THE NORTH-WESTERN SAHARA AQUIFER SYSTEM

BASIN AWARENESS

MATHEMATICAL MODEL
VOLUME IV

FEBRUARY 2004

OBSERVATOIRE DU SAHARA ET DU SAHEL

THE NORTH-WESTERN SAHARA AQUIFER SYSTEM

A Basin Awareness

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MATHEMATICAL MODEL

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PREFACE

Extending over an area of more than one million km², the North-Western Sahara Aquifer System—which is shared by Algeria, Tunisia and Libya—consists of continental deposits enclosing two major groundwater aquifers: the CI (Continental Intercalaire) and the CT (Complexe Terminal). The structural configuration and the climate of the region are such that the reserves are very little renewed: these are geological reserves whose natural outlets (springs and foggaras) had led to the development of oases where the centuries-old lifestyles have remained for a long time in perfect symbiosis with the Saharan ecosystem.

For the last century and, more particularly, for the past thirty years, exploitation by wells has seriously undermined this groundwater reserve. The water abstractions, used both for farming purposes (irrigation) as well as for drinking water supply and for industry, have soared from 0.6 to 2.5 billion m3/year, via water points (now numbering 8800), and, as the springs dried up, they were replaced by deeper wells.

This intensification of water exploitation generates a certain number of problems of which, in particular, a steady drop in water level, an increase in pumping costs, a decrease in artesian exploitation, a drying up of natural outlets and an increasing risk of deterioration of water quality by salinisation ….

The three countries concerned have soon become aware of the problems related to the use of these aquifer resources from a sustainable perspective and have endeavoured to improve the state of knowledge relating to these resources, as well as their management. Accordingly, and as early as 1970, a major Algerian-Tunisian programme, known as ERESS and implemented by UNESCO, had led to establishing, based on a preliminary modelling which focused on the border zones of the two countries, an evaluation of the usable resources of this aquifer system, as well as forecasts concerning the evolution of their use. This programme was continued under UNDP in 1984.

Twenty years later, that is in 1992, the Sahara and Sahel Observatory (OSS) organised in Cairo (Egypt) the first workshop on “Aquifers of the Major Basins”, thus initiating the inception of its “Major Basins Aquifers” programme which was to pave the way for the advent of the “NWSAS Project” in September 1997, following a series of regional seminars and workshops. This NWSAS project was the first of its kind to take into consideration the basin as a whole, that is up to its natural boundaries.

Upon request by the three countries, OSS sought out and obtained financial support from the Swiss Cooperation Agency, IFAD and FAO for a first three-year phase which was officially initiated in May 1999 in Rome and whose main objective was to update the evaluation of the resources exploitable, as well as to set up a consultation mechanism between the three countries.

Compared with its predecessor, i.e. ERESS, the NWSAS project was to avail itself of a major asset: participation by Libya and use of the data compiled over the last thirty years. These data were to allow:

- the establishment of a joint data base for the three countries which was intended to enhance the value of the information gathered and to serve as an information exchange tool;
- the design of a model simulating the hydrodynamic behaviour of the aquifer system and making it possible to forecast the impact of increased exploitation.

These two activities have been carried out by eliciting, in a continuous manner, the contribution of national experts from the three countries. The results were presented to the three countries and have been enlightening to the decision-makers as to the development prospects and the related risks. This has also proved to be an occasion for the three countries to show interest in strengthening the sustainability of the updating, monitoring and information exchange programmes, as well as giving concrete expression to a gradually emerging concept of “basin awareness”.

What prospects for NWSAS at the conclusion of this first survey phase?

For Algeria, just as much as for Tunisia and Libya, the CT now and the CI very soon are set to be in such a state of exploitation that it would be necessary for the three countries at once to exercise control over abstraction rates, and thus give concrete expression to their mutual determination to secure the future of the region, in particular, by applying a jointly agreed policy for preserving their water resources.

The implementation of such a partnership, in the course of the NWSAS project, has made it possible to gradually build mutual trust among the technical teams, awareness that the problems faced by any of the parties depend to a certain extent on the actions undertaken by the other parties, and conviction that the exchange of information—which is the pillar of any form of solidarity—is an activity that is not only possible but also necessary.

Aware of the need for a sustained consultation and for conferring an institutional aspect on the cooperation initiated under the present project, the three NWSAS countries have expressed their agreement for the set up of a permanent tripartite consultation mechanism for a joint management of NWSAS. The need for a developed and sustainable institutional mechanism now being an established fact, its implementation has been designed according to a gradual approach. At the beginning, its prerogatives will be mainly focused on the development of data bases and models, promoting studies, research and training, designing monitoring indicators, as well as on considering the future development of the said mechanism. OSS welcomes the Coordination Unit entrusted with this mechanism, according to the will of the three countries.

By its activities and its outcomes, at both the scientific and the technical levels, the NWSAS project does represent an example in terms of approach to the study and management of non renewable water resources from a sustainable perspective. Through the exchange of information and the will to engage in consultation which it has elicited, the project may serve as a model for regional cooperation. This project stands, indeed, as a success story for South-South and North-South cooperation, which is perfectly in tune with the OSS objectives and mission.

I would like to acknowledge all those who have contributed to the implementation and the success of this first phase. First of all, I must express my gratitude to the Ministers in charge of water resources and the following national institutions: the National Agency for Water Resources (ANRH) in Algeria, the General Directorate for Water Resources (DGRE) in Tunisia, and the General Water Authority (GWA) in Libya, which have always been both ready and willing to exchange information, participate in scientific activities and take the appropriate decisions within the Steering Committee; their readiness and willingness have been, indeed, the key factor in the achievement of the project objectives. I would also like to thank the OSS cooperation partners which have not only provided financial assistance to the project but also shown particular interest in its implementation and offered insightful and enlightening remarks during the various Steering Committee meetings. Last but not least, I would like to thank the project team within the OSS Executive Secretariat: the permanent staff, the national teams and consultants, as well as the eminent specialists who have helped us validate the scientific findings of the project.

Dr. Chedli FEZZANI

Executive Secretary

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July 1999 - October 2002: The conducting of the study on the North-Western Sahara Aquifer System has claimed forty months of uninterrupted effort and cooperation—essential work which, though not always easy, was always indispensable, and a fine example of unwavering solidarity.

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INTRODUCTION

1970-2000, thirty years after the implementation, in Algeria and Tunisia, of the ERESS project, and since the considerable impetus given to the investigation of deep waters in Libya during the 70's two indicators are essential to measure all the way undergone by Saharian hydrogeology: the number of water points surveyed over the main aquifers rose from 2000 to nearly 9000, and the abstractions made by means of deep wells increased from 450 Million m3/year to 2,2 billion m3/year. In terms of elements used to better know the aquifer system, the large body of information and speculations accumulated over the last thirty years, generated by the socio-economic and hydraulic developments of Saharian regions, seems to be as intense and important as the one marking the thirty previous years, justified by the profusion of explorations brought about by the discovery of Saharian oil. Consequently, the NWSAS project requirements in terms of research and analysis of all acquired data, then processing of this data, any additional geological and hydro-geological synthesis, imagination and design of a reliable and modern conceptual modeling of aquifer systems, enables to measure the scope of the challenge carried by this new project. The effort to analyze data and documents, the subsequent hydro geological synthesis capacity, and strength to come up with a proposal required for the design of a representative model, that can be renewed and sustainable, shall be as important as the challenge.

Two main sub-systems make up the North-Western Saharian Aquifer System: the aquifer of the Continental Intercalaire and the aquifer of the Complexe Terminal. Both aquifers are subject to constraints limiting the faculty of exploiting their potential. These constraints are certainly economic, but the environmental risks related to the exploitation and vulnerability of Saharian aquifers, due to their level of development, today constitute the most determining constraints. The problem gets more complicated as three countries share the same resource, but do not share, in principle, the same vision concerning the future of Saharian aquifers. This is always true when several users share a very solicited aquifer: as long as ignorance of impacts frees actions while mutual information reinforces solidarity. This is true for individuals as well as for States – we can design the model as a powerful educational tool and an objective instrument enhancing dialogue and mediation.

This final report gives an account of all the works conducted in the framework of NWSAS project, between January 2000 and June 2002, for the design of a mathematical model of the North-Western Sahara Aquifer System. This report has been preceded by a number of intermediate reports, also accounted for. These intermediate documents include the report drafted by the Model Evaluation Committee, namely:

- Design of the Conceptual Model , August 2000
- Report on the choice of the software, June 2000
- Construction and Adjustment of the Simulation Model, May 2001,
- Second phase for the Adjustment of the Model. Revision of the Tunisian outlet of the Continental Intercalaire, October 2001,
- Definition and calibration of exploratory simulations, November 2001
- Point of View of NWSAS Model Steering Committee, January 2002
- Model Resumption in the Oriental Basin. Integration of new data acquired in Libya, May 2002.
- Results of predictive simulations. Search of Scenarios for the exploitation of aquifers, May 2002

This document is organized in three parts:

- One first part called: Characterization of the Aquifer System and Conceptual Model, namely including the geological, hydrological and hydro-dynamic characterization of the basin,

- The second part is called: Design of the Mathematical Model, describing the construction and calibration phases of the model in steady and transient states
- The third part is devoted to the Execution of Predictive Simulations. This part successively develop: the definition and execution of exploratory simulations, the construction of a NWSAS miniature model to investigate the reservoir, the definition and performing of predictive simulations.

PART I

CHARACTERIZATION OF AQUIFER SYSTEM AND CONCEPTUAL MODEL

I- CONCEPTS

I.1- Systems, aquifers and models

Before tackling issues inherent to the North-Western Sahara Aquifer System « NWSAS », it is useful to make a brief reminder in this first part of a number of concepts, namely related to the definition and apprehension of a system, of an aquifer, of an aquifer system, of a model, of a conceptual model …

We may, with Dooge, define a system as "*any process or structure, relating a material input, cause or impulsion, or an energy or information with a material output, effect or response, energy or information*". This definition can be applied to aquifer systems.

One of the first known examples of the aquifer system (fig.1), is presented by THEIS.

(1940)[1]: How does this system react in response to the launching of the pumping operation ?

- Through an increase of recharge induced by draw-dawn ?,
- Through a decrease of the discharge at the level of the outlet ?,
- Through the reduction of reserves ?
- Through all three at the same time ?

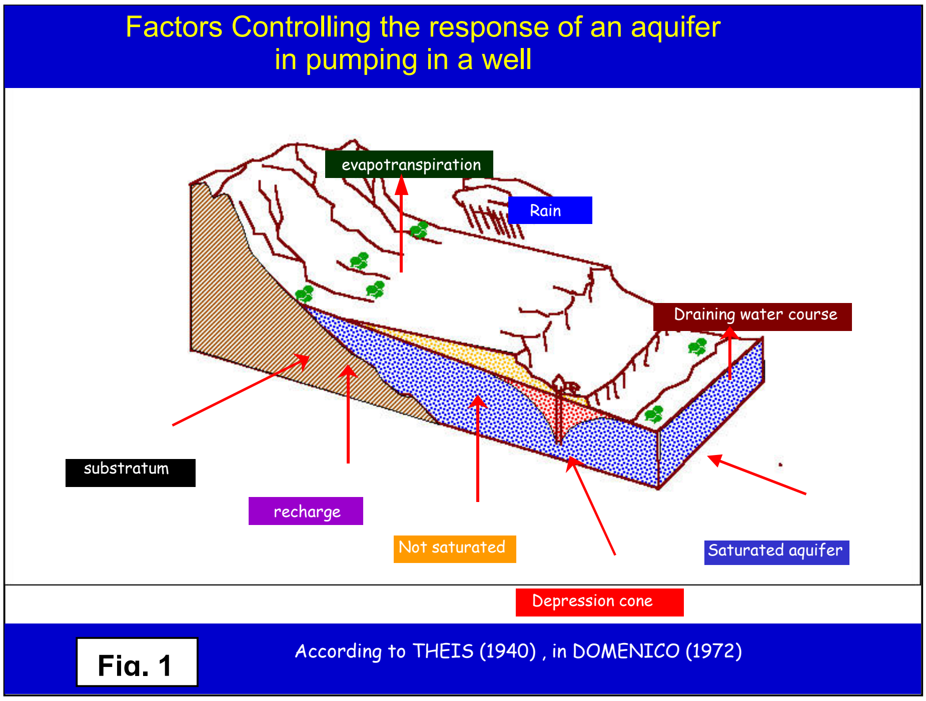


Fig. 1

Such a problem can be tackled in two different ways: the geologist, for example, will refer to a set of permeable rocks authorizing a certain flow, limited by other impervious rocks. The hydro-dynamician will refer to a hydrodynamic system integrating the potential field on the same domain defined by its boundary conditions. The hydrologist can represent the same problem by juxtaposing defined reservoirs. The geographer can describe everything by means of a geographical information system.

In each of these system « conceptions », there is a representation, a model of the space. There will then exist as many aquifers system models, or modeling levels, as there are

[1] In Domenico: Concepts and Models in Groundwater Hydrology ; IC Graw Hill, 1972

modeling domains (or fields of competences; Bogardi, 1994)[2] that we may assign to the underground domain. The retained system, or the model representing it, will definitely result from the interweaving of two circles: the representations circle and the domains circle (fig. 2 & 3).

Fig. 2: Representations Circle

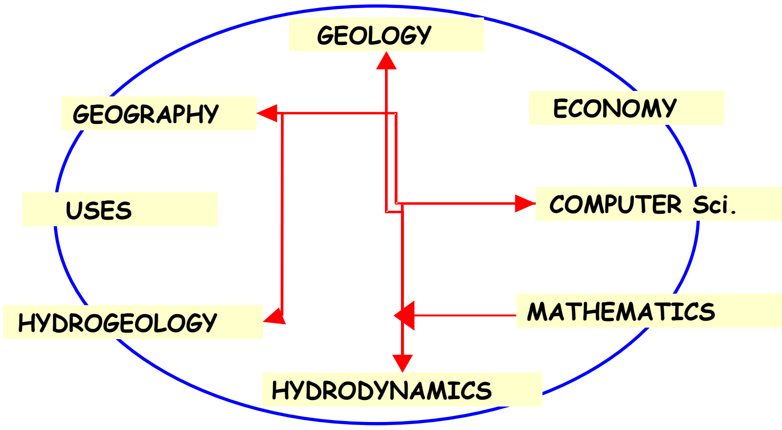
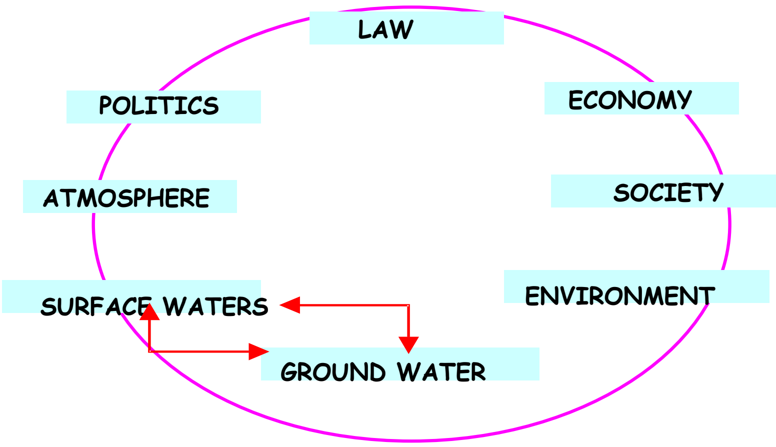


Fig. 3: Circle of modelable domains



So defined, the system can be represented by the Inputs-Outputs graph suggested by Hall & Dracup (1970)[3]: controlled and non controlled inputs, desired or non desired outputs. Transposed over the aquifer system management model and particularly over **the North-Western Sahara Aquifer System** « NWSAS », this representation helps in the identification of Inputs and Outputs (fig. 4). The purpose of any management model is to help the decision maker to maximize desired outputs and minimize undesired ones, by acting on controllable inputs called « decision variables ».

[2] Introduction of systems analysis: terminology, concepts, objective functions and constraints, in «Multicriteria Decision Analysis in Water Resources Management » ; ed. Bogardi, Nachtnebel, UNESCO, 1994.

[3] Water resources systems engineering ; IC Graw Hill , 1970.

Fig. 4: NWSAS Inputs – Outputs

INPUTS	OUTPUTS
CONTROLS	*DESIRED*
- Investments	- Water resources
- Structure implementation	- Financial resources
- Monitoring	- Useful information
PARTIALLY CONTROLED	*NOT DESIRED*
- Illicit pumping	- Present quantity needs not satisfied
- Abstraction not coordinated between countries	- Needs for future generations not satisfied
- Artificial recharge	- Deterioration of water quality
- Salt contamination	
NOT CONTROLLED	*NEUTRAL*
- Natural recharge	- Natural leakages from the aquifer system

The system transformation, due to decision variables and uncontrolled inputs, is described by a series of "state variables". This response of the system (change of state variables due to a variation of entries) will be characterized by "system parameters" (see fig.5).

Fig. 5: Conceptual Model of an Aquifer System

STATE VARIABLES	PARAMETERS
Piezometric levels	**Number of Aquifers (permeable & semi-permeable)**
Salinity (temperatures)	**Geometry K, T, S, n; K, S'**

I.2- Conceptual Model

The content of the conceptual model is, from a very synthetic perspective, described by Fig.5. Traditionally, two levels of analysis are required to reach an appropriate definition of the conceptual model of an aquifer system:

I.2.1- the hydro-geological characterization

This is the preliminary phase before any modeling operation. This phase includes the compilation, the analysis and the processing of all available information.

- Data concerning the geology of regional surface and sub-surface,
- Topographic data including water streams and water plans,
- Cartographic data: choice of the model cartographic medium,
- Existence of geological sections and lithostratigraphic correlations,
- Times series of hydrometric and meteorological data,
- Data related to the hydrodynamic operation: recharges, flows, outlets,
- Times series: pizometries, abstractions, salinities,
- Estimates of hydraulic characteristics.

I.2.2- Conceptualization of aquifer systems

All the data describing the hydro-geological system are organized and translated in terms of flow systems defined in particular by a field of possibilities and boundary conditions. Points to develop for the design of a conceptual model are namely:

- design a hydro-geological outline as a succession of permeable and semi-permeable aquifers,
- for every determined permeable aquifer, define the spatial distribution of:
    - piezometric levels, at least at a given date,
    - transmissibility or permeability,
    - top and substratum elevations,
    - Input and drainage areas, with a preliminary estimate of flow exchange rates.
    - Potential exchanges of flow with adjacent aquifers.
- For each permeable aquifer, identify, analyze and design the times series of the levels, abstractions, and salinities; and determine the spatial distribution of storage coefficients.

All of these elements can be organized in homogeneous groups. In the following, the analysis of the NWSAS system will be conducted throughout three characterization formats:

A- Geological characterization

B- Hydrological characterization

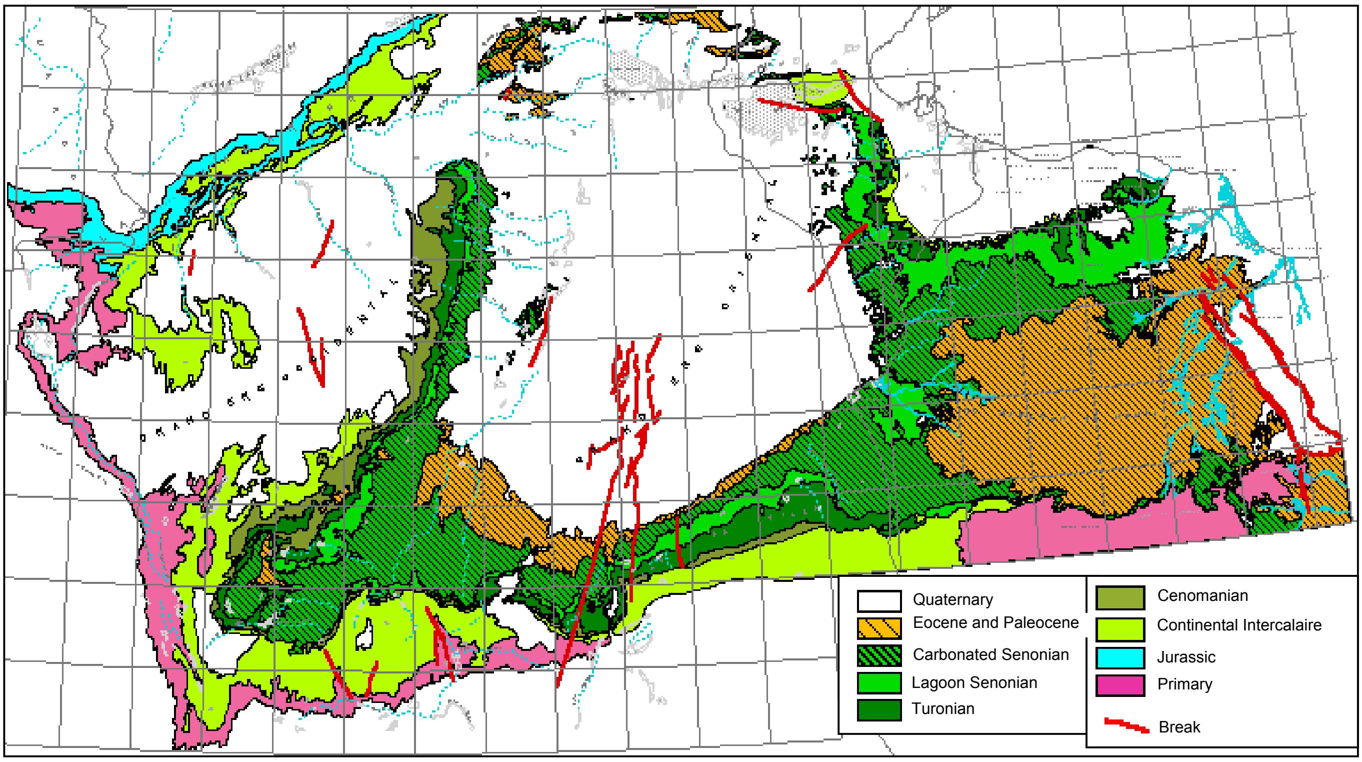
C- Hydro-dynamic characterization

II- GEOLOGICAL CHARACTERIZATION

II.1- Geological Facies of the Northern Sahara

The geological map of the north-Saharian platform (fig.6) shows important outcrops of the Upper Cretaceous, beginning with the Cenomanian transgression, and covers an area of **700.000 km^2**.

Fig. 6 Map of NWSAS geological outcrops



II.1.1- Continental Intercalaire Facies

Directly topped by Cenomanian clays, the formations of the Continental Intercalaire [CI] are spread up to the platform border, in the continuous ring of El Golea until the southern boundary of Hamada El Hamra. In the north western part of the basin, the CI follows all the way alongside the Saharian Atlas, and in the North East the Dahar and Djebel Neffusa. More to the south, the CI directly lies on Palaeozoic marine formations, which a continuous belt, under the form of an outcrop, connecting the Moroccan border to the North Western boundary of the basin, until the city of Hun in the most south eastern end of the region.

The observation of outcrops enables then the definition of the Continental Intercalaire as all the continental comprised between Hercynian folds, which forced the sea out of Saharian platforms, and the marine invasion of the upper Cretaceous. This set includes mainly sandstone-argilous continental formations of the Lower Cretaceous, to which the study of drilling sections associated marine or Lagoon sediments, post-palaezoic and ante-cenomanian inserted within the CI.

This definition of the Continental Intercalaire, constituting the widest aquifer formation in the region, determines the boundaries attributed to the study area of the North-Western Sahara Aquifer System. These boundaries, based at the same time on the study of geological outcrops and on the study of drills, are:

- to the North West ; the South side of Saharian Atlas, marked at its emergence by the Albian-Cenomanian contact,

- to the West and south-west; the boundary of the Palaeozoic outcrops of Ouarta, marked by the course of Zousfana and Saoura,
- to the South, the boundary of CI's outcrop on the Palaeozoic, progressing from Adrar to Hun, describing the northern boundaries of Tassili and Djebel Hassaouna,
- to the North, the South Atlas accident in the North of the Chotts, relayed towards the Gulf of Gabes by El Hamma-Medenine fault,
- to the North-East, the outcrops of the Continental Intercalaire on the Dahar and Djebel Nefussa,
- to the East, the aquifer formations of the lower Cretaceous extend well beyond Hun Graben. But to the East of Meridian 16°, and while crossing Syrta basin, the CI waters become salty: this is the passage that was adopted as the boundary of the study area of CI soft water aquifers.

In order to determine the lithostratigraphic sections, making up the first architectural structure for all hydro-geological modeling, it is necessary to define the scale of facies equivalencies throughout the whole basin. For this purpose, a first series of simplifications may suggest, for each of the three countries, a model-section of all formations within the C.I.

In Algeria

This section describes more particularly the facies of the Lower Sahara (region of Hassi Messaoud, Ouargla & Toggourt), likely to be correlated to Tunisia and Libya. Above the Hercynian discordance, we can distinguish from top to bottom:

- **The Triassic**:
    - Lower argilous-sandstone Triassic containing saturated salty water;
    - Upper evaporitic Triassic made up of massive salt likely to be more than 1000 m thick, constituting a watertight top and isolating soft water aquifers from the CI.
- **The Liassic**: marked by a marine incursion, some Lagoon deposits but especially carbonated.
- **The Dogger**: the carbonated facies is overwhelming.
- **The Malm**: marine regime, alternating calcareous and Lagoon deposits.
- **The Neocomian**: argilous in the North, sandstone in the South East and covered with salty water.
- **The Barremian**: argilous-sandstone in the North, clearly sandstone in the South, contains soft water. The sandstone Barremian marks the first "useful" and important aquifer level of the large aquifer of the Continental Intercalaire s.s [thick. # 100m]
- **The Aptian:** located between two continental sets, the Barremian and the Albian, the Aptian corresponds to a marine invasion materialized by a 20 to 30 m thick dolomitic bar.
- **The Albian**: sandstone sedimentation more important than that of the Barremian, soft water reservoir.[thick.# 600m]
- **The Vraconian**: limited in the North by the platform, argilous, marks the top of CI and a resumption of marine sedimentation.
- **The Cenomanien**: clays, marl and argilousclay sandstone. [thick.# 400m]

In Tunisia

In a very simple form, we observe from top to bottom:

- **The Triassic**:
    - Lower sandstone Triassic containing salty water, then transformed into soft water but at very high depth
    - Saliferous Upper Triassic, isolating soft water aquifers of IC s.s

- **The Liassic**: this is the upper saliferous, gypsum, anhydrite, dolomites.
- **The Lower Jurrassic**:
  - The Bathonian & Callovo-Oxfordian ; the carbonated facies is overwhelming in the north, sandstone in the south, and contains salty water ("Jurassic aquifer")
- **The Upper Jurassic**:
  - Kimmeridgian , argilous facies.
- **The Neocomian-Barremian**: this is a series of purbecko-wealdian sands, sandstone and argilous sands of « Merbah el Asfer » in the South, the main C.I's soft water continental formation [thick.#300m], transformed in the North into Kbar el Haj formations, woody sandstone and Bou Dinar.
- **The Aptian**: dolomitic bar.
- **The Albian**: marine sedimentation with clay and carbonate in the North East. In the south, (Ain Gurttar facies) and the NW (Sidi Aich facies), development of continental detritic facies and passage to the Albian facies in the lower Algerian Sahara.
- **The Cenomanian**: generalized marine invasion; limestone and dolomites, marl and marlaceous limestone.

In Libya

- **The Palaeozoic:** Sandstone and Quartzites of the Cambro-Ordovician ; contains considerable soft water reserves alongside Dj. Hassaouna, directly relating to the aquifer formations of the Lower Cretaceous. More to the North, it is covered in depth by carboniferous impervious formations.
- **The Triassic**: contains from bottom to top:
  - Sandstone, and argilous sand in Ouled Chebbi and Ras Hamia,
  - Limestone, dolomites, gypsum, and clay in Azizia and Bou Chiba. In the south and the south west, the Triassic becomes a clearly sandstone facies containing soft water (Zarzaitine).
- **The Liassic**: powerful evaporitic series, gypsum, anhydrite (Bir El Ghenem, Abreghs), isolating the Triassic from the Lower Cretaceous. This series expands to the Bathonian (Giosc and Tokbal).
- **The Malm**: Callovo-Oxfordian and Kimmeridgian "Chameau mort" (Dead Camel) and Shakchouk) ; Sandstone, sands, clays, limestone and dolomites. The overwhelming continental sediments: this series mixes with the Lower Cretaceous to form CI's aquifer s.l.
- **The Lower Cretaceous**: Neocomian, Barremian, Aptian and Albian ; Continental sandstone ; constant facies over all the Libyan basin (Kiklah formation) containing soft water ; constituting the CI s.s ; the Kiklah formation expands to the NE (Tawurgha) with a dolomite facies. On the east of Meridian 16°, the Kiklah aquifer contains salty water.
- **The Cenomanian**: Return of marine sedimentation ; clays, gypsum, limestone, dolomites, marl, salt ; (Ain Tobi and Yefren formations) ; constitutes the CI impervious top.

II.1.2- The Complexe Terminal

Traditionally, and according to the definition of K. Killian, the term "Terminal Continental" refers to MioPliocene continental formations, sandy and argilous. But according to Bel and Demargne (1966): " the Terminal Continental aquifer contained in MioPliocene sands is more or less related to the aquifers dating back to the Eoceian, Senonian and Turonian eras, in that at the scale of the whole Sahara, all different levels are considered to constitute one single aquifer: the Terminal Continental aquifer as opposed to the Continental Intercalaire ».

The notion of “Complexe Terminal” appeared with the ERESS Project, published for the first time by Bel and Cuche (1969): “ this term of “Complexe Terminal Aquifer” which gathers under the same label several aquifers located in different geological formations, was chosen as these aquifers indeed belong to the same hydraulic set. Intercommunications between the Senonian, Eocene and MioPliocène are obvious throughout the basin, except in the region of the Chotts, where the impervious Middle and Upper Eocene fit in between. The Turonian aquifer is more individualized as a consequence of the impervious cover of the Lagoon Senonian; however, these levels comply with the levels found at the Senonian or MioPliocene on the borders of the basin ».

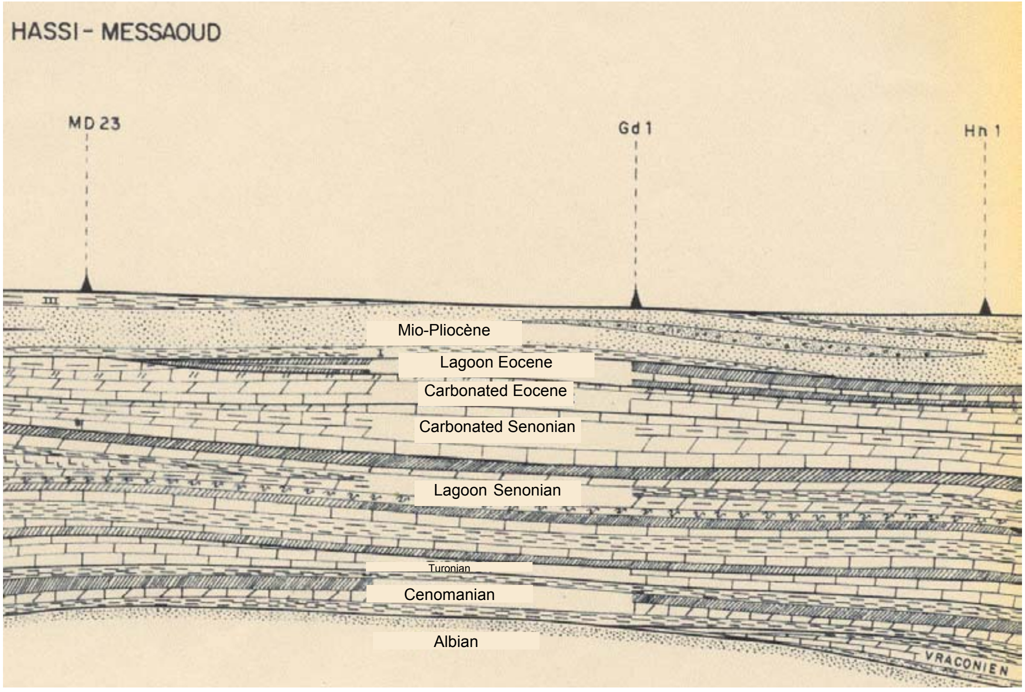
Processing country by country as was the case for the CI (Continental Intercalaire), a simplified standard-section of the Complexe Terminal (CT) is proposed below:

In Algeria

The description of the CT is limited to the Central Basin, bordered on the west by Mzab ridge.

- The Turonian: Calcareous and dolomitic formation, aquifer and extended all over the basin, only at the most northern boundary where it becomes marly and little permeable. The Turonian aquifer, with a good chemical quality all around the basin, shows high salinity rates in the sector of Hassi Messaoud.
- The lower Senonian or Lagoon Senonian: little permeable, certainly constitutes the largest and most efficient screen between the CI and the CT.
- The Upper Senonian or carbonated Senonian: permeable carbonated formation.
- The lower Eocene or carbonated Eocene: permeable carbonated formation, constituting one single and same lithostratigraphic ensemble with the carbonated Senonian.
- The average Eocene or evaporitic Eocene: gypsy clays whose existence is limited to the northern part of the central basin (Chotts region)
- The Mio-Pliocene: Fluvio-continental sedimentation showing a high degree of heterogeneity and a lenticular structure, where Bel and Demargne identify four levels, from bottom to top:
    - **Level 1**: argilous, not thick, present only in the middle of the Central Basin.
    - **Level 2**: sandstone-sandy, this is the thickest level (400m south of Gassi Touil) and the most constant. It covers all the central basin as well as parts of the western basin. It represents the main aquifer level of the MioPliocène.
    - **Level 3**: quasi non-permeable sandy clays, thick and constant in the region of the Chotts.
    - **Level 4**: sandy, very thick in the region of the Chotts. Emerges over wide areas.

Fig. 7: the series of the Terminal Continental according to Bel and Demargne (1966)[4]



In Tunisia

- **The Turonian**: permeable dolomite bar that is 80 to 100 m thick; shows an aquifer interest in the region of Nefzaoua but likely to contain salty water in Kebili peninsula.
- **The Lower Senonian or Lagoon Senonian**: constitutes a little permeable screen
- **The upper Senonian or carbonated Senonian**: aquifer formation, particularly permeable in the regions of Nefzaoua and Djerid.
- **The Palaeocene**: argilous and marly serie, El Haria formation.
- **The lower Eocene:** little thick limestone serie (Metlaoui formation: 20m) not recognized as aquifers.
- **The Middle Eocene**: or evaporitic Eocene.
- **The Mio-Pliocene:** shows two main facies:
    - The Pontian or Beglia formation: thick sands with argilous strings.
    - Segui formation: coverage sandy clays.

In Libya

- **The lower Cenomanian (Ain Tobi formation)**: dolomite limestone in the north, assimilated detrital facies in Kiklah to the south.
- **The average Cenomanian (Yafrin formation)**: marly series (thick.#150m) constituting a screen between Kiklah and the aquifers of the upper Cretaceous. In the valley and on the East, the thickness of the marl considerably reduced.
- **The Turonian [& Upper Cenomanian] (Nalut formation)**: dolomite limestone, good aquifer on the basin's northern half, more marly to the South.
- **The lower Senonian (Tigrinna formation)**: clays, marl, and gypsum. This is the Lagoon Senonian. (thick .#150m)

[4] BEL and DEMARGNE ; 1966: Geological Study of Continental Intercalaire; DEC, Algiers.

- **The Middle Senonian (Mizdah)**: limestone series contituting a good aquifer in the eastern basin.
- **The Upper Senonian (Maestrichtian) and the Palaeocene (Zmam formation)**: marl and marly limestone, very developed in the Hamada el Hamra plateau and the basin of Syrta.
- **The Eocene**: calcareous series developed only in the valley and on the East. Rather poor aquifer.
- **Oligocene**: Limestone ; present only in the South of the valley in Hun and Waddan.
- **The Mio-Plio Quaternary**: developed along the Northern coast. Transgressive series on the upper Cretaceous. From bottom to top, we observe:
  - Fissures limestone of the Aquitanian aquifer;
  - Marls of the Middle Miocene;
  - Limestone, marl and gypsum of the Upper and Plio-Quaternary Miocene.

II.2- Lithostratigraphic Correlations

In order to establish the relationship between the succession of all geological formations identified respectively in Algeria, Tunisia and Libya, a large number of sections and lithostratigraphic correlations have been conducted throughout the whole region.

We have established a geological database including 365 boreholes:

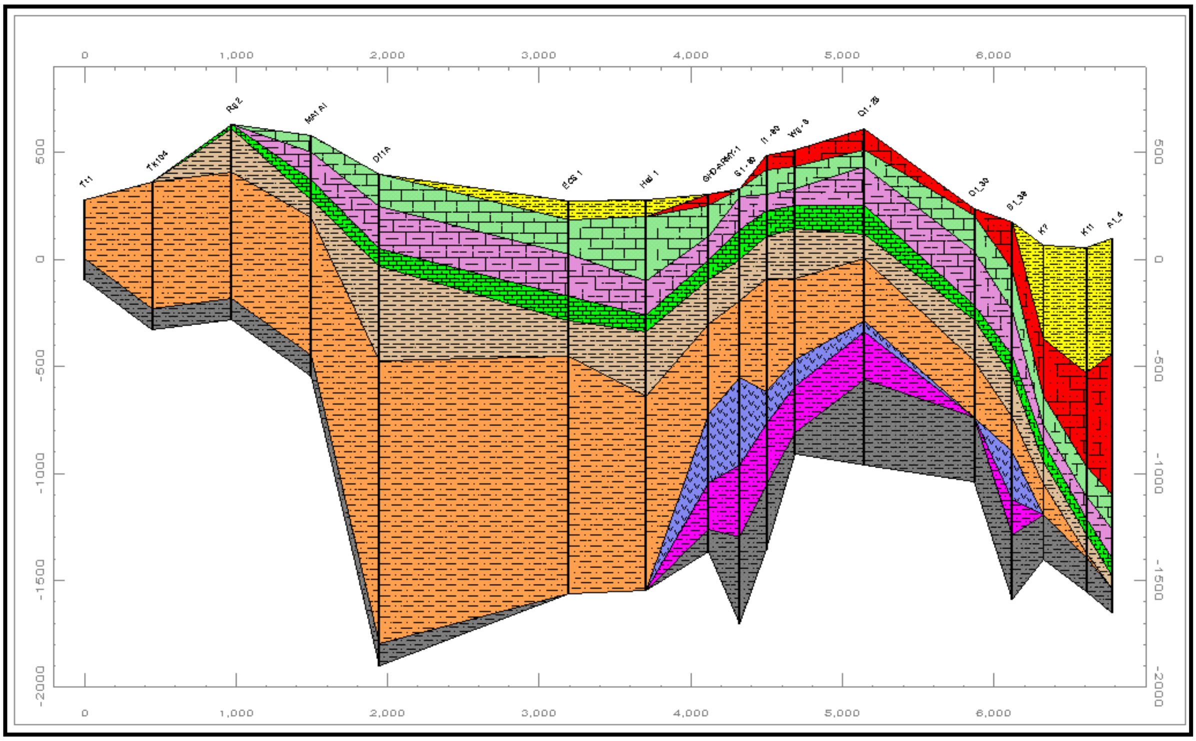
- **175 boreholes including a complete section integrating the CI & the CT.**
- **120 boreholes with information about CI only.**
- **70 boreholes with information about CT only.**

The conceptual model constitutes the output of a succession of simplifications, originating from the stratigraphic sectioning recognized at the level of geological outcrops, and cross driven in depth with drillings logs. The result of these investigations can be succinctly summarized by the three geological sections presented in Fig. 8, 9, and 10.

In the first section, W-E cross-section throughout the Northern Sahara, we clearly observe NWSAS general structure spread over three basins:

- **The western basin** limited here within the springs sector,
- **The central basin**, the largest in terms of area and depth, it contains the thickest aquifers and whose resources are shared by all three countries, limited on the west by the M'zab ridge and on the east by Hamadah el Hamra plateau,
- **The eastern basin** characterized by the collapse of the Hun valley and the accumulation of tertiary sedimentations.

Fig. 8 Southern W-E cross section through NWSAS, from FOGGARAS in ADRAR to Hun Graben

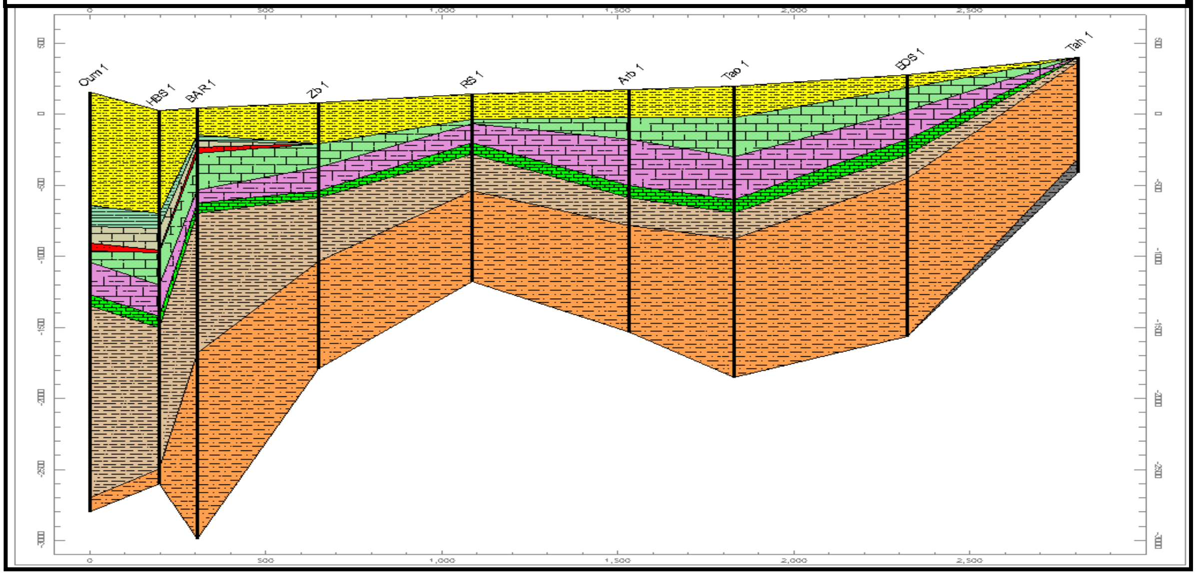


MP	Text
Em	Text
Ei	Text
Palc	Text
SenC	Text
SenL	Text
Tu	Text
Cen	Text
CIK	Text
LIK	Text
Trias	Text
Palz	Text

In the second North-South cross-section, and strictly median to NWSAS, we can clearly observe:

- The approach of CI outcrops in the Tinhert,
- The submergence of CI formations in the North, in the South-Atlas subduction depression, and the considerable thickening of the Cenomanian cover at this site,
- The appearance of the Eocene limestone covered by evaporitic Eocene, both limited to the Chott Northern region
- The considerable extension of the Mio-Pliocene sedimentation in the Central Basin,
- Finally, and this can be observed through all three sections (excluding the western basin), the omnipresence and the high regularity of successive formations of Cenomanian, Turonian and Lagoon and the Senonian.

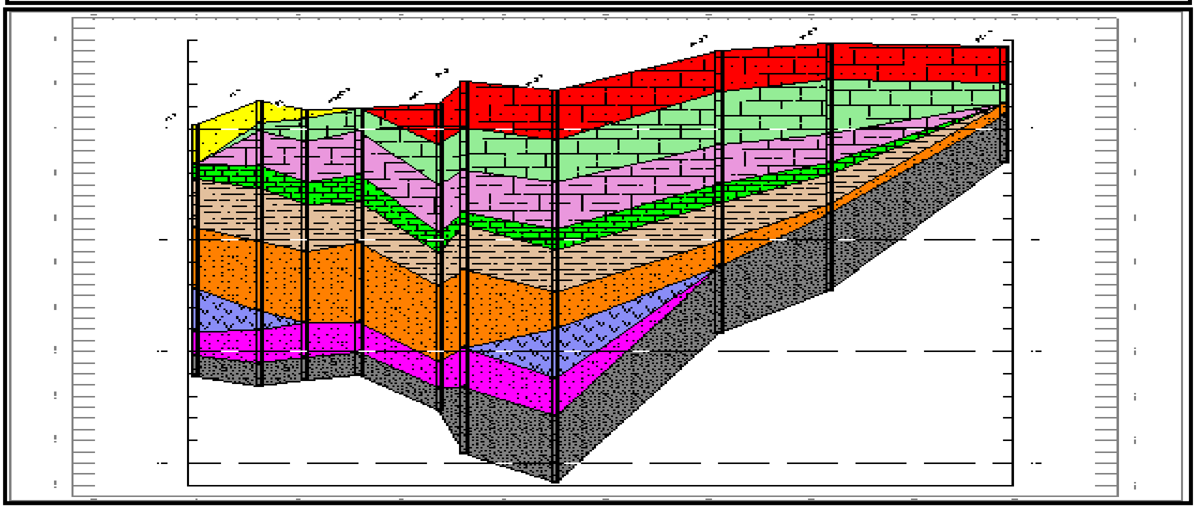
Fig. 9: N-S Meridian Cross Section (Meridian 7°30)



In the third section, we note two interesting observations:

- Towards the North (Tawargha sector), the sandstone of Cambro-Ordovician (Palaeozoic), the sandstone Triassic and the Kiklah formation perfectly communicate and constitute one single aquifer;
- In the South, and closer to the shallows of Dj. Hassaouna, there is no separation between the Continental Intercalaire and the Cambro Ordovician.

