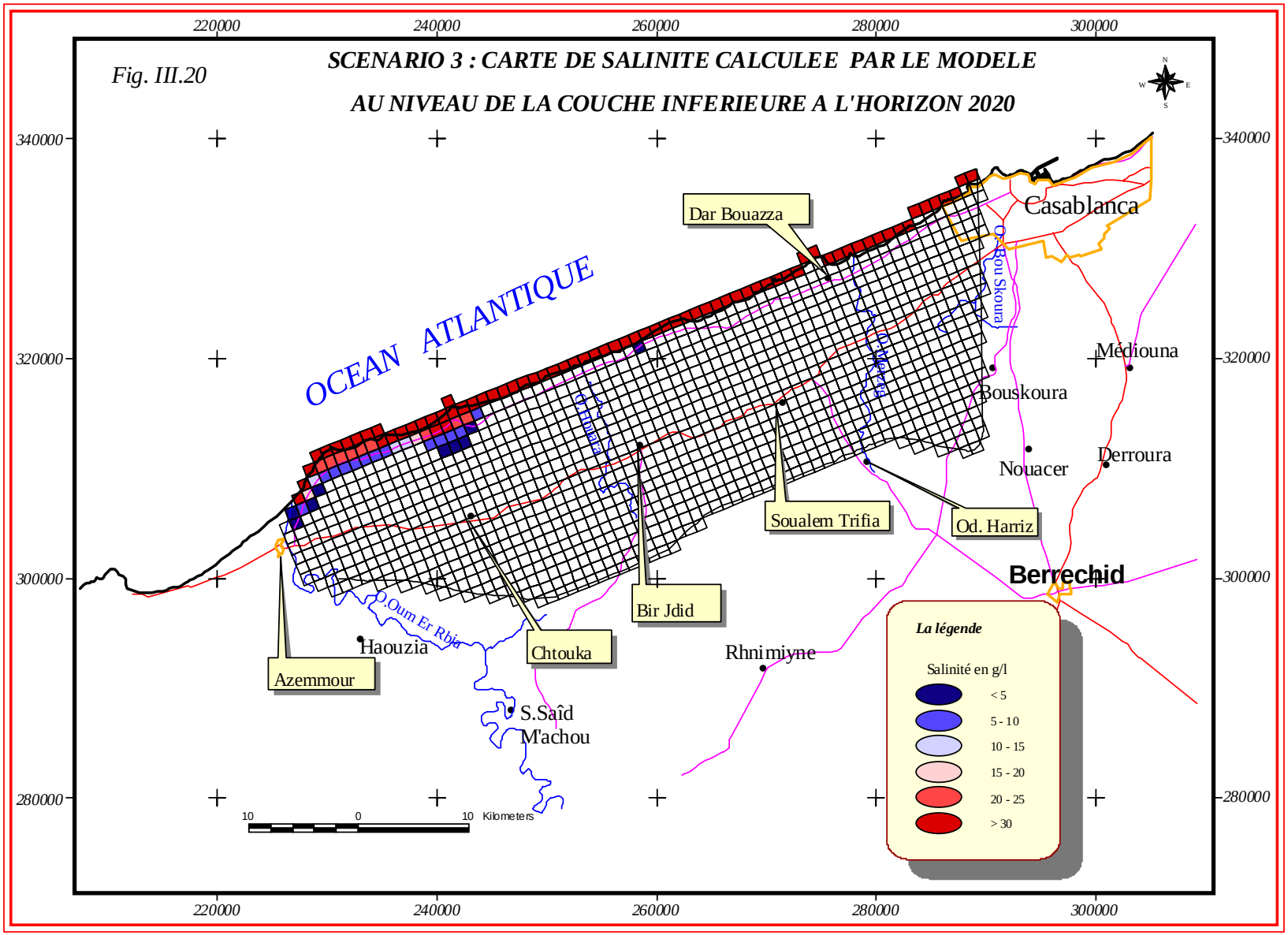
- **Previsional seawater intrusion volumes ($Mm^3/yr$)**

| Année | 2005 | 2010 | 2015 | 2020 | 2030 | 2040 |
|---|---|---|---|---|---|---|
| Scénario 3 | 1.45 | 1.42 | 1.40 | 1.41 | 1.43 | 1.47 |
| Scénario 4 | 2 | 2.3 | 2.6 | 3 | 3.4 | 4 |