Fig. 10: N-S Cross Section at NWSAS eastern boundary



Thanks to the stratigraphic scale, which ensures temporal and spatial concordances, and thanks to performed lithostratigraphic cross sections[5], we can now combine Algeria, Tunisia and Libya. The objective being to develop a coherent outline of the hydro-geological plan, it was necessary beforehand to:

- Be able, first in the terminology adopted in each country, to relate all identified lithostratigraphic formations to the universal stratigraphic scale ;

[5] The developed geological database enables the instantaneous drawing of lithostratigraphic correlations.

- Translate these formations in purely lithological terms, in order to assess their degree of permeability;
- Finally translate the obtained lithological formation in terms of aquifer formations or aquitards and aquicludes.

These phases, for each of the three countries, are shown in Table 1.

Table 1: Hydro-stratigraphic Correlations in Algeria, Tunisia and Libya

<table>
<tr><td colspan="5">ALGERIA</td></tr>
<tr><td colspan="2">Stratigraphic Unit</td><td>Litho-stratig. Units</td><td>Lithological units</td><td>Aquifers & aquitards</td></tr>
<tr><td colspan="2" rowspan="4">Mio-Pliocene</td><td rowspan="4">Terminal Continental</td><td>Sand</td><td>2^{nd} sand aquifer</td></tr>
<tr><td>Clay</td><td>Semi-permeable</td></tr>
<tr><td>Sand & clay</td><td>1^{st} sand aquifer</td></tr>
<tr><td>Clay</td><td>Semi-permeable</td></tr>
<tr><td colspan="2">Middle Eocene</td><td>Evaporitic Eocene</td><td>Gypseous clay</td><td>Semi-permeable</td></tr>
<tr><td colspan="2">Lower Eocene</td><td rowspan="2">Carbonated Eocene</td><td rowspan="2">Limestone</td><td rowspan="5">Calcareous Aquifers</td></tr>
<tr><td colspan="2">Paleocene</td></tr>
<tr><td rowspan="3">Upper Senonian</td><td>Maetrichtian</td><td rowspan="3">Carbonated Senonian</td><td rowspan="3">Limestone</td></tr>
<tr><td>Campanian</td></tr>
<tr><td>Santonian</td></tr>
<tr><td colspan="2">Lower Senonian</td><td>Lagoon Senonian</td><td>Clay, Gypsum, Salt</td><td>Impervious</td></tr>
<tr><td colspan="2">Turonian</td><td>Dolomite Turonian</td><td>Dolomite</td><td>Turonian aquifer</td></tr>
<tr><td colspan="2">Cenomanian</td><td>Argilous-evaporitic Senonian</td><td>Gypsum green clay & marly calcareous</td><td>Impervious</td></tr>
<tr><td colspan="2">Albian</td><td rowspan="4">Continental Intercalaire</td><td>Continental sandstone</td><td rowspan="3">Continental Intercalaire Aquifer</td></tr>
<tr><td colspan="2">Aptian</td><td>Limestone & dolomite</td></tr>
<tr><td colspan="2">Barremian</td><td>Sandstone & continental clay</td></tr>
<tr><td colspan="2">Neocomian</td><td>Clay & sandstone</td><td>Salty water</td></tr>
<tr><td rowspan="2">Malm</td><td>Kimmeridgian</td><td rowspan="3">Jurassic</td><td rowspan="2">Calcareous and Lagoon deposits</td><td rowspan="3">Jurassic Aquifer</td></tr>
<tr><td>Calovo-Oxfordian</td></tr>
<tr><td>dogger</td><td>Bathonian</td><td>Carbonates</td></tr>
<tr><td colspan="2">Liassic</td><td>Upper Salifere</td><td>Lagoon and carbonated deposits</td><td rowspan="3">Impervious top</td></tr>
<tr><td colspan="2">Keuper</td><td rowspan="2">Salifere Triassic</td><td rowspan="2">Massive salt</td></tr>
<tr><td colspan="2">Mushelkalk</td></tr>
<tr><td colspan="2">Bundstandstein</td><td>Sandstone Triassic</td><td>Argilous - sandstone</td><td>Triassic salty aquifer</td></tr>
</table>

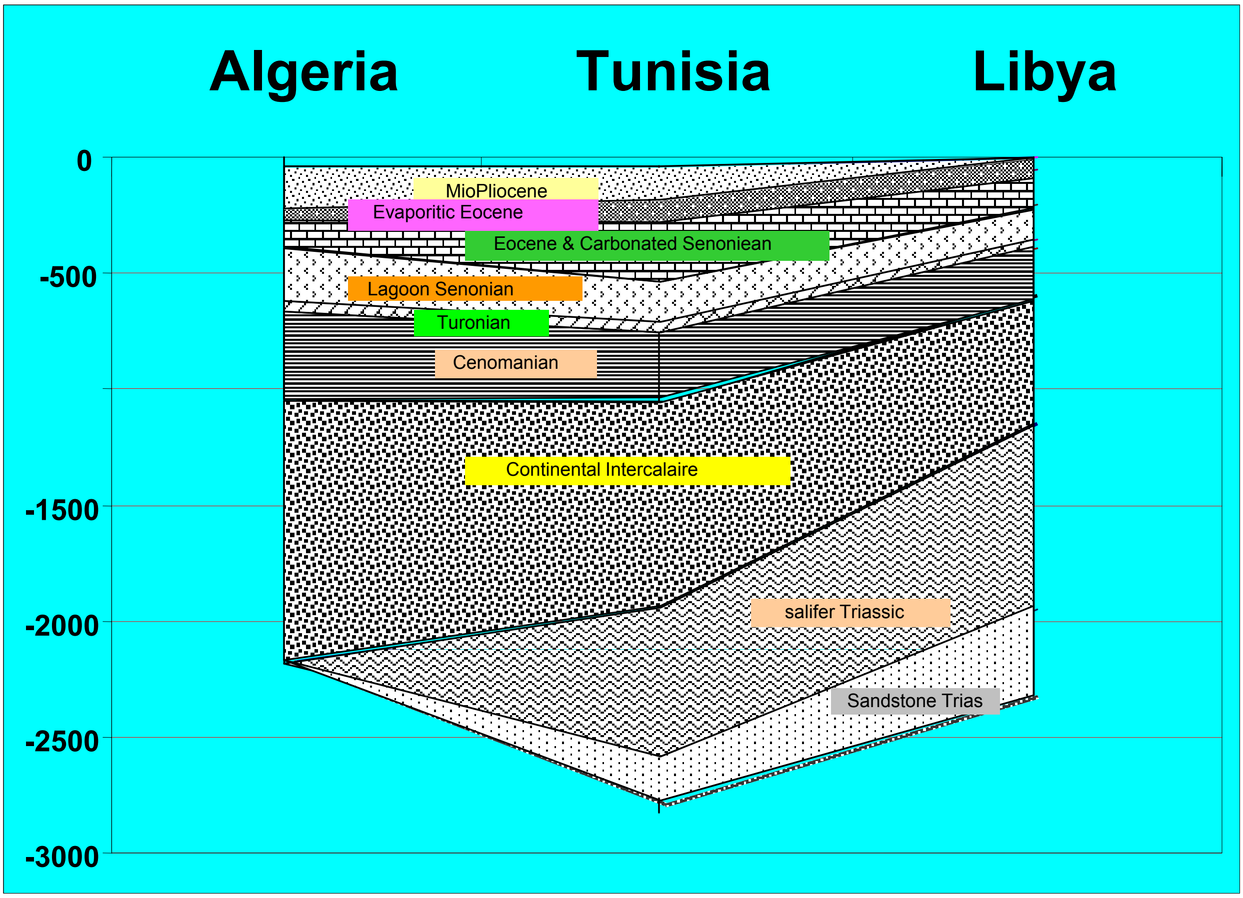
TUNISIA				
Stratigraphic Unit		Litho-stratig. Units	Lithological units	Aquifers & aquitards
Mio-Pliocene		Terminal Continental	Clay	Impervious top
			Sand	Djerid sands aquifer
Middle Eocene		Evaporitic Eocene	Gypsy clay	Semi-permeable
Lower Eocene		Metlaoui	Limestone	Non recognized aquifer
Paleocene		El Haria	Transition clay	Semi permeable
Upper Senonian	Maetrichian	Abiod	Limestone	Nefzaoua upper calcareous aquifers
	Campanian			
	Santonian	Aleg	Marly gypsy unit	Semi permeable
Lower Senonian		Upper Zebbagh	Limestone	Nefzaoua lower calcareous aquifers
			Marly gypsy unit	Semi-permeable
Turonian		Dolomite El Guettar	Calcareous dolomite & dolomite	Turonian aquifer
Cenomanian		Middle Zebbagh	Clay, marl & gypsum, marl, limestone	Impervious
Albian		Ain Guettar	Sandstone West, carbonated East	Continental Intercalaire Aquifer
Aptian		Aptian dolomite	Clay & massive dolomite	
Barremian		Merbah El Asfar Series	Sandstone & argilous sands	
Neocomian: Wealdian			Wealdian sands	
Malm	Kimmeridjian	Merbah El Asfer basal	Dominating clay	Jurassic Aquifer
	Calovo-Oxfordian	Foum Tataouine	Limestone & marl	
Dogger	Bathonian	Kechaoua Limestone	Carbonate anhydrite benches	
Liassic		Upper Salifere: Mestaoua Gypsum	Anhydrite, dolomites, clay	Impervious top
Keuper		Lower salifere	Evaporitic Triassic	
Mushelkalk		Rehach dolomites	Dolomitic triassic	
Bundstandstein		Much sandstone	Red & black sandstone	Triassic aquifer

LIBYA					
Stratigraphic Unit		Litho-stratig. Units		Lithological units	Aquifers & aquitards
Plio-quartenary		Plio-Quarternary		Limestone, Marl, Gypsym	Local aquifer
Miocene		Miocene		Marl	Semi-permeable
Aquitanian		Aquitanian		Fissured limestone	Aquifer
Oligocene		Oligocene		Limestone	Local aquifer
Eocene		Eocene		Limestone	Poor aquifer
Paleocene		Zmam		Limestone, marl, calceranite	Upper cretaceous, Paleocene, Mizda aquifer
Upper senonian	Maestrichian				
	Campanian	MIZDA	Thala	Marly gypsum, dolomite	
	santonian		Mazuza	Compact limestone	
					Semi-permeable
Lower senonian			Tigrinna	Clay, Marl, Gypsum	Turonian aquifer
Turonian		Gharyan - Nalut		Dolomite, calcareous dolomite	Nalut aquifer
Cenomanian		Sidi Assid	Yefren	Limestone, marl, dolomite, gypsum, salt	Impervious
			Ain Tobi		
Albian		Kiklah s.i	Kiklah s.s	Sand, sandstone, dolomite limestone	
Aptian			cabao	Sandstone & argilous sands	Jurassic, lower cretaceous Kiklah Aquifer
Barremian					
Malm	Neocomian: Wealdian				
	Kimmeridgian		schakshouk	Limestone, dolomite	
	Calovo-Oxfordian		“Chameau Mort” Dead camel	Sandtone, sand, clay	
Dogger	Bathonian	Giosc & tacbal		Sandtone, gypsum, limestone	Impervious top
Liassic		Les abreghs		Anhydrite, dolomites	
		Bir ghenem		Limestone, dolomite, gypsum, anhydrite	
Keuper		Bouchiba		Clay, gypsum	
Mushelkalk		Azizia		Limetone, karstified dolomite, gypsum	
Bundstandstein		Ras Hamia		Sandstone, argilous sands	Triassic: Aziza aquifer
		Oueld Chebbi		Sandstone	

II.3- Schematization of Saharian Multi-aquifers

The ultimate geological simplification level of the Northern Sahara, through the design of separate standard sections for each country, then the definition of regional lithostratigraphic correlations, is reflected in the design of the block diagram of Fig. 11. Though schemed at its most extreme drawing norms, which definitely gives it a local erroneous character[5], this diagram shows an exceptional continuity within Saharian platform sedimentary series. This scheme namely suggests the continuity and homogeneity of large aquifer formations as well as semi-permeable series.

Fig. 11: NWSAS simplified geological Block-diagram



More precisely, the last reading phase of the standard section per country was to translate findings into «aquitards». Once compared and related to the stratigraphic scale, these series provide the scheme shown in fig. 12, where are represented in blue the most significant soft water aquifer formations, in pink salty water aquifers. The remaining formations [semi-permeable formations, non-permeable, poor quality aquifers] are colorless.

If we exclude salty waters aquifers present in the Triassic, Jurassic and Neocomian in Algeria, the Libyan sandstone Triassic (containing soft water, but relatively well isolated from other aquifer systems), we will find, based on purely litho-stratigraphic criteria, four major superposed aquifer systems, certainly with different sizes, and whose vertical organization and regional connections can be clearly observed. We shall see from bottom to top:

- The Continental Intercalaire aquifer in Algeria-Tunisia, crossing Libya at the level of the Kiklah-Aquifer formation, including the Jurassic and the Lower Cretaceous.

[5] example, the evaporitic Eocene has a reduced spatial extension and does not exist in Libya.

- The Turonian aquifer in Algeria-Tunisia, crossing Libya at the level of the Nalut-aquifer formation.
- The Limestone aquifer in Algeria [Carbonated Senonian +Carbonated Eocene], crossing Tunisia at the level of the limestone aquifer [lower and upper ones] in Nefzaoua, the equivalent of Mizdah-Aquifer in Libya.
- Mio-Pliocene Sands aquifer in Algeria, crossing Tunisia at the level the Pontian sands in the Djerid, having their equivalents[5] in Libya, the two aquifers, respectively of the Aquitanian and the PlioQuaternary.

Fig. 12: NWSAS Aquifers and Aquitards

Stratigraphic Unit		Aquifers & Aquitards: ALGERIA	TUNISIA	LIBYA
Plioquartenary	Mio-Pliocene	2nd sands aquifer	Impervious Top	Local aquifer
Miocene		Semi-permeable		Semi-permeable
Aquitanian		1st sands aquifer	Aquifer of the Djerid sands	Aquifer
Oligocene		Semi-permeable		Local aquifer
Middle Eocene		Semi-permeable	Semi-permeable	Poor quality aquifer
Lower Eocene		LIMESTONE aquifer	Unrecognized aquifer	
Palaeocene			Semi-permeable	Upper Cretaceous-Paleocene Mizda Aquifer
Maestrichtian	Upper Senonian		Aquifer of Nefzaoua Upper Limestone	
Campanian				
Santonian			Semi-permeable	
Lower Senonian		Impervious	Aquifer of Lower Limestone/Nefzaoua	Semi-permeable
			Semi-permeable	
Turonian		Turonian Aquifer	Turonian Aquifer	NALUT aquifer
Cenomanian		Impervious	Impervious	Impervious
Albian		Aquifer of the Continental Intercalaire	Aquifer of the Continental Intercalaire	Jurassic-Lower Cretaceous KIKLAH Aquifer
Aptian				
Barremian				
Neocomian		Salty water		
Kimmeridgian	Malm	Jurassic aquifer	Semi-permeable	
Callovo-Oxfordian			JURASSIC aquifer	
Bathonian	Dogger			Impervious
Lias		Impervious top	Impervious	
Keuper				
Mushelkalk				Trias AZIZIA Aquifer
Bundstandstein		Trias salty aquifer	Trias aquifer	

An additional simplification degree enables us to design the scheme shown in Fig 13, where aquifers are represented by lively colors and the semi-permeable aquifers by a blue-black color**.**

If we exclude the aquifers of the Palaeozoic aquifer and the sandstone Triassic in Libya, and if we gather, as commonly made, the limestone aquifer of the upper Cretaceous, that of the

[5] This « equivalency » is measured in terms of stratigraphic positions ; but these Libyan aquifers are limited to the eastern basin and have no physical relation with the equivalent aquifers in Algeria and Tunisia.

carbonated Eocene, and the sands aquifer of the MioPliocene (resp. Mizdah and Plio-Quartenary), the NWSAS Multi-aquifers will be represented in the form of three superposed aquifer systems, separated by (or communicating through) semi-permeable formations; which are:

- Continental Intercalaire aquifer – Kiklah
- Turonian aquifer – Nalut
- Complexe Terminal aquifer - Mizdah

Fig.13: Outline of the Saharian Multi-aquifers

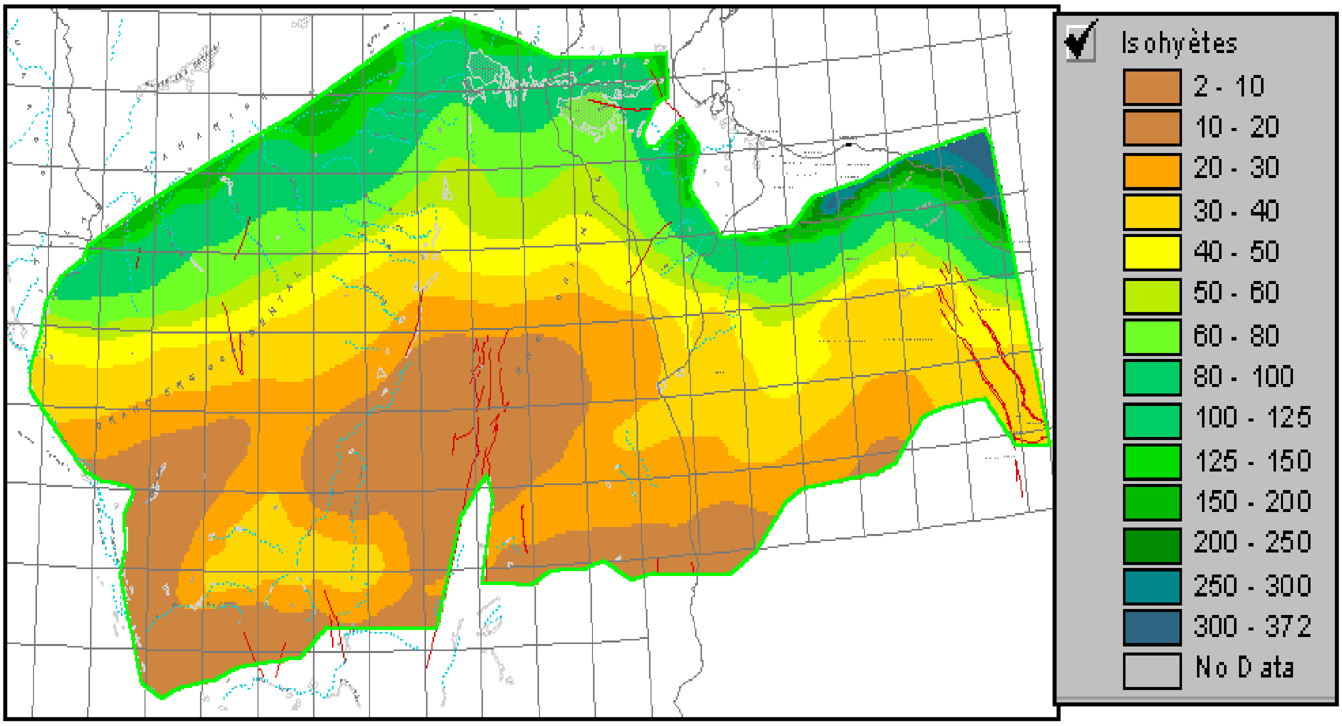
HYDRO-GEOLOGICAL SCHEME OF THE NORTHERN SAHARA		
ALGERIA	TUNISIA	LIBYA
Impervious top	Impervious top	
Sand aquifer	Sand aquifer in the Djerid	MioPlioQuartenary aquifer
Semi permeable	Semi permeable	Semi permeable
LIMESTONE aquifer	LIMESTONE aquifer - Nefzaoua	Upper Cretaceous-Paleocene: MIZDAH
Impervious	Semi permeable	Semi permeable
TURONEN Aquifer	TURONEN Aquifer	NALUT Aquifer
Impervious	Impervious	Impervious
CONTINENTAL INTERCALAIRE SL	CONTINENTAL INTERCALAIRE & Jurassic	Jurassic Lower Cretaceous – KIKLAH
Palaeozoic	Impervious	Impervious
		Triassic: AZIZIA Aquifer
		Palaeozoic

III- HYDROLOGICAL CHARACTERIZATION

III.1- Precipitations in NWSAS domains

When extrapolating the rainfall map in isohyetic curves designed by DUBIEF (1954), we will have a grid (in 5kmx5km cells) representing the average water stage (average over 25 years 1926-1950), of all points contained in the NWSAS domain[5] (fig.14).

Fig. 14: Isohyets Map in mm/year



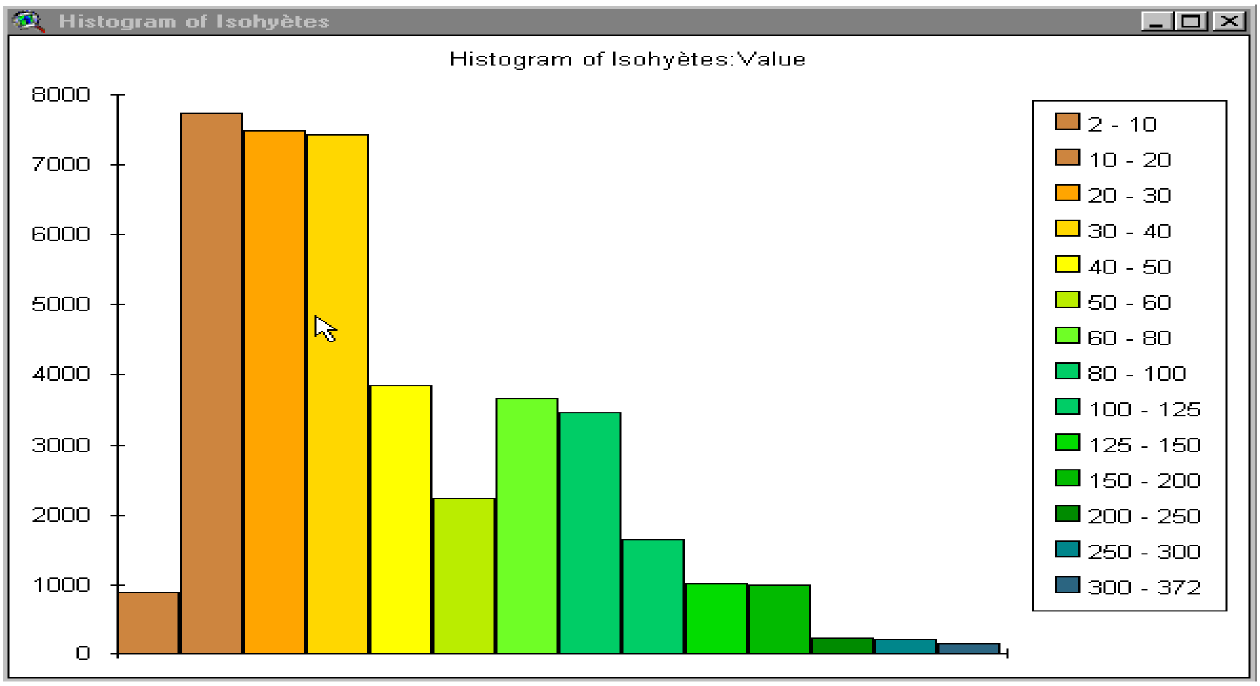
The histogram constructed on the basin of this grid (fig.15) provides data for the calculation of the average rainfall in the catchments basin.

If n_i is the number of cells per class in the histogram, and y_i is the class average value, the average water wave P falling onto the basin is obtained by: $P = \frac{\sum ni.yi}{\sum ni}$; or P = 51 mm.

For a total surface of 1.027.000 Km2, the volume of NWSAS average Rain Resources amounts to 52 billion m3/year.

[5] The domain of Fig.14 represents the extension boundaries of the Continental Intercalaire aquifer. Except for the Biskra region where the Complexe Terminal slightly spills out onto the North, we can consider that NWSAS domain corresponds to the Continental Intercalaire boundaries.

Fig. 15: Isohyets Histogram



III.2- Runoff within NWSAS

Since DUBIEF works (1953), there have been few runoff observations in that region and the Saharian hydrology in general seems not to have drawn much attention, with the exception described below[5]. However, if we examine the Sahara altimetric structure, and if we focus in a first phase on the Central region, we may define (fig.16), from the 28th to the 35th parallel, and from the 3rd to the 11th meridian, a “catchments area of the Chotts” covering an area of about 500.000 km2. One third of this basin is certainly covered by the Large Erg Oriental and the former bed of Igharghar river, and one fifth of the basin is covered by Tinghert and Isaouane, whose contribution to surface flows can be contested (Dubief, 1953). There remains a number of active catchments areas covering an area of 250.000 km2, down from the Saharian Atlas, Mzab ridge and the Dahar.

Concerning the Dahar in particular, the contribution of M. FERSI (1979)[5] is valuable. By considering observations of flows in eight catchments areas in Central and Southern Tunisia (see Table 2), Fersi developed an empirical formula applicable in an arid climate, which related the flowing wave to the rainfall (annual average) and to the physiographical characteristics summarized by the average slope. Adjusted over experimental points (Fig.17), Fersi equation is written as:

$$\overline{Lr} = 0.017 * \overline{P} . \sqrt{IG}$$

where $\overline{Lr}$: average flowing wave in mm

[5] Dubief is certainly the only researcher to have “believed” in the present recharge of Saharian aquifers by surface waters. For fifty year, the separated and parallel development of surface and underground hydrologies, the progress and appeal of palaeo-hydrology, a rather quick reading of radiometric dating results, the difficulty and importance of a rational approach for the recharge of Saharian tables, and finally a certainly suitable climate have reinforced the image of “water mines under the desert” (expression of J.Margat and K.Saad) and the concept of Saharian “fossil water tables” has gradually become a real ideology.

[5] FERSI. M. ; 1979: Estimate of the average annual flows in the Catchments areas of E, SW and Southern Sahel; DGRE

$\overline{P}$: average rainfall in mm

IG : Basin average slope in m/Km

This formula enabled Fersi (1979) to suggest the average flows estimations over all catchments areas in Southern Tunisia.

fig. 16: Catchments Basin of the Chotts

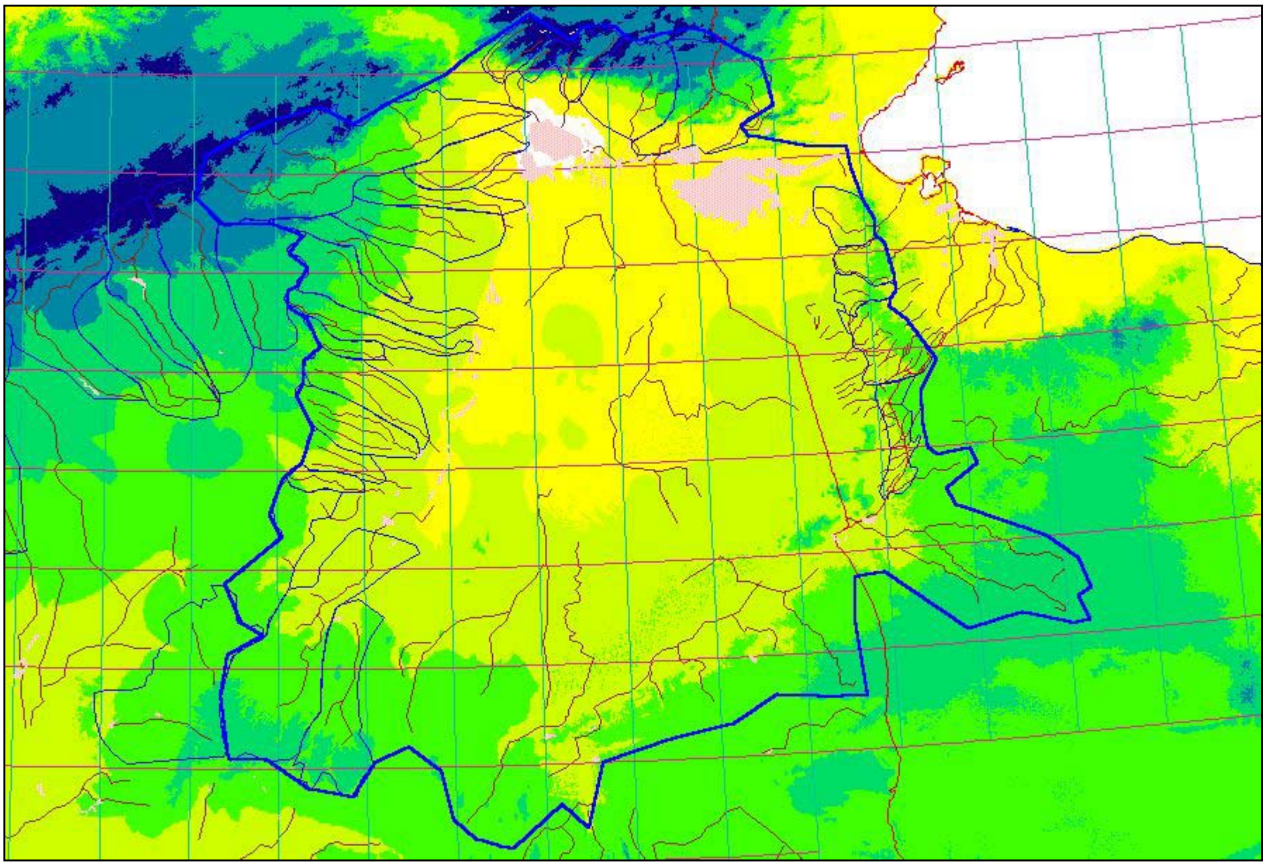
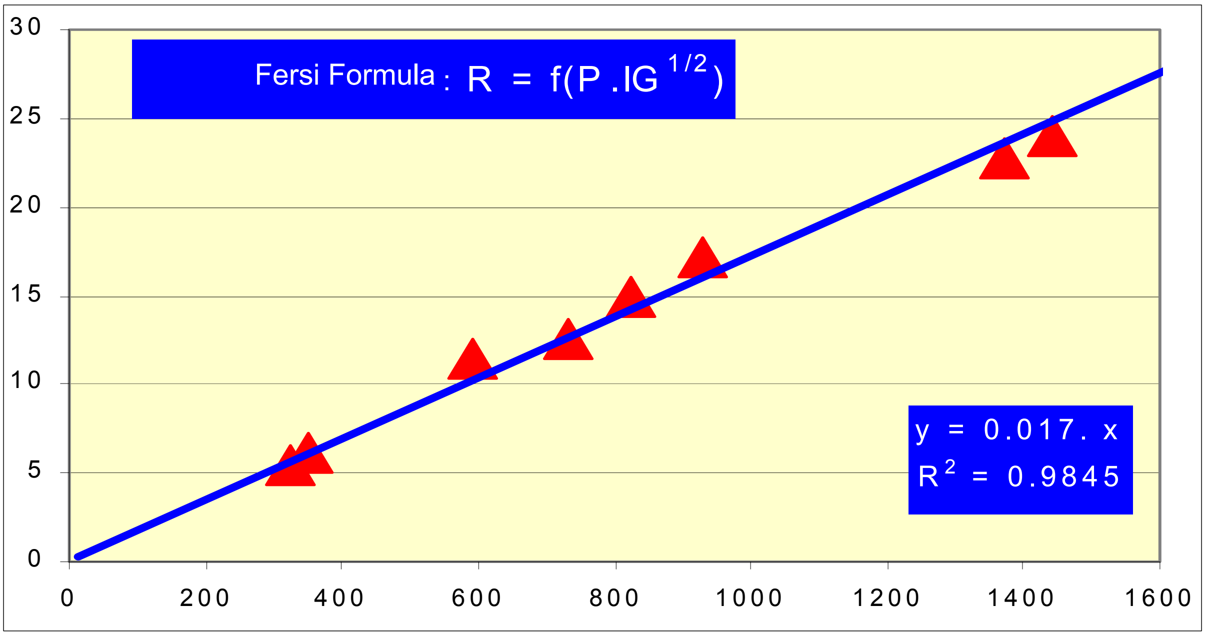


Table 2: Runoff in Central and Southern Tunisia (according to Fersi, 1979)

Catchments Basin	S (km2)	IG (m/km)	P. Mm	R. Mm	$PxIG^{1/2}$
Oued El Hamma	735	4.8	160	6.1	351
Oued Chaffar	240	3.6	170	5.5	323
Oum Ezzessar in Koutine	285	16.5	180	12.5	731
Oued Gabes Bridge GP1	88	10.8	180	11.5	592
Oued Zita	3.4	30	170	17.1	931
Oued Merguellil in Haffouz	675	13	380	22.7	1370
Oued Hatteb in Ain Saboun	813	13	400	24	1442
Oued Zeroud in Kt-Zazia	2200	6.6	320	15	822

S: Area, Ig: Slope general Index, P: rainfall, R: Runoff

Fig. 17: Fersi's Runoff Law with regard to the annual rainfall and the slope of the Catchments Basin



Application to the Runoff Estimate in the Saharian Atlas

We may define eight main catchments basins going downhill the Saharian Atlas towards NWSAS influence area (fig.18):

1: Catchments basin of Zousfana-Saoura wadi
2: Namous wadi basin
3: Rharbi wadi basin
4: Mazar wadi basin
5: Seggeur wadi basin
6: Zergoun wadi basin
7: Mehaiguene Wadi basin
8: Djeddi Wadi basin

Two out of these basins have been subject of hydrometric observations: Wadi Namous in Hassi Mamoura, and wadi Seggeur at Brezina station. We will use these observations, reported by BRL (1998)[5], to check whether Fersi's formula is applicable under the conditions of the Saharian Atlas.

[5] BRL engineering ; 1999: Study of the General Development Plan of Saharian Regions – Overall Information.

Fig.18 : Southern Catchments Basins of the Saharian Atlas

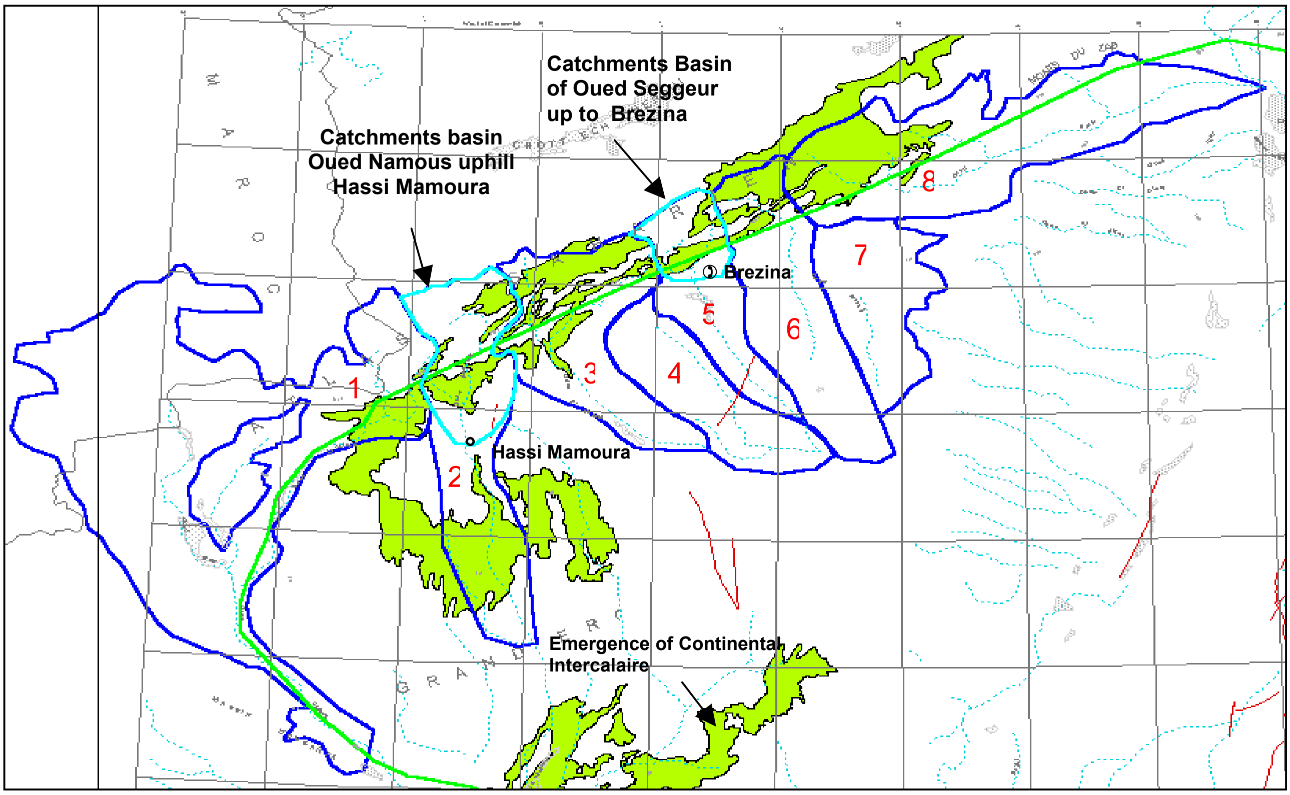


Table 3 shows at the same time observation data concerning these two rivers (wadis) and the corresponding annual average runoff values calculated by means of Fersi formula.

Table 3: Observed and calculated runoff in the Saharian Atlas

Catchments basin	P_{moy} (mm)	I_G (m/km)	L_r(mm) Calculated (Fersi)	L_r(mm) observed (BRL)	S (km^2)	V_r (Mm^3) calculated	v_r(Mm^3) observed (BRL)
O.Namous to hassi Mamoura	**189**	**8.17**	8.85	7	**8910**	79	62
Oued Seggeur to Brezina	**245**	**12.1**	13.97	13	**3905**	55	50

For each catchments area, we determine the index of the gradient IG. The average rainfall is obtained as follows: the interpolation (linear compared to distance reverse values) of DUBIEF (1953)[6] isohyets yields an area spread over cells of 5kmx5km. The breakdown on the histogram, of cells of the same value on a given catchments area will provide the average rainfall compared to this basin (Fig. 19a et 19b).

[6] **DUBIEF. J ; 1953: Essai sur l'hydrologie superficielle au Sahara ; SES , Algiers.**

Fig. 19a: Areas of average precipitation on the catchments area of wadi Namous

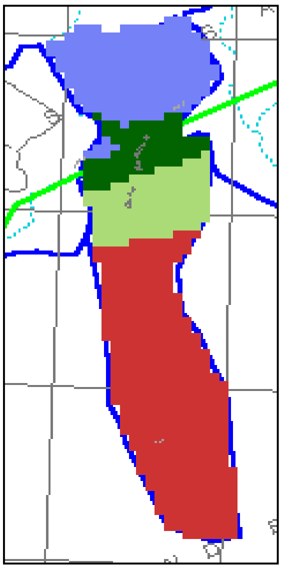
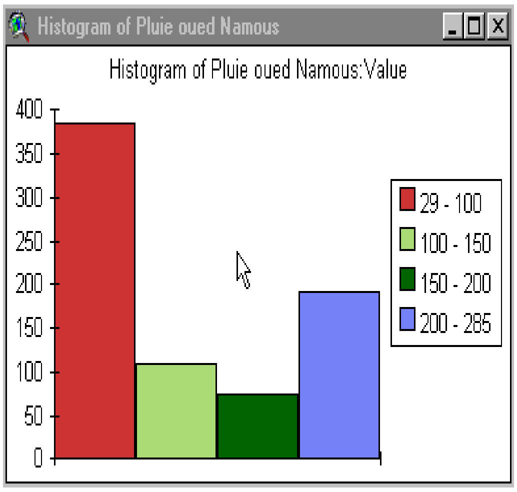


Fig. 19b: Cell Histogram of average precipitation on the catchments basin of wadi Namous



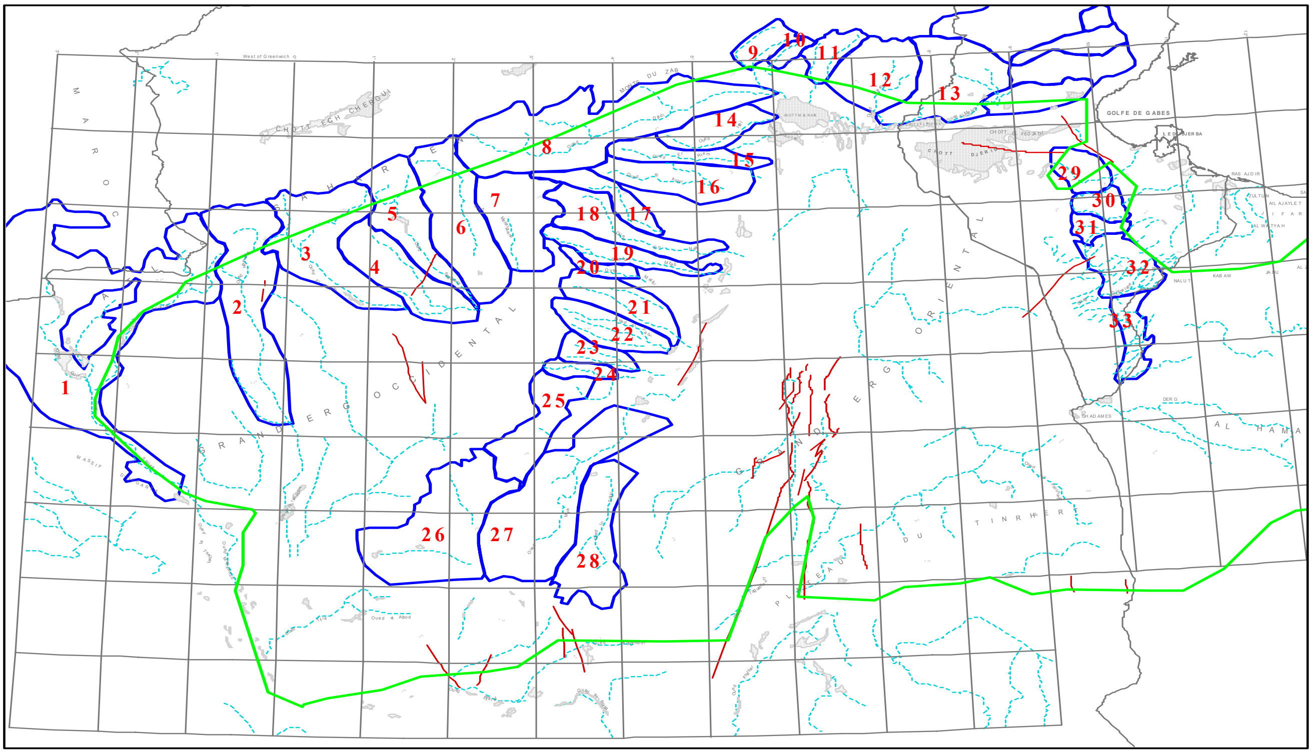
The yielded result is extremely favourable. FERSI's formula, valid for two important wadis of Saharian Atlas, can therefore be applied to other catchments areas of the North-Western Sahara Aquifer System. In a first analysis, we can identify thirty basins (fig. 20 and Table 4).

Table 4: Catchments areas of the Northern Sahara[7]

1: Wadi Bechar – Saoura	**12:** Wadi Djedah	**23:** Wadi Gouiret Moussa
2: Wadi Namous	**13:** Wadi El Melah	**24:** Wadi Djafou
3: Wadi Rharbi	**14:** Wadi Ittel	**25:** Wadi Djoua
4: Wadi Mazar	**15:** Wadi Rtem	**26:** Wadi Ech Cheguig
5: Wadi Seggeur	**16:** Wadi Attar	**27:** Wadi Mya
6: Wadi Zergoun	**17:** Wadi Zegrir	**28:** Wadi In Sakki
7: Wadi Mehaiguène	**18:** Wadi N'sa	**29:** Wadi Hallouf
8: Wadi Djeddi	**19:** Wadi M'zab	**30:** Sector Mahbes
9: Wadi Biskra	**20:** Wadi Metlili	**31:** Sector Lisseri
10: Wadi Biraz	**21:** Wadi Touil	**32:** Sector Djneiene
11: Wadi El Arab	**22:** Wadi Fahl	**33:** Sector Tiaret

[7] Libya not included

Fig. 20 Catchments Basins of Northern Sahara Septentrional



Runoffs calculated by means of FERSI's formula on the catchments basins of the Saharian Atlas are represented below:

Table 5: Runoff calculated on the Saharian Atlas

	Catchments Basin	P_{moy} (mm)	I_G (m/km)	L_r (mm)	S (km^2)	V_r (Mm^3)
SAHARIAN ATLAS	Wadi Namous (the whole basin)	128	4.09	4.24	19052	81
	O.Namous in hassi Mamoura	*189*	*8.17*	*8.85*	*8910*	*79*
	Wadi El Rharbi	159	4.48	5.52	14974	83
	Wadi Seggeur (the whole basin)	154	6.04	6.20	9662	60
	Wadi Seggeur in Brezina	*245*	*12.1*	*13.97*	*3905*	*55*
	Wadi El Mazar	78	2.22	1.90	10590	20
	Wadi Zergoun	113	3.93	3.67	15729	58
	Wadi Mehaiguene	79	2.23	1.92	10581	20
	Wadi Djeddi	177	2.71	4.78	26068	124
	Wadi Saoura	*114*	*3.76*	*3.62*	*58447*	*212*
	Total Atlas (Saoura not included)					446

Table 6 below presents the annual average runoff calculated on the Dahar, in the Aures, Chott Gharsa and M'zab ridge.

Table 6: Runoffs in the other catchments basins of the Northern Sahara

Catchments Basin	P_{moy} (mm)	I_G (m/km)	L_r (mm)	S (km^2)	V_r (Mm^3)
Sector O. Hallouf	130	6.28	5.34	3396	18
Sector O. Mahbès	Calculated by FERSI (1979)				6
Sector O. Lisseri					3
Sector O. Djeneiene					11
Sector O. Tieret					5
1.1.1.1.1 Total DAHAR					44
Wadi Biskra	186	20	13.66	2800	38
Wadi Biraz(ou Abiod)	175	25	14.35	1100	16
Wadi El Arab	206	16	13.51	3100	42
Wadi El Djerah	174	13.21	10.36	8650	90
Total AURES					186
Wadi El Melah	160	8.72	7.75	12156	94
Total GHARSA					94
Wadi Ittel	95	3.44	2.89	5000	14
Wadi Rtem	103	3.26	3.05	4500	14
Wadi Attar	88	3.08	2.54	8000	20
O. Zegrir	108	2.97	3.06	4100	13
O. N'sa	85	2.54	2.22	7800	17
O. M'zab	66	2.49	1.71	5000	9
O. Metlili	59	3.72	1.88	1700	3
O. Touil	42	2.53	1.10	6326	7
O. Fahl	37	2.47	0.96	5777	6
O. Gouiret Moussa	35	1.09	0.59	2755	2
O. Djafou	33	1.58	0.68	1790	1
O. Djoua	26	3	0.74	8106	6
O. Ech Cheguig	28	0.95	0.44	19407	9
O. Mya	23	1.43	0.44	21972	10
O. In Sekki	23	1.49	0.46	11113	5
1.2 Total MZAB RIDGE					136

As a conclusion, we can consider in a first analysis that all the average inter-annual runoff on NWSAS[8] domain amounts to 1 billion m3/year.

III.3- Recharge areas and Aquifers Recharge

There are few accurate data and works quantifying the recharge operations of Saharian water tables, and this question has always remained unanswered. The development of models, likely to calculate recharging by calibration transmissivities, gave credence to this situation. This has been the case, that project after project, study after study, the knowledge of CI and CT recharge has never been subject of specific research, which could extract it from its status of scientific vanity showing little practical interest.

[8] Libya not considered

The comments of the ERESS project concerning this issue are telling:

« The recharge of CI aquifer is made through the infiltration of:

- Runoffs at the periphery of the domain … namely the Saharian Atlas, the Dahar …, the Tademait, the Tinhert
- Exceptional annual precipitation on the Grand Erg Occidental. … Though recharge areas are known, it was impossible to consider a campaign of measurements to get to a serious evaluation … It was wiser to represent these areas by an imposed potential and to calculate using the inflow calculation model …"

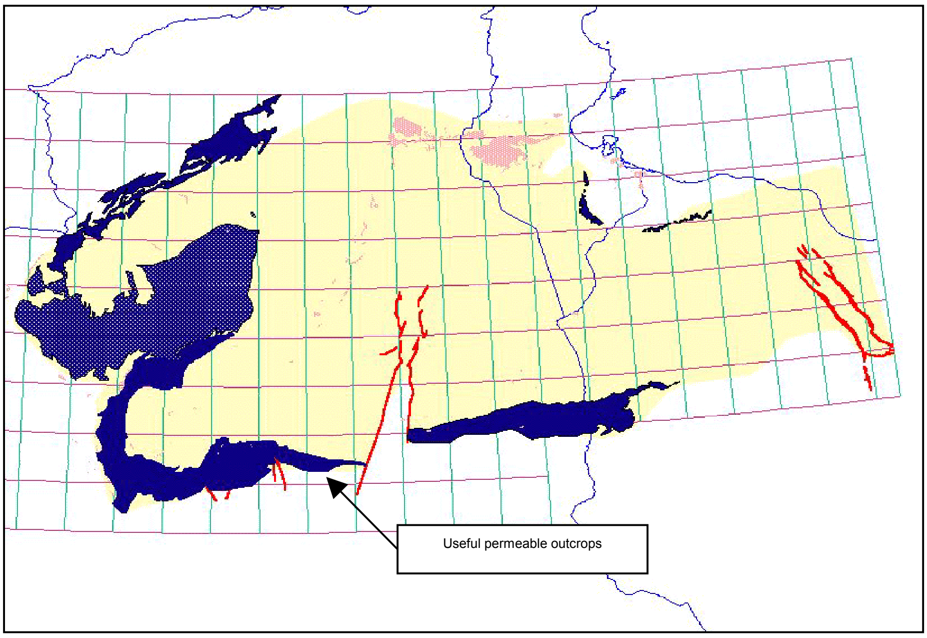
It is very probable that a direct recharge takes place at outcrops of CI and the Grand Erg Oriental, following exceptional rainfall… As it is impossible to practically measure the importance of this phenomenon, … we assumed that the whole recharge comes from the boundaries of the domain … boundary with imposed potential….»[9]

It is true that thirty years after ERESS, we are still at this point, and that NWSAS model will eventually represent recharge as has been the case for previous models. However, we considered to try to approach the phenomenon real size models, so that, before (or after) developing the model, we may include all collected data, or criticize yielded results. In order to do this, the following elements are available:

- Average precipitation in every point ;
- Cartography of geological outcrops;
- A first evaluation of runoff quantities in the catchmentss basins.

These elements have been used to design a first estimate of supply with it two aspects:

Fig. 21: CI useful permeable outcrops



[9] UNESCO , 1972

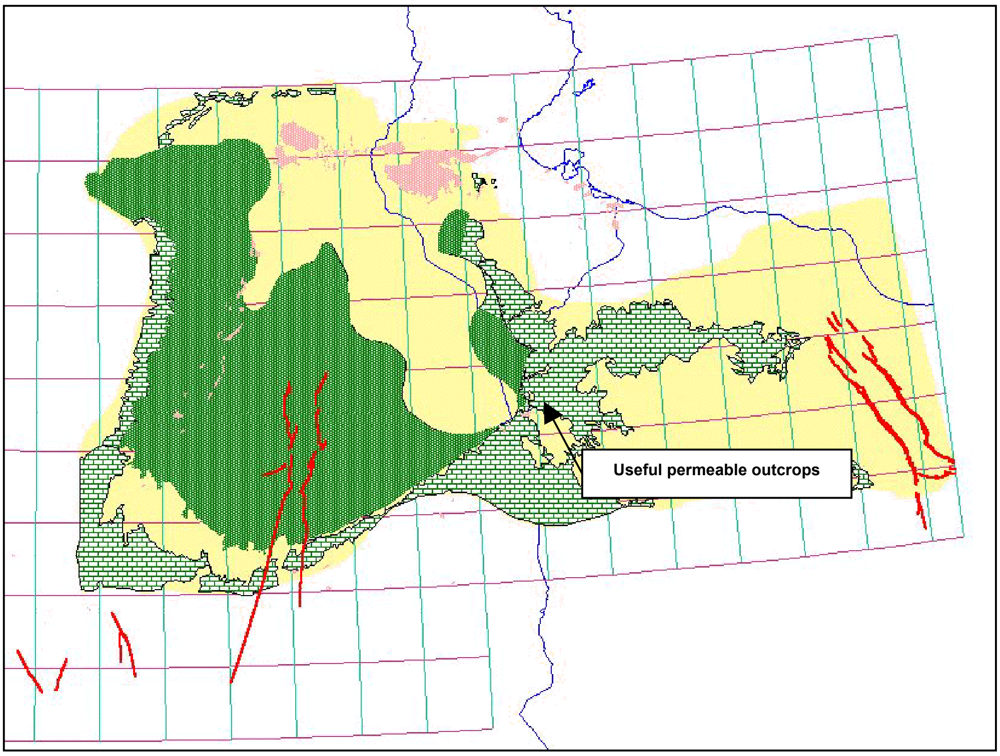
III.3.1- Direct Infiltration at the level of Outcrops:

The maps shown in fig. 21 and 22 represent the extension of all "useful" outcrops of NWSAS permeable formations, those used in regions where the table is unconfined and which contribute to the recharge of aquifers, respectively of CI and CT through direct infiltration of the precipitation.

The conjugation of this map with that of the average precipitation will yield Table 7, which shows that:

- The useful[10] permeable outcrops cover almost 60% of the total surface of NWSAS domain
- The "rain resource" of these outcrops represents 30 billion m^3/year as an inter-annual average,
- By varying 1% to 10% the rain infiltration coefficient, the globally infiltrated volumes in the NWSAS vary between 0,3 and 3 billion m^3/year.
- Finally, all of NWSAS recharge estimates that have been published so far[11] are more or less 1 billion m^3/year [of which 2/3 for CT and 1/3 for CI], which represents, in the logic of previous calculations a direct rain infiltration coefficient of 3% [regardless indirect infiltrations of floods]. This coefficient drops to 2% only if we consider infiltration inputs resulting from the floods of wadis.

Fig. 22: CT Useful permeable outcrops



[10] located in unconfined aquifer sectors

[11] DDC-Burgeap (19063), Geopetrole (1964), Unesco (1972), Srivastava (1983), Zammouri (1990), Geomath (1994)

III.3.2 – Infiltration of floods of Wadis

The average inter-annual runoff on all NWSAS catchments areas has been estimated at 1billion m^3/year.

Concerning infiltration of floods through the beds of Wadi's in arid areas, there are few validated works and models pertaining to real size experiment. In this context, studies of flood infiltration of Wadi Zeroud and Marguellil in the course of their beds crossing the plain of Kairouan, may constitute an interesting reference (Y. Nazoumou, 2002). These studies show that the infiltrated volumes, in inter-annual average values, globally represent 30% of runoff total input. By analogy, all floods infiltrations in NWSAS domain may amount to a total volume of 300 Millions m^3/year.

It would be very careless to try to look beyond these data in the present state of knowledge.

Table 7: Direct infiltration on NWSAS permeable outcrops

Continental Intercalaire						
Water bed	ZONE	Area (km^2)	Ave.R (mm/y)	Average Rain Vol. (Mm^3y)	Infiltrated Volume with infil. Coef. 1%	Infiltrated volume with infil. Coef. 10 %
CI	**IC Saharian Atlas**	**23302**	**218**	**5080**	**50.80**	**507.98**
CI	**Adrar B Drich-Tinrhert**	**28129**	**14**	**394**	**3.94**	**39.38**
CI	**Tidikelt-Touat-Gourara**	**55855**	**15**	**838**	**8.38**	**83.78**
CI	**Western Grand Erg**	**87533**	**38**	**3326**	**33.26**	**332.63**
CI	**Nefusa-Yefren**	**585**	**217**	**127**	**1.27**	**12.69**
CI	**Dahar Tataouine**	**1157**	**130**	**150**	**1.50**	**15.04**
Total CI		196500	50	9900	99	992
Total CI+CT		583000	51	30090	300	3000

Complexe Terminal						
Formation	ZONE	Area (km^2)	Aver. R (mm/y)	Average rain volume (Mm^3/y)	Infiltrated volume with infil. Coef 1%	Infiltrated volume with infil coef.10 %
Sen-C	**North of the chotts**	**2582**	**151**	**390**	**3.90**	**38.99**
Sen-C	**Mzab**	**9328**	**48**	**448**	**4.48**	**44.77**
Sen-C	**Tadmaït**	**22721**	**24**	**545**	**5.45**	**54.53**
Sen-C	**Tinrhert**	**27943**	**28**	**782**	**7.82**	**78.24**
Sen-C	**Tunisia-Libya**	**40329**	**57**	**2291**	**22.91**	**229.15**
Sen-C	**South of Libya**	**1036**	**29**	**30**	**0.30**	**3.00**
Sen-C	**Dahar Matmata**	**208**	**89**	**19**	**0.19**	**1.85**
Sen-C	**Tunisian Atlas**	**0**		**0**	**0.00**	**0.00**
Total Sen-C		**188800**	**65**	**12300**	**123**	**1230**
MPL	**Miopliocene, yc Western Grand Erg**	**197200**	**40**	**7890**	**78.**	**789.**
Total CT	SenC + MPL	386000	52	20190	202	2019

III.3.3 – Deep Evaporation

In the case of a shallow aquifer, the evaporation regime from the unconfined surface is determined by meteorological conditions. When the level of the water table drops, the evaporation rate of flow decreases and tends to a limit value corresponding to the maximal rate of flow that the ground can transmit. The determination of the evaporation rate of flow has been addressed by a number of research studies, of which Gardner model (1958)[12] to assess the water maximal flow that the ground can transmit.

$$E_{\lim} = c(n) a d^{-n} \qquad (1)$$

where: Elim is the evaporation flow,

- d the depth of the water table,
- a and n are empirical constant values characterizing the ground hydraulic conductivity.

Other researchers neglect ground properties. This is the case of Averianov formula which only takes in account the surface evaporation and the annual average temperature:

$$E = E_{pot}\left(1 - \frac{d}{d_{cr}}\right)^n \qquad (2a) \qquad \text{where} \qquad d_{cr} = 170 + 8T \pm 15 \qquad (2b)$$

where:

- E is the annual evaporation,
- E_{pot} the surface potential evaporation,
- d the depth of the water table,
- T the average annual temperature (in °C),
- n a coefficient ranging between 1 and 3
- dcr is the depth of the aquifer beyond which evaporation can no more be considered.

Coudrain-Ribstein et al (1998)[13] suggest a universal formula applicable in arid areas to calculate the limit flow of deep evaporation (in the case of bare grounds):

$$E_{\lim} = \frac{71.9}{d^{1.49}} \qquad (3)$$

The water table of the Continental Intercalaire can be subject to major losses through evaporation in outcrop areas where it is free and close to the ground surface. The depth of MI levels is low on most part of the CI outcrops in the Gourara-Touat-Tidikelt region (cf.fig. 23 where the grey-blue parts represent areas where the unconfined surface is less than 30 m deep).

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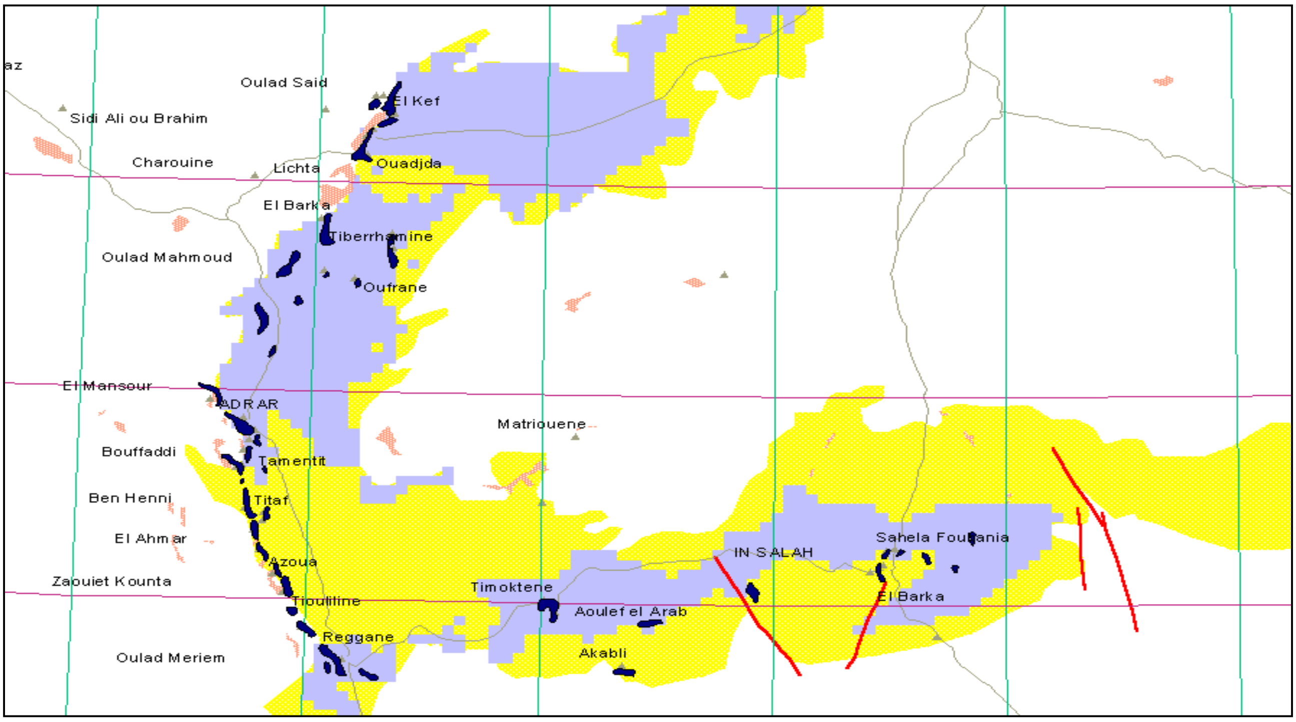
[12] Gardner, W.R., 1958. Some steady state solutions of the unsaturated moisture flow equation with application to evaporation from a water table. Soil. Sci., 85, 228-232.

[13] Coudrain-Ribstein, A., Pratx, B., Talbi, A., Jusserand, C., 1998. L'évaporation des nappes phréatiques sous climat aride est-elle indépendante de la nature du sol ? ; C.R. Acad. Sci. Paris, Sc. terre, 326, 159-165.

Fig. 23: Gourara-Touat-Tidikelt ; Position of foggaras and shallow areas of CI unconfined shallow aquifer

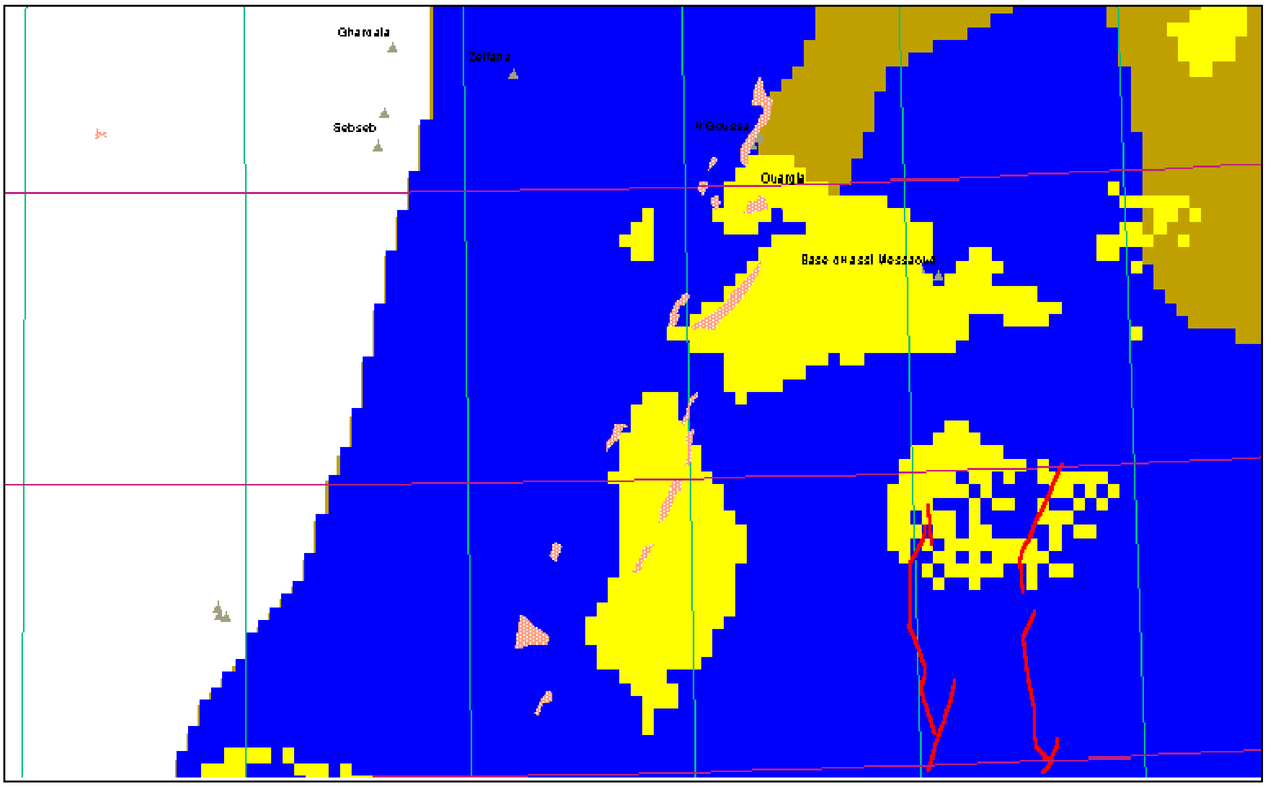


The evaporation rate of flow is calculated through equation (2), by imposing at the surface the potential evaporation. By referring to climatologic data measured at Adrar station, the annual average temperature developed over 29 years is 23.7° C, which defines 4 m as a critical depth (see equation 2b), beyond which evaporation becomes insignificant. Data about ET are scarce. The average ETP calculated by Penman formula of 1970 mm in Idri (Libya) located at the same altitude as Adrar has been considered. When so calculated, the average evaporation in the region represents a continuous discharge equivalent to 10.m^3/s, which seems significant, at least for a first approximation.

In fact, in order to evacuate such a discharge in the region, inputs into the CI aquifers must be sufficient through infiltration in the Erg Occidental as well as in Tademit plateau in the sector of the western basin. The implication of this hypothesis certainly has important consequences for the modeling of the system, but do not contradict potential recharge areas that have been identified.

As for the TC aquifer, it is also affected by the deep evaporation, mainly in the sector of Wadi Mya (see fog. 24 where yellow parts refer to areas where the free surface is less than 30 m deep).

Fig. 24: Shallow aquifers at the Unconfined Zone of CT



IV- MECHANICAL CHARACTERIZATION

IV.1- Schematization of CI Piezometric map

The layout of a system piezometric map as wide as the CI always involves a subjective aspect: ***the representation of flows constitutes the first level of hydrodynamic modelling***, implying that ideas concerning the origins, directions and futures of these flows have been made; this is however not an easy task even if we have all measurements. Such a map has not been yet drawn over all NWSAS territory[14]. Representation concerning parts of the territory already exist, each providing some elements to better know the system.

The first significant contribution to the knowledge of CI flows is certainly the one made by A. CORNET (1964), which identifies two main flow directions: the first heading to the Atlas towards the drainage axis of Gounara, Touat and Tidikelt, the second main drainage area is made up of (fig.25) "Chotts of the low Sahara in Southern Constantine and southern Tunisia." Some years later, the study commissioned by the Technical Body for the Development of Saharian Underground Resources, conducted by SCG- BURGEAP(1963), concluded that: « ... **The hypothesis of the rise of waters of the Continental Intercalaire towards the Chotts of Southern Tunisia (Fedjej-Djerid) where they evaporate, must be rejected. The main outlet of CI's aquifer seems to be constituted mainly by Cretaceous and Miocene aquifers of the Gabes region, where supply is made through El Hamma large fault.** ».

This vision will be adopted by the ERESS project (fig.26), which considers the « Tunisian Outlet » as the single outlet in NWSAS central basin aquifers. In the region's most western part, the Miopliocene is used as a relay with regard to CI, and flows are made towards Saoura.

The flows of Kiklah formation towards the Gulf of Syrta were decribed by GEFLI (1978)[15], then by P. PALLAS (1978)[16] who confirms the **Libyan Outlet**, as well as inputs generated respectively by outcrops of Adrar Ben Drich in the south and Djebel Nefussa in the North. Later, GEOMATH (1994)[17] will adopt a significantly different vision: Aquifers in Kiklah and the sandstone Triassic are mixed, the aquifer is limited on the East by the valley's first fault, right uphill where an impressive piezometric anomaly is attributed to input through a Palaezoic funnel, finally in the north, the Triassic flows obstruct Kiklah, which does not receive any inputs from Dj. Nefussa, and the main outlet is attributed to the aquifer of Djeffara, in Libya as well as in Tunisia.

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[14] **A small scale representation was suggested by Mr. Besbes and Mr. Zammouri in 1988: Extension to Libya of the Algerian-Tunisian CI model ; int. Conf. Comput. methods and water resources, Rabat.**

[15] GEFLI ; 1978: Survey for the development of the Central Wadi Zone & Gulf of Sirte ; Groudwater resources ; Final synthesis report ; Text & App 2&3- water analyses, hydrogeol cross sections, maps.- ref: AL-WR-205.

[16] P. PALLAS ;1980:Water resource Socialist People's Arab Libyan Jamahiriyya. In Salem & Busrewille: the geology of Libya ; Ac. Press ; vol II

[17] GEOMATH ; 1994: Western Jamahirya System; Hydrogeological Modelling of aquifers & well fields; Final Report ; Text & pl . ref: AW-MI-579.

Fig. 25: Isopiezes of the Continental Intercalaire, A. CORNET (1964)

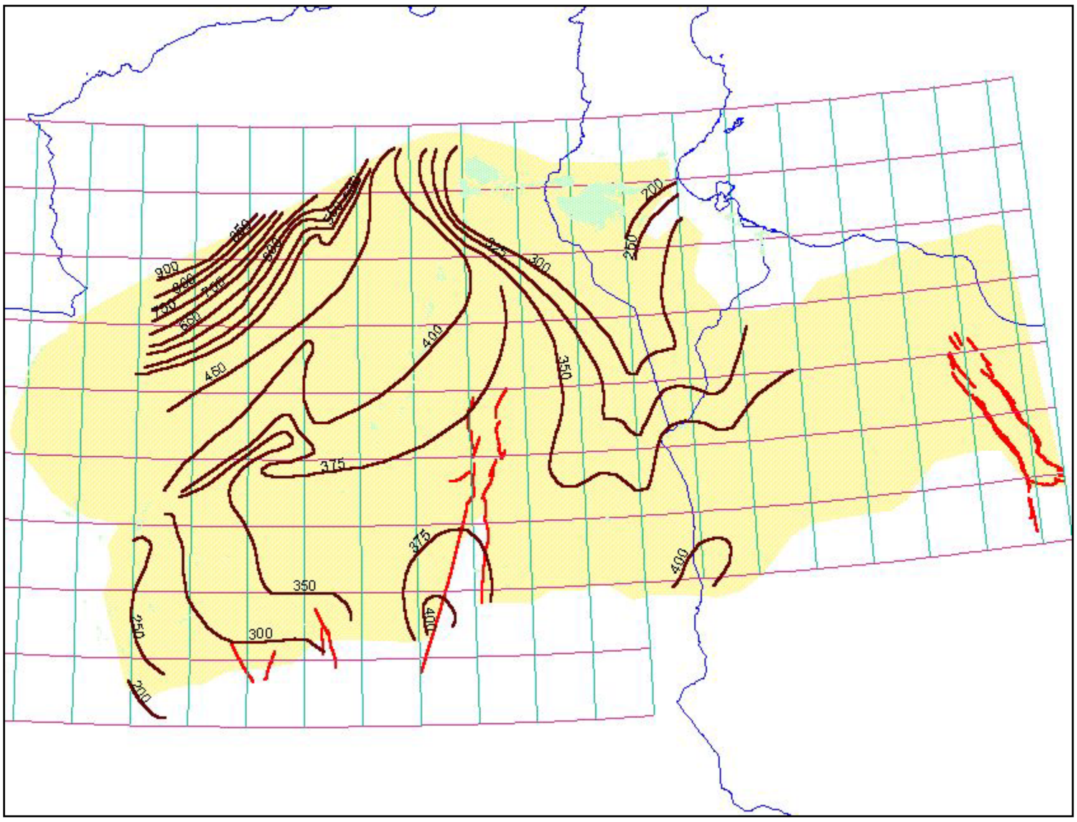


Fig. 26: Piezometry of the Continental Intercalaire ; ERESS (1972)

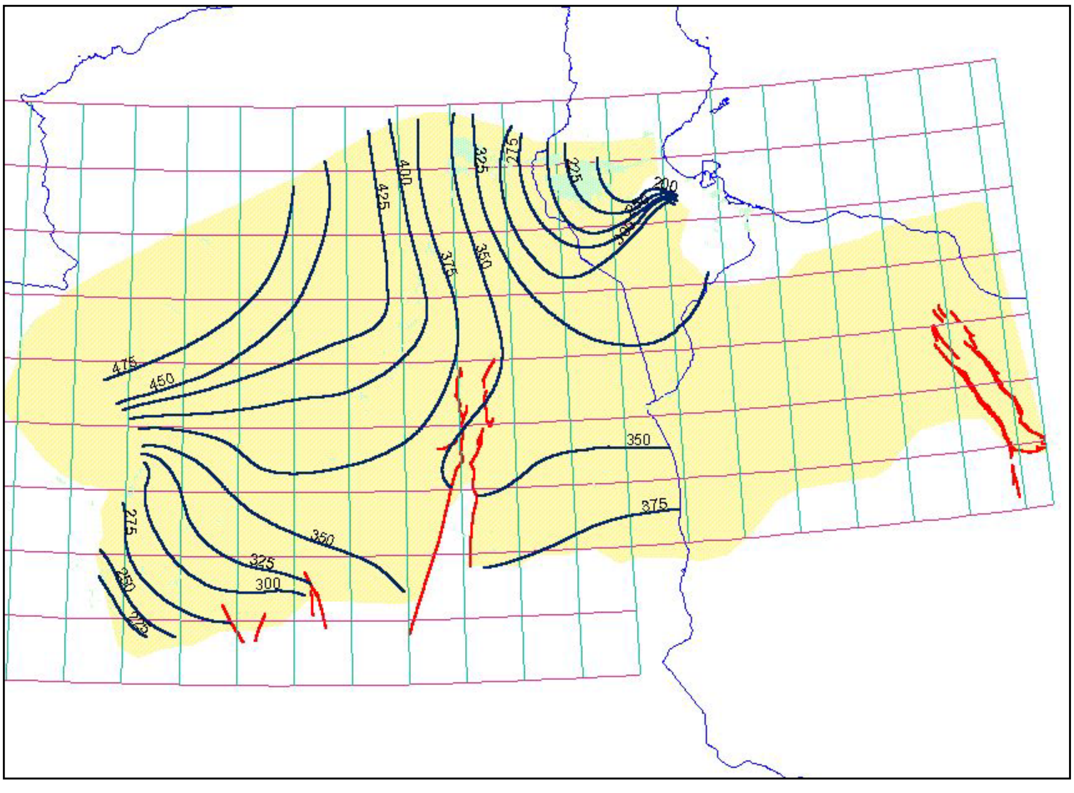


Fig. 27: Aquifer of the Lower Cretaceous ; P. PALLAS (1978)

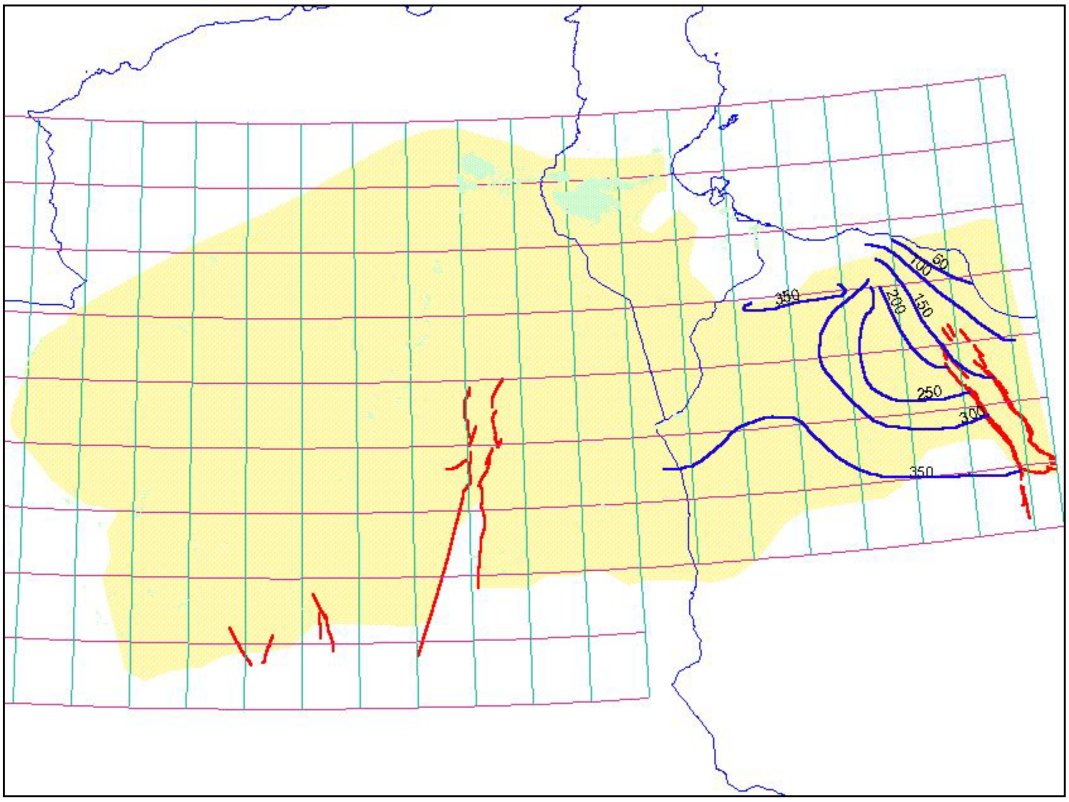
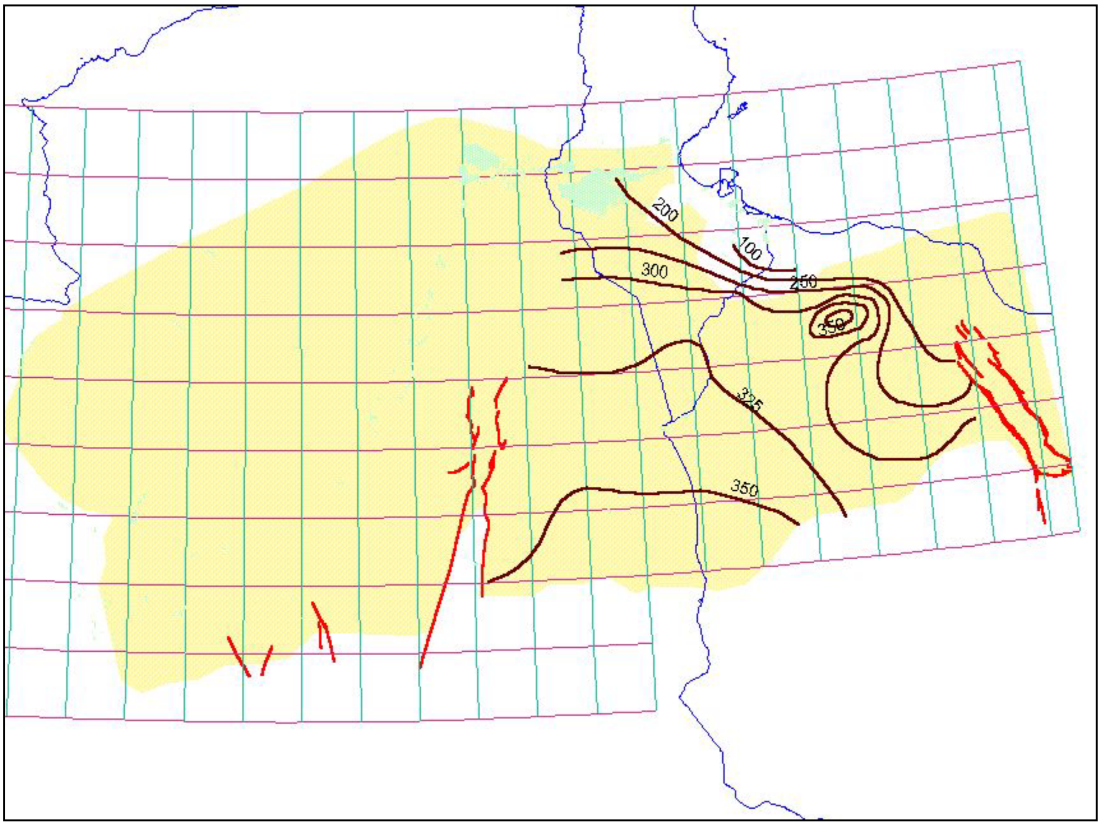
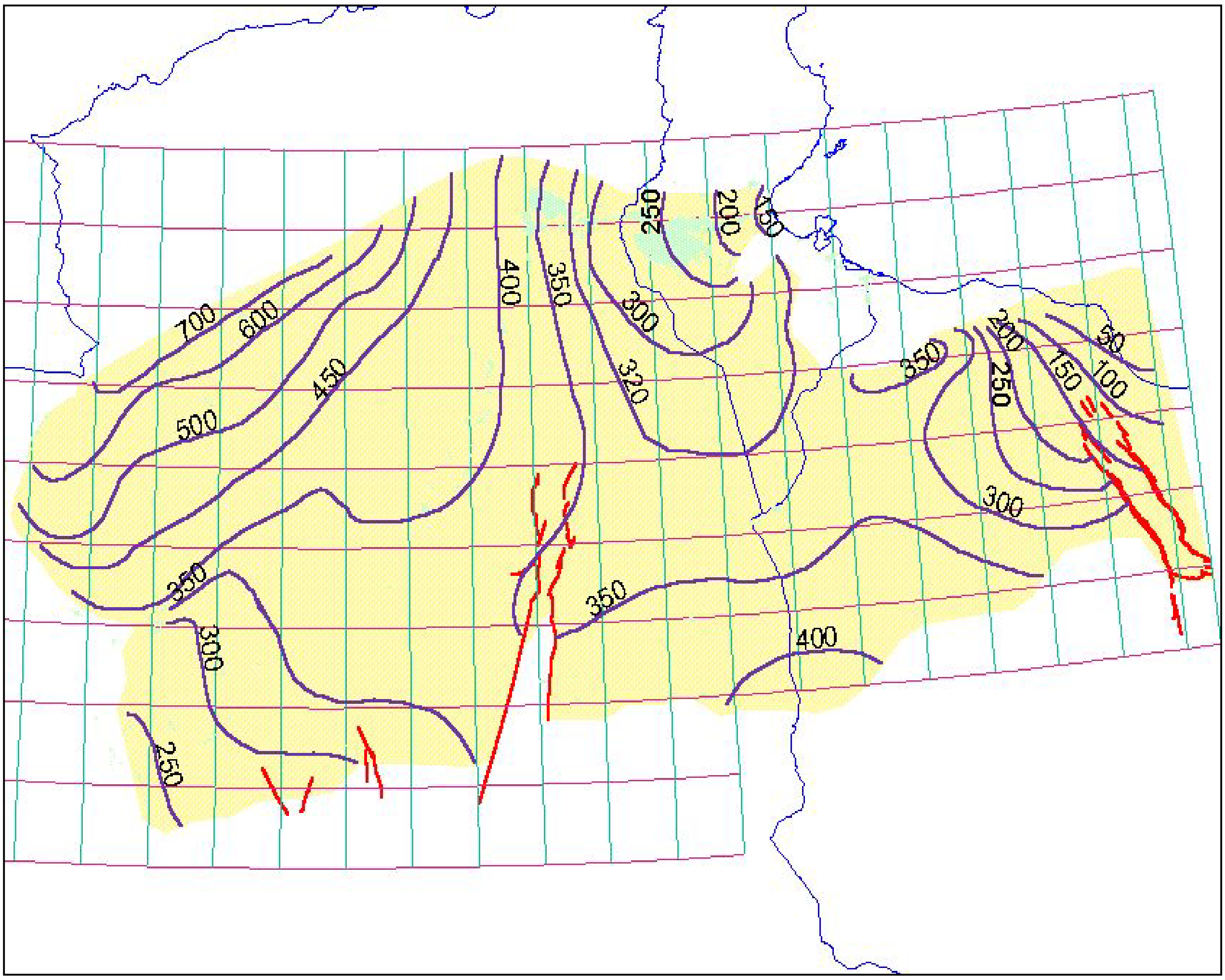


Fig 28: Aquifer of the Lower Triassic-Jurassic-Cretaceous ; GEOMATH (1994)



In the framework of NWSAS project, it was necessary to develop an overall piezometric map, taking into consideration previous contributions, so as to present a coherent flowing scheme about the whole basin. The result, shown in fig.29, is a synthesis of all such contributions. This map defines flows of the Continental Intercalaire aquifer at the “natural” state, with no or little impact of pumping operations. This spatial representation of the piezometric surface is supported by a number of measurements, not necessarily all synchronic but dated prior to the most significant pumping action, old measurements taken from documentary sources, presented in the Annex.

Fig. 29: Reference initial Piezometry for the Continental Intercalaire



IV.2- CT piezometric Map

As for the IC, the flows general cartography at the scale of the whole Complexe Terminal results from the accumulation of successive contributions developed over these last forty years, since the publication, by A. Cornet (1964) of the first piezometric map covering all “the Terminal Continental” of the Sahara. Among the most significant contributions, we can namely cite Bel et Cuche (1969)[18], ERESS project (1972), A. Levassor (1975), A. Mamou (1976), Armines-ENIT (1984), Srivastava (1983), Idrotecneco (1981), Gefli (1978), P. Pallas (1978), Geomath(1994). All these works helped in the design of an “initial” piezometric map or still not influenced, at the scale of the whole NWSAS region (see fig.30), which can be

[18] **BEL et CUCHE ; 1969 : Mise au point des connaissances sur la nappe du Complexe Terminal ; ERESS ; Ouargla.**

used as a reference to describe the system in a steady regime. Located values, relatively old, taken from previous references, or in archives of national services, and the database of the NWSAS project, are shown in the Annex devoted to CT piezometric levels.