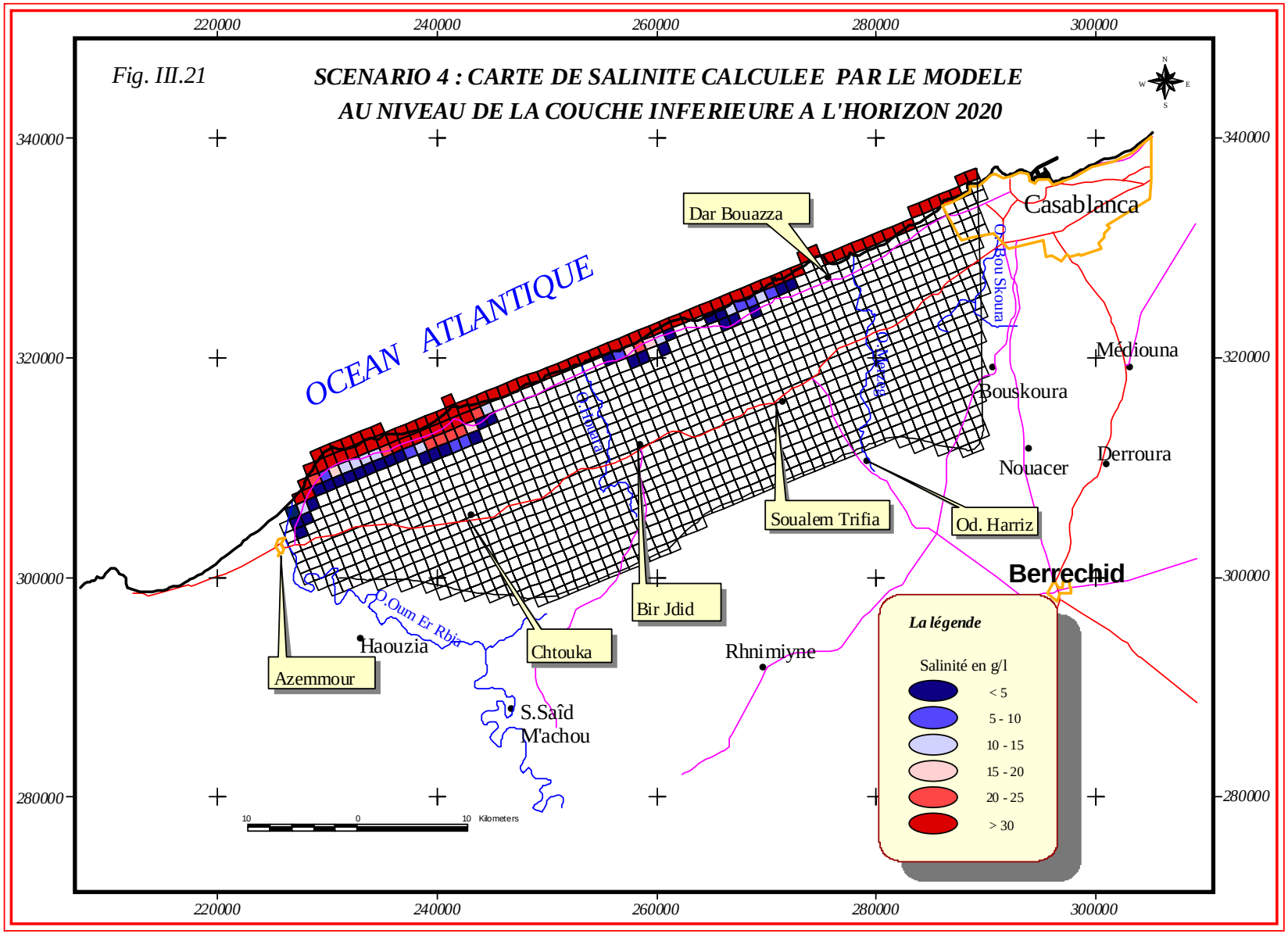



- **New equilibrium state after 2005**
- **Groundwater salinity continues to increase**
- **Both GW salinity and SWI continue to increase**
- **No stabilisation is expected**




- **Quality degradation**
- **GW salinity will exceed 15g/l in 2020 in the deeper levels**