Fig. 30: Reference initial Piezometry for the Complexe Terminal

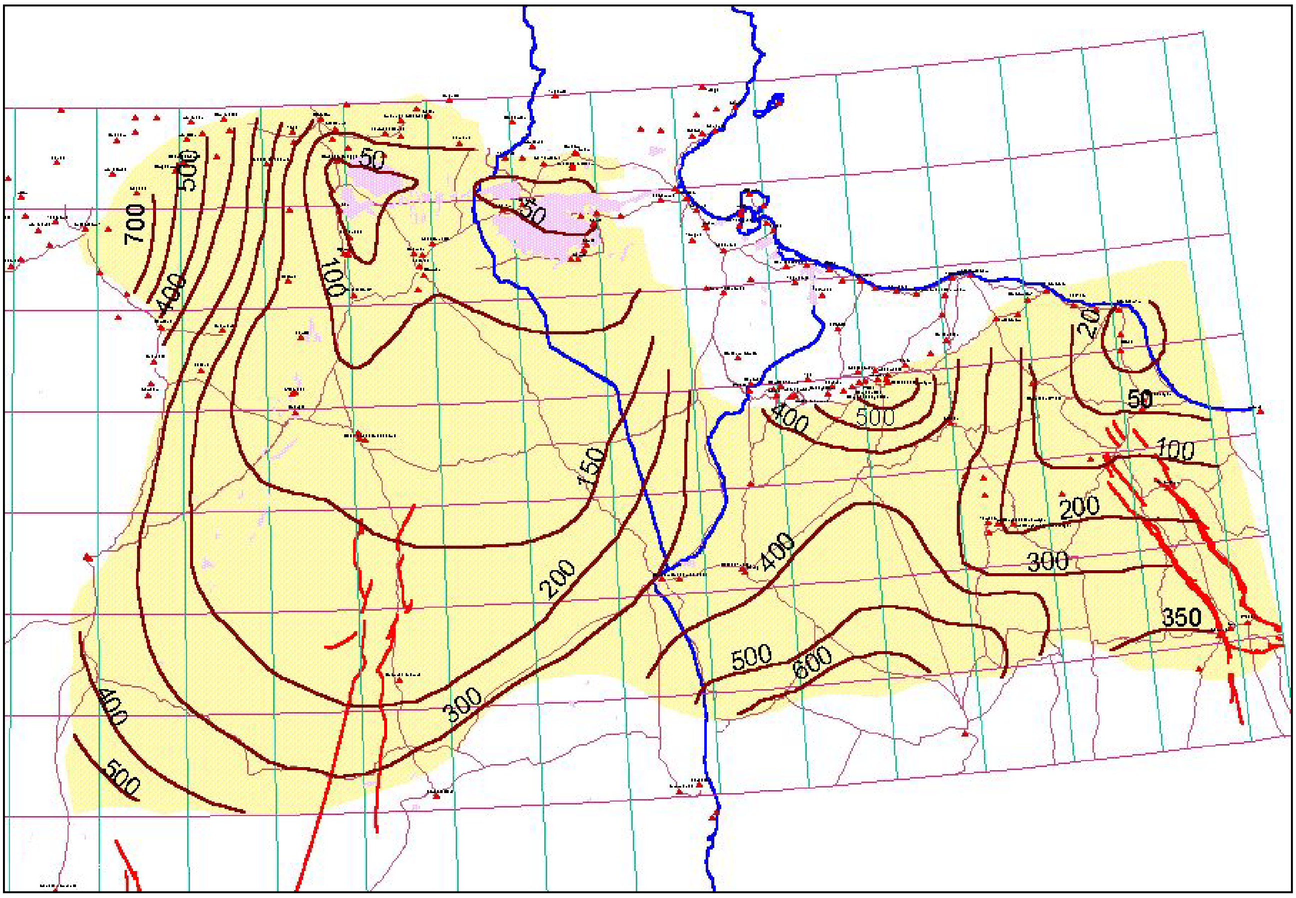


Fig. 31: Isopiezes of the Terminal Continental; A. CORNET (1964)

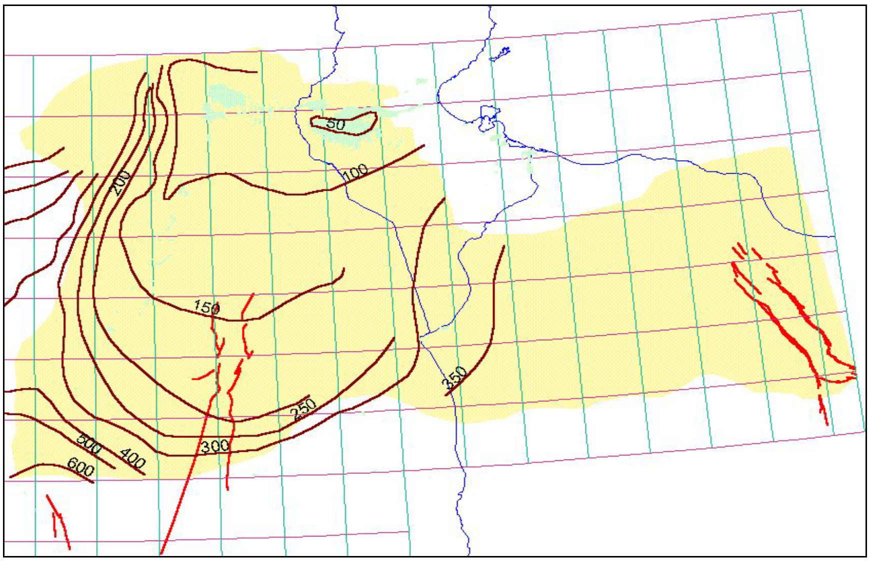


Fig. 32: Complexe Terminal ; ERESS (1972)

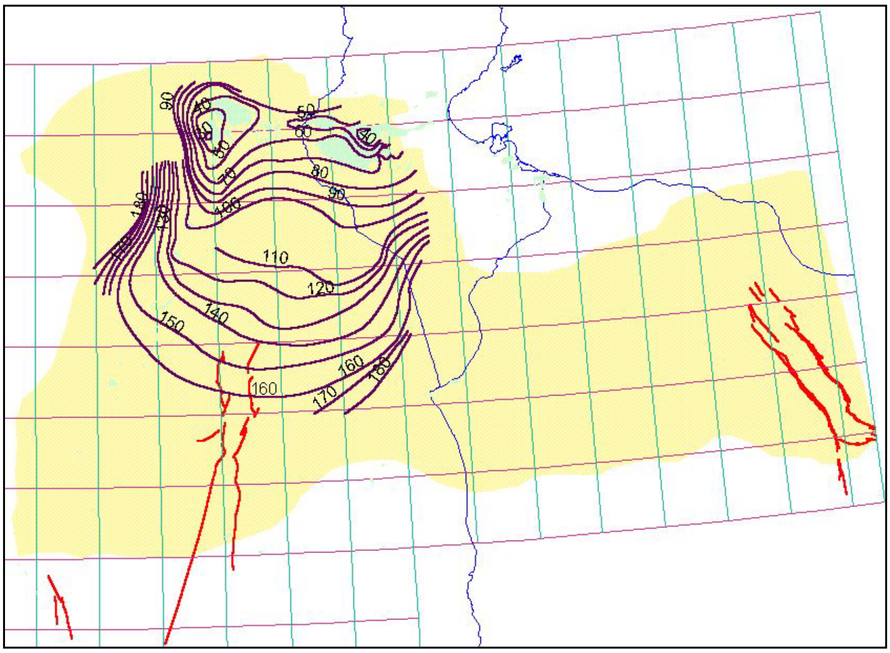
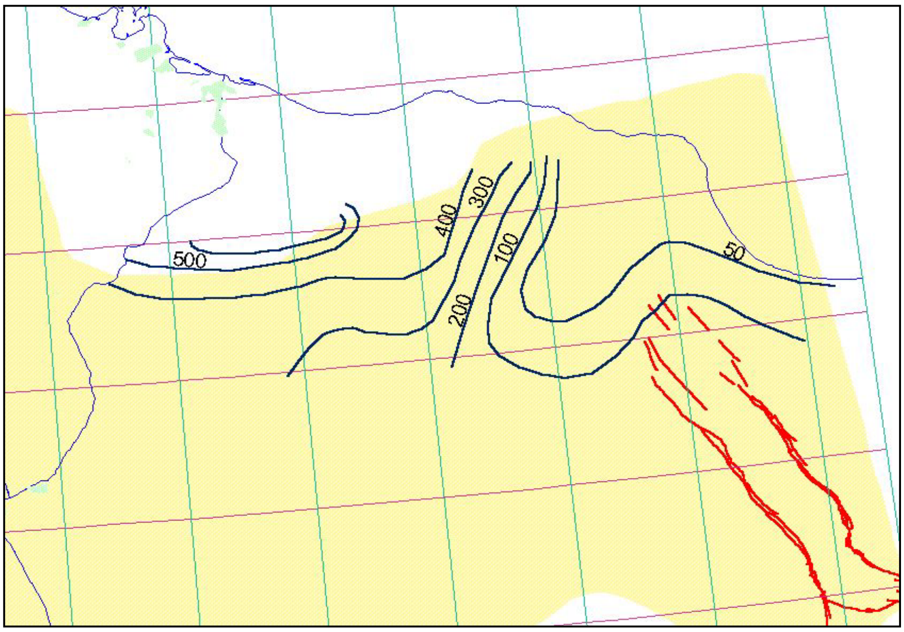


Fig. 33: Piezometry of “Nalut” formation aquifer; P. PALLAS (1978)



IV.3- Integration of isotopic data in the hydrodynamic outline

The isotopic data concerning carbon 14 activity have been gathered, as well as their corresponding ages. Over the 72 CI water points with activity values published in the various studied documents (see. References), only twelve points include an estimation of the corresponding age. The regression of values representing the age of water by carbon 14 activity (fig. 34) gives a perfectly linear relation, which provides an estimation of the age of waters for the whole abstraction containing 72 water points (see. table 9). The most elevated ages are 45500 years; they correspond to deep wells close by the Tunisian outlet, or also located in the southern part of the Hun valley. The youngest dated waters are 25 years old; a first analysis reveals that they are located in obvious recharge areas: the Dahar, the

Saharian Atlas, the Grand Erg Occidental. Considering the whole abstraction, the average age is 18.000 years and the mean value is 17.500 years, which reflects a normal distribution, justified by the shape of the classified ages histogram. (fig. 35).

Fig.34: Age of water according to content in carbon 14

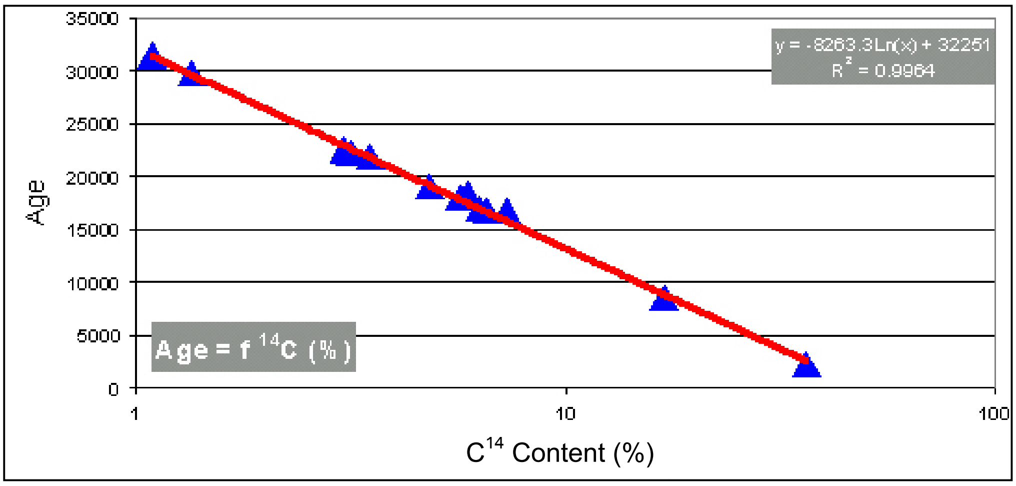
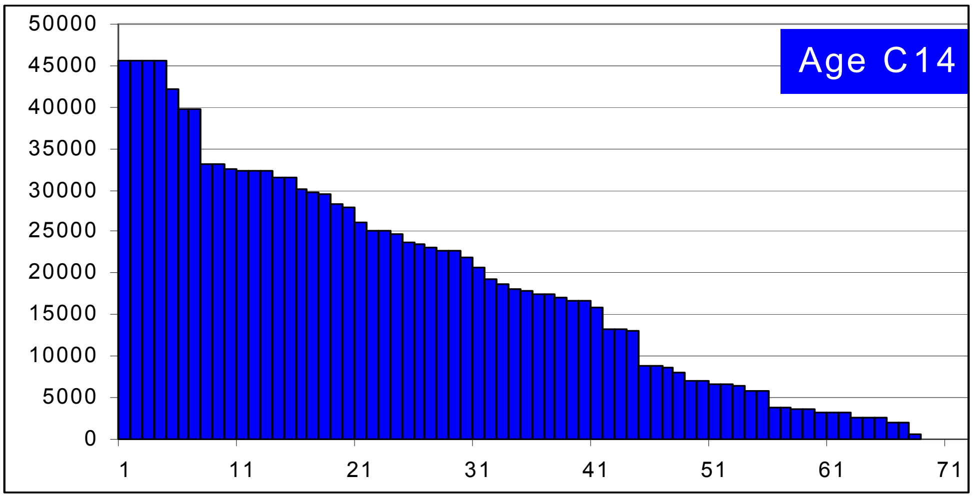


Table 8: Water age according to carbon 14 content

Country	Identifier	Date	^{14}C (%)	Age (years)
L	T/276/77	1977	1.09	31500
L	T/359/89	1989	1.35	29800
L	Agric. Project		3.05	22500
L	T/25/87	1987	3.15	22200
L	WG22		3.5	21900
L	Zintan		4.82	19100
L	T/203/80	1980	5.68	18000
L	1285/3/1		5.92	18400
L	T/96/76	1976	6.28	17000
L	T/64/78	1978	6.55	16800
L	H 5		7.3	16800
L	T/277/77	1977	16.9	8600
L	Seb. Mezezzem		36.3	2200
L	T/276/77	1977	1.09	31500
L	T/359/89	1989	1.35	29800
L	Agric. Project		3.05	22500
L	T/25/87	1987	3.15	22200
L	WG22		3.5	21900
L	Zintan		4.82	19100
L	T/203/80	1980	5.68	18000
L	1285/3/1		5.92	18400
L	T/96/76	1976	6.28	17000
L	T/64/78	1978	6.55	16800
L	H 5		7.3	16800
L	T/277/77	1977	16.9	8600
L	Seb. Mezezzem		36.3	2200

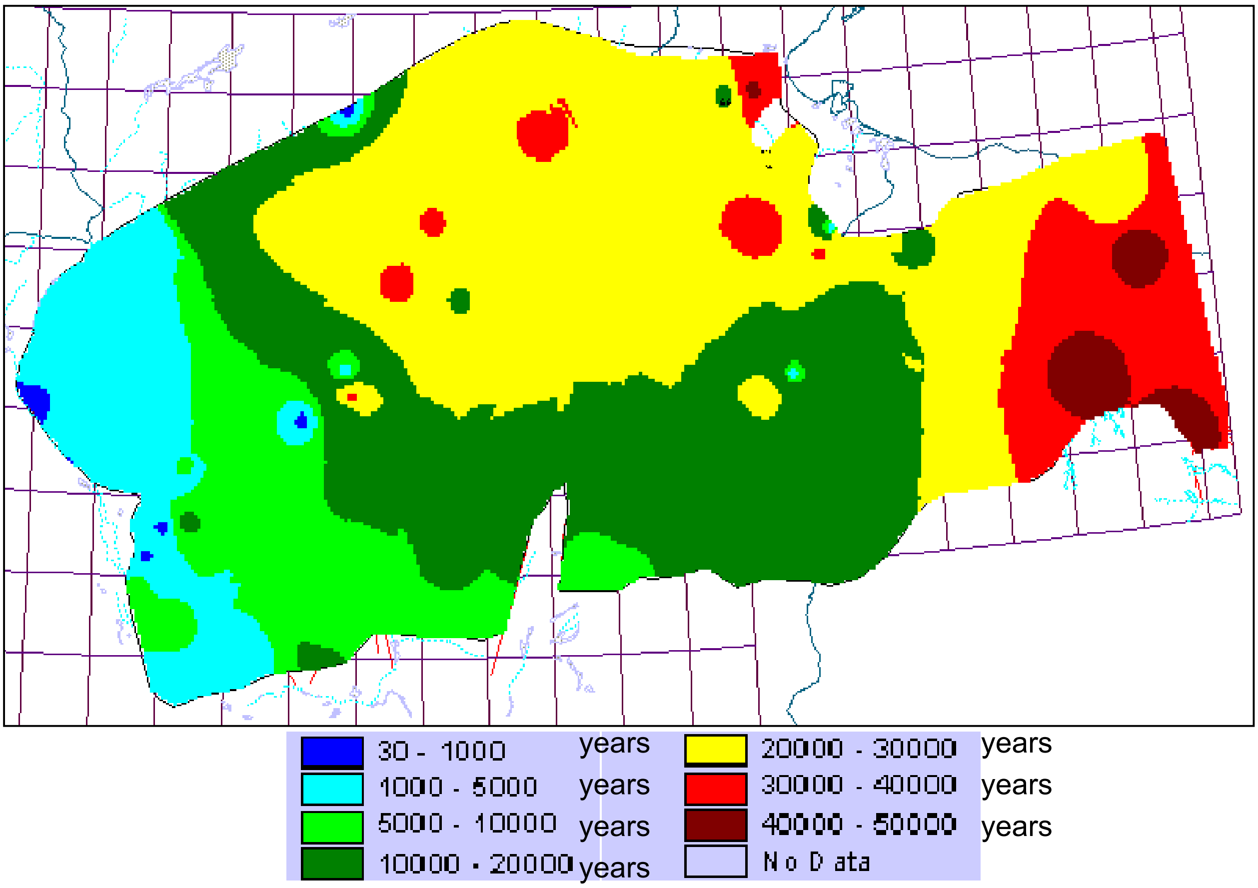
Fig. 35 : Waters of the Continental Intercalaire – Histogram of classified ages



Cartography of Groundwater Ages

It was then possible to collect a series of representative data, well distributed in the NWSAS domain (see table 9). Through an interpolation over a cartographic medium, fig. 36 represents the distribution of C14 activities measured in deep wells, translated in age-equivalent of the Continental Intercalaire equivalent waters.

Fig. 36: Age of CI waters according to their carbon 14 content (in years)



The reading of the map of ages reports, at the same time, on the aquifer geological deposit and its hydrodynamic behaviour. In fact, though it is difficult to correspond the waters hydrodynamic age with their radiometric age, we clearly find, in the C14 ages spatial distribution the NWSAS organization according to three geological and hydrodynamic basins.

In the western basin, all waters are young (less than 10 000 years). All along their course (more than 500 km) from the main recharge area which is the Saharian Atlas, toward the main outlet area that is the Gourara Valley, Touat and Tidikelt, the waters of the Continental Intercalaire are permanently renewed throughout their transfer. This observation is coherent with the regional geology; in fact, the CI is no longer covered here by the upper Cretaceous and the CI aquifer has an unconfined surface.

In the eastern basin, waters are ancient. As opposed to what is observed around the Tunisian outlet, where there is concordance between the hydrodynamics and the evolution of ages, this is not the case here. In fact the Taourgha spring, located in the outlet area, is also generated by a mixture of CI ancient waters and younger (and shallower) waters of the Complexe Terminal; consequently, the age of waters here is not the highest. Paradoxically, the highest values are found uphill the flows, at the southern boundary where Kiklah is in direct contact with the Palaezoic waters of Djebel Hassaouna. If we consider that the latter belong to the “fossil waters” category, the anomaly of ages can be well explained: the IC is here « recharged », « renewed », not by means of current waters, but through the ancient waters of the Cambro-Ordovician.

Gradients of dwell times

The radiometric age of an underground water abstraction corresponds to the average dwell time of all waters contained in the abstraction. This can represent very different ages corresponding to various transit spectra. It is necessary not to insist on corresponding the abstraction radiometric age (made up of a mixture of fluid particles of various ages) with the hydrodynamic age of the considered abstraction: an enlightening example with the case of Ain Taourgha. Nevertheless, the cartography of average dwell times gradient can give indication concerning the average traffic velocities of underground waters.

Table 9: C14 Activity-Age Relations of Waters* in CI

Country	identifier	Denomination or Location	Aquifer	Type of equipment	X = ^{14}C (%)	Y = estimated age	Source
A	**71/16**	**Hamaguir (103 K 1)**	**CI**	**Deep well**	**18.9**	**7964**	**CONRAD MM., FONTES J.C., 1972**
A	**70/16**	**Timimoun**	**CI**	**Wells**	**30.9**	**3902**	**CONRAD MM., FONTES J.C., 1972**
A	**70/15**	**Hi. Marroket (66 L 7)**	**CI**	**Deep well**	**1.0**	**32588**	**CONRAD MM., FONTES J.C., 1972**
A	**70/14**	**El Goléa**	**CI**	**Deep well**	**32.0**	**3613**	**CONRAD MM., FONTES J.C., 1972**
A	**70/9**	**Adrar**	**CI**	**Wells**	**24.4**	**5853**	**CONRAD MM., FONTES J.C., 1972**
A	**70/10**	**Bou Ali (344 O 4)**	**CI**	**Spring**	**22.3**	**6597**	**CONRAD MM., FONTES J.C., 1972**
A	**70/11**	**Town reg.**	**CI**	**Wells**	**33.2**	**3308**	**CONRAD MM., FONTES J.C., 1972**
A	**71/14**	**Plateau Reg.**	**CI**	**Deep well**	**33.5**	**3234**	**CONRAD MM., FONTES J.C., 1972**
A	**71/15**	**Aoulef El Arab (53 O 5)**	**CI**	**Spring**	**38.8**	**2020**	**CONRAD MM., FONTES J.C., 1972**
A	**70/13**	**In Salah**	**CI**	**Wells**	**21.3**	**6995**	**CONRAD MM., FONTES J.C., 1972**
A	**71/9**	**Tit 101**	**CI**	**Deep well**	**36.0**	**2639**	**CONRAD MM., FONTES J.C., 1972**
A	**130 H 7**	**Laghouat**	**CI**	**Deep well**	**54.7**	**25**	**GONFIANTINI et al., 1974**
A	**408 H 11**	**Tamerna**	**CI**	**Deep well**	**1.1**	**31463**	**GONFIANTINI et al., 1974**
A	**119 I 8**	**Berriane**	**CI**	**Deep well**	**1.3**	**30083**	**GONFIANTINI et al., 1974**

Country	Identifier	Denomination or Location	Aquifer	Type of equipment	X = ^{14}C (%)	Y = estimated age	Source
A	17 I 9	Guerrara 2	CI	Deep well	1.7	27866	GONFIANTINI et al., 1974
A	436 I 11	Sidi Mahdi	CI	Deep well	2.1	26120	GONFIANTINI et al., 1974
A	112 I 8	Melika	CI	Deep well	2.5	24679	GONFIANTINI et al., 1974
A	11 J 9	Zelfana 2	CI	Deep well	0.0	32251	GONFIANTINI et al., 1974
A	447 J 10	Ouargla 1	CI	Deep well	1.4	29471	GONFIANTINI et al., 1974
A	4 K 9	Daïet Remt	CI	Deep well	5.2	18628	GONFIANTINI et al., 1974
A	Hi Messaoud	Hi Messaoud	CI	Deep well	4.1	20592	GONFIANTINI et al., 1974
A	7 K 12	Rde el Baguel AB7	CI	Deep well	2.4	25017	GONFIANTINI et al., 1974
A	12 N 12	Tin Fouyé	CI	Deep well	17.3	8695	GONFIANTINI et al., 1974
A	1 N 12	Tabankort	CI	Deep well	9.9	13307	GONFIANTINI et al., 1974
A	Fort Flatters	Fort Flatters	CI	Deep well	22.8	6414	GONFIANTINI et al., 1974
A	1 J 8	Hassi Fahl	CI	Deep well	0.9	33123	GONFIANTINI et al., 1974
A	El Goléa	El Goléa	CI	Deep well	32.0	3613	GONFIANTINI et al., 1974
A	66 L 7	Hi Maroket	CI	Deep well	1.0	32251	GONFIANTINI et al., 1974
A	Hi Infel	Hassi Infel	CI	Deep well	59.6	25	GONFIANTINI et al., 1974
A	Od Mahmoud	Oulad Mahmoud	CI	Deep well	54.0	25	GONFIANTINI et al., 1974
A	Adrar Wells Samatrach	Adrar Wells Samatrach	CI	Deep well	24.4	5853	GONFIANTINI et al., 1974
A	334 O 4	Bou Ali (344 O 4)	CI	Deep well	22.3	6597	GONFIANTINI et al., 1974
A	Sbaa	Sbaa	CI	Deep well	46.5	524	GONFIANTINI et al., 1974
A	Reggane	Reggane	CI	Deep well	33.5	3234	GONFIANTINI et al., 1974
A	53 O 5	Aoulef El Arab	CI	Deep well	38.8	2020	GONFIANTINI et al., 1974
A	In Salah	In Salah	CI	Deep well	5.6	18015	GONFIANTINI et al., 1974
A	In Salah Wells Hydra	In Salah Wells Hydraulique	CI	Deep well	21.2	7015	GONFIANTINI et al., 1974
A	Tit 101	Tit 101 Deep well	CI	Deep well	36.0	2639	GONFIANTINI et al., 1974
A	73 L 7	Garet Louazoua	CI	Deep well	10.0	13224	GONFIANTINI et al., 1974
A	3 N 7	Timeldjane	CI	Deep well	10.2	13060	GONFIANTINI et al., 1974
A	4 N 7	El Hassene	CI	Deep well	17.0	8839	GONFIANTINI et al., 1974
T	6664	Wadi Nakhla	CI	Deep well	0.2	45550	GONFIANTINI et al., 1974
T	5664	CF1	CI	Deep well	0.9	33123	GONFIANTINI et al., 1974
T	7305	Seftimi 2	CI	Deep well	6.6	16658	GONFIANTINI et al., 1974
T	BZA1	Bir Zobbas	CI	Deep well	0.4	39823	GONFIANTINI et al., 1974
T	Ez A1	Om Zab	CI	Deep well	2.9	23453	GONFIANTINI et al., 1974
T	ECH A1	Ech Chouech	CI	Deep well	6.0	17445	GONFIANTINI et al., 1974
T	6511	Wadi Lorzot	CI	Deep well	0.0	32251	GONFIANTINI et al., 1974
T	6855	Wadi Ouni	CI	Deep well	53.3	25	GONFIANTINI et al., 1974
T	5717	Ksar Gihilane	CI	Deep well	1.6	28367	ERESS
L	T/25/87	Mizda	CI	Deep well	3.15 ± 2.37	22770	BRL, 1997
L	T/64/78	Sinawan	CI	Deep well	6.55 ± 1.2	16720	BRL, 1997
L	T/96/76	Derj	CI	Deep well	6.28 ± 1.3	17068	BRL, 1997
L	T/203/80 New	T203/80 new (Ghadamis)	CI	Deep well	5.68 ± 0.74	17898	BRL, 1997
L	T/276/77	T276/77 (Ghadamis)	CI	Deep well	1.09 ± 1.15	31539	BRL, 1997
L	T/277/77	T277/77 (Ghadamis)	CI	Deep well	16.9 ± 3	8888	BRL, 1997
L	T/359/89	T/159/89 (SE Derj)	CI	Deep well	1.35 ± 2.63	29771	BRL, 1997
L	WG22	WG22 (Ghadamis)	CI	Deep well	3.5 ± 0.83	21899	BRL, 1997
L	Agric. Project	Agricultural Project	CI	Deep well	3.05 ± 0.41	23036	BRL, 1997
L	Zintan	Zintan (E Nalut)	CI	Deep well	4.82 ± 1	19255	BRL, 1997
L	Seb. Mezezzem	Seb. Mezezzem	CI	Deep well	36.32 ± 4.36	2566	BRL, 1997
L	H 5	Hamada Al Hamra			7.3	15825	Idrotecneco, 1982 (P.66)
L	WS-2	Wadi Qirzah, well WS-2	Kiklah		0,0 ± 0,4	39823	GWA
L	B1-39	Well B1-39	Kiklah		0,2 ± 0,4	45550	GWA
L	ZZ13	Wadi Zamzam ZZ13	Kiklah		0,2 ± 0,4	45550	GWA
L	W-6	Ash Shuwayref W-6	Kiklah		0,2 ± 0,4	45550	GWA
L	Wadi Marmuta	Wadi Marmuta	Kiklah		2,4 ± 1,4	25017	GWA
L	Wadi Faysal well n° 3	Wadi Faysal well n° 3	Kiklah		3,2 ± 0,5	22640	GWA

Country	Identifier	Denomination or Location	Aquifer	Type of equipment	X = ^{14}C (%)	Y = estimated age	Source
L	1285/3/1	1285/3/1 (c.s.)(Ghadamis)	Kiklah		5.92 ± 0.72	17556	GWA
L	J-18	Al Jufrah J18	Paléozoique		0.3 ± 0.4	42200	GWA
L	Tawurgha spring	Tawurgha spring	Source		2.8 ± 0.8	23743	GWA

(*) see annex 8 of volume 2: Hydrogeology

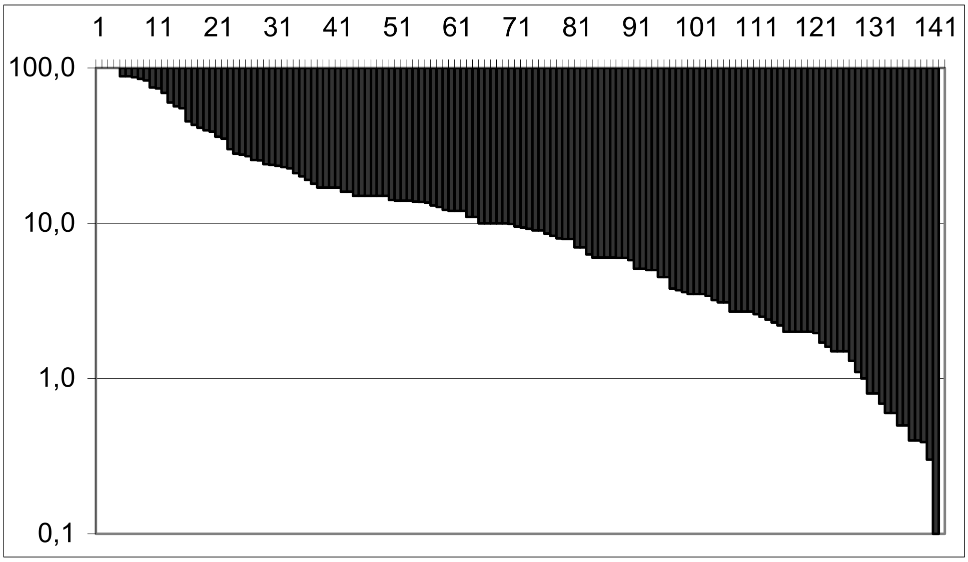
IV.4- Spatial distribution of transmissivities

Over all the Continental Intercalaire, the tranmissivities values collected by the project amount to 140. They are 302 for the Complexe Terminal (see hydrogeology volume)[19]. These data existed on several media: national databases, archives, published and unpublished reports. All these values, whose geographic position is shown in fig. 39 and 41, are described in annexed Tables.

The series of CI transmissivities, whose distribution is represented in Fig. 37, considers as an average the value 20.E^{-3} m2/s and as a Mean 10.E^{-3} m2/s . As for the TC series, its average is 16.E^{-3} m2/s and its Mean is 9.E-^{03} m2/s, which yield statistical characteristics very close for both formations.

Maps shown in fig. 40 and 41 give a more accurate idea of the transmissivities spatial distribution respectively in the CI and the CT. This distribution can be used as benchmark for the calibration of the simulation model in a steady regime.

Fig. 37: Distribution curve of CI transmissivities: Tx10-3 m^2/s



[19] NWSAS, Final Report, Hydrogeological Volume.

Fig. 38: Distribution curve of TC transmissivities: Tx10^{-3} m^2/s

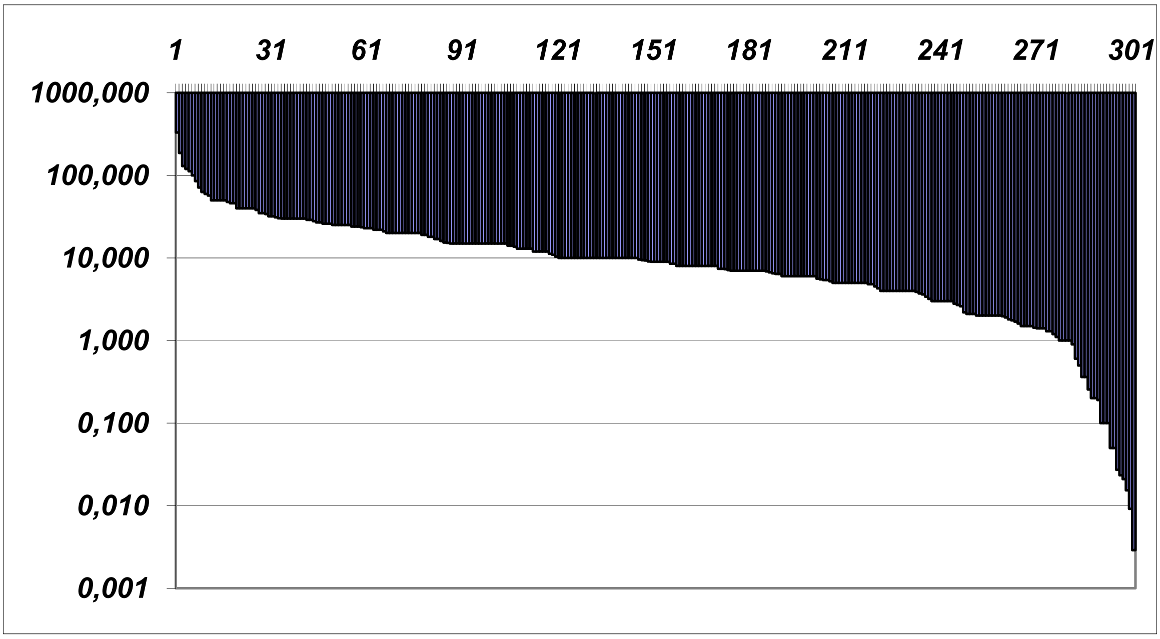


Fig. 39: CI Transmissivities collected in the NWSAS

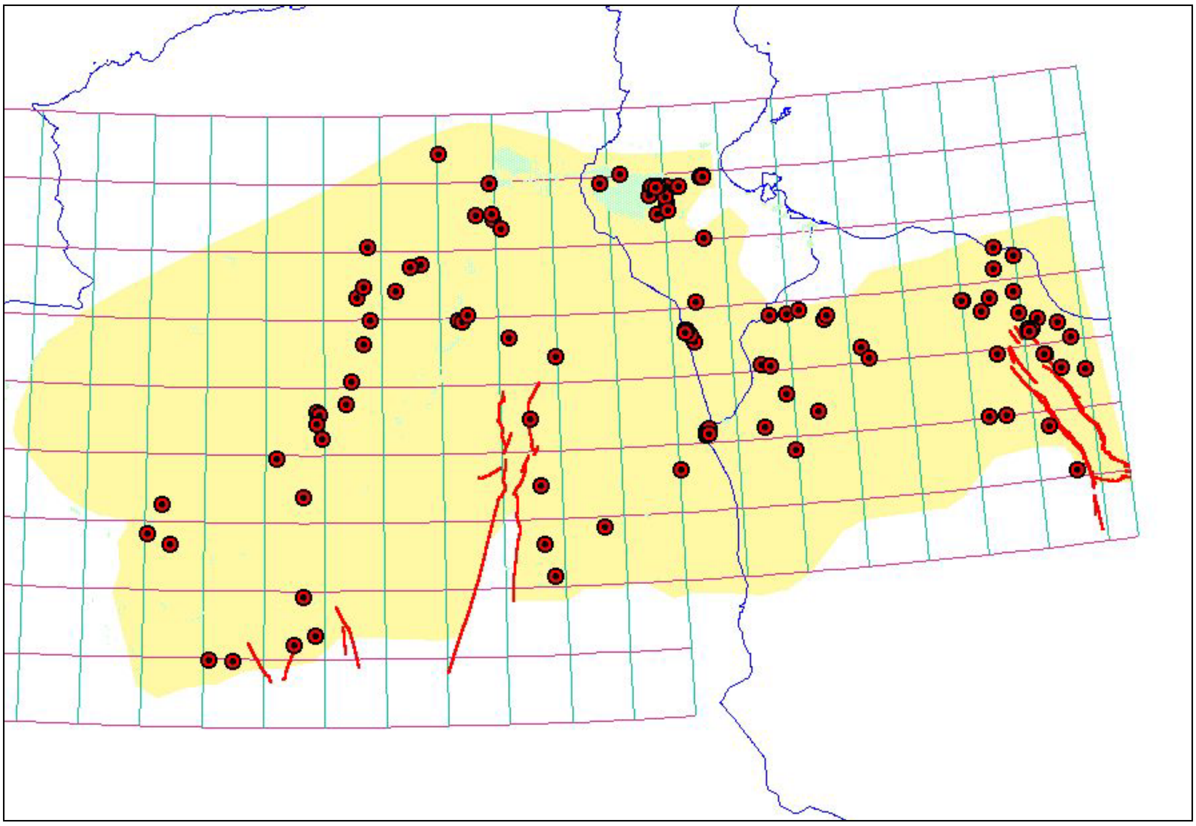


Fig. 40: Spatial Distribution of CI transmissivities (m^2/s)

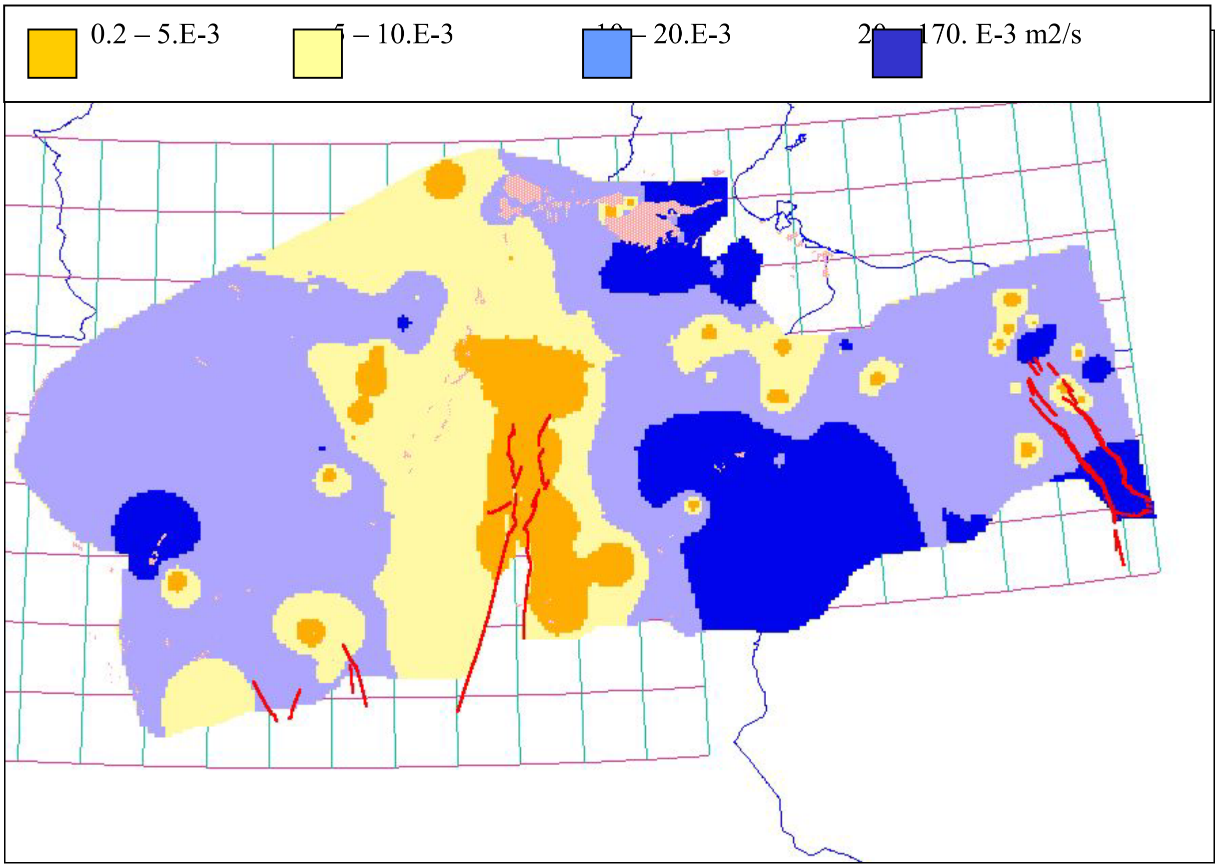


Fig. 41: Spatial Distribution of CT transmissivities (m^2/s)

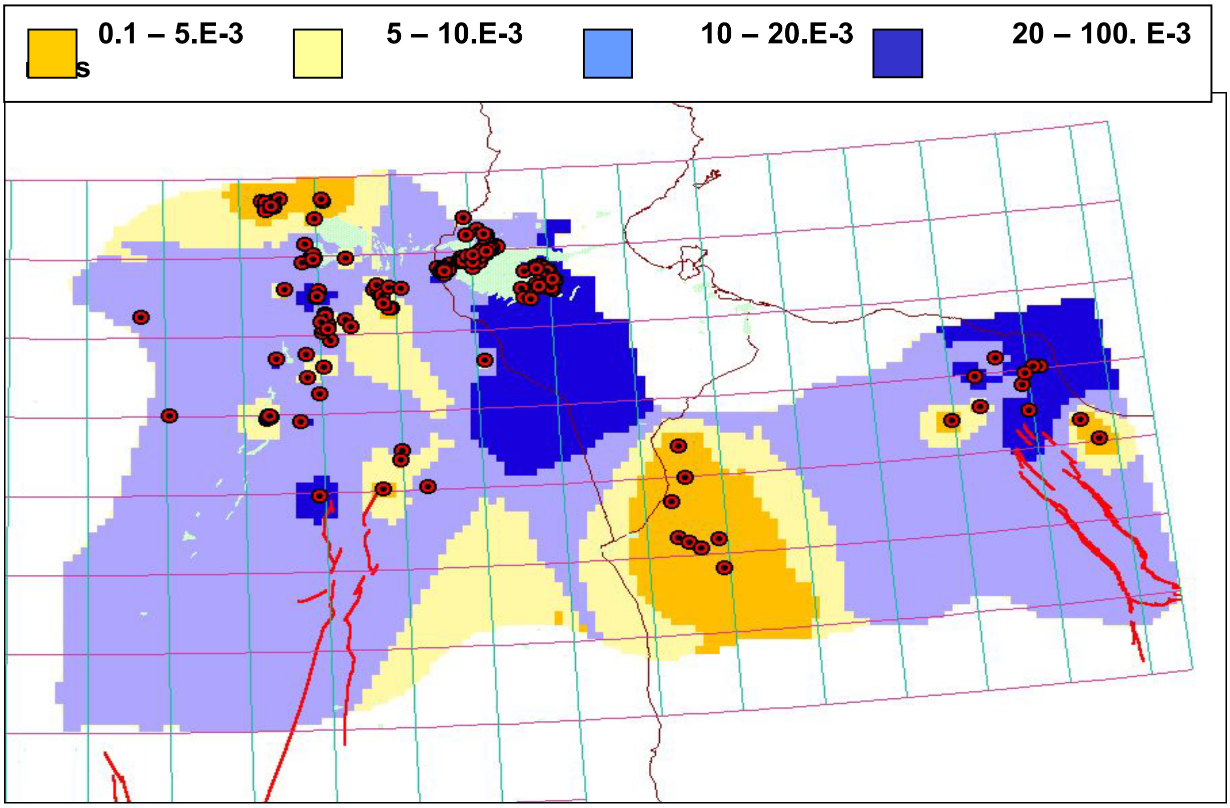
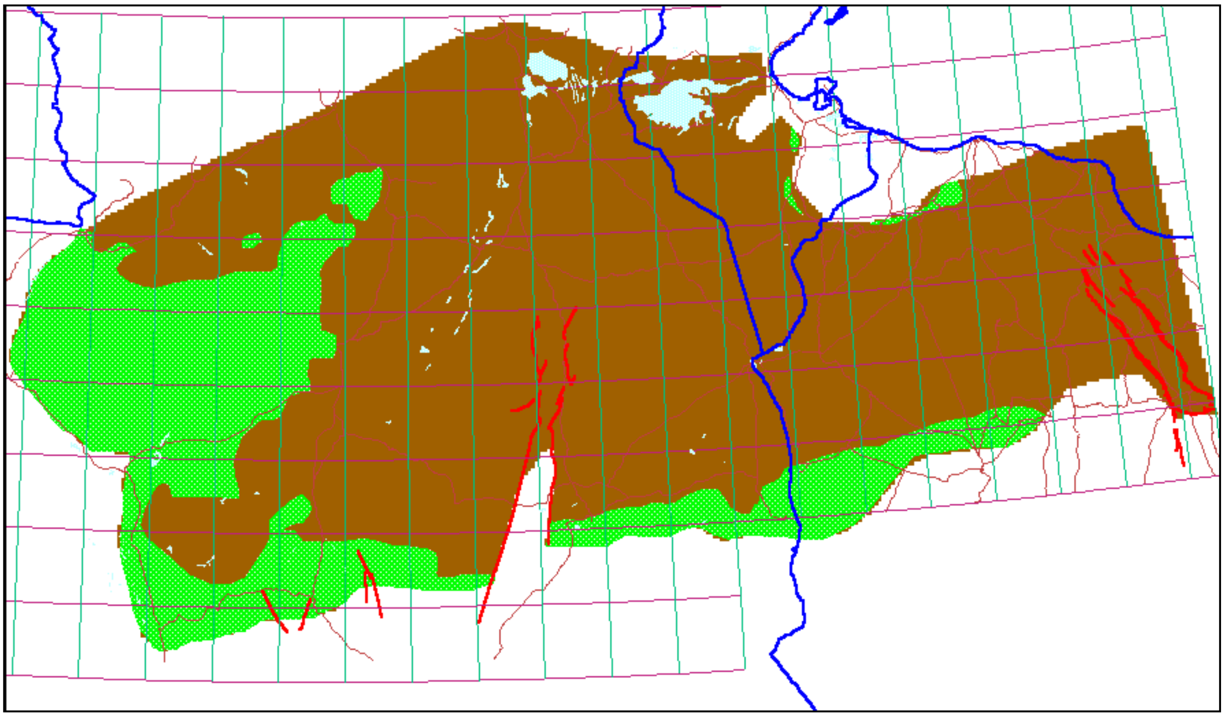


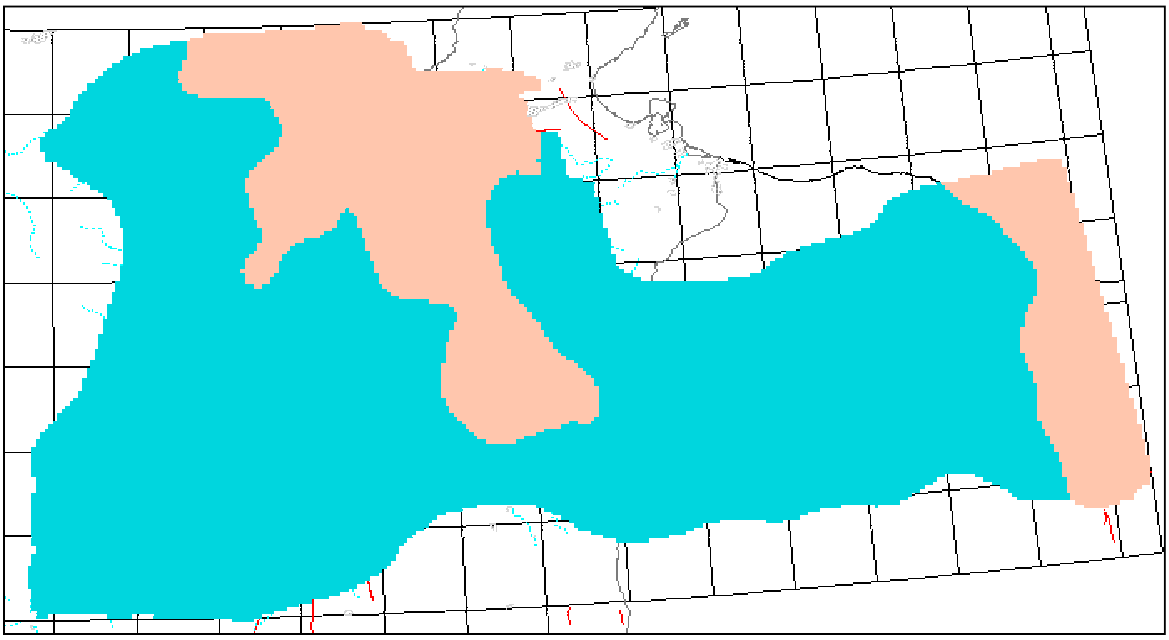
Fig. 42: Extension (in green) of the Continental Intercalaire area with an unconfined surface



IV.5- Storage Coefficients

All available information pertaining to the storage coefficient of the CI and the CT can be found in Volume 2 of NWSAS final report (hydrogeology). It was considered to be useful, for the design of the model, to develop a map showing the extension of the unconfined surface area, fully obtained through the difference between the formation top level and the level of the reference piezometric point ("initial" piezometric map), respectively for the CI and the CT. These limits constitute a first indicator for the assignment of the storage coefficients of the unconfined aquifer when calibration of the model in a steady regime.

Fig. 43: Extension (in blue) of the unconfined surface area of the Complexe Terminal



IV.6- Time series of piezometric levels

IV.6.1- The Continental Intercalaire (CI)

IV.6.1.1. Piezometric Evolutions of IC in Algeria

The most significant evolution area represented below, in fig. 44 and 45, is gathered by a homogeneous and representative geographic sector: Tamerna for the artesian basin with strong ground pressures , Kef n°27 for areas close to unconfined surface areas.

Fig. 44

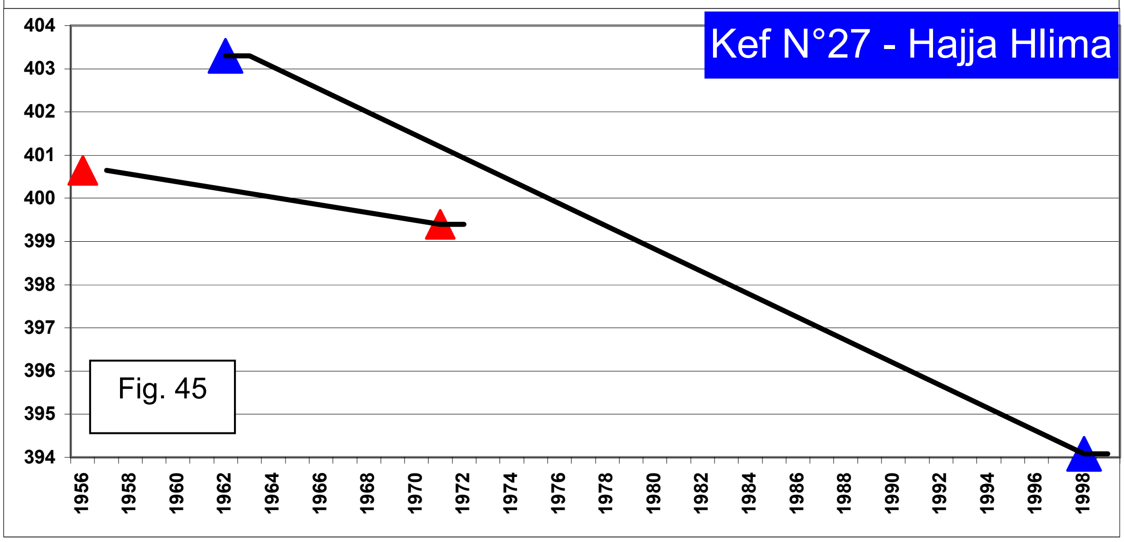
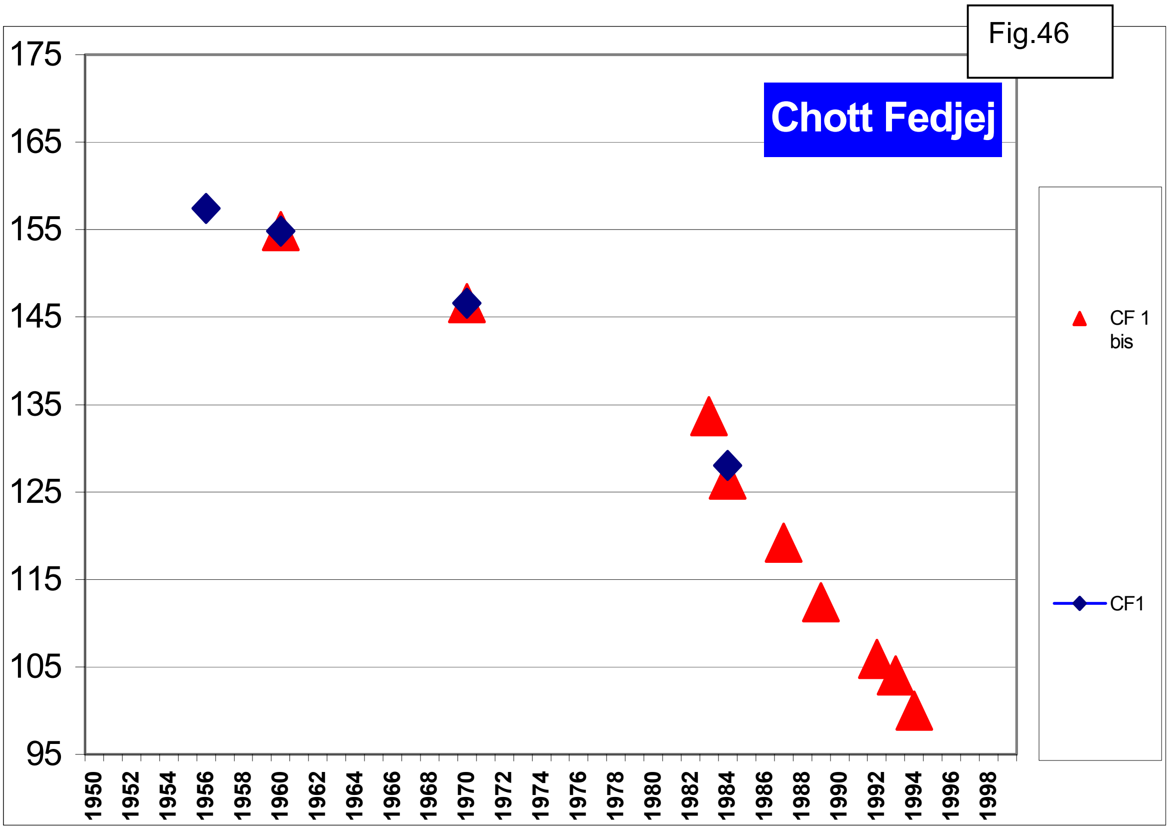


Fig. 45

IV.6.1.2. Piezometric Evolutions of CI in Tunisia

The piezometric follow up is generally here more dense, which facilitates the analysis of series. The first degree of analysis of series is to draw, as in Algeria, the graphs h(t) by grouping them in homogeneous geographic sectors. This construction is presented, for two particular sectors, Fedjej and Djerid, in fig. 46 and 47.

Fig.46


Chott Fedjej
175
165
155
145
135
125
115
105
95
1950
1952
1954
1956
1958
1960
1962
1964
1966
1968
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1972
1974
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1988
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1992
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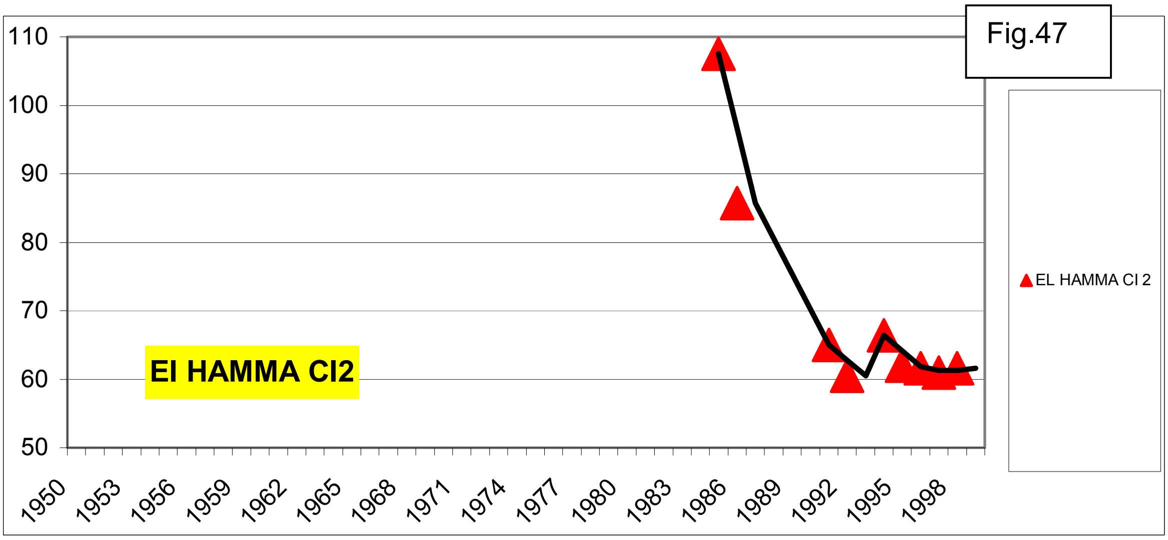
1998
CF 1 bis
CF1

Fig.47


El HAMMA Cl2
110
100
90
80
70
60
50
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
EL HAMMA CI 2

IV.6.1.3. Piezometric Evolutions of the CI in Libya

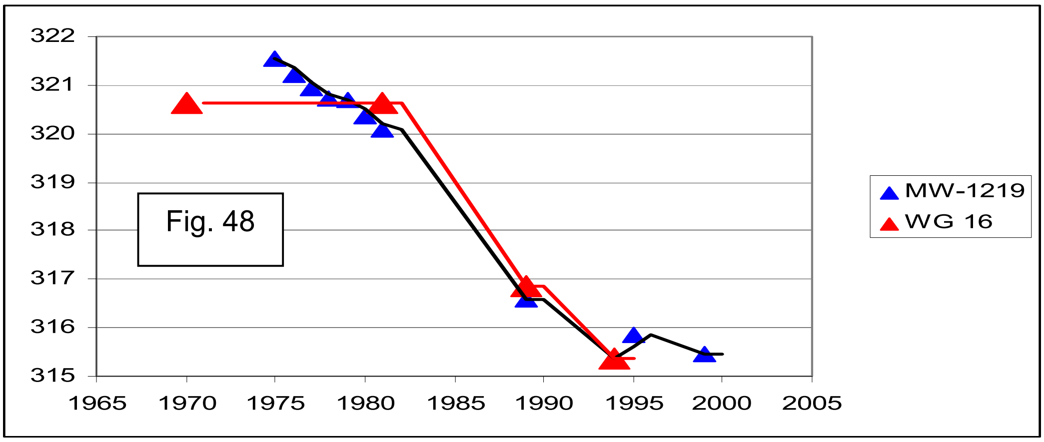


Fig. 48

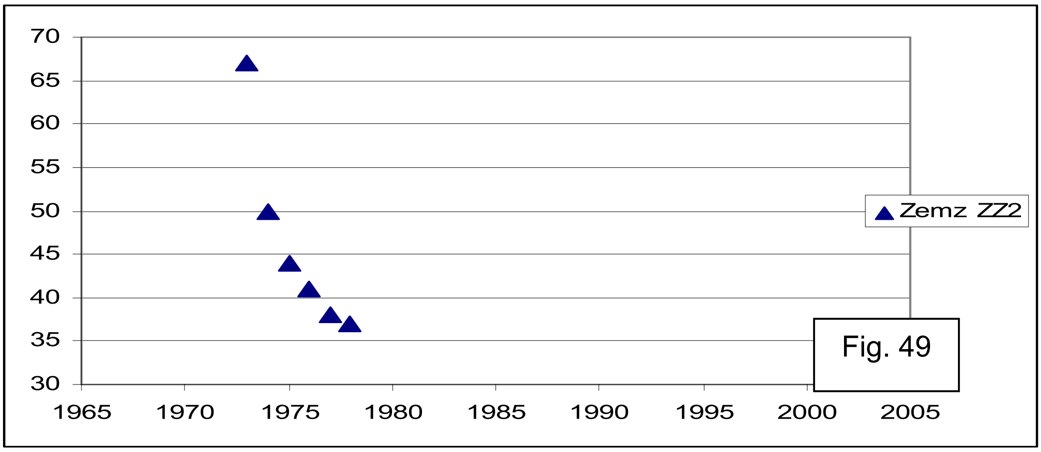


Fig. 49

IV.6.2- The Complexe Terminal (CT)

As was the case for the CI, a first selection resulted in the design of a map of possible time series (two measurements at least). The elimination of points showing anomalies that are "impossible to correct" helped in the selection of "useful" deep wells, which could be used to design represented historical evolutions.

V.6.2.1. Piezometric Evolutions of CT in Algeria

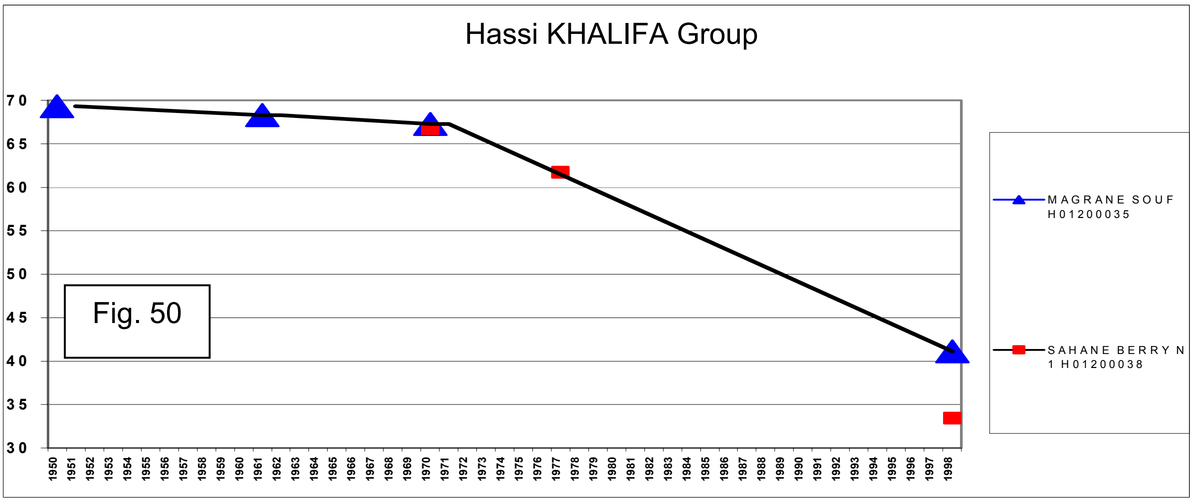
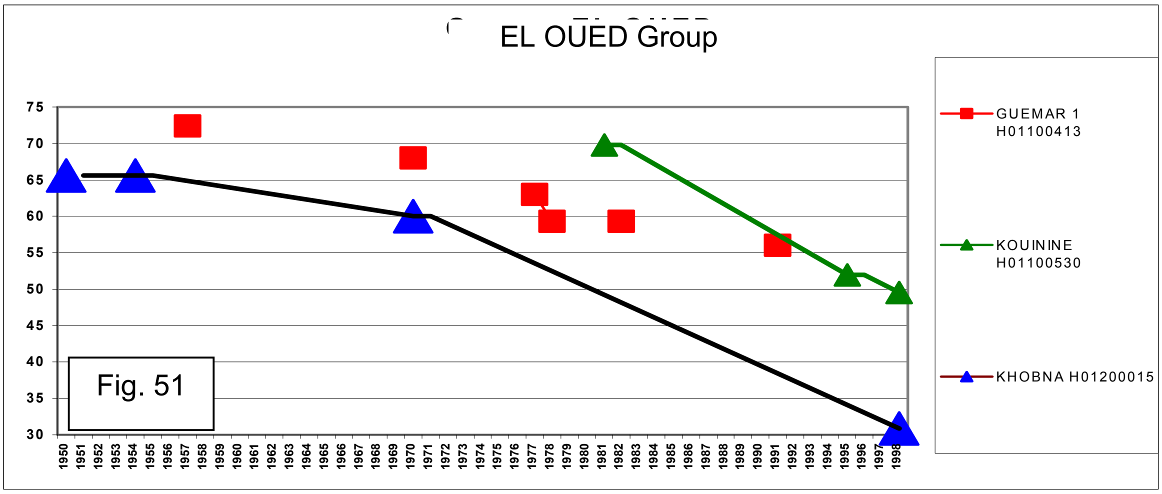


Fig. 50

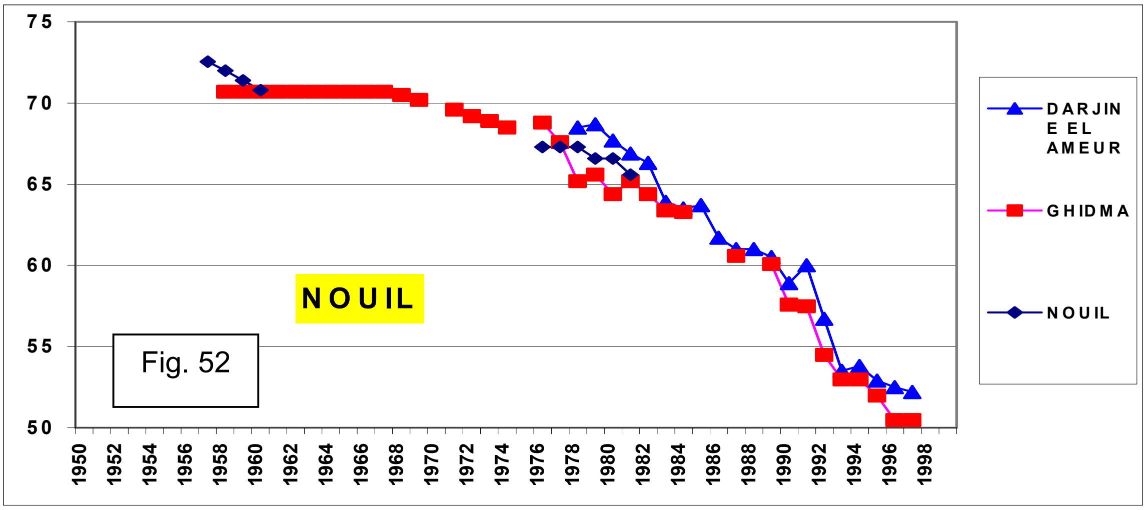


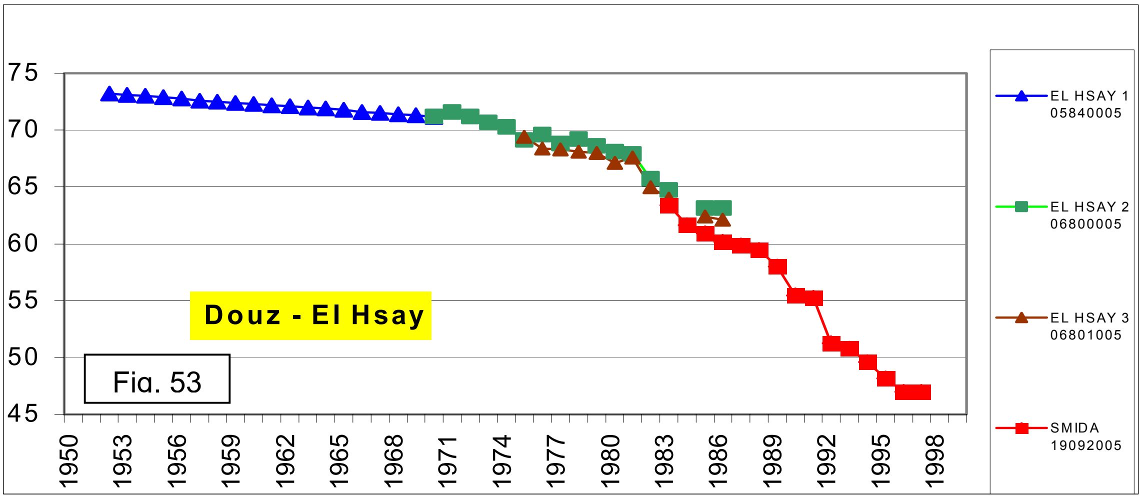
IV.6.2.2. Piezometric Evolutions of CT in Tunisia:

As was the case for CT in Tunisia, the presentation of piezometric evolution curves is made through homogeneous geographic collection.

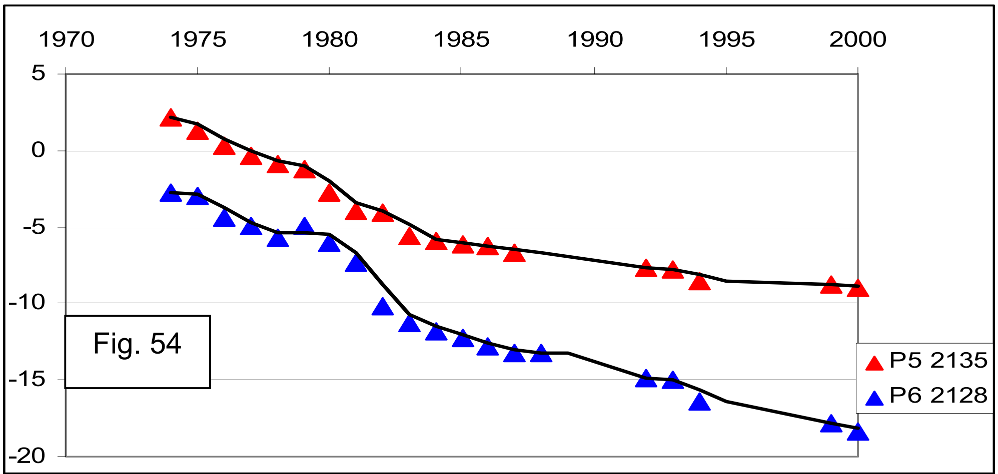
However an uncommon situation has arisen: a multitude of observed deep wells, a very large number of measurements, but few long enough series to make a justified interpretation of the evolution of the aquifer system over a period that is as long as the research (50) years, for a reason sometimes too simple, which is the lifetime of deep wells.

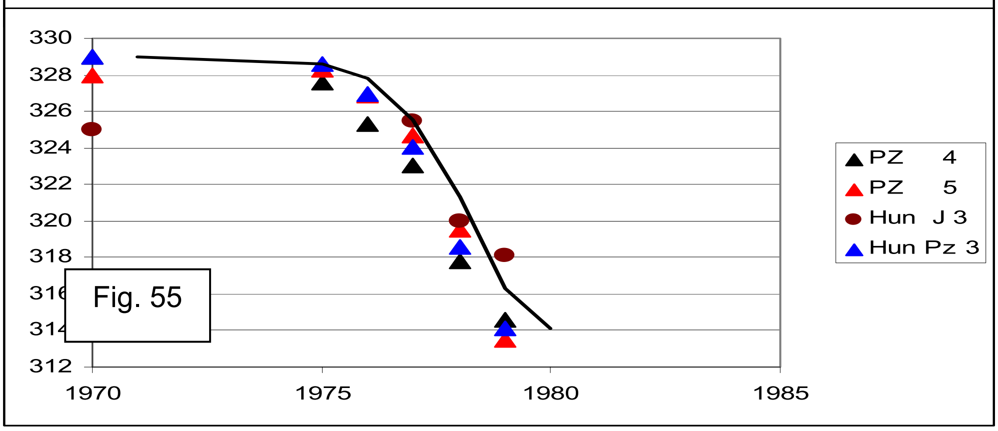
Considering the profusion of available data, and in order to simplify the models transitory calibration, we considered the design, for each geographic group, a standard series, or a “synthesis curve”, through the aggregation of available data over the whole group. The procedure is shown in fig. 52 and 53.





IV.6.2.3. Piezometric Evolutions of CT in LIBYA





The positions of all points used for the control of piezometric levels in a transient state are reported in fig.86 (second part), for the CI a well as for the TC.

IV.7- Abstraction Time-Series

IV.7.1- Diversity of Methodologies and Sources of Information

In the reconstitution of NWSAS time-series, three consecutive periods should be identified during each period, the teams in charge of acquiring and processing abstraction data used specific methods.

These periods or phases are the following:
- ERESS Project period: 1950 - 1970
- RAB Project period : 1971 - 1981
- The period covering the database for NWSAS Project: 1982 - 2000

Some significant figures reflect the importance of the task:
- The number of deep wells in the Continental Intercalaire, having been permanently or temporarily subject of pumping during the period of 1950-2000 is estimated at 1200
- This number reaches 2000 deep well for the Complexe Terminal during the same period
- In addition, one should consider the springs in Tunisia and Libya and the springs of Adrar, all together amounting to a thousand water points.

When we know the big difficulty of evaluating with precision the abstraction flow rates from an aquifer bearing several thousand wells, and the multiplication of these difficulties when trying to reconstitute the evolution of these flows throughout time, we should expect it to be a hard task to relate the three periods, including in Tunisia, where over the last thirty years, yearbooks reporting on the exploitation of deep aquifers have been regularly issued.

The most significant difficulty encountered concerns the accounting and yield control mode which differs from one period to the other, and sometimes within the same period. In fact:

- During the ERESS project, the yield were calculated for each palm grove or deep well. On the other hand, springs were considered like pumping drills

- During the RAB project, flows were calculated per geographic sector and according to the model unit cell (15 km x15 Km in the CT and 25 km x25 Km in the CI): the yield of a cell could include without distinction, the yield of deep wells as well as that of natural springs located within the grid.

- As for the NWSAS project, it focuses on the development of a database, where every deep well and every spring are individually identified, and must therefore have their own particular history.

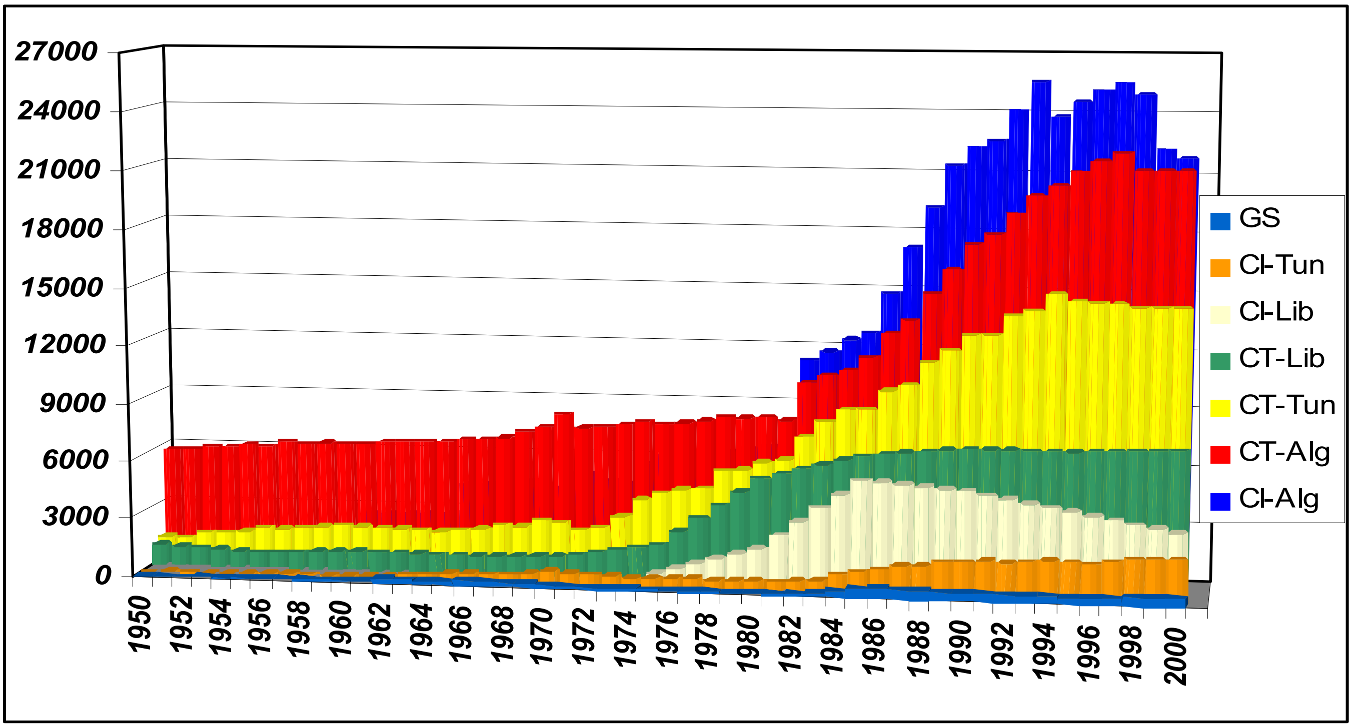
- During the same NWSAS project, the estimation method varies from one country to the other:

    - In Algeria, inventories have been realized by ANRH during the 1990s in every concerned Wilaya: EL Wadi, Ouargla, Ghardaia, Adrar, Illizi, Biskra…, some have even been subject to two inventories (El Wadi). Therefore, we hold a time located estimate of exploitation flows, in case measurements or evaluations were not appropriately conducted. The difficulty was then to reconstitute its evolution through time.

    - In Tunisia, the DGRE maintains the exploitation yearbooks since 1973, which has enormously facilitated historical reconstitution. The difficulty that was encountered here concerns drilled wells, called “manual drills”, where information are much less precise, and abstractions are not made individually but rather in groups of deep wells, especially in the CT of Kebili.

    - In Libya, no historical archives are available for individual wells: all the information concern exploitation related to groups of pumps ; there are fifty groups for the whole country, which is in principle very insufficient and may result in the artificial concentration of pumping operations, detrimental to the representation of models to be developed.

Fig. 56: Evolution of Abstractions from deep wells, per aquifer[20] and country



IV.7.2- Data Processing and Results

The time-series of processed abstractions, individually assigned to each exploited water point, are grouped in NWSAS DATABASE [table for « points » and table for « exploitation »]. The evolution of abstractions per deep well, inserted per aquifer and per country in Table 10 and in fig. 56, shows that everywhere in NWSAS, there was a tendency for stabilization over the 1950s, 1960s and 1970s, then a sudden acceleration during the 1980s, whatever the country and the aquifer are, and then finally sometimes a tendency to recession toward the end of the 1990s. However, this last phenomenon is just an artifact, perhaps due in Algeria to the interruption of large inventories between 1994 and 1998, in Libya (where no individual estimate per deep well had been made) to the very importance given to the operation of GMRP pipelines. Nonetheless, some flagrant anomalies should be noted, so that the calibration operations of the transient model can be balanced accordingly, and particularly:

- At the CI in Algeria: between 1981 and 1982, the flow dramatically increased from 7m3/s to 11 m3/s. While in the opposite, between 1988 and 1999, it dropped from 25 m3/s to 22 m3/s.
- At the CT in Algeria: from 1950 to 1980, the total flow increases only from 6 m3/s to 8 m3/s over 30 years. Then within one single year, from 1981 to 1982, it increases from 8 m3/s to 10 m3/s.
- At the CI in Libya: the flow of deep wells passes from 5.6 m3/s to 3.3 m3/s between 1985 and 2000.

[20] The aquifer of upper sandstone [GS in the map key] is further shown, in the part of « Model Setting».

Table 10: Withdrawn time-series of abstractions per deep wellsfrom 1950 to 2000 (in l/s)

Abstraction 1950-2000 in l/s for each aquifer in each country																
Year	**CI-Alg**	**CT-Alg**	**CI-Lib**	**CT-Lib**	**CI-Tun**	**CT-Tun**	**GS**		**Year**	**CI-Alg**	**CT-Alg**	**CI-Lib**	**CT-Lib**	**CI-Tun**	**CT-Tun**	**GS**
1950	485	5770		1059	2	1281										
1951	487	5826		1005	42	1277			1976	5836	7862	802	2551	508	4556	104
1952	462	6000		950	42	1569			1977	5888	8011	1086	3268	525	4616	102
1953	524	5978		895	42	1584	38		1978	6301	8229	1370	3986	451	5567	91
1954	905	6158		841	42	1695	36		1979	6427	8190	1654	4704	490	5645	78
1955	899	6119		786	44	1924	52		1980	6597	8251	1938	5422	485	6055	68
1956	1017	6372		828	144	1841	36		1981	7038	8121	2678	5686	480	6247	70
1957	989	6257		869	144	1957	50		1982	11137	10100	3417	5950	547	7454	123
1958	300	6343		910	134	2035	95		1983	11608	10507	4157	6214	617	8269	206
1959	310	6305		951	114	2147	92		1984	12266	10791	4896	6478	955	8896	301
1960	2476	6334		993	118	2094	90		1985	12623	11510	5635	6742	1139	8946	460
1961	2481	6469		984	138	2055	86		1986	14691	12717	5553	6833	1273	9930	530
1962	2500	6525		975	153	2056	240		1987	17068	13474	5470	6925	1503	10252	479
1963	2524	6558		966	277	2033	224		1988	19171	14827	5387	7017	1498	11438	508
1964	2550	6556		957	307	1998	205		1989	21283	16051	5305	7109	1748	12079	447
1965	4143	6703		948	412	2112	190		1990	22238	17397	5222	7201	1794	12876	403
1966	4166	6718		965	437	2154	294		1991	22568	17921	5038	7195	1904	12896	408
1967	4215	6855		981	426	2434	254		1992	24086	18961	4853	7189	1825	13889	428
1968	4347	7211		998	446	2366	226		1993	25572	19871	4668	7182	1903	14176	401
1969	3997	7443		1014	507	2719	207		1994	23818	20397	4484	7176	2018	15037	387
1970	4811	8205	4	1031	670	2642	174		1995	24559	21105	4299	7170	1927	14679	356
1971	4835	7485	4	1185	587	2284	124		1996	25176	21667	4112	7210	1860	14652	383
1972	4549	7559	4	1339	562	2444	119		1997	25553	22103	3925	7251	2033	14563	369
1973	4406	7673	4	1493	541	3048	116		1998	24963	21212	3738	7292	2169	14415	476
1974	5525	7918	4	1647	467	3952	120		1999	22207	21212	3551	7332	2214	14432	477
1975	5998	7776	518	1833	450	4343	115		2000	21778	21212	3364	7373	2215	14432	477

PART II

CONSTRUCTION OF THE MATHEMATICAL MODEL

CHAPTER 1 - CONSTRUCTION OF THE MODEL

I- GENERAL FRAMEWORK FOR THE CONSTRUCTION OF THE NORTH WESTERN SAHARA AQUIFER SYSTEM/NWSAS MODEL

In the Algerian/Tunisian Sahara, knowledge of data still relies mainly on the results of the three fundamental contributions that were:

- The hydro-geological synthesis published by A. CORNET: **« Introduction to Saharan hydrogeology »**[1], which suggested a still pertinent architecture of the main aquifer levels and a general description of their hydrodynamic operation.
- The study conducted by BEL and DEMARGNE[2], which provides an accurate analysis of the different levels, aquifers and aquitards respectively, constituting all that would later be labelled **« Complexe terminal »**, or "**CT**". This study also includes structural maps and stratigraphic sections throughout all deep wells, which constitute an unavoidable reference for CT study.
- The "**Study of the Sahara Continental Intercalaire**"[3], or «CI». This study has particularly been useful to:
  - Suggest structural maps of CI formations still used today, thanks to the analysis of oil rigs and deep wells ;
  - Design a flowing outline of the CI aquifer, that would be strictly coherent from a hydro-dynamic perspective, boundary supply areas and determine its main outlets. It is particularly in this document that one can find the first reference to the "Tunisian Outlet" and the first estimate of its flow, considered to be 3.2 m3/s;
  - Validate all these hypotheses and suggest a first plausible plan for the CI, still valid, with the construction by Geopetrole[4], of the first analogical model of the CI system.

In the Libyan NWSAS part, it is only fifteen years later that three other major contributions were added, fixing a still pertinent knowledge of the hydro-geological systems. They are:

- The synthesis published by P.PALLAS in 1980: **« Water resources of the socialist people's Arab Libyan Jamahiriyya »[5].** This is the first contribution to a coherent understanding of the hydrodynamic operation of all NWSAS aquifer formations;
- This contribution was **followed by the construction by IDROTECNECO of the first regional model**[6], representing on a large part of NWSAS extension, all aquifer layers of interest to us: the Kiklah formation, CI equivalent, and the Upper Cretaceous formation, CT and Turonian equivalent. This model integrates Cambro Ordovician sandstones, which constituted a privileged target.
- **The Idrotecneco model** having been limited to the east by the large Hun fault, will be relayed (for the sake of our present study) by the GEFLI[7] study conducted in 1978. This study is very rich in terms of deep geological correlations, which are used to set boundaries for the NWSAS domain eastern closure, not at the level of the Hun fault, but up to the Gulf of Syrta, thereby integrating the Tawargha spring and the **sea leakage into** the system, which would make up a set called "the Libyan Outlet of the Continental

[1] Review of Physical Geography and Dynamic Geology (2), vol. VI, Manual1 ; 5-72, 1964.
[2] « Geological Study of the Terminal Continental», DEC, Algiers, 1966
[3] Conducted under the supervision of M.GOSSELIN by BURGEAP & the Fuel Department (IFP) for the Technical Agency in charge of developing Saharan Underground Resources, 1963
[4] GEOPETROLE ; 1963: Analogical Study of Saharan Intercalary Aquifer », for the Technical Agency in charge of developing Saharan Underground Resources.
[5] In « The Geology of Libya ; Ac.Press ; vol II ; Salem & Busrewille(ed)»,1980.
[6] « Hydrgeological study of Wadi Ash Shati, Al Jufrah and Jabal Fezzan area. Annex 3: Construction of the Model, Final Report », 1982.
[7] Survey for the development of Central Wadi Zone &Golf of Sirte ; Groundwater resources,1978.

Intercalaire Aquifer". In addition, the Gefli study includes a very fine analysis of the system hydrodynamics, and a first representation on the digital model of all different studied aquifers horizons.

These six fundamental contributions have later been enriched and complemented by major studies and particularly simulation models whose successive achievements have gradually reinforced the knowledge acquired throughout the last thirty years. Among such contributions, the ERESS Project[8] (1972) undoubtedly remains as the most important and pertinent in terms of availability and reliability of proposed simulation tools, the pedagogy and clarity of produced documents.

After ERESS, and concerning the Algerian-Tunisian part of the reservoirs, we can also note the major contribution of the Rab80[9] project, ARMINES[10], ARMINES-ENIT[11] and Brl-Ecole des Mines[12]. As for the Libyan reservoir portion, we can consider that the "updated" points of view related to the layers architecture, the hydrodynamics and system's water budget must be investigated respectively in GEFLI (1978) for the eastern part and in GEOMATH[13] and BRL[14] for the central part and Hamada El Hamra, as well as of course in the article written by Pizzi and Sartori[15].

We should finally note that a first integral modeling of the Saharan Continental Intercalaire, at an Algerian-Tunisian-Libyan scale has already been presented by Besbes and Zammouri[16] (1988) and Zammouri (1990)[17].

Based on the above, and to be able at the same time to valorize the enormous quantity of acquired information, data and accumulated experience, and ensure a harmonious integration of the hydro-geological visions in all three countries, the general design of the model to construct should respond to two major concerns, apparently contradictory, but in fact complementary:

1- Remain within the general stream of the major studies conducted, namely by ERESS, GEOMATH and GEFLI, in order to integrate the expertise of the system accumulated over the last thirty years, and hence contribute to the development of knowledge acquired about this system. This stream implies the adoption, adaptation and regional consistency of the main options related to:

- The general distribution of Transmissivities and storage capacities;
- The general outline and distribution of flows at the regional level ;
- The nature and situation of boundaries conditions, namely of recharge areas and outlets;
- Respect of sizes of the various terms of the water balance.

2- Give up the duality of CI versus CT adopted by ERESS, in favor of a multi-layer representation, whose design of a "Conceptual Model" has proven to be the only model likely to federate all three present hydrogeologies, mainly Algeria-Tunisia, with Libya. Such a representation, which would certainly "make" the model "rather cumbersome" on a digital level, will help to preserve the best simulation condition integrating the Turonian and considering the leakage flows between the CI and the CT in the long term.

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[8] Study on Water Resources in Northern Sahara, UNESCO, 1972.

[9] Updating of ERESS Models, UNDP, 1987.

[10] Multi-layer Modelling of Oued Rhir, 1975.

[11] Nefzaoua-Djerid sub-model, 1984.

[12] CT and CI models, CDARS, 1998.

[13] Western Jamahirya system hydrogeological modelling of aquifers and well fields; final report.

[14] Ghadames Project water resources ; Mathematical Model, 1997.

[15] Journal of Hydrology, 75 ; 1984.

[16] M. BESBES, M. ZAMMOURI; 1988: Extension to Libya of the Algerian-Tunisian CI model; int. Conf. Comput. methods and water resources, Rabat

[17] M.Zammouri: Doctoral Dissertation, Faculty of Science - Tunis,1990.

II- GENERAL STRUCTURE THE MODEL

The initial structure, adopted after the design of the Conceptual Model, includes four aquifers layers separated by three "aquitards" (fig. 57):

Fig. 57: Model Initial Structure

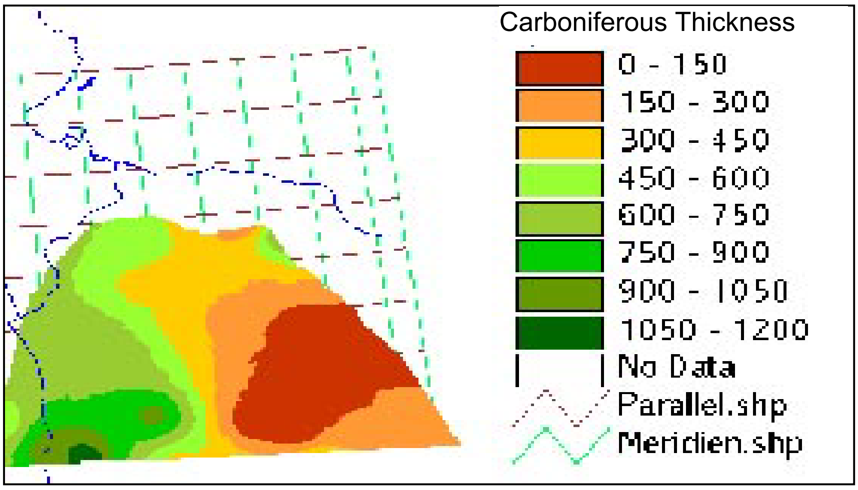
COMPLEXE TERMINAL
LAGOON SENONIAN
TURONIAN DOLOMITE
CENOMANIAN
CONTINENTAL INTERCALAIRE
CARBONIFEROUS
CAMBRO - ORDOVICIAN

The two main aquifer layers are the **COMPLEXE TERMINAL** (Mio-Pliocene sands, Eocene Limestone and Carbonated Senonian), and the **CONTINENTAL INTERCALAIRE**.

The Turonian is represented in Algeria and in Tunisia, to ensure the unity and follow up of the hydrological circle, as well as, because of its capacity in the sector of Hassi Messaoud in particular, to constitute a possible contamination source in the long term. In Libya, it constitutes a good quality aquifer in the Basin's northern half.