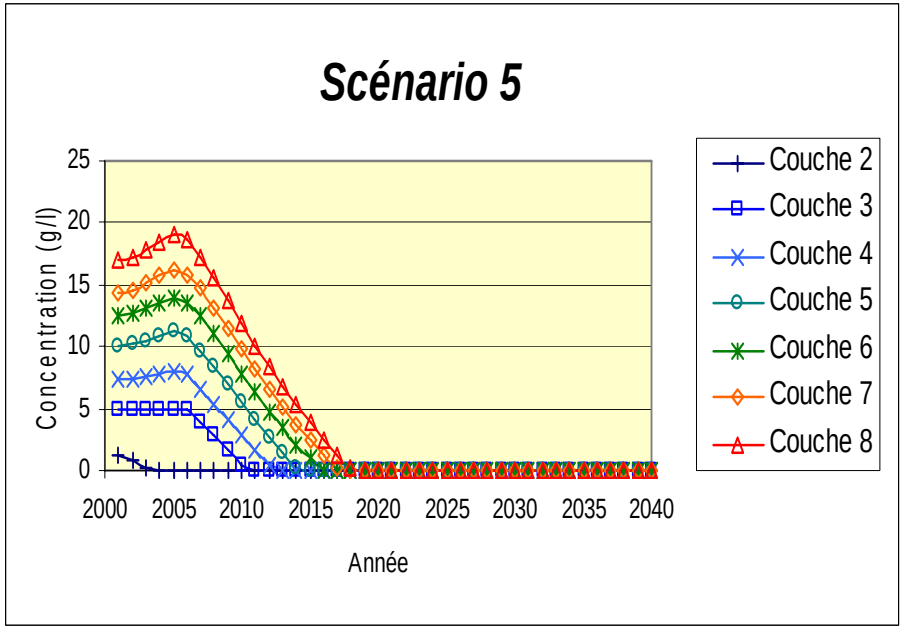


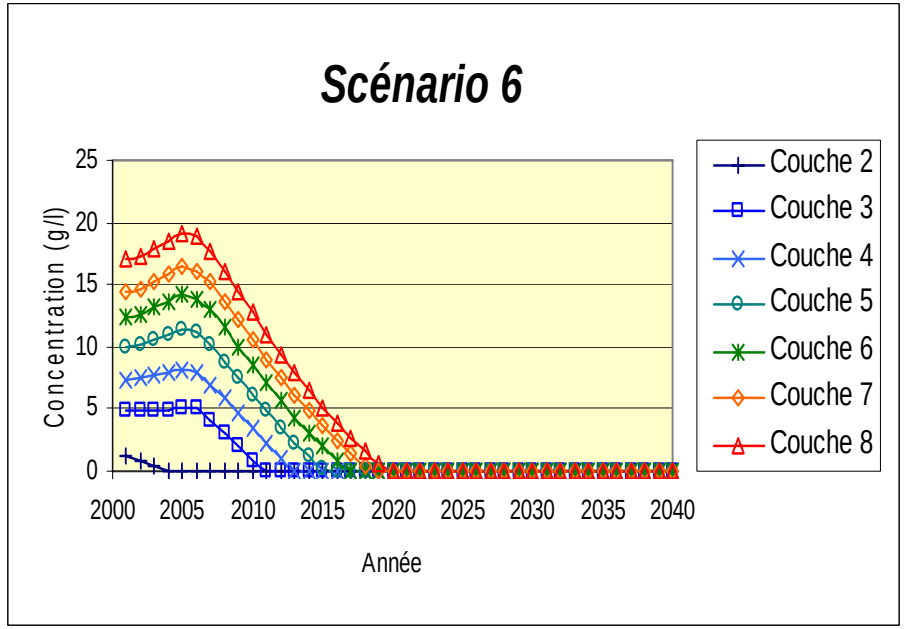

- **GW salinity would exceed 20g/l in 2020, in the deeper levels**
- **Seawater intrusion extent will reach 3km from the coast**
- **Large part of the North-East coastal zone will be intruded too**

# SCENARIO 5 and 6

## Previsional seawater intrusion volumes ($Mm^3/an$)

| Année | 2005 | 2010 | 2020 | 2030 | 2040 |
|---|---|---|---|---|---|
| Scénario 5 | 1.45 | 0 | 0 | 0 | 0 |
| Scénario 6 | 2 | 0.06 | 0.26 | 0.31 | 0.5 |




- Restablished equilibrium after 2005
- Net quality improvement after 2010

- Less volumes of SWI
- Water quality improvement after 2010
- SWI invads the north-East

# CONCLUSIONS and RECOMMENDATIONS

- Increase of SWI volume from 0.4 $Mm^3$ in 1985 to 4 $Mm^3$ in 1995
- SWI volume reduced to 1.1 $Mm^3$ in 2001, due to the abundoned pumping wells in the contaminated area
- Extent of SWI on 2 km of distance from the shoreline, and along 20 km South East of the coastal aquifer
- High salt concentration in the invaded zone by SWI along 1km from the coastline

- Improvement of the situation :

  Reduce the pumping well rates

- Stabilization of the present pumping abstractions, by artificial recharge, which will improve significantly the groundwater quality, especially in the coastal sectors of the aquifer

- La mise en application urgente de l ’arrêté fixant les seuils des autorisations de creusement des puits ou forages et des prélèvements par pompage dans la nappe conformément aux articles 26 et 38 de la loi 10/95
- L ’amélioration des techniques d ’irrigation et la rationalisation de l ’usage des pesticides et des fertilisants
- la mise en place d’un réseau piézomètrique représentatif, parfaitement nivelé et constituées d’ouvrages publics
- le suivi régulier des relevés piézomètriques en y intégrant systématiquement les mesures de conductivité électrique, de la température et du pH

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- la programmation de campagnes périodiques de mesures de profils de salinité au niveau de la bande côtière

- la réalisation d'une étude d'hydrologie isotopique pour mieux caractériser l'origine de la salinité dans toute la plaine

- la réalisation des études technique, économique et environnementale de réutilisation des eaux usées pour la recharge artificielle