As for the Cambro-Ordovician (COD), it is introduced in the form of a layer of grids with an imposed potential. Its representation must help determine the flows it may generate into the Continental Intercalaire in a steady state which inputs it is likely to recover later with the beginning of the exploitation of the catching fields of Dj Hassaouna, as suggested by the small thickness of the separation semi-permeable layer (Carboniferous, see fig. 58) and the direct contact, very developed between the two aquifers (CI & COD) in the Basin southern sector. (see section fig. 10)

Fig. 58: Carboniferous Thickness (in m) at the extension limit of the Cambro-Ordovician



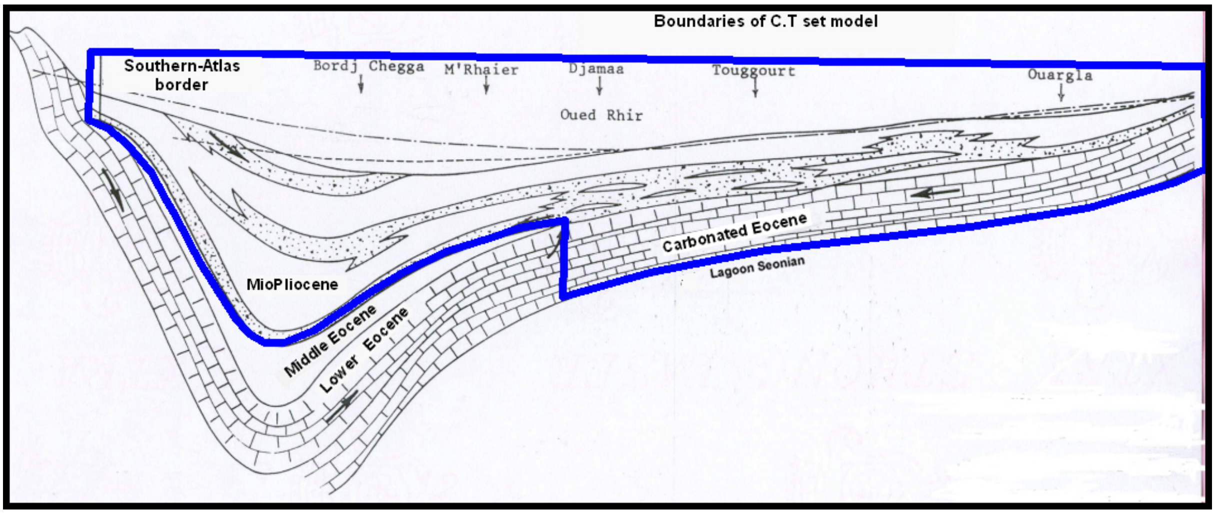
II.1- CT Particular Schematization in the North of the Chotts

In reality, the Complexe terminal aquifer covers several aquifers in the Miopliocene and in the carbonated Senonian. This series, which can go beyond a thickness of 1000 m, cannot constitute a homogeneous reservoir; however, at the scale of the whole Sahara, it would be reasonable to simplify this aquifer set through a mono-layer hydraulic system, even if this simplification would not reflect the local scale.

Nonetheless, there are areas where the impervious intercalations are important enough to belie this scheme. This is in particular the case of the Northern area of the Chotts where “the Miopliocene gravels lay over gypsifereous marl bearing of the Middle Eocene and the limestone of the lower Eocene are no more exploited: they rapidly plunge into the North under Miopliocene pit which, W-E oriented, reflects a maximal subsidence area before the Southern-Atlas fault, unless they disappear through the change of the facies (F.Bel et D. Cuche, 1969[18]) ».

« In the northern region of the Chotts … with regard to the little practical importance of Eocene limestone with poor transmissivity, , this aquifer ha been considered only as a source of upply for sub-jacent formations … in the form of an injection yield of 200 l/s fixed in the North of Djemaa (UNESCO, 1972[19]) ».

Fig. 59 : N-S cross section in Oued Rhir
ERESS, (1972)
Overall Structure of the Complexe terminal and Domain
[in blue] represented on the NWSAS Model



II.2- Hun Graben Structure

The Hun Graben is a caved corridor, whose displacement, poor in the North, reaches 1000 m in the South in Jufrah sector. The deep aquifer formations [Palaeozoic, Kiklah] are continuous on both sides in the North in wadi Zamzam region, while in the south, the aquifer layers are disconnected as indicated by the outline, but indirect flows can start through the western fault. A for shallower aquifer formations [Mizdah, Oligocene], we can consider that they are overall continuous, from the west to the east.

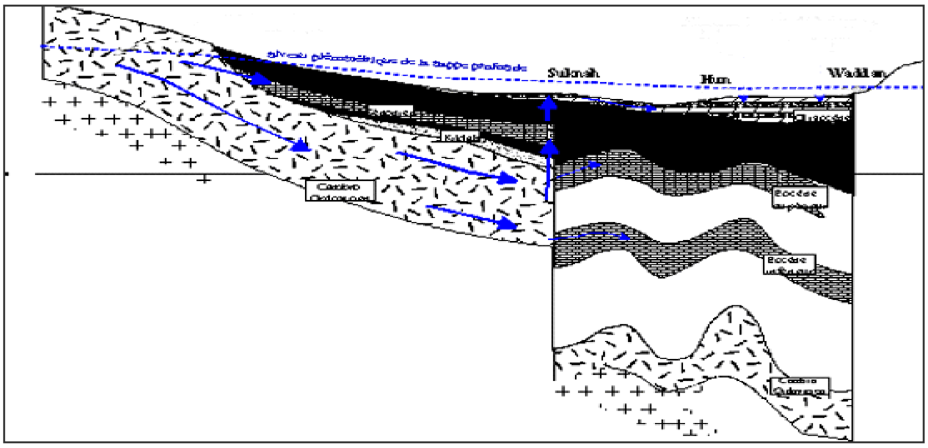
As a resulting outline for the model, we can consider that the two main aquifers as well as the Nalut, are continuous throughout the valley, provided we can correctly restitute in the CI

[18] F.Bel et D.Cuche: Fixing Knowledge about Complexe terminal Aquifer; Rap.int. SES/ERESS, 1969
[19] ERESS, Plaquette 3: the Complexe terminal Aquifer, Mathematical Model

and through an appropriate transmissivity operation, important load losses observed in the southern half of the valley, clearly visible on the layout of piezometric curves. (cf. fig.29).

We can on the contrary note that, with refard to the CT piezometric trend, the crossing of the valley is stable (fig.30).

Fig. 60: Structure of Hun Graben, according to Hydrogeology Vol., Final Report NWSAS-OSS, 2002



II.3- Particular structure of the Continental Intercalaire in Tunisia

By the end of the first phase of the model adjustment, it became clear that it was necessary to review the very structure of the model in Southern Tunisia. Decision has then been made with Tunisian hydrogeologists[20], to reconsider all sections made to existing deep wells and to reanalyze all hydrogeological data in order to be able to design a new structural vision of IC main formations, that would be at most faithful to the current state of knowledge.

II.4- CI Conceptual model in Southern Tunisia

The processing of all collected lithostratigraphic data enabled the constitution of a geological database specific to Southern Tunisia, covering one hundred and fifty deep wells. These deep wells are spread over the five geological provinces traditionally identified within the region:

- The Djerid
- Fissures of the Chotts (Sillon de Chotts)
- The Mole of Melaab
- The Saharan Platform
- The most southern part

Inter-province correlations identified by the comparative studies of the facies are based on the following elements:

- Relating to the universal stratigraphic scale
- Description of the local stratigraphic formations and their equivalencies
- Their translation in hydraulic terms in the form of aquifers and “Aquitards”

[20] B. Abidi: Aquifer of the Continental Intercalaire in South-eastern Tunisia ; Rapp.int. DGRE/OSS ; Dec. 2001
B. Ben Baccar: Aquifer of the Continental Intercalaire at the level of the fissures of Nefzaoua Chotts, geological and hydro-geological characteristics, and relations with Saharan platform ; int. report DGRE/OSS ; May 2002
L. Moumni: Sandstone Aquifer of Sidi Aich or Continental Intercalaire of the Djerid; Int. Report DGRE/OSS;Nov.2001

These correlations generated a « hydro-stratigraphic » scale including, from top to bottom,

six aquifer entities separated by semi-permeable layers. These six entities, present overall or part of the region, are:

- The ALBIAN – AIN GUETTAR, found only in the deep south
- The "Grès Supérieurs" (Upper Sandstone) and their equivalent in the west: SIDI AICH sands
- Grès à Bois" (Woody Sandstone)
- SANDSTONE of the CHOTT
- The PURBECKO-WEALDIAN and its equivalent in the North: KBAR el HAJ formation
- The dolomite JURASSIC containing salty waters

The developed geological sections (see fig.61) were used to determine the continuity of each identified aquifer. Due to the very reduced extension of the Chott sandstone for instance, or the very limited number of deep wells catching "grès à bois" (woody sandstone), it was not possible to represent all these formations as full status aquifer layers on the model. On the other hand, the Albian, due to its absence outside the deep south, could be integrated into the Purbecko-Wealdian, so that passage to Algeria and to Libya could also be operated with harmony.

It was therefore decided to boundary CI's representation in Tunisia to a bi-layer structure including:

- ➢ the purely CONTINENTAL INTERCALAIRE, constituted in the south by the Wealdian, topped by the Albian, and in the North by the merge of Kbar el Haj formation with the Chott sandstone, and the "grès à bois" (Woody sandstone).
- ➢ The "Grès Supérieurs" (UPPER SANDTONE) whose uniqueness is justified by a temporal and spatial atypical piezometric behavior, apparently not related to the Continental Intercalaire.

fig. 61: Geological section reflecting all formations identified in the CI of Southern Tunisia and its bi-layer representation

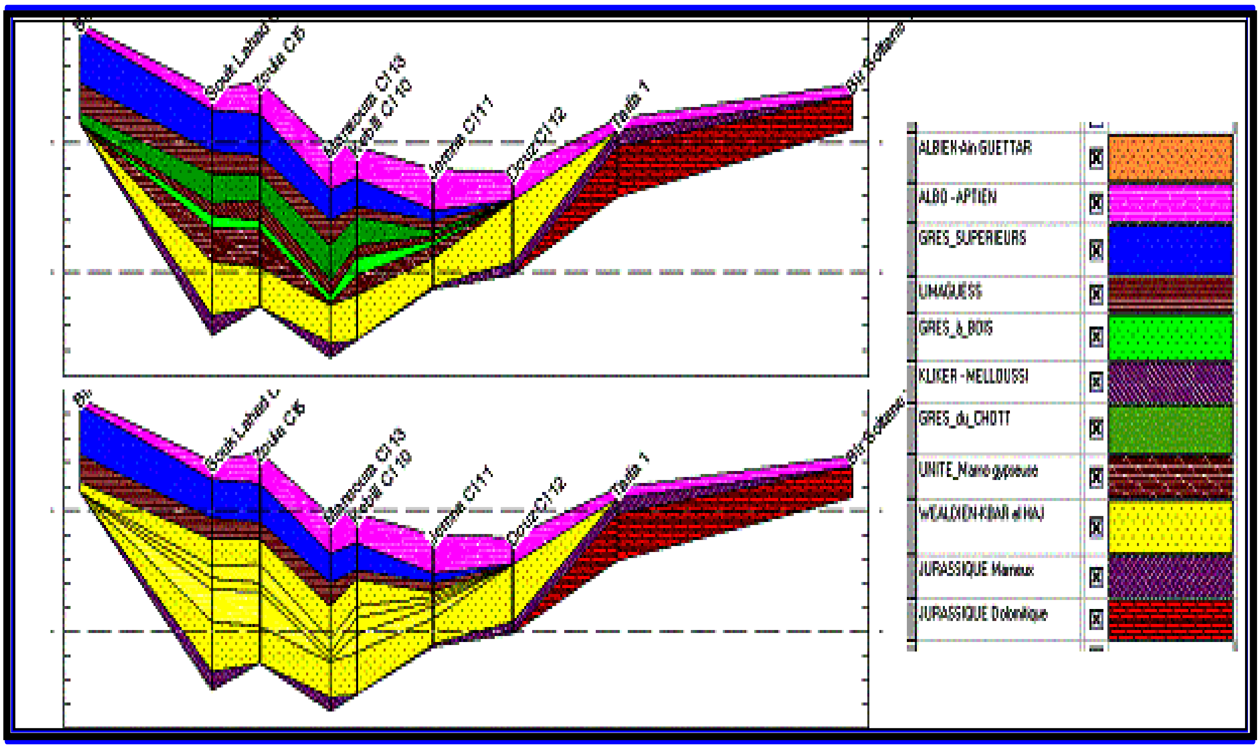
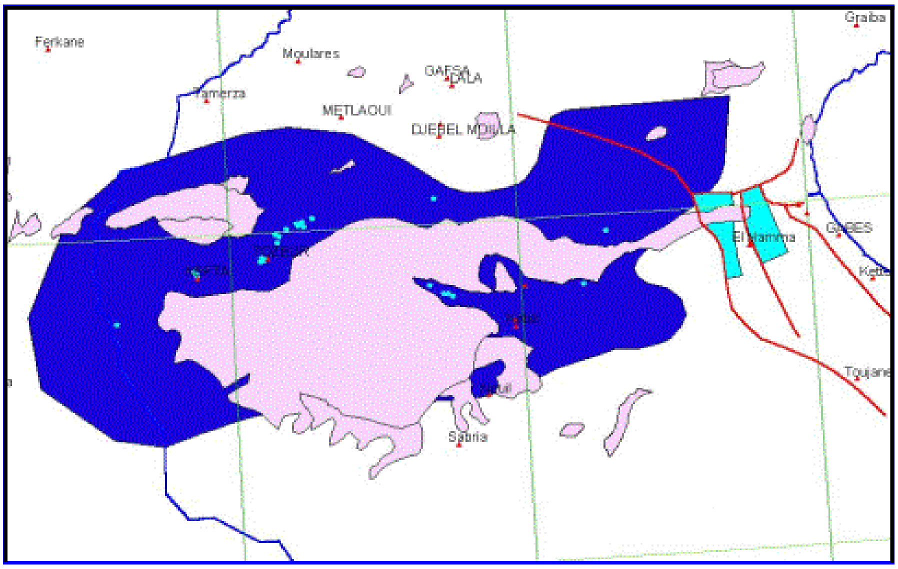
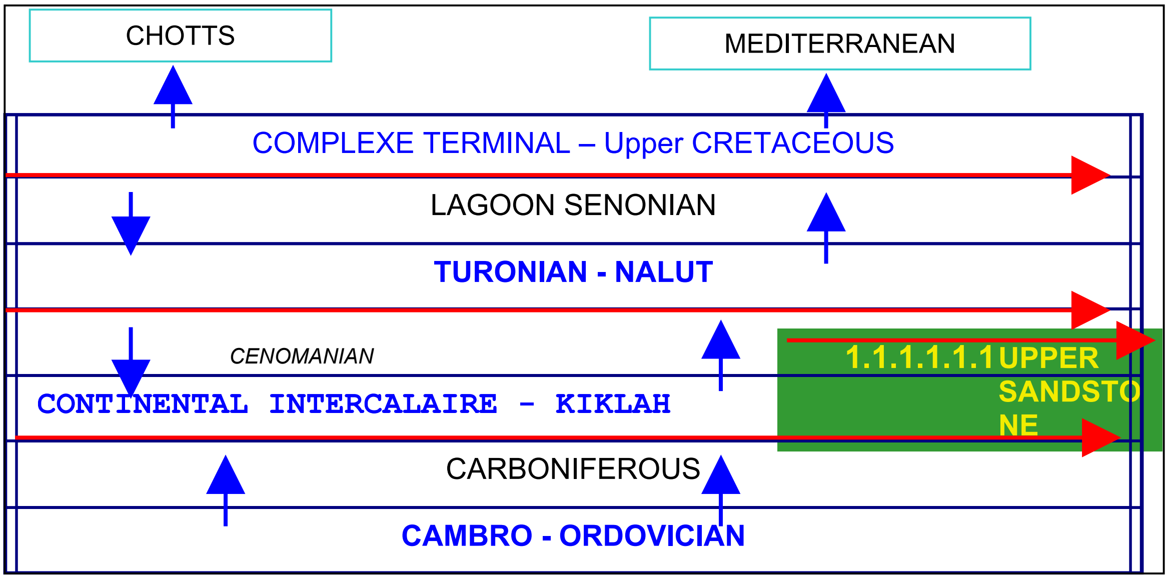


Fig. 62: Extension of the UPPER SANDSTONE layer



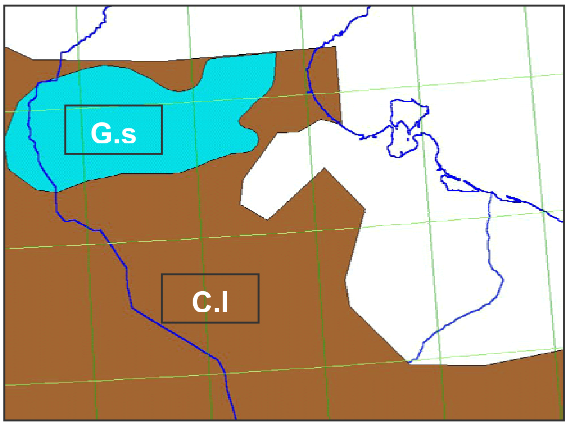
The new structural outline of NWSAS model (fig.63) will then include an additional aquifer layer: the upper sandstone aquifer (extension fig. 62-a). On the other hand, the new IC boundary in Gabes region includes an important gap corresponding to the Mole of Melaab, where the aquifer is considered to be definitely[21] absent (see fig.62-b).

Fig. 63: New structural scheme of NWSAS Model



[21] The absence of aquifer in the mole of Dj. Melaab was found out right after the construction of the first CI model by GEOPETROLE (1963). ERESS first model conserved this gap in a first calibration phase, then opted for « the priming » of the mode in order to enlarge the Tunisian outlet and facilitate the transit of a more important flow. This last outline was adopted during the first adjustment phases of the NWSAS model [see. M.BESBES and M. ZAMMOURI: « Construction and Adjustment of the simulation model, Phase report ; SASS-OSS, May 2001 »], this outline was then abandoned at the end of CI's fine structural analysis conducted in Southern Tunisia.

Fig. 62-b: Respective boundaries of CI and upper sandstone



Key:

upper sandstones outlet

CI S.L. outlet

III- AQUIFER EXTENSION AND DELIMITATION

The extension of the two main layers of the model is presented in fig.65 and fig.66.

III.1- The Continental Intercalaire

The minimal adopted extension represents the union of the respective models:

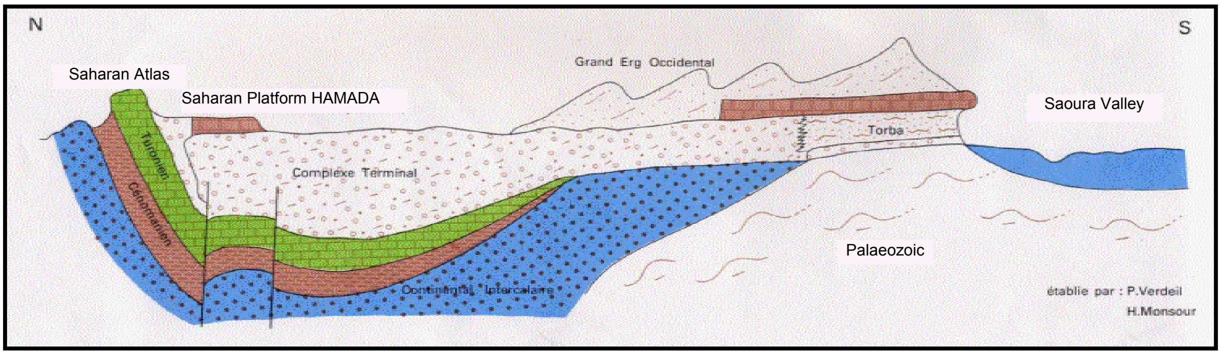
- The CI of ERESS ;
- The TRJLC (Triassic-Jurassic-Lower Cretaceous) of GEOMATH ;
- The KIKLAH formation as represented by GEFLI.

The boundaries of the Continental Intercalaire in Algeria and Tunisia are more or less the same as the ones adopted by ERESS.

However in Algeria, the model is extended to the west and the north-west to include the CI recharge areas of the Saharan Atlas and the Grand Erg Occidental until Saoura. This modification is justified by the fact that the Continental Intercalaire is relayed by the sandy formations of the Mio-Pliocene (western basin of the Complexe terminal) covering the Atlas piedmonts, then more to the south the dunes of the Grand Erg Occidental. All these formations constitute together hydraulic relays (see fig.64); they are assimilated to the CI.

The integration of this aquifer additional volume suggests the consideration of the very important water reserves contained: due to the concentration of unconfined surface areas in this region, the latter constitutes the real “water tower of the Continental Intercalaire”. This new extension can be used to reserve the possibility of simulating the exploitation of these reserves, even if, due to difficulties of access, these regions are still not well known.

Fig. 64: Schematic section of the Atlas in Beni Abbès



As for the eastern boundaries in Libya adopted in the model, we can note in particular that:

- The South-Eastern boundary is a natural boundary for the extension of the Lower Cretaceous formations, but they represent here the continuity of the Cambro-Ordovician aquifer,
- In the North East, the Sandstone formations of the Continental Intercalaire become dolomite carbonates, and this change of the facies is translated by an important reduction of transmissivities along the coast, but the aquifer continues in the sea;
- In the east, the aquifer formations of the Lower Cretaceous continue well beyond the valley. On the east of Meridian 16°E, CI aquifer shows poor transmissivities and a high salinity. As a result, it no more shows interest, but due to the presence of important exploitations (Wadi Washkah, Wadi Zamzam, Wadi Bayy al Kabir) located nearby, the boundary adopted for the useful CI is positioned along Meridian 16°30’ so that the model can eventually assess the effects of an increase in abstractions in this neighboring area.

III.2- The Complexe terminal

The NWSAS model constitutes the union between the ERESS yielded CT, the « Upper Cretaceous» formation of GEOMATH, and the Mizda and Nalut formations represented by GEFLI.

The western and north western of the CT are the same as those adopted by ERESS and constitute natural boundaries.

In the north, the boundary follows the outline of the atlas flexure and corresponds to the Miopliocene extension boundary.

In the south of the Algerian Sahara, where ERESS arbitrarily stopped at the level of parallel 30°, the boundaries of the model were moved away towards the south up to the natural outcrop boundaries of the Carbonated Seonian, as described by Bel and Demargne (1966) ; this helps to better consider unconfined surface reserves represented by important aquifer volumes previously not considered.

The basin eastern part moves, in favor of the Hun Graben, to the Syrta basin, where the highly developed tertiary sedimentation replaces the upper Cretaceous, which profoundly sinks and becomes very little tranmissive and salty. The boundaries of the model adopted for the CT layer correspond to the natural boundaries of the two aquifers of the Cenomano-Turonian (Nalut) and the Senonian (Mizdah), corresponding to the north and to the south, at the extension boundaries of these formations. On the East, the formation still exists under the tertiary cover, but beyond Meridian 16°30, the two aquifers become very little transmissive and salty. This is the boundary that has been set on the east of CT.

III.3- The Turonian

This layer holds the same boundaries of the CT, only on the Dahar and Djebel Nefussa, where outcrop areas very slightly differ.

III.4- The upper sandstone

The boundaries of the modal comply to the layer geological boundaries.

III.5- The Cambro Ordovician

The boundary of this layer (see. fig.58) is the one adopted by GEOMATH, limited in the south where it is arbitrarily cut out at the level of the most southern boundary of the Continental Intercalaire, in parallel with the grid of the model.

IV- SPATIAL DISCRETISATION AND MATHEMATICAL MODEL

In order to facilitate the transfer of data of previous models (mainly in the case of ERESS where the Project also had digital data) towards the one to develop, a discretisation grid similar to the Continental Intercalaire (ERESS, 1972) has been used in advance, which happens to be the mot widespread within NWSAS space. This grid represents a regular 25 km x 25 km mesh square. This first representation enabled the testing and validation of the feasibility of NWSAS multi-layer modeling. Later, and with the progression of the calibration operation, it was decided to divide into four the previous mesh sections for a finer representation of the system. Consequently a final mesh network of 12,5 km x 12,5 Km, representing each of the layers:

- Complexe terminal 4295 meshes
- Turonian 4295 meshes
- Upper sandstone 109 meshes
- Continental Intercalaire 6639 meshes
- Cambro-Ordovician 1185 meshes

Hence a total of 16523 mesh units representing a developed area of nearly 2580000 km². Fig. 65 and 66 represent the mesh sectioning of the two main "active" aquifer layers of the model: the CI and the CT.

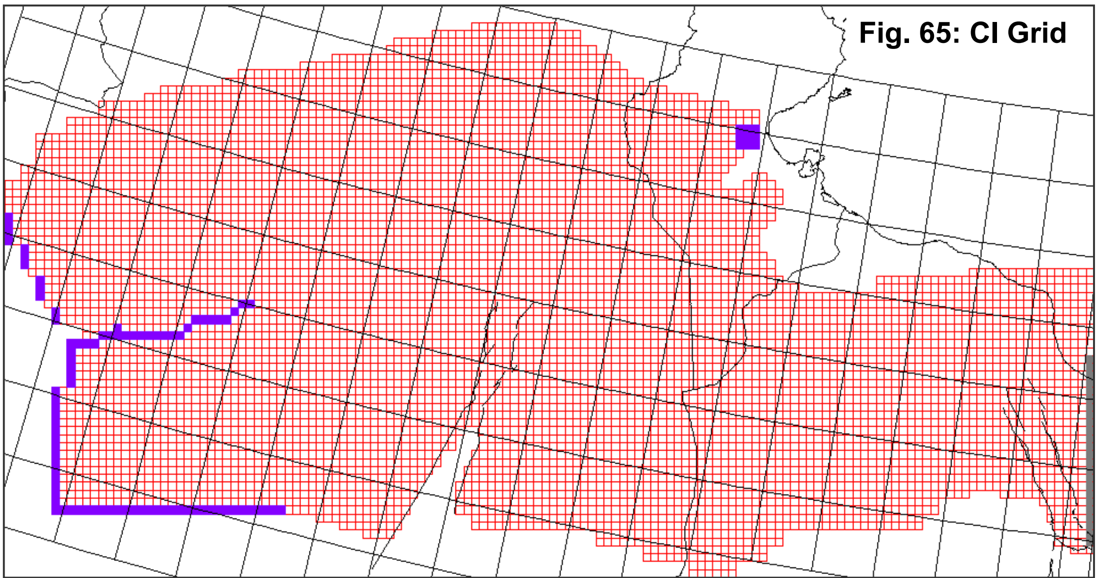


Fig. 65: CI Grid

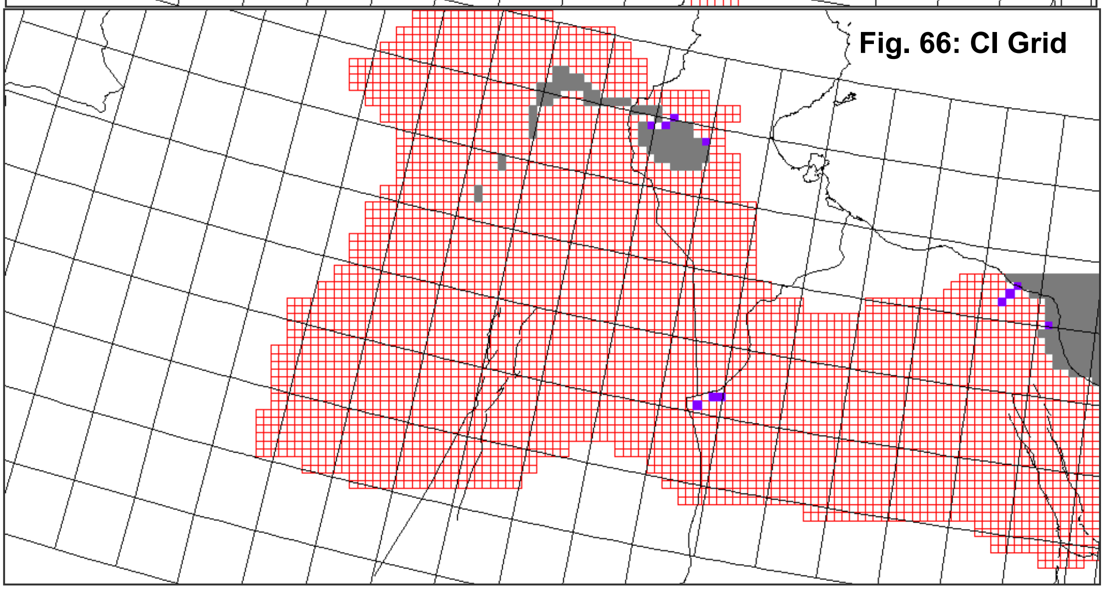


Fig. 66: CI Grid

As for the semi-permeable layers, they are represented by vertical flows that cross them under the effect of load differences between super-posed aquifer layers: they are the leakage flows. In fact, we use a quasi-three-dimensional Model based on the “Multi-layer hypothesis”, which suggests that flows in the semi-permeable layers (aquitards) are strictly vertical when we consider that flows in the main aquifers are horizontal. We prove that this hypothesis is well justified when the permeability contrast between adjacent formations (aquifer/aquitard) is considerable: a 10^4 ratio is sufficient. This is well the case in the Sahara where studies have been conducted (whether in Algeria, Tunisia or Libya), which locate the vertical permeability of the Cenomanian and lagoon Cenonian rather towards 10^{-10} to 10^{-13} m/s [see further: aquitard vertical permeability]. In these conditions, the flows general equation in the multi-layer, which constitutes NWSAS Mathematical Model is represented by the following formula:

$$\frac{\partial}{\partial x}\left(T_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T_y\frac{\partial h}{\partial y}\right)+q_H+q_B=S\frac{\partial h}{\partial t}+q$$

$$q_H=K_v\frac{H_H-H_C}{e_H}$$

$$q_B=K_v\frac{H_B-H_C}{e_B}$$

where:
T_x is the aquifer Transmissivity according to Ox
T_y is the aquifer transmissivity according to Oy
Ox and Oy are anisotropy main axis
q_H est le Flux spécifique de Leakage vers le Haut
q_B est le Flux spécifique de Leakage vers le Bas
h est la Charge hydraulique dans l’aquifère
Hc est la charge hydraulique moyenne dans la maille courante
H_H est la charge hydraulique moyenne dans la maille supérieure
H_B est la charge hydraulique moyenne dans la maille inférieure
Kv est la perméabilité verticale de la couche semi-perméable
e_H est l’épaisseur de la couche semiperméable supérieure
e_B est l’épaisseur de la couche semiperméable inférieure

V- MODELLING SOFTWARE

With regard to NWSAS structural complexity, it was necessary that the construction phases of the Model [transition from the conceptual model to the digital model] and the calibration in permanent and transient regimes be conducted by means of a "transparent" on the hydro-geological plan. The selected tool could also ensure that NWSAS model should be easily transported between all three countries, which necessarily implied a PC installation and a Windows exploitation mode. The best tool available today and responding to software requirements is the **PMWIN** software and namely its PM5 version.

Version 5 of the Processing Modflow Software (PM5), developed by W. H. Chiang and W. Kinzelbach[22], uses Modflow code designed by the US Geological Survey, and enables the modeling of water transfers in a multi-layer aquifer system through the method of finished differences.

The mathematical model of the flows module is shown in the previous framed figure.

Other utility codes are incorporated in PM5. They are PMPATH (outline of current lines and flowing velocity), the PEST code which is an automatic optimization and calibration program, and also the transport module MT3D.

PM5 also includes a stochastic modeling module and an interpolator integrating Shepard methods (distance reverse), Akima and Renka triangulation, and Krigeage process.

In addition to usual boundary conditions (imposed potential, imposed flow and Cauchy mixed condition), particular conditions can also be outlined: faults, evapo-transpiration, and groundwater layer exchange – superficial flow in a drainage network or in a channel.

Other modeling aspects can be treated such as dewatering, transfer of the boundary of the confined-unconfined aquifer, subsidence and densitary flows due to salinity or temperature.

The introduction of data is made mesh by meshl, which generates some drawbacks at the level of abstraction time-series recording especially when, as is the case for NWSAS, historical developments are very long and assigned not to cell units but to deep wells. It was then **necessary to develop an interface program between the database and PM5 Pre-processor**. The structure for the input of abstraction time-series (wel.dat) being in ASCII, this operation remains feasible.

As for the graphic presentation of results, it can be saved in a DXF, HPGL or BMP format.

Nonetheless, it is better that the value maps (piezometry, draw-down, subsidence, concentration, hydraulic parameters, eCT..) be recorded in the form of ASCII files or in a form that can be directly read by SURFER or ARCVIEW in order to improve the presentation of results. This observation is also valid for chronological series.

[22] Wen Hsing CHIANG & Wolggang KINZELBACH: 3-D Groundwater Modeling with PMWIN, Springer-Verlag, 2001

VI- SIMULATIONS BOUNDARIES CONDITIONS

VI.1- Continental Intercalaire boundaries

- **Algeria-Tunisia Northern Boundary**

In the North, the CI formations plunge very deep through subduction under the Atlas flexure, as reflected in the deep wells of Ouled Djella and Guanntass. On the other hand, between Laghouat and Hamma Gabes, the isopiezeic curves of the Continental Intercalaire are always octagonal to the atlas flexure, confirming the impervious nature of the northern boundary.

- **North western boundary**

The piezometric curves allocate a major role to this boundary in the recharge of CI aquifer. Further to the brief hydrological analysis described above, it was not possible to make an estimate of this supply with an acceptable accuracy. During the first phases of the model calibration, supply will be represented and deduced based on conditions of the space variable fixed head, which values are extracted from the reference[23] piezometric map (cf. fig.29).

- **Western Boundary**

It corresponds to Zousfana valley and Saoura. The aspect of piezometric curves indicates that this an outlet, represented on the model by drains.

- **South Western Boundary**

In the valley of Gouara, Touat and Tidikelt, the bucket of foggaras (natural springs) is represented by a drains line, whose flow shall be restituted through the calibration of the model. In the northern part of this boundary, Timimoun Sebkha is also represented by drains.

- **Southern Boundary**

On the east of In Salah up to Amguid ridge where IC is absent, there is a boundary with a nil boundary. In the Tighert, inputs through the outcrops of Adrar Ben Drich, over a length of nearly 400 km along the border, are represented and deduced based on conditions of the space variable imposed potential, which values are extracted from the piezometric map. More to the east until the Hun Valley, the CI finishes in an impervious boundary, knowing that in a large part of this region, contact with the sandstone aquifer of the Cambro-Ordovician will determine important vertical exchange.

- **Eastern Boundary**

There is no precise hydraulic boundary on the east of the reservoir. The boundary of the model is here represented by a fixed head condition through a resistance, which should authorize a first estimate of exchanges between this CI aquifer and its salty oriental extension, whether in its current state or during provisional simulation.

- **The Gulf of Syrta**

The Continental Intercalaire, relayed here by less permeable carbonated formations, extends into the sea. The model finishes by a series of fixed heads through a resistance, likely to simulate sea percolations, through the top of the CI confined aquifer.

[23] It is true that knowledge about the piezometric levels in this region is particularly poor, as is the case for transmissivities. This state will be commented during the examination of calibration result in a permanent phase. This is the reason why we sought to record size values of recharge estimates already suggested by NWSAS predecessors, which were reinforced and compared by the brief hydrological analysis presented in the first part.

- **Boundaries of North Libya and East Tunisia**

Marked by CI outcrops on the height of Dj. Nefussa and Dahar, this boundary contributes to the recharge of the aquifer. It is figured by a series of fixed heads determining, by model calibration, the infiltration outflows.

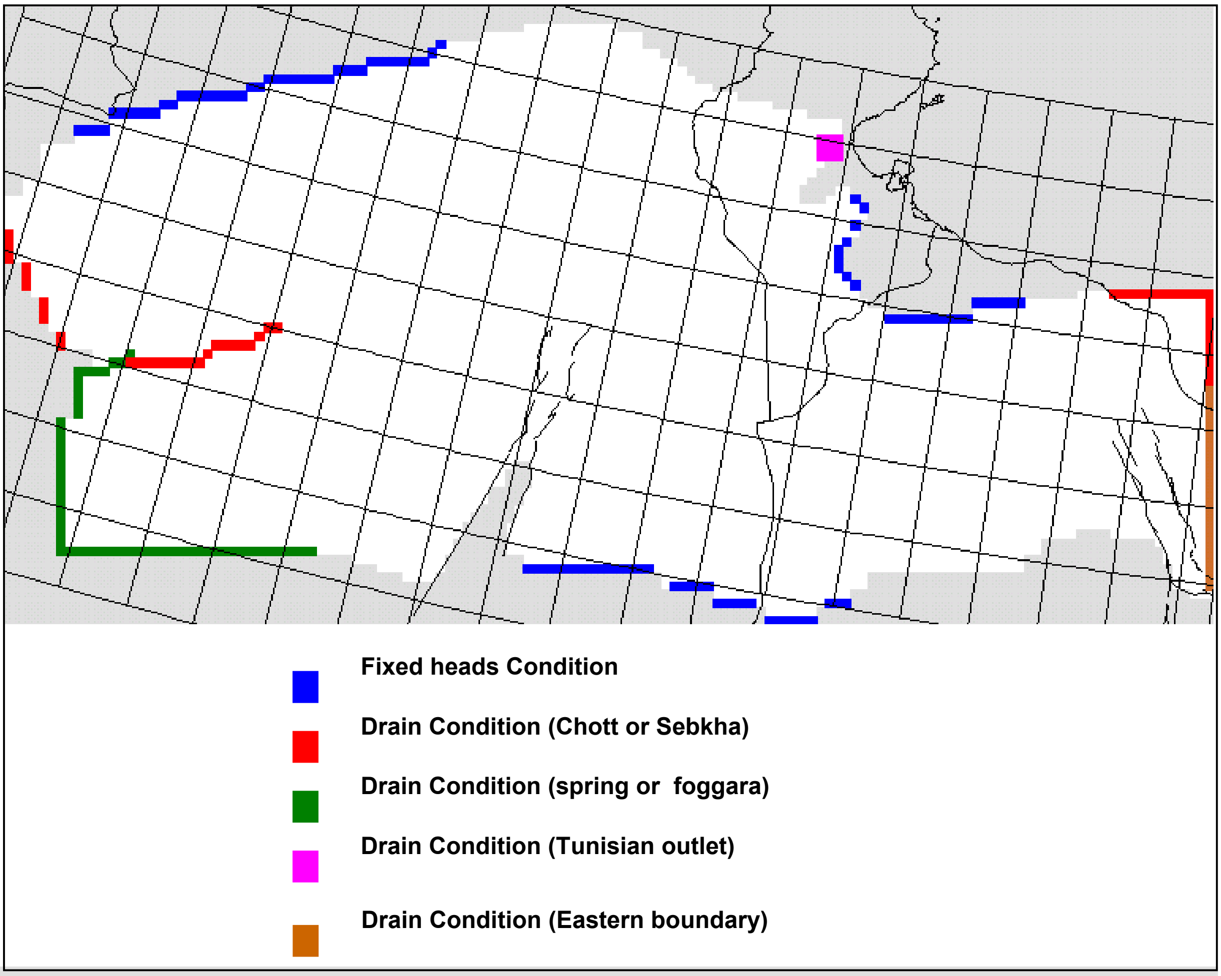
- **El Hamma Threshold**

This threshold is represented by Drains conditions, where the model will be used to calculate the flow which transits through the Tunisian outlet.

- **Cambro-Ordovician representation**

The Cambro-Ordovician (COD), is presented in the form of a grid mesh with imposed potential. Its representation must help determine flows likely to be carried to the Continental Intercalaire in a steady state regime which inputs it will take later after starting the exploitation of the confined fields of Dj. Hasouna, as suggested by the low thickness of the semi-permeable separation layer (Carboniferous) and the very developed direct contact between the two aquifers (CI & COD) in the sector.

Fig. 67: Continental Intercalaire; boundaries Conditions adopted in a steady state



VI.2- Complexe terminal Boundaries

- **Northern boundaries of the Chotts, from Biskra to Gafsa**

This boundary follows the layout of the Atlas flexure and corresponds to the extension boundary of the MioPliocene in the North. This region is marked by the occurance of very important flows coming from the Aures and the Gafsa basin, but the potential contribution of these inputs into the aquifer is limited, on the one hand by the reduced surface of outcrops and by transmissivities relatively low in the upstream. In any case, this boundary is figured by fixed head conditions.

- **North-Western Boundary, the Saharan Atlas**

If we stop at the Miopliocene of the Central Basin, as is usually the case for the definition of the model CT layer, this boundary corresponds to the extension of formations topping the impervious Middle Eocene. This boundary namely receives inputs from Wadi Djedi, as well as from other les important basins. It is represented by of fixed head conditions.

- **Western and South-western Boundary**

It corresponds to the layout of Mzab ridge, and covers approximately 400 km from the 32nd to the 28th parallel. This is the extension boundary, to the west by the aquifer of the Complexe terminal; it receives inputs of the floods of wadis streaming down the ridge and infiltrations through the Carbonated Seonian and the Miopliocene. It is represented by fixed head conditions.

- **South Algerian Boundary**

Located between parallels 29th and 28th, and the Mzab ridge by the Libyan borders, it corresponds to the southern extension boundary of the Carbonated Seonian formations. These formations extend to the plateaus of Tademait and Tinhert, dominated by isohyets 20 mm! this means that the direct infiltration of rainfall should not constitute a source of dominating inputs. But this boundary receives inputs from Wadi Mya, and is crossed by the fossil bed of Oued Lgharghar, whose catchments basin extends up to the Hoggar block. This boundary is represented by fixed head conditions.

- **Southern-Libya Boundary**

Between meridians 10th and 14th, it corresponds to the southern extension boundary of the upper Cretaceous. It is represented by fixed head conditions.

- **Model Eastern Boundary**

This boundary is represented by a nil-flow condition.

- **Eastern Tunisia and Northern Libya boundaries; Dahar and Dj. Nefussa**

Due to the unavailability of preliminary estimates of inputs along these boundaries, they are represented by fixed head conditions.

- **Representation of internal percolations; Drains Conditions**

The aquifer natural outlets are represented by conditions of drain, simulating CT percolation to the following systems:

a) Chotts of Melrhir, Merouane, Djerid and Rharsa.

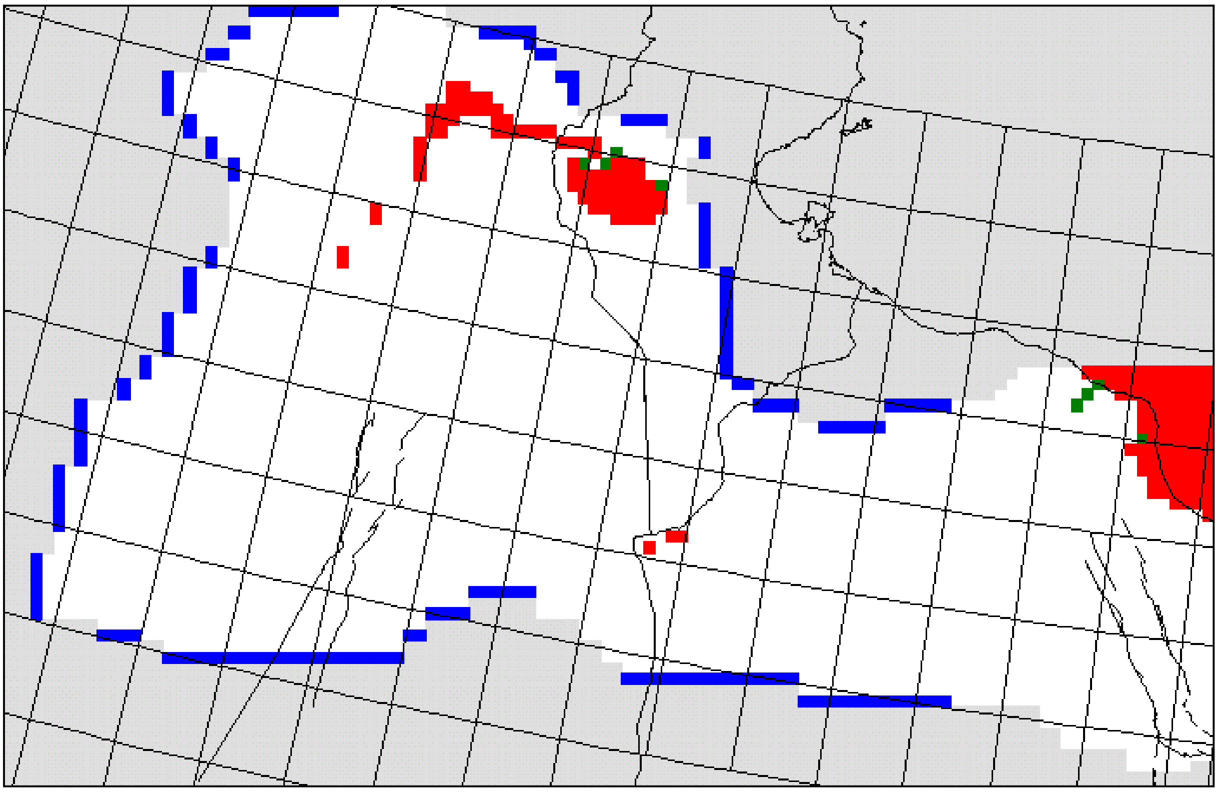
b) Sebkhas El Hajira, Ngoussa, Mjazzam and Tawergha.

c) The Mediterranean in the Gulf of Syrta.

d) Springs of the Djerid and Nefzaoua

e) Ain Tawergha springs and that of Wadi Kaam

Fig. 68: Complexe terminal; boundaries conditions adopted in a steady state (the key is of fig. 67)



Note: All the piezometric levels values adopted on fixed head limit, used for calibration in the calculation of aquifers supply outflows, are represented, area by area, in the Annexes of the second part.

VII- INITIAL HORIZONTAL TRANSMISSIVITIES

The initial maps of the transmissivity distribution (used to start the calibration of the model), have been mainly designed on the basis of results of previous modeling operations, where the project could reach information pertaining to transmissivity. They are (see. fig.69 & 70):

- The two CT and CI mono-layer models (ERESS) constructed in 1972 by UNESCO and updated in 1984 (UNDP 1985), including the Algerian-Tunisian part of CT and CI aquifers,
- The multi-layer model constructed by GEOMATH (1994) in Libya. They are aquifer layers located in the basin of Hamada al Hamra and referred to by GEOMATH respectively as:
  - Upper Cretaceous,
  - Lower Triassic-Jurassic-Cretaceous,
  - Cambrian-Ordovician-Devonian ; pertaining to the Libyan part of NWSAS study system. The first layer contains the aquifer reservoirs of Mizda and Nalut; the second corresponds to Kiklah.
- The Algerian-Tunisian CI model (BRL- School of Mines, 1998) covering ERESS Model Domain, and extends a little to the North West, without integrating the whole basin of the Grand Erg Occidental,
- The three mono-layer models respectively representing the aquifer of Mizda, Nalut and Kiklah, models realized in 1978 by GEFLI and extending to the basin of Sirte and Zam Zam in the North East of Libya.

This situation constitutes the starting point of the calibration of the NWSAS system under a steady state. This information will later be enriched by all values of transmissivities gathered in the three countries during NWSAS project, a cartographic representation of which is shown in fig. 40 et 41.

As for the Turonian of the Algerian-Tunisian sector, which has not been subject to any regional hydro-geological study, it has been used as an indicator of transmissivities, the facies variations described by Bel and Demargne [calcareous-marly in the south of El Golea parallel and in the north of Djamâa, and calcareous between El Golea and Djamâa, as well as some values ($5\ 10^{-6}$ to 10^{-5} m^2/s) resulting from the results of pumping tests conducted by Sonatrach in the Hassi Messaoud region (Franlab, 1978) to design an initial transmissivities map.

Fig. 69: CI Transmissivities by ERESS Model, 10-^{3}m2/s

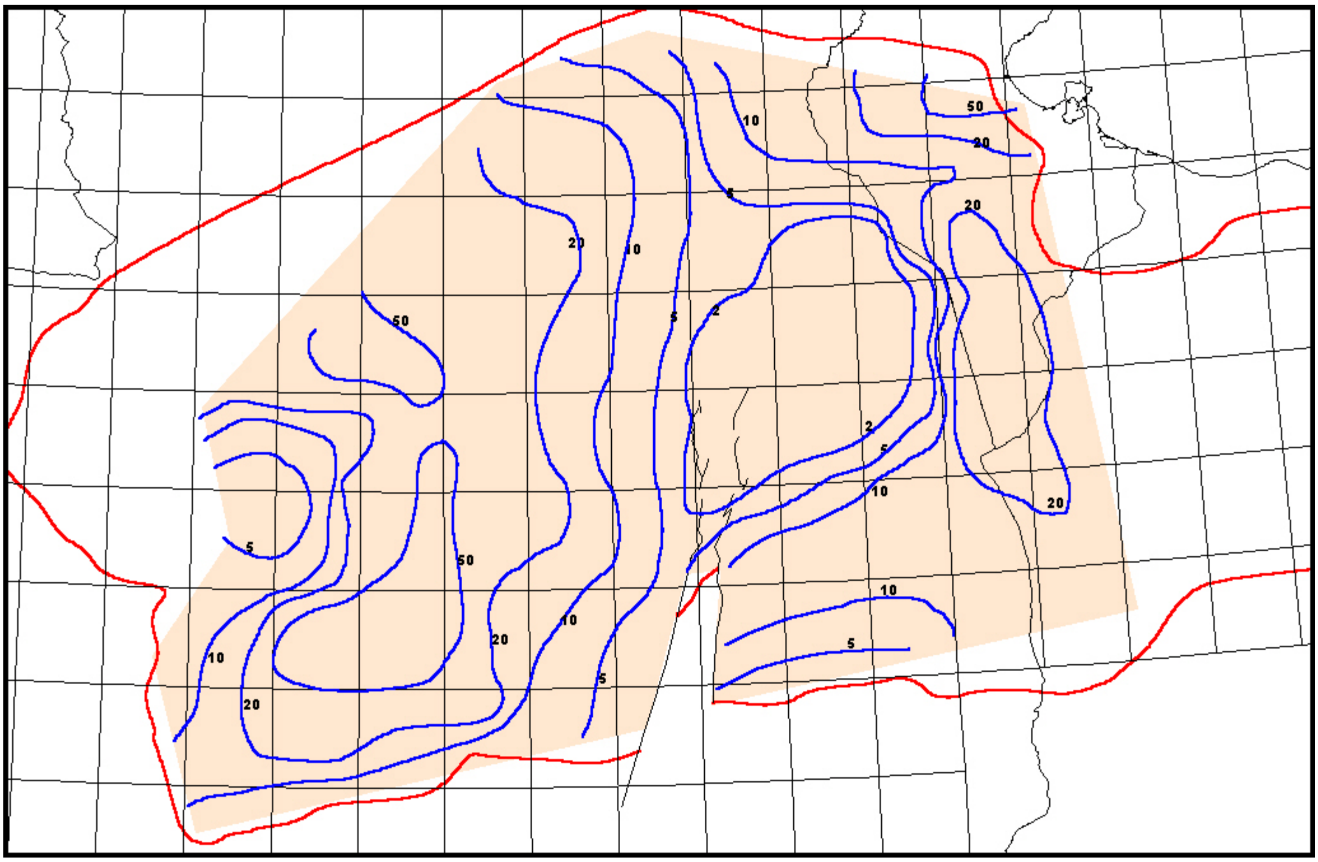
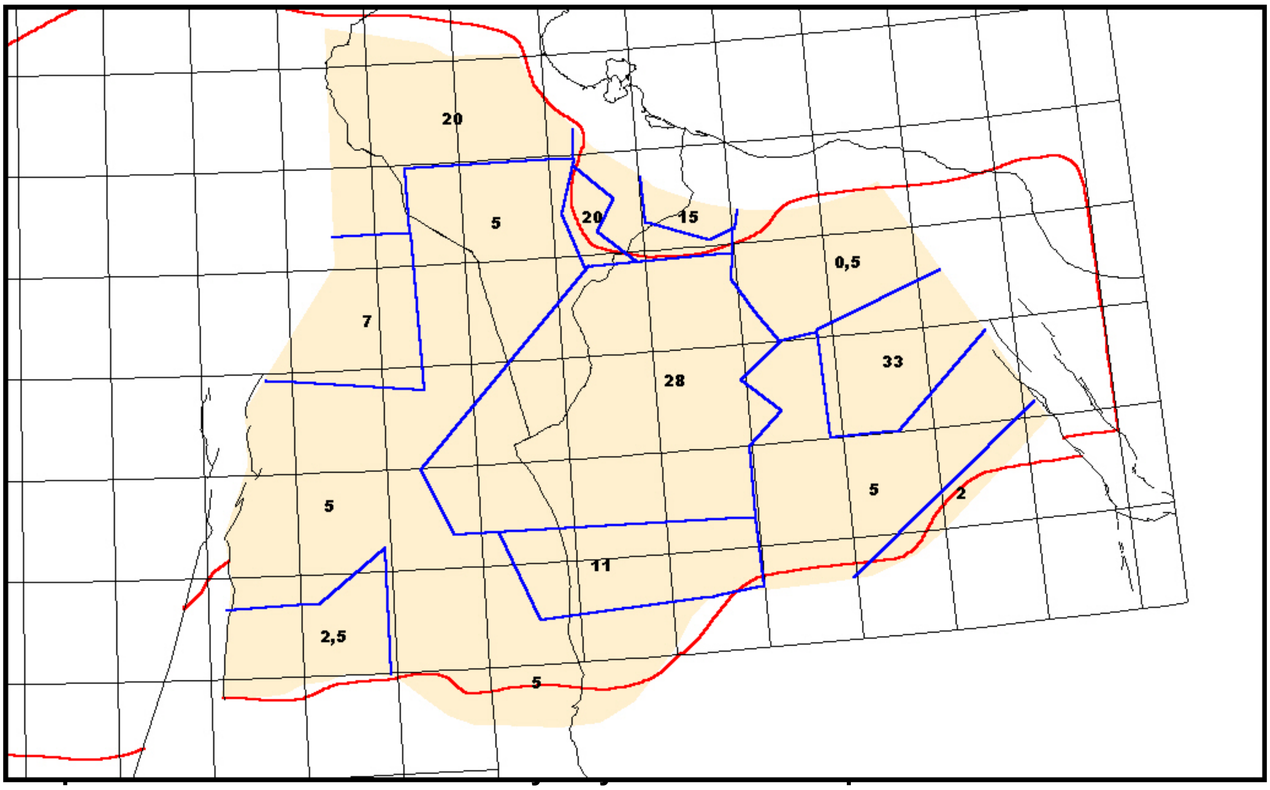


Fig.70: TRJLC - Kiklah   Transmissivities by GEOMATH Model,10-^{3} m^{2}/s



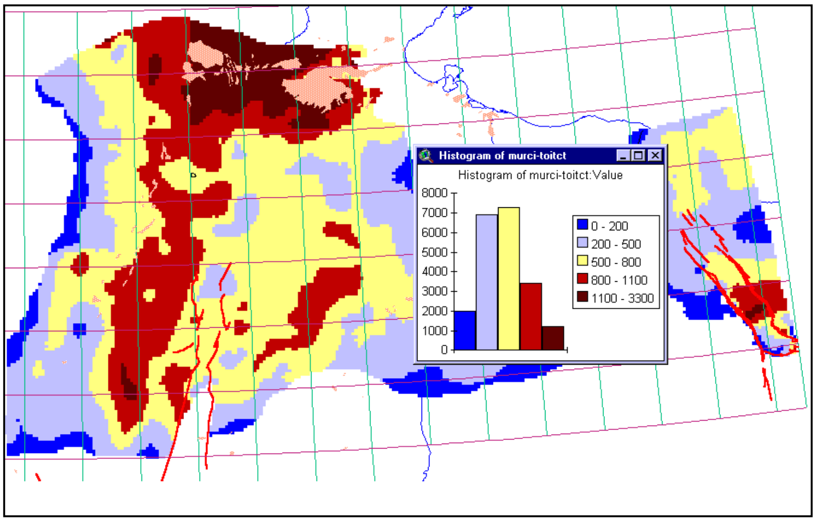
- The lagoon Sanonian fitting between the CT and the Turonian, with an average thickness of 150 m in Algeria-Tunisia and 30 m in Libya ;
- The Cenomanian separating the Turonian and CT aquifers, with an average thickness of 300 m in Algeria, 200 m in Tunisia, and 80 m in Libya.
- The Carboniferous separating CI aquifer and COD aquifer.

While in the Libyan reservoir part, there are some reference values, at least in terms of real scale, resulting from the successive modeling operations of the Iderotecneco (1982), Geomath (1995) and BrI (1997) studies, in the Algerian Tunisian part, there is, at the level of ERESS studies, no indicator enabling a reliable regional representation of this parameter.

Based on information acquired through the geological database and the structural analysis now made at low cost, it was possible to determine the thickness of obstacles obstructing the flow traffic between the CI and the CT; these obstacles are formations namely made up of the lagoon Senonian and Cenomanian. Fig. 71 represents the thickness map of formations included between the CI top and TC bottom: this thickness exceeds 1000 m over large areas of Central Sahara, and its average value (see. Frequency histogram) can be considered as 500 m.

Between the CI and the CT, leakage flows are theoretically possible, with regard to the distribution of load differences between these two aquifer layers. Fig. 72 represents losses of such vertical loads, for which an average value of 200 m can be allocated (see histogram).

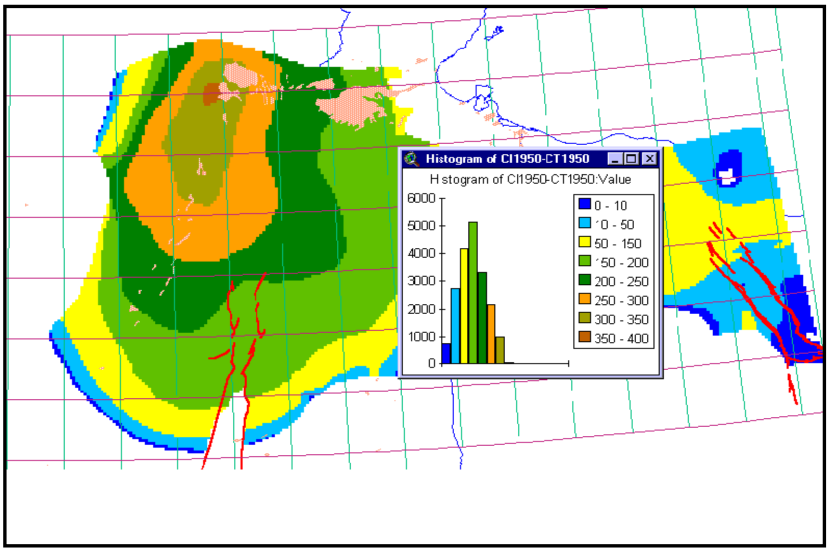
Fig. 71: Thickness (in m) of formation separating the CI and the CT



Very roughly, the average vertical hydraulic gradient can be estimated at 0.4. On the other hand, the recharge of CI aquifer is generally estimated at a value amounting to about 10 m3/s, while the total flow of the natural outlets of the aquifer (foggaras, Tunisian outlet and participation to Ain Tawurgha) amounts to approximately 9 m3/s, hence and theoretically, a flow worth of 1m3/s is reserved to CI□CT leakage.

Considering a potential leakage area of 500.000 km², the vertical permeability is about $5.\ 10^{-12}$ m/s. This value shall be an average over the whole basin, tolerating spatial variations according to existing formations.

Fig.72: Heads differences between CI and CT (in m)



As a vertical permeability, an initial average value (initial in terms of first model calibration tests) of 10^{-12} m/s was considered in the lagoon Senonian overall the domain. In areas of common recharge of the CT and the Turonian, a hundred time bigger value has been taken to report on the hydraulic communication between both aquifers. As for the initial vertical permeability of the Cenomanian, it is supposed to be 10^{-11} m/s in Algeria-Tunisia and 5. 10^{-11} m/s in Libya. As for the Carboniferous, a value of 10^{-12} m/s has been adopted, passing to 10^{-10} m/s in the South East.

VIII- AQUITARDS VERTICAL PERMEABILITIES:

The aquitards considered in the multi-layer system are from top to bottom:

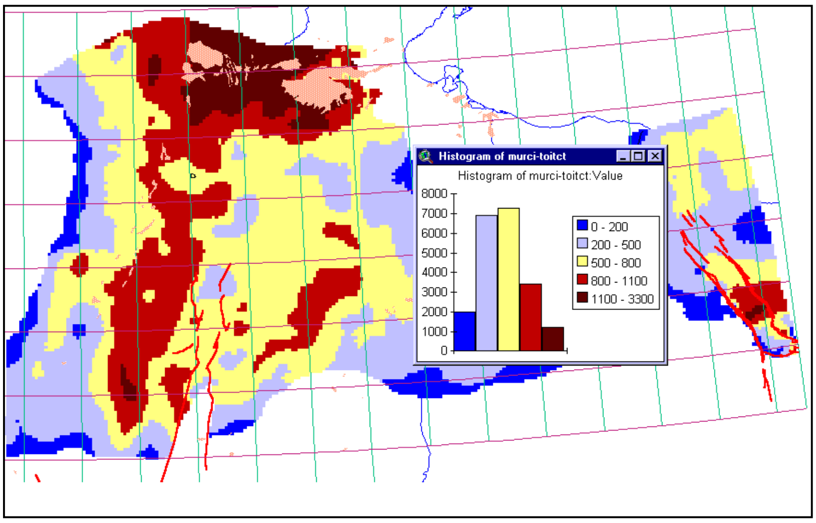
- The Lagoon Senonian which is intercalated between the aquifers of the CT and of the Turonian, of which the average thickness is of 150m in Algeria-Tunisia and 30m in Libya
- The Cenomanian which separates the aquifers from the Turonian and the CI, with a average thickness of 300m in Algeria, 200m in Tunisia and 80m in Libya.
- The Carboniferous aquitard which separates the CI aquifer from that of the Cambro-Ordovician.

While in the Libyan part of the basins, there exist some reference values, at least in terms of order of magnitude, resulting from successive modeling by IDROTECNECO (1982), GEOMATH (1995) and BRL (1997), in the Algerian-Tunisian part, there does not exist, on the level of the ERESS studies any index authorizing a reliable regional representation of this parameter.

However, by combining the information acquired based on the geological data base and the structural analysis which these data allow, from now on, to conduct at lower cost, it was possible to trace the chart thickness obstacles which constitute a hindrance to flow circulation between the CI and the CT; these obstacles are primarily the formations of the Lagoon Senonian and the Cenomanian. Figure 71 presents the chart thickness of the formations ranging between the top of CI and the bottom of the CT: this thickness exceeds 1000m over large areas of the central Sahara and whose average value (cf. the frequencies histogram) may be considered as of about 500 m.

Between the CI and the CT, leakage flows are theoretically possible, subject to the conditions of distribution of the differences in load between these two aquifers. Figure 72 represents these vertical pressure losses, for which there may be allowed (cf. histogram) an average value of 200 m.

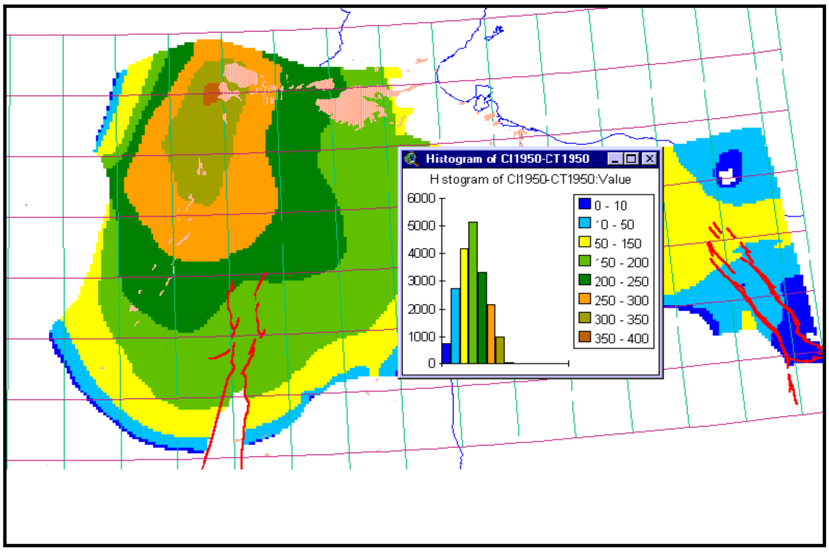
Fig. 71: Thicknesses (in m) of the formations separating the CI aquifers from those of the CT



It may be said, in a very summary fashion, that the average vertical hydraulic gradient can be estimated as 0.4. In addition, the recharge of the CI aquifer is generally estimated at a value of about 10 m3/s, whereas the total flow of the natural discharge system of the aquifer (wells, foggaras, Tunisian outlet system and supply to Ain Tawurgha) is estimated as 9 m3/s approximately, that is to say, and by way of assumption, a flow of 1m3/s reserved to leakage CI-CT.

Assuming a leakage area of about 500.000 km2, vertical permeability is about 5. 10^{-12} m/s. This value would be an average for the whole the basin, which tolerates variations in space and according to the formations involved'.

Fig.72: Differences in load between the CI the CT (in m)



Like vertical permeability, an initial average value has been adopted (initial in the sense that it results from the first tests of the model) is equal to 10^{-12} m/s in the Lagoon Senonian over the whole area. In the common zones of recharge of the aquifers of the CT and the Turonian, a value that is a hundred times higher was posted to account for the hydraulic communication between the two aquifers. As for the initial vertical permeability of the Cenomanian, it is assumed to be equal to 10^{-11} m/s in Algeria-Tunisia and to 5. 10^{-11} m/s in Libya. For the Carboniferous aquifer, the value adopted was of 10^{-12} m/s which rises to 10^{-10} m/s in South-east.

CHAPTER II – MODEL CALIBRATION

I- MODEL CALIBRATION

Traditionally, the first phase of a model calibration is calibration in a steady state, in order to minimize the number of parameters for adjustment, and with the aim of ensuring the coherence of all introduced data concerning boundary conditions, piezometry and tranmissivity.

The second phase of model calibration is verifying its operation in a transient regime, over a period during which the evolution of the system state would be significant in terms of sampled flows and drawdowns of recorded levels.

Parameters to adjust during this second verification phase are the distribution of storage coefficients and the temporal supply evolution, but it is clear, in the case of NWSA, that the supply flows cannot be subject of modeling through time, as on the one hand their knowledge is still rudimentary, and on the other, the distance between input areas and pumping sites is so big that search for such an accuracy will have no impact on model previsions.

In fact, in the case of NWSAS, a larger calibration procedure has been implemented: in addition to calibration parameters, for which transmissivities have also been adjusted during the transient calibration, in some cases, elements considered to be certain have been put into question during calibration: this was the case for the *evolution of draw off flows*, the *final form of the eastern boundary of aquifer layer,* and the *very structure of the aquifer system.*

The system's geological complexity and the difficulty of acquisition of accurate data concerning current abstractions and piezometric levels, required the execution of several revisions of the model. After presenting a first version of the model, set and presented to the project Pioneering Committee in Tripoli in June 2001, a version called "Tripoli Model", the most important revisions were:

a) Revision of Abstraction records in Algeria:

Additional research, conducted by ANRH during spring 2001, yielded an important revision of the Algerian abstraction records, representing a global reduction of 15% during the year 2000 with regard to previous estimates. It was therefore necessary to resume the calibration of the model with consideration to these developments.

b) Revision of the Tunisian Outlet of CI aquifer:

At the end of the first adjustment phase of the model, there was necessity to resume the model in Southern Tunisia where CI calibration, with reference to the evolution of draw-downs recorded between 1950 and 2000, was considered not to be acceptable. The impossibility to reduce important gaps persisting in the field of Chott Fedjej (CF) and the major anomalies remaining unexplained in all the Djerid, called for a full revision of the very design of the modal in these regions.

c) Resumption of the Model in the Eastern Basin:

In its report dated January 2002, the model evaluation committee issued a number of recommendations concerning, on the one hand, the positions of the Northern and North Eastern boundaries of the model in Libya, and on the other the representation of abstractions from the Libyan group, in terms of geographic positions but also temporal evolution, as admitted and adopted in NWSAS database.

II- MAIN PHASES CALIBRATION

II.1- Tripoli Model, June 2001

This model represents the first full trial to integrate the hydro-geological knowledge in the North-Western Saharan Aquifer model. The quasi-three-dimensional structure of the model includes three aquifers (CT, Turonian, CI) overall the space where these aquifers exist, separated by two aquifers (lagoon Senonian and Cenomanian). The model includes two layers with a top-to-bottom imposed potential, representing the region of Algerian and Tunisian Chotts and the Gulf of Syrta (upper layer), and the Cambro-Ordovician aquifer (lower layer).

The hydraulic parameters (transmissivity and storage) of the CT and CI aquifers are practically the same as the ones used in previous models (ERESS, GEOMATH and GEFLI). The hydraulic parameters of the Turonian aquifer and the aquitards vertical hydraulic conductivity have been determined based on some tests conducted by Sonatrach in the region of Hassi Messaoud, for the Turonian, and on literature data concerning the aquitards vertical conductivity.

The calibration of this model in a steady state is very positive; the hydraulic heads and the calculated water quantities relatively match observations. Unfortunately, this model proved to be unable to report on the CI transient behaviour in the region of Tunisian Chotts (Chott Fedjej, Chott Djerid). Based on these results, the CI structure in Southern Tunisia has been entirely reviewed.

II.2- Impact of the charges in Algeria

At the end of a last series of verifications conducted by ANRH teams in Algiers and Ouargla, a number of errors could be corrected, bringing the total number of abstractions in Algeria during 1998, including all aquifers, from 52.3m3/s to 45m3/s.

Table 11: Corrections of withdrawal rate in Algeria

CI Aquifer		1998 abstraction by WILAYA , in l/s							Total
source	Foggaras	ADRAR	BISKRA	EL OUED	GHARDAIA	ILLIZI	OUARGLA	TAMANRAS	
ANRH - original	2700	6370	1600	2300	8000	1020	4700	3160	29850
ANRH – corrected	2700	6100	1720	1370	6740	1360	3550	1420	24960

CT Aquifer	1998 draw off by WILAYA , in l/s					Total
Source	*BISKRA*	KHENCHELA	TEBESSA	EL OUED	OUARGLA	
ANRH – original	350	300	200	9300	12400	22550
ANRH – corrected	350	420	200	10680	9350	21000

Without altering the model's structure or parameters, records of newly acquired flow for Algeria have been simulated according to the Libyan model. This operation included no calibration, but a simple calculation of the piezometric levels and new statements.

The yielded result, in terms of calculated drawdowns, compared to "Tripoli" drawdowns, and in terms of flow balances calculated in 2000, shows the scope of modifications induced by these changes of imposed pumping, thereby reflecting the necessity of a revision of the model throughout Algeria.

This revision of the model has been implemented simultaneously with the modifications required by the new representation of the Tunisian CI outlet.

II.3- First effects of CI new structural configuration

The new structure adopted by CI in Southern Tunisia includes two aquifers: the lower aquifer represents purely CI formations, while the upper aquifer represents “Grès Supérieurs” (upper sandstone) formations. The division of CI in two layers is justified by the big difference in hydraulic loads between the two aquifers. Concerning upper sandstone formations, the piezometric reference map dating back to 1950 has been reconstituted. A revision of abstraction records for the 1950-2000 period has also been conducted, both for upper sandstone and for the CI.

The quasi three-dimensional structure of **August 20** model results from the addition of the “Grès Supérieurs” layer to Tripoli Model, and a new configuration of CI boundary in the Gabes region, where the Melaab dome has been excluded from the aquifer. Some preliminary calculations, taking in consideration Algerian and Tunisian abstraction (the latter for purposes of considering an inter-layer re-allocation within the CI), showed that **the calculated flow rate of the Tunisian CI outlet in a steady state cannot then exceed 1.8 m3/s** (while **the flow rate generally authorized from this outlet is 3.6 m3/s**).

With the field of recorded transmissivities, the new mole abstraction and conditions of the imposed potential to supply boundaries, **the recharge of CI by the Dahar drops to 0.6 m3/s, while it was 2.6 m3/s according to the Tripoli Model and 1.99 m3/s according to the ERESS Model**.

II.4- Model of August 20th, 2001

Once it was proven to be impossible to use the Tunisian outlet for the transit of a flow that is consistent with the ERESS field of transmissivities[24], it was decided to leave this distribution for a while, namely in areas, where the absence of deep wells, and consequently of transmissivity values, could authorize such an option. This modification in the field of transmissivity became unavoidable if we wanted to restore a flow worth of 3.6 m3/s at the level of the Tunisian outlet [in fact 3.9 m3/s if we consider percolation in Chott Fedjej].

Origin of flows in the Tunisian CI outlet, according to ERESS Model

Dahar Recharge = 1.99 m^3/s ; Libya boundary = 0.49 m^3/s
Tinhert Plateau = 0.22 m^3/s ; Saharan Atlas = 1.2 m^3/s [complement to 3.9]
If we consider , in a very first approximation, a recharge on the Dahar, amounting to 0.6 m3/s (see “first effects” above), it is then necessary that the contribution of the Saharan Atlas to the flow of the Tunisian outlet be considerably increased.

In order to produce such an increase, **it was eventually necessary to construct a 100 km large power tube between Touggourt and El Hamma fault, where CI transmissivities were set to 2. 10^{-2} m^2/s:** ; the highest transmissivities increase (up to ten times that of ERESS) being located in the Erg Oriental region, characterized by the absence of measurements. Such an increase may seem arbitrary in the absence of references; but NWSAS is not the first to considerably increase transmissivities in this sector: GEOMATH (in BRL, 1997) which developed a cross-boundary model of CI, had adopted high transmissivities in the same place (2. 10^{-2} m2/s) for the Tunisian outlet, certainly to « compensate the loss », of flows that the ERESS Model brought from Libya, and hence be able to drain more inputs from the Atlas on the west. But comparison with GEOMATH is limited to this, the latter considering all Tunisian-Libyan Djeffara as an CI outlet.

The other important modification in hydraulic parameters (with regard to Tripoli) concerns leakage coefficients for which a “window” has been constructed under Chott Djerid between, on the one hand the “Grès Supérieurs” (upper sandstone) layer

[24] This impossibility has already been established by FRANLAB (1972). In fact, as the Melaab mole was represented, ERESS first model could not transfer a flow exceeding **2 m3/s by E.T**.

and the Turonian, and on the other the Turonian and the Complexe terminal on the other.

Before proceeding in terms of calibration, it was decided to test the model predictive capacity by means of a provisional calculation maintaining the 2000 abstractions constant. The first results clearly indicate that the CT piezometric level are “maintained” by the Chotts, which remain connected to the aquifer even when dewatered, due to adopted conditions of imposed potentials in the chotts, and consequently contribute to the “re-supply” of the aquifer as soon as the piezometric level drops below the Chott level.

This phenomenon is particularly visible under Chott Djerid, where a not-much blown back wide circular sector could be observed, due to, in a first analysis, whether to:

- Recharge flows of the Chott aquifer,
- An excess leakage generated by the Turonian, encouraged by the “windows” of Chott Djerid,
- An over-estimation of the storage coefficients adopted in unconfined aquifers, or simply to the fact there are no exploitation deep wells within the Chott.

In order to be able to evaluate with full knowledge, the effects of previous parameters, it was decided to develop a new version of the model, where:

- The Chott cells will be automatically disconnected from the CT, as soon as the piezometric level of this aquifer drops below the level of the Chott,
- The leakage window of Chott Djerid (Grès Supérieurs. → Tur. → CT) disappears to be replaced by a more diffuse and spatially homogeneous leakage,
- The calibration of level records in a transient regime should authorize a substantial decrease of storage coefficients in « unconfined aquifers », namely in the Complexe terminal sectors where previous values were considered excessive, in very wide sectors without any measurement or test (Grand Erg Oriental).

Storage Coefficient in unconfined aquifers

This degree of additional freedom that needs to be adopted at this phase of the calibration is justified by the absence of reference values in these regions. It seems useful at this level to recall the criteria adopted by the ERESS Model for the allocation of storage coefficient values in free surface sectors:
« the nature of the aquifer reservoir required the distinction between two cases:
Rocks with intergranular porosity … for which an average value of 150. 10^{-3} has been adopted as a storage coefficient;
Fissured rocks … for which a lower value has been adopted, ranging between 100. et 150. 10^{-3} » [ERESS, plaque 3: CT aquifer,p37]

II.5- Model of September 10th, 2001

Compared to the previous one, this model is characterized by:

- The removal of the leakage window of Chott Djerid, replaced by a diffuse leakage;
- A substantial reduction of the transmissivities of Grès Supérieurs formations;
- The modification of the structure of Grès Supérieurs whose “piezometric cavity” is no longer represented as resulting from a percolation towards the Djerid, but rather by a drainage of Chott Fedjej in drain conditions ;
- A modification of conditions to boundaries imposed on Algerian-Tunisian Chotts: from a mesh layer with imposed potentials presented in August 20 model, the Chotts move to a

flow drain condition – nill boundary, which prevents them from any re-supplying by the Chotts;

- A readjustment of the field of IC tranmissivities required by all previous modifications: generally speaking, the current transmissivities are globally 20 to 25% higher that those of August 20 Model;
- A re-evaluation of the calculated flow of the Tunisian outlet, which increases from 2.75m^3/s to 3.3m^3/s, and hence considerably adopted traditional estimates ;
- Finally, a substantial reduction, in the Complexe terminal, of storage coefficients in unconfined surface areas [the storage coefficient in an unconfined aquifer plays a major role in the long term behaviour of the aquifer system: unfortunately, in the CT, we have: - neither measured values of the storage coefficient in unconfined aquifers, nor control points in sufficient and reliable numbers which would enable, as is the case for CI, to rectify S values through calibration, based on drawdown records].

II.6- Model of September 23rd, 2001, Return on Transmissivities structure

The **September 23 Model** was developed by the model evaluation committee, by replacing the model CI transmissivities of September 10 Model by that of Tripoli Model (equal to those of the ERESS). The calibration results have the same quality as September 10 Model (**we shall in particular note the excellent agreement between the calculated and measured draw-downs of Chott Fedjej**). As expected, **the flow in a steady state of the Tunisian CI outlet is only 1.9m²/s.** This model corresponds to the choice to allocate more confidence to estimates of transmissivities based on field data, than on flow of the Tunisian natural outlet, having formed the subject of various studies but remained unobvious.

II.7- Model of September 30th, 2001

The **September 30, 2001 model** derives from the September 23 model by doubling CI transmissivities in the region of Biskra, El Oued and Nefzaoua. **Results generated by the calibration of this model have an excellent quality and the permanent flow of the Tunisian outlet is 3,1 m^3/s, which is very close to this flow previous estimations.**

The September 30 model is therefore a synthesis, a compromise between the two options described above. In reality, the geological information available in the triangle area of Biskra, El Oued, Nefzaoua is very limited, and decision to double transmissivities used by ERESS Model does not contradict experimental data.

The September 30 Model can then be considered as an acceptable final state for the calibration of the NWSAS Model. This model is the best to respond to all criteria and constraints imposed for calibration, and seems the most suitable for the execution of provisional simulations aiming at the development of water resources in the NWSAS.

II.8- Revision of the Model in the Eastern Basin

Consideration of new data acquired in Libya, during the first semester of 2002, required the updating of the model. These works became necessary further to the rectification of eastern and north eastern boundaries of the model layout, so as the catchments fields of Soknah and Waddan in the SE, collecting the Oligocene formations, cold be integrated in the Complexe terminal, that the deep collection point in Waddan could be related to CI, and that the fields of Khoms-Zliten could also be represented, which was not the case before, the construction of the model having been realized well before the updating of abstraction data in Libya. On the other hand, the evolution of abstraction records has been reviewed and corrected. The model has been redesigned to integrate all new information. This has certainly required a considerable work load: reconfiguration of the boundaries and some conditions at boundary location, re-calibration in permanent than transient regimes. So that **the last version of the Model could be the one to be used in future exploitation simulations of water resources in the NWSAS.**

III- PREPARATION OF DATA REQUIRED FOR CALIBRATION

III.1- Data concerning abstraction and their Evolution

The abstraction operations, their spatial distribution and evolution throughout time constitute, with supply, the "**source term**" of the mathematical model, term which is not subject, as is the case for transmissivities, of a tentative calibration, and which should not be consequently uncertain or discontinuous, otherwise we would not know what the yielded model would mean. This rule is truly very often infringed concerning recharge flows; this is an additional reason to be as careful and as meticulous as possible when preparing data concerning abstraction.

Very long months were necessary for the project team and for the national teams to be able to design, verify, then validate abstraction records, for every single water point, and this over an as long period of time as possible, that is fifty years from 1950 to 2000.

Maps shown in fig. 16 and 17 represent the geographic distribution of abstraction operations conducted during the year 2000 for each of CT and CI aquifers. As for fig. 16 and 17, they show the historical evolution of total abstractions in each of the aquifers.

This information represents a considerable quantity of data, about **7**x**10**^{4} of annual flow values [nearly 1200 « activated » deep wells in the CI, 2000 in the CT, for an operation period of 20 years in average]. It is obviously not possible to introduce these values manually in the model, especially that they have already been processed and stored in the database. This is why the NWSAS project team had to develop a specific interface database/model compatible with the Processing MODFLOW .

Table 12: Number of deep wells or groups of deep well having been exploited Throughout or partly during 1950-2000 period

Algeria	CI	928
	CT	1326
Tunisia	CI	126
	CT	690
	SG	46
Libya	CI	29
	CT	29
Total		**# 3200**

Due to the continuous arrival of new data and information regularly corrected, it was not possible for the modal to rigorously integrate the same information as the last versions of the data base. On the other hand, the abstraction at certain water points not having coordinates, or coordinates locating them outside the model (water points whose notoriety did not allow the project team to replace them using their own means) were not calculated in the model abstractions. These points are surveyed in the following table:

Table 13: Deep wells exploited in 2000, outside the model boundaries

Exploitation - 2000 _ Deep Wells beyond the boundaries of the Model

Continental Intercalaire

NOCLAS	NOM (Denomination)	P	X_LAMB	Y_LAMB	Q-m3/an
L00700099	Ker 2	A			1324512
N00300032	BOUDA 4	A			699840
N00300033	BOUDA 3	A			209952
N00300034	EL MANSOUR	A			524880
X00100057	bbm 3	A	314962.94	-1033163.57	147168
X00100058	bbm 4	A	312033.96	-1028938.18	378432
X00100060	bbm 6	A	346912.98	-1075752.08	105120
X00100063	bendrou	A			1419120
X00100067	emp 13	A			388800
X00100092	pk 200	A			77760
X00100286	bordj el assa	A			1198368
X00100479	tafzioune	A			1261440
X03000023	Tinfouyé I	A			78840
X03000024	Tinfouyé II	A			78840
X03000026	B.O.D F 5 prison	A			473040
X03000028	B.O.D F 7 tab tab 2	A			946080
X03000033	Tabankort Tab 1	A			1892160
X03000034	Tab 2 (Maouar)	A			1576800
X03000035	RNS A.SKHOUNA	A			2522880
X03000036	TFT 603 ENTP	A			126144
X03000042	Z.S.M A. TIARA	A			630720
20454005	Oued Ennakhla	T	1261209	225556	29664
P00400130	REGGANE IND 1	A	275363	-502840	482112
P00400132	TAARABET	A	244818	-498515	414720
P00400133	REGGANE III	A	230000	-500812	165888
TOTAL-CI					**17153280**

Complexe Terminal

NOCLAS	NOM (Denomination)	P	X_LAMB	Y_LAMB	Q-m3/an
J01100118	Base 24/2 HTT	A			567648
X04000033	DJEDIDA (D13 F..)	A			814680
X04000085	AIN BOUZOUID D4 F84	A			946080
X04000239	RNS ALCIM	A			261749
X04000248	RNS ENTP 1	A			65437
X04000249	RNS ENTP 2	A			130874
X04000252	RNS GTP	A			261749
X04000655	F14 La Douane	A			1198368
I01100469	Ain Chemora D34 F107	A	808624	504906	412859
19924005	Dar El Gaied 1 bis	T	1119330	362837	1185624
19941005	Dar Kouskoussi 1 bis	T	1110046	364246	554364
20750005	CRDA Kebili	T	1110105	363300	3024
Total-CT					**6402456**

These reporting errors reflect a discrepancy in the flow amounting to 0.9 m^3/s for the year 2000, whose major part is due to points with no coordinates; this represents an error of 1.1 %.

Table 14: Discrepancies between the model and the database

Flows 2000 Model vs BD	MODEL	DB	Difference
CI-Alg	21.2	21.8	0.6
CT-Alg	20.9	21.2	0.3
CI-Lib	3.4	3.4	0.0
CT-Lib	7.4	7.4	0.0
CI-Tun	2.2	2.2	0.0
CT-Tun	14.4	14.4	0.0
GS	0.5	0.5	0.0
TOTAL	70.0	70.9	**0.9**

III.2- Data concerning piezometric level and their evolution

The hydraulic load (piezometric level) constitutes the State Variable of a modelled system, that the model aims at restoring, to the best of its performance, by the end of the calibration operation. A good knowledge of the size, uncertainties related to its acquisition, its spatial distribution and its evolution over time is therefore necessary for the execution of the model and the quality of its calibration.

The oldest known **loads spatial distributions** (dated) are the ones published (after Bel & Demargne) by ERESS in Algeria and Tunisia. They date back to 1950 for the Complexe terminal and 1956 for the Continental Intercalaire.

In Libya, there is no old information as efficient as ERESS data. In addition, data here are more fragmentary. Therefore, in order to design an “initial” piezometric map covering the whole Libyan territory included in the NWSAS; then be able to “connect” it to ERESS data, it was necessary to reconstitute the fragments of the puzzle by digging into a number of documents, the most important of which are: the synthesis made by P.PALLAS (1980), GEFLI study (1978), SRIVASTAVA report (1981), IDROTECNECO study (1982), GEOMATH Model (1995) and BRL study (1997).

The result of this « construction » of a pizometric map, commonly called « **Piezometry 1950** », though the precise concordance with this date is not guaranteed everywhere, is presented in fig.29 and 30, respectively for the Continental Intercalaire and the Complexe terminal, and fig.73 for the Upper Sandstone aquifer.

Critique and Validation of Piezometric[25] data

In Hydro-geology, the complexity of the problems is generally measured more by the degree of the systems geological complexity than by the multitude and diversity and heterogeneity of information to be handled. Therefore, there are no traditions, and hence no experimented tools, systematic analysis, critique or validation of hydro-geological data in large number.

The problem of the NWSAS has from this perspective been exemplary, and constitutes an exceptional case study in terms of quantity, diversity, and heterogeneity of the data acquired by the project. These data certainly have an unequal quality, and some could even present anomalies that made them useless as they were. It was therefore necessary, at the end of the content processing of NWSAS database, to look for methods and tools for the systematic analysis and validation of these data, through the design of a certain number of suitable tools.

The use of these tools has enabled the identification then correction of detected aberrant data. These tools namely concerned **Piezometric Data Field**: Inventory of “possible” records; detection and correction of aberrant values (as the Systematic Correction of Signs); the verification and plausibility of corrected piezometric heights.

Once all preliminary corrections – systematic character corrections – were made, it was not sure that the yielded values of the piezometric height could still be corrected and used. Therefore, it was necessary to check their plausibility by means of filtration procedures and specific and precise criteria. For this reason, they were scrutinized through the following four processes:

- Report on the map and different figures according to the model ;
- Layout of values,
- Coherence of declared altitude with regard to the one drawn from the field Digital Model ;
- Coherence with the global piezometric map.

As for the knowledge of the **temporal evolution of piezometric height**, from 1950 to the present, it is very unequally distributed over time. If we calculate the piezometric series recorded so far in NWSAS database, we will find several hundred series, but with a very unequal and sometimes poor quality (see box). To simplify the problem, and consider that this large number of data, though unequal, could be valued to ensure a better adjustment of the model, they were grouped according to their homogeneous geographic sectors. Therefore, and through a visual comparison it became possible to conduct (with many

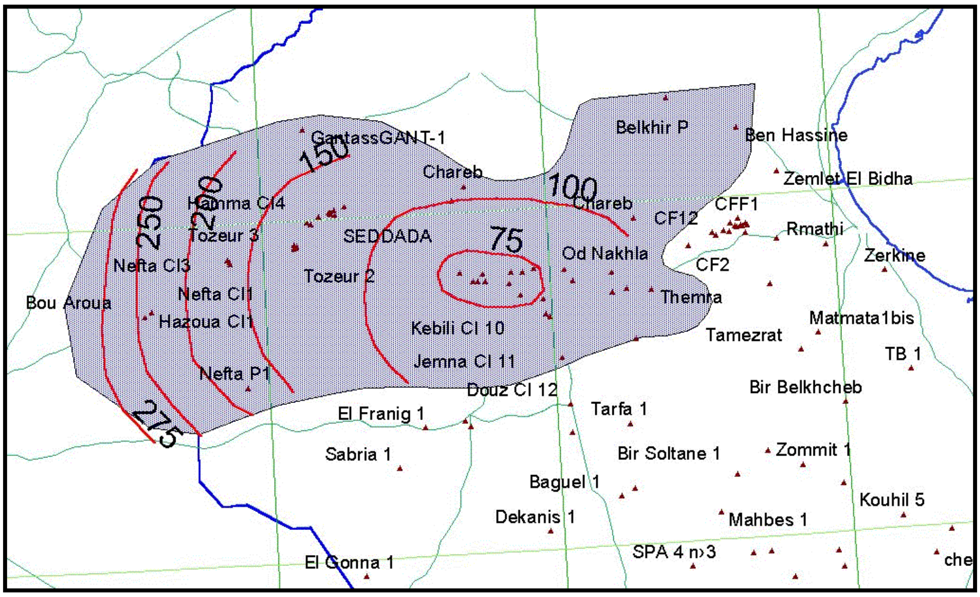
[25] Cf. SASS note: Data Analysis (2001).

precautions though) to fill in the gaps of the "**standard**" series of the group, which is the longest series and the one considered to be the most consistent with the regional history, by "**borrowing**" from other piezometers or deep wells of the same group. The result of this operation provides "**synthesis series**", generally one series per geographic group or sector.

Such a process can be used risk-free and with the most "**dense**" series, while this is not at all possible in "**scattered**" series including a very little number of measurements.

Values of piezometric Levels selected in these original or synthesis series, chosen based on their sectors, and that will be used for the calibration of the model in transient regime are presented in the NWSAS database; nonetheless, they are reproduced here in the Annex.

Fig. 73: Reference Initial Piezometry in the Upper Sandstone



IV- MODEL CALIBRATION IN STEADY STATE

IV.1- Definition of a Reference State

The State Reference for the calibration of the model must reflect a quasi-steady state of the system. Considering the large lateral extension of modelled reservoir, and the important distance existing between the traditional exploitation centres of the Lower Sahara and the basin hydraulic boundaries, the represented aquifers must behave like practically infinite catching aquifers: consequently, it is theoretically difficult to be able to observe permanent behaviours beyond some two dozen kilometres around catching fields.

In a configuration like this, the choice is very limited, as there is no piezometric situation representing the whole system before 1950, and that the deep wells of Wadi Rhir and the Djerid used to draw off then important quantities from the Complexe terminal Aquifer, amounting to 7 **m3/s**. This is then the period, **the year 1950 assimilated to a steady state that will be used as a reference for the calibration of the model in a steady state.**

This choice is consolidated by the possibility of laying out a piezometric map, if not “observed” **everywhere,** at least “reconstituted**” for the two aquifers of the CT and the CI over all the domain (see. fig. 29 et fig. 30).**

IV.2- Definition of criteria of calibration in a Steady state

The criteria and objectives of the calibration are to reconstitute as faithfully as possible the system state variables, respectively made up of:

- The global piezometric maps developed for the CI and the CT, representing a quasi-balanced regime dating back to nearly 1950.
- The localized piezometric values recorded or thought to be collected in the framework of studies conducted in advance (see Table, in the Annex)
- The flow of natural re-emergences recorded in that period. They are the springs of the Djerid and Nefzaoua in Tunisia CT, the springs of Ain Tawergha and Wadi Kaam in Libya for the CT aquifer (the first partly supplied by a deep leakage coming from the CI), and the Algerian foggaras for the CI.

IV.3- Main modifications during calibration

The modifications summarized below, with regard to adopted initial values, relate to the model hydrodynamic parameters:

- The horizontal transmissivities were modelled in the bordering region between Libya and Algeria-Tunisia to reduce the abrupt contrast presented by the map of transmissivities respectively issued by ERESS and GEOMATH models.
- The reference piezometric map of the CT aquifer shows a low hydraulic gradient at the level of the South Western sector (certainly one of the least known) that the model could not restore. Transmissivity here had to be set at 0.3 m^2/s.
- The Cenomanian vertical permeability as well as that of the Lagoon Senonian were increased in the Libyan sector, namely at the level of the Hun valley, where semi permeable layers are fractured and become much less impervious.
- The vertical permeability of the Cenomanian and the lagoon Senonian was considerably reduced in the Algerian-Tunisian part, except at the level of El Biod (Southern Algeria) where the CI waters pour into the Turonian through Amguid faults.

- The horizontal transmissivity of the Turonian aquifer was decreased in Algeria-Tunisia because the CT drainage through this layer remained important.
- An impervious fault (possible on PM5) was introduced at the level of the Hun Graben in order to reproduce isopiezic curves in this sector, namely in the CI. The piezometric aspect has been modified but with no relation to the observed piezometric map. The fault has later been disregarded.
- The vertical permeability of the Carboniferous has been increased in areas with little thickness, to favour the vertical exchange between the COD and the CI? And also between the COD and the Turonian in the (Jufrah) areas where the IC is absent.

IV.4- Evaluation of the calibration in a Steady state

IV.4.1- Reconstitution of global Piezometric maps of the CI and the CT

In order to evaluate the Model which best reproduces the reference regional Piezometric state, the following was conducted:

- First the « discretisation » (transformation of curves into points) of the drawn isopiezometric curves fig.29 & 30,
- Then the interpolation of the field of values obtained overall the aquifer domain

Finally, on the same grid, the interpolation on the same domain of values calculated at the cell center by the model.

The distribution of differences at the piezometric level [Calculated by the model - Recorded] constitutes a good indicator of the « regionalized fidelity » of the model with regard to the field-reality. (see fig. 74 for the CI and fig.75 for the CT). The yielded results are quite positive: 70% of the aquifer area both for the CI and the CT show gaps smaller than 25 km² there are certainly still "red" areas where the gap exceeds 75 m, but they are usually peripheral sectors containing few observation points if none, where the interpolation result is uncertain and where it would have been useless to persist on the calibration: the Atlas piedmonts and the "Grand Erg Occidental" constitutes a representative example.

Fig. 74: Calibration gaps in the CI steady state

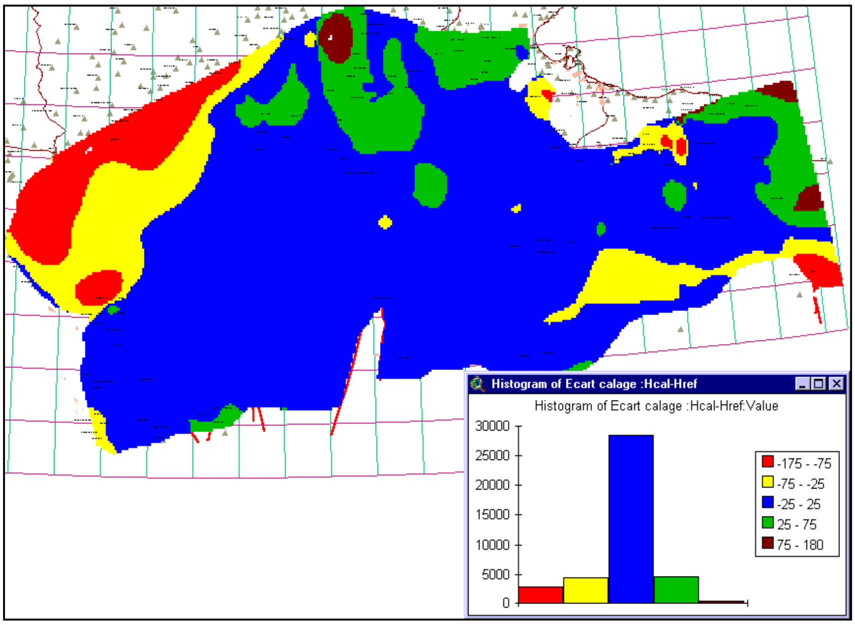
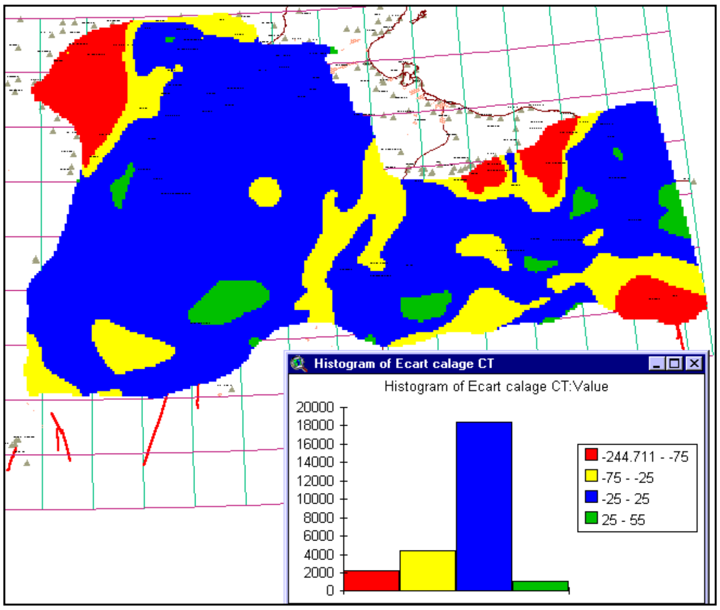


Fig. 75: Calibration gaps in the CT steady state



The superposition of the calculated and recorded piezometric curves also gives a good idea about the model capacity to "**fit**" forms of drawn curves. In fact, though the position of these drawn curves is not rigorous from a mathematical perspectives (they are generally drawn based on what is "**judged**" through a visual interpolation) their shape reflects the hydro-geologist's experience and know-how. Consequently, these curves can be considered as the priority reference criteria: they reflect **the *aptitude of the model to match the hydro-geologist's point of view.*** (See fig.78 and 80) .

IV.4.2- Reconstitution of piezometric height at control points

IV.4.2.1- Spatial distribution of Control Points

The piezometric heights of CI aquifer cover almost all the modelled domain, with however, a less important density at the level of the Grand Erg Occidental, the Tademait Plateau, the sector comprised between Hassi Messaoud and the Algerian-Tunisian border a well as in the south of Hamada El Hamra basin. At the level of CT basin, the piezometric observation points are concentrated in the exploitation areas: Oued R'hir valley, the sector included between Hassi Messaoud and El Borma, the Djerid, Nefzaoua, Ghadames, Hun and Sirt. Elsewhere, the absence of piezometric data is total. As for the Turonian aquifer, piezometric observations can be made in Libya. In Algeria, one single point in the central Sahara, was observed at the level of the petroleum deep well of Hassi Messaoud, where water contains more than 200g of dissolved salt content per litre as well as a high temperature (Franlab, 1978). The piezometric level has been corrected through the conversion of salty water column height into a soft water height – equivalent according to the pressure balance height:

At a point of z level, p_1 and p_2 pressures exercised respectively by an h_s salty water **height** and an h_d soft water column are written as follows:

$$p_1 = \rho_s \times g \times h_s$$

$$p_2 = \rho_d \times g \times h_d$$

thus by balancing the pressures:

$$h_d = \frac{\rho_s}{\rho_d} h_s$$

Measurements of flow, salinity and pressure at a level of **–700** m with regard to the average sea levels were conducted in CI deep wells made by SONATRACH in Hassi Messaoud. The sampled water shows a salinity rate of **210 g/**l, a temperature of 70° C and a density of **1.137** (Franlab, 1978). The measured hydraulic load being **80 m**, the corresponding height of the water column in the wells is then 780 m. If we apply the relation stated above, the height of the equivalent soft water column would be of 887 m, or a corrected hydraulic load of **187 m**.

Fig. 76: Correction of the density effect on the piezometric height

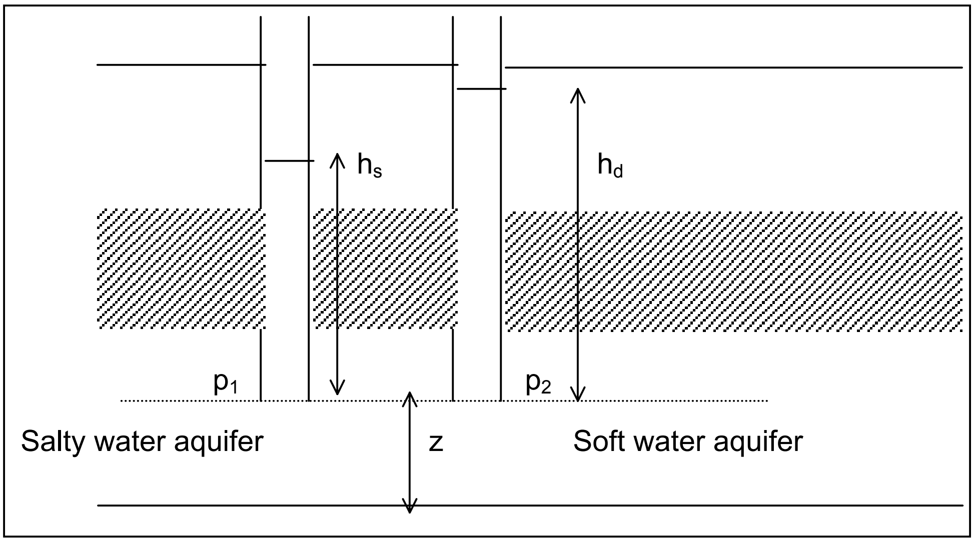


Fig. 77: CI 1950 - Calculated Piezometric Map

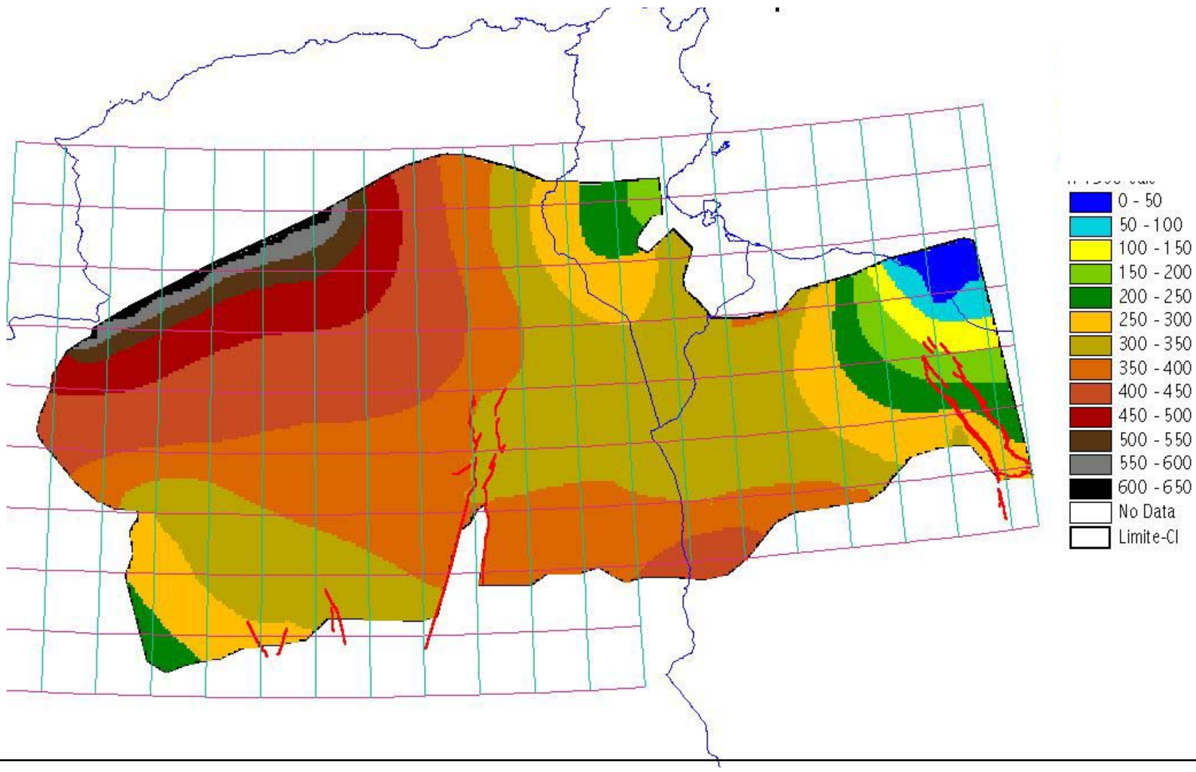


Fig. 78: CI – Steady state – Calculated Piezometric Heights (in blue) and traced reference curves (in mauve)

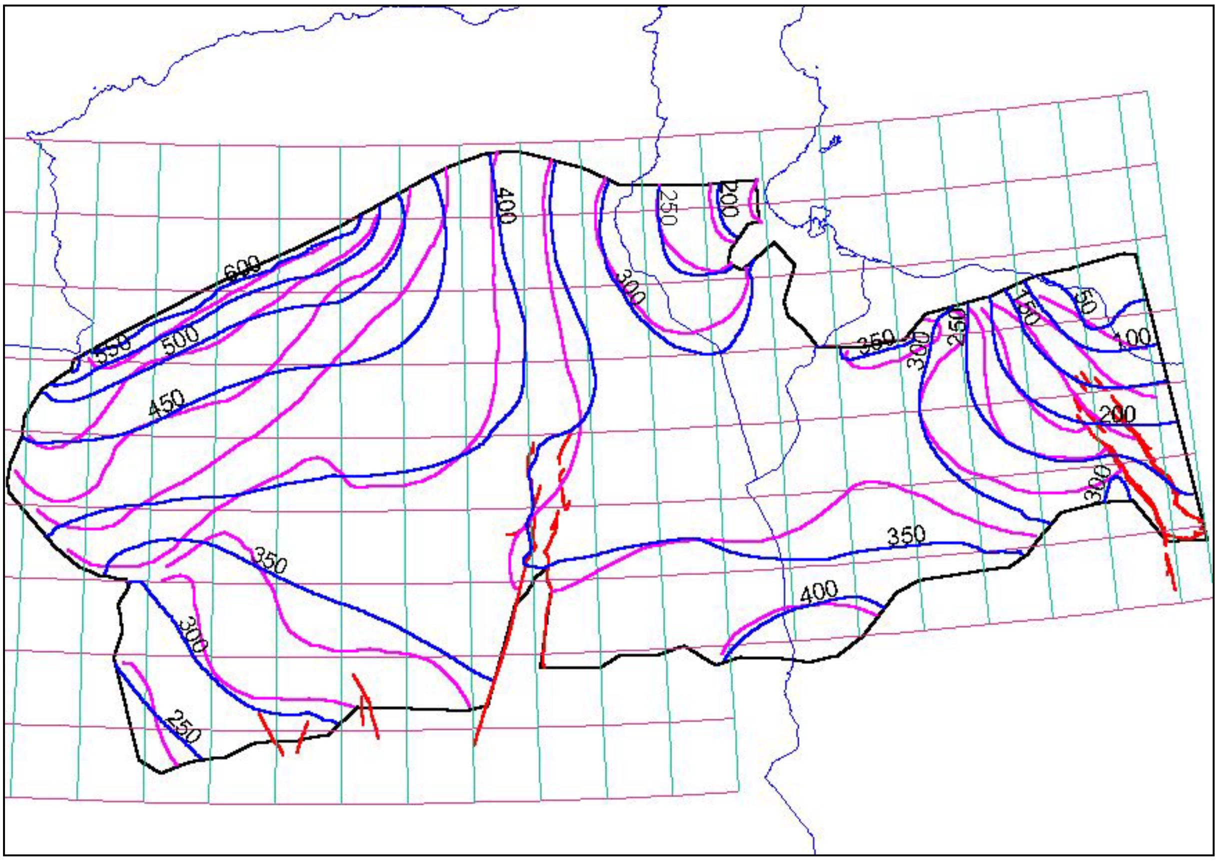


Fig. 79: CT - Calculated 1950 Piezometry

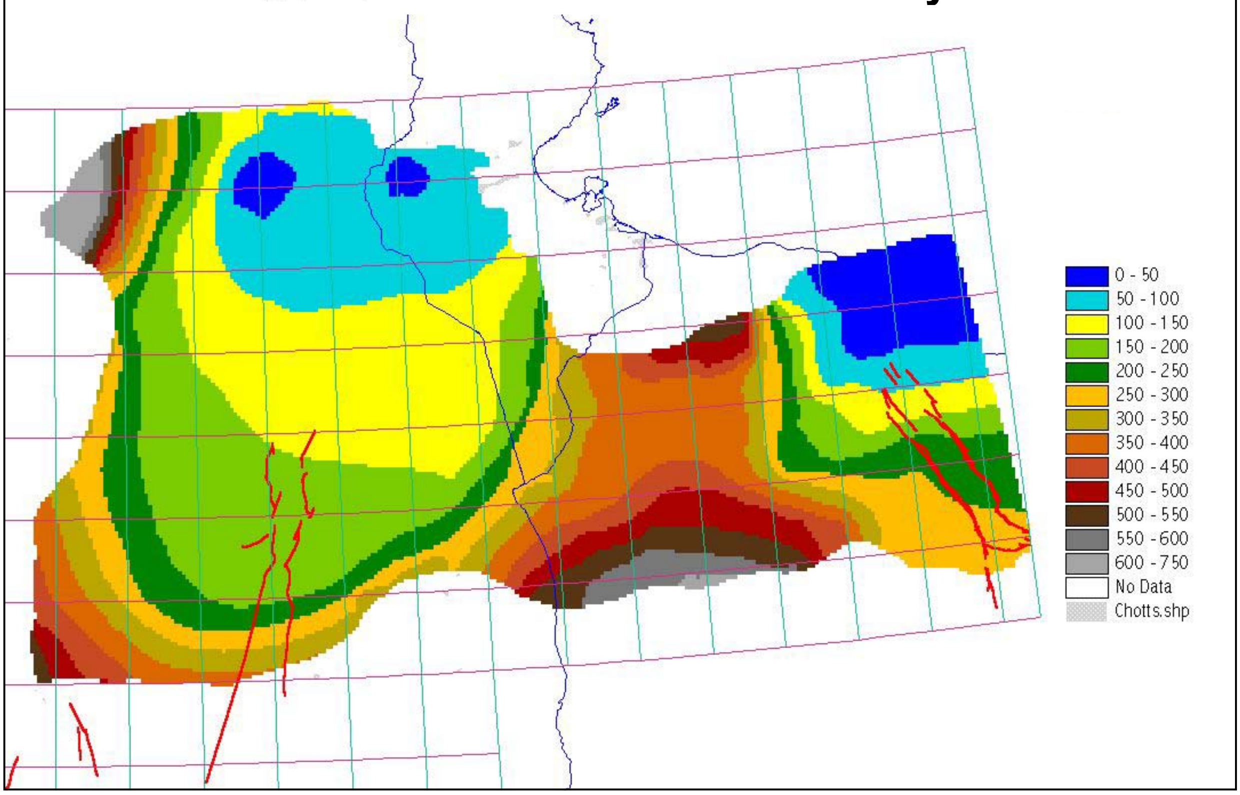
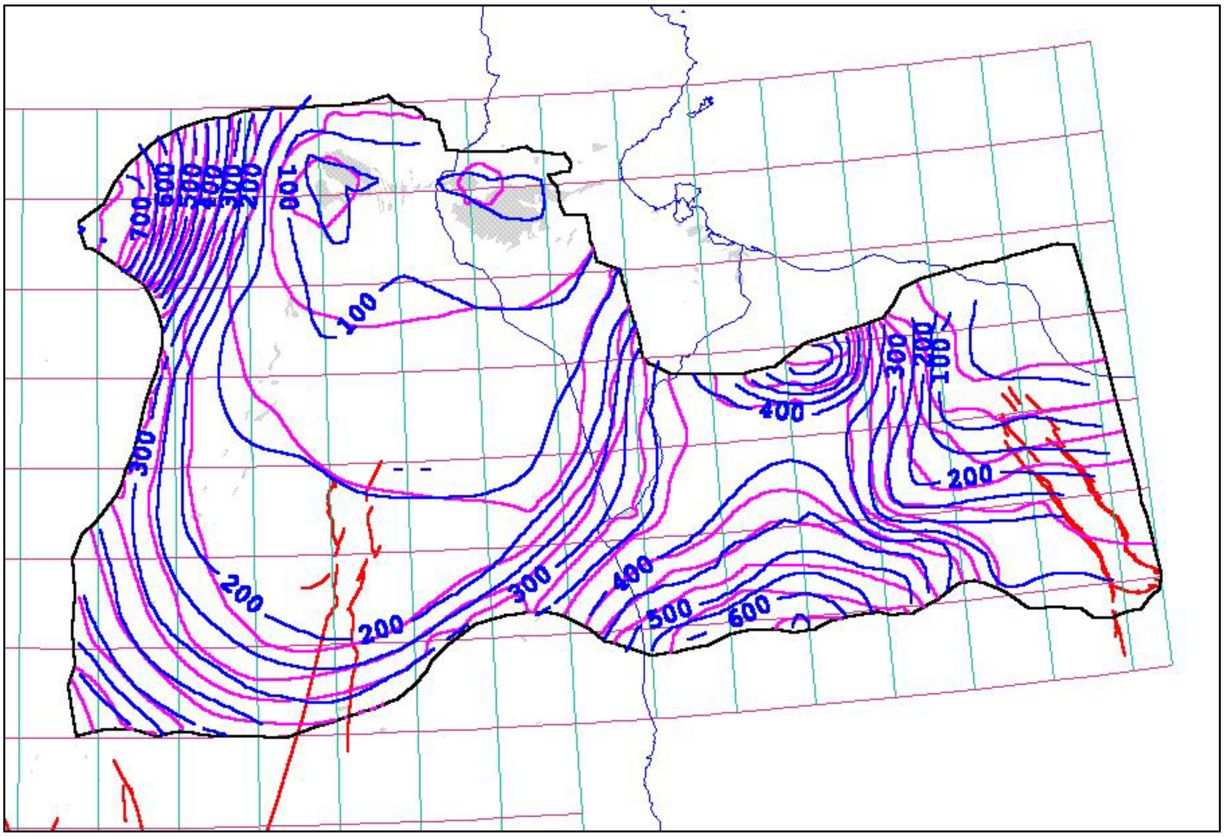


Fig. 80: CT – Steady state – Calculated piezometric heights (in mauve) and traced reference curves (in bleu)



IV.4.2.2. Spatial-temporal dispersion of measurements

In the Algerian-Tunisian domain, the piezometric data are distributed over the 1950-1970 period. They correspond to the years 70-73 in the Libyan sector, while the model is supposed to restore a state observed in 1950. Such an approximation can be accepted for the CI as this aquifer had not been very prompted by abstraction operations: this period can therefore be considered as representative of the aquifer stationary state. As for the CT aquifer, the exploitation by means of deep wells was relatively high in 1950 (# 7.m^3/s), and concentrated in the region of the Algerian-Tunisian Chotts. Nonetheless, due to the unavailability of data prior to 1950, we can consider that the archived data do not reflect any significant regional piezometric cut.

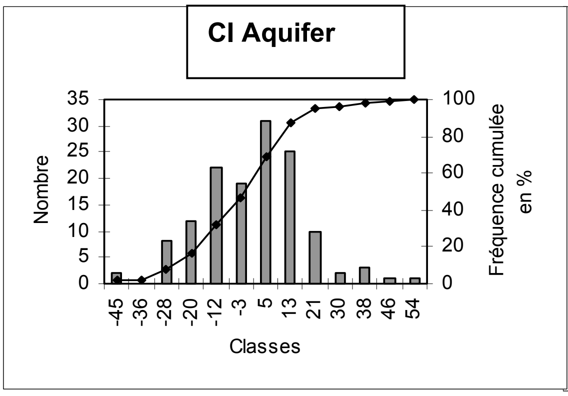
IV.4.2.3. Analysis of calibration gaps in punctual localized levels

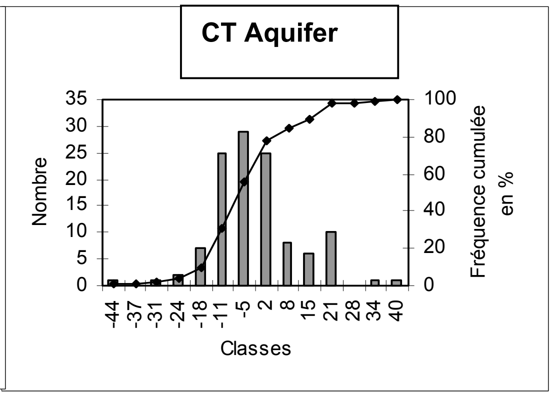
The collating of piezometric levels calculated on the Model with recorded values shows, respectively for the CT, CI and Turonian aquifers, average gaps of 0.4. m, 4.8. m and 9.5. m (Table 15). Points where the gap is below 10 m in absolute values represent a set of 70 % for the CT and 50% for the CI. The concordance is less positive for the Turonian where the gap exceeds 10m in 70% of the points.

Table 15 – Calibration discrepancies in a Steady state

Aquifer	Number of points	Average (m)
CI	**136**	**4.8**
CT	**118**	**0.4**
Turonian	**23**	**9.5**

Distribution Histograms of Calibration Gap in a Steady state





IV.4.3- Reconstitution of the Flows of Springs and Foggaras

Table 16- Emergencies Flows rates observed and calculated by the Model in 1950

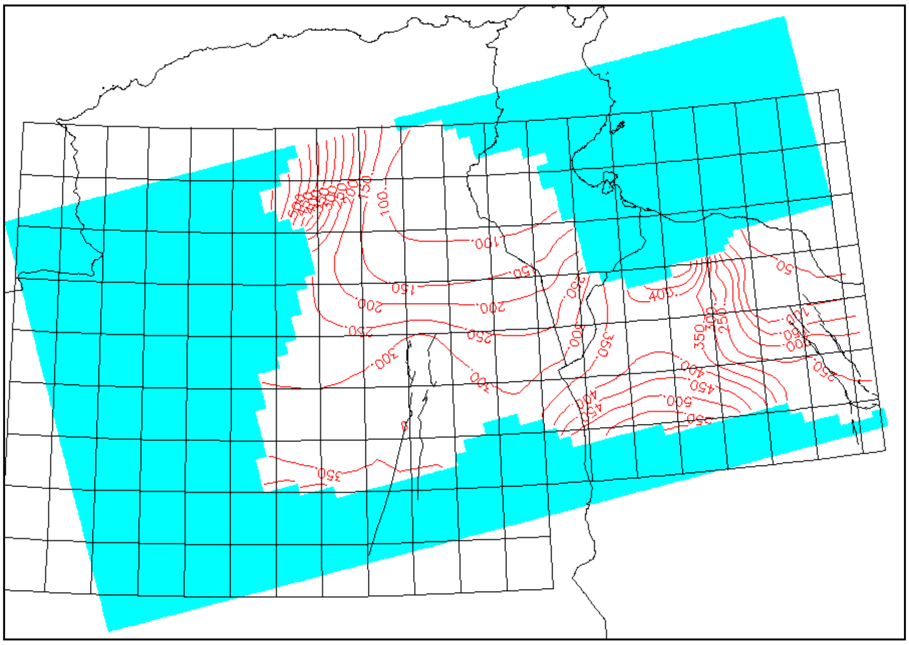
Name	Recorded flow (l/s)	Calculated Flow (l/s)
Ain Tawergha	**2130**	**1995**
Wadi Kaam	**360**	**269**
Oued Tozeur	**697**	**690**
Corbeille de Nefta	**543**	**569**
El Hamma– El Oudiane	**310**	**325**
Nefzaoua	**468**	**476**
Foggaras	**3665**	**3598**

IV.5- Calibration Results in a Steady state

IV.5.1- General aspect of Flows calculated by the Model

Fig 77 and 79 show maps calculated for the CI and the CT. Fig 81 shows a first representation test of the flows in the Turonian aquifer (PM5 exits). Due to the high salinities in some sectors of the Turonian (across the field of Hassi Messaoud in particular), all hydraulic loads here are expressed in soft-water equivalent-loads. By studying this map, we can note that the position of isopiezes seems acceptable in Libya. In the Algerian Sahara, and namely in Hassi Messaoud, the single reference value available in the region: 187m (soft water equivalent) against 189.8m calculated by the model, the Turonian acquires an intermediate piezometric configuration between the CI and the CT.

fig.81: 1950 Piezometry of the Turonian, calculated by the Model



IV.5.2- Model Hydro-dynamic parameters

Fig. 82 and 83 show the distribution of transmissivities after Calibration in the CI and the CT

Fig. 82: CI - Transmissivities (x 10^{-3} m^2/s)

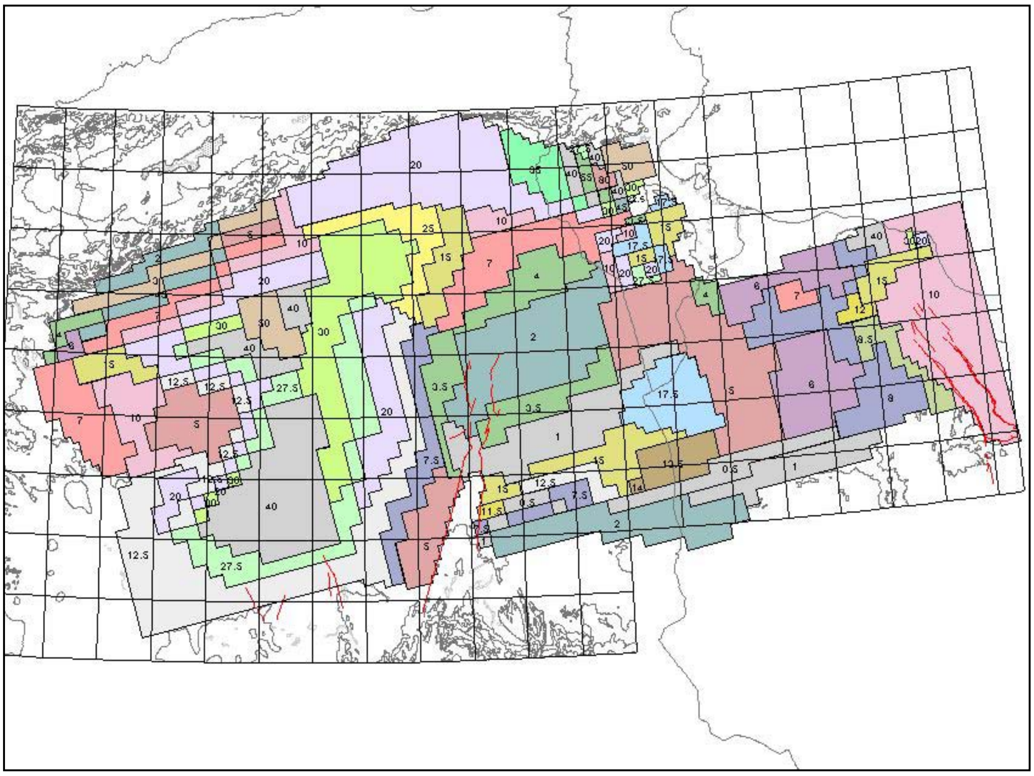


Fig. 83 : CT - Transmissivities (x 10^{-3} m^2/s)

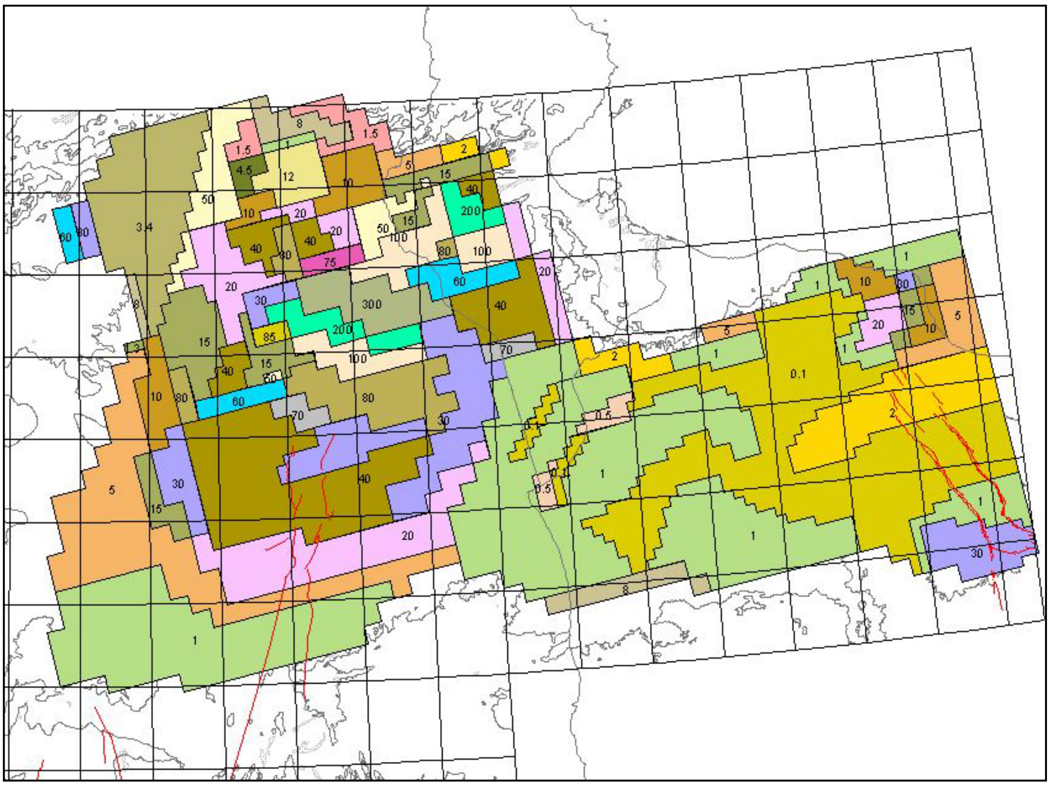


Fig 84 and 85 show the distribution of Leakage coefficients (Kv/thickness of the semi-permeable) through respectively: The Lagoon Senonian (CT/Turonian) and the Cenomanian (Turonian/CI).

Fig. 84: Leakage coefficients of the Lagoon Senonian [s^{-1}]

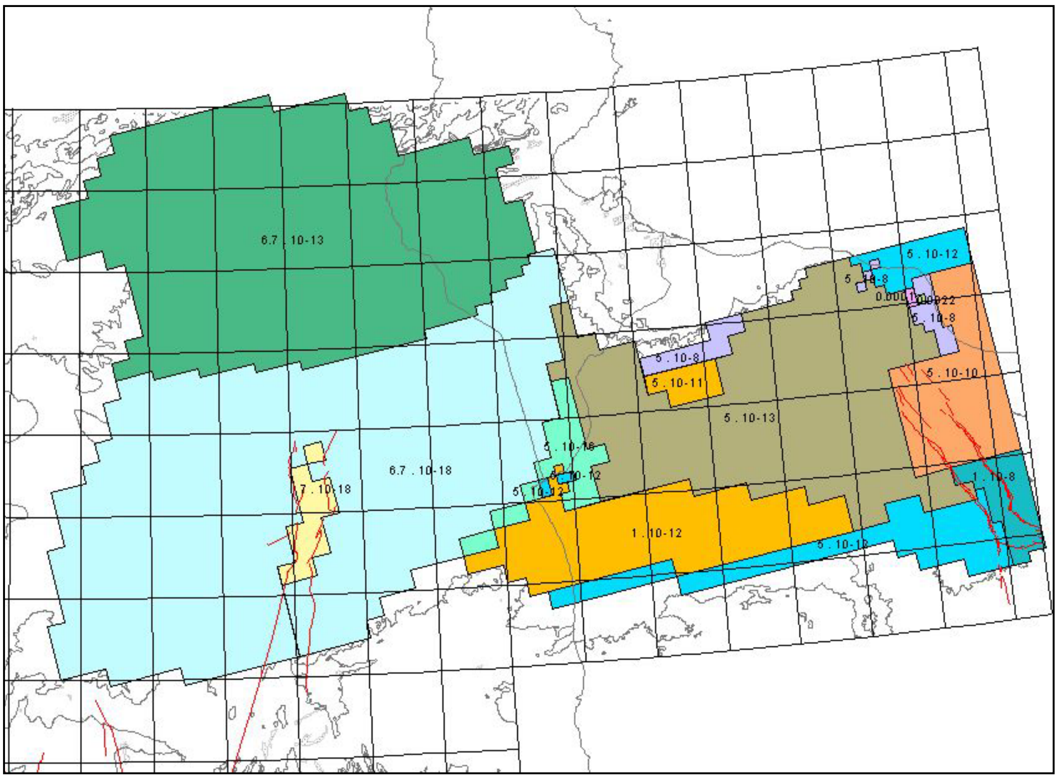
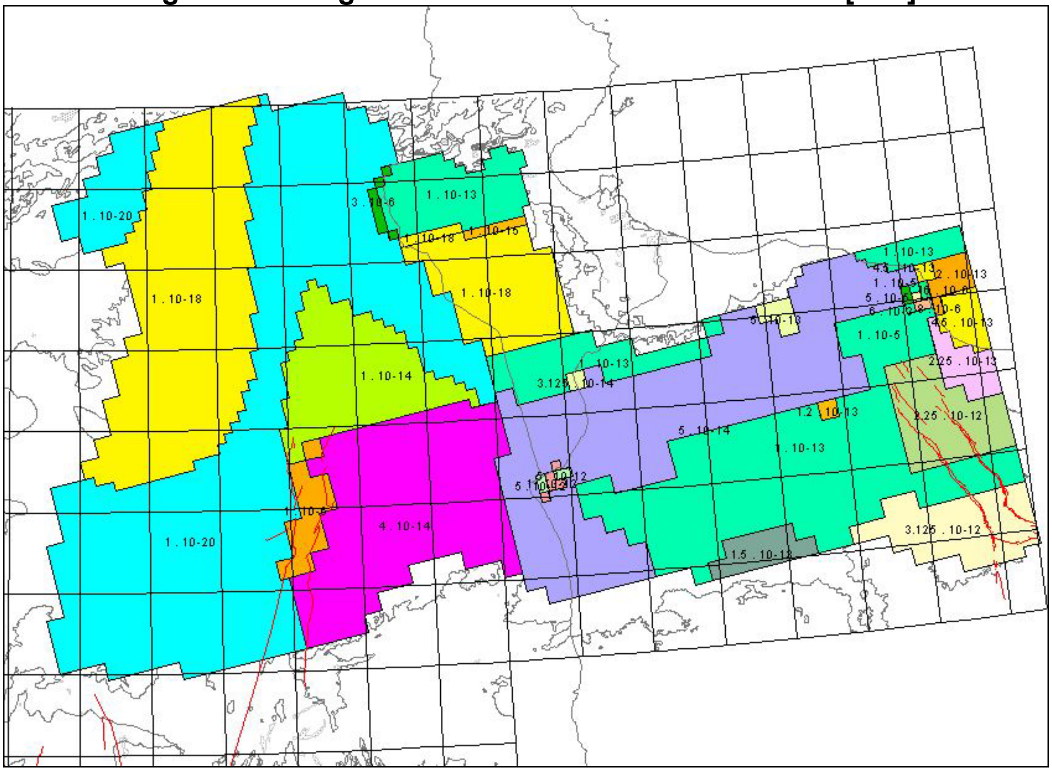


Fig. 85 : Leakage Coefficients of the Cenomanian [s^{-1}]



IV.5.3- Water balance of the Saharan Multi-Aquifer

Budget Terms: supplies through infiltration, natural outlets, vertical exchange through leakage between different aquifer layers, pumping, are presented in Table 17. We can note that the flows calculated at diffuse natural outlets, whose values can be hardly measured (evaporation in the Chotts and Sebkhas, leaks due to faults, deep percolation) are as important as those calculated by all different previous models. The evaporation of CT waters in the Algerian-Tunisian chotts and sebkhas (8.7m^3/s) can be compared to the one calculated by ERESS model (9m^3/s). The flow of the Tunisian outlet, set as about 3.6m^3/s by the budget studies of the Tunisian Djeffara aquifer (Unesco, 1972 ; UNDP, 1985) has also been restored by the model. The supply through infiltration amounts respectively to 18m^3/s and 10. m^3/s for CT and CI aquifers. Its regional distribution clearly indicates that most supply into CI aquifer (Table 18) is generated by the Saharan Atlas.

Table 17 – NWSAS Budget calculated in 1950 (m^3/s)

	CT	CI	Upper sandstone	NWSAS
Inputs m^3/s				
Total Supply	**18.2**	**9.4**		**27.6**
Cambro-Ordovician Input		**2.0**		**2.0**
High Leakage	**-**	**0.5**		***[0.5]***
Low Leakage	**5.4**	**-**	**0.4**	***[5.8]***
Total	23.6	11.9	0.41	35.9
Outputs m^3/s				
Chotts & Sebkhas				
Tunisia	**5.95**	**-**	**0.26**	**6.2**
	CT	CI	Upper Sandstone	NWSAS
➢ **Algeria**	**2.7**	**0.2**		**2.9**
➢ **Libya**	**0.2**	**-**		**0.2**
Gulf of Syrta	**0.6**	**0.8**		**1.4**
Tunisian Outlet	**-**	**3.1**		**3.1**
Springs or Foggaras				
➢ **Tunisia**	**2.0**	**-**		**2.0**
➢ **Algeria**	**-**	**3.6**		**3.6**
➢ **Libya**	**2.3**	**-**		**2.3**
Pumping	**7.5**	**0.5**		**8.0**
High Leakage	**-**	**3.7**	**0.15**	***[3.85]***
Low Leakage	**2.4**	**0.0**		***[2.4]***
Total	23.6	11.9	0.41	35.9

*** the leakage represents flows internal to the system, flows with a nil total sum*

At the level of inputs into the CT aquifer, the relief contribution of the western border (the Saharan Atlas up to Tademais plateau) is considerable. Supplies coming from Dahar and Djebel Nafoussa represent more than 1/ 3 on CT total inputs.

Table 18 – Recharge of infiltration in a steady state

IC Aquifer	**Calculated flow (l/s)**
Sahara Atlas	7540
Dahar and Dj.Nafussa	1580
Tinrhert and Adrar B.Drich	290
Total	**9410**
CT Aquifer	**Calculated flow (l/s)**
Saharan Atlas	3775
Dahar and Dj.Nafussa	6705
Western Boundary	2450
South Western Boundary	980
Tademaït	2585
Southern Libya	1060
North of Algerian Chotts	305
North of Tunisian Chotts	150
Limestone.Eocenes contrib.	200
Total	**18200**

V- MODEL CALIBRATION IN A TRANSIENT STATE

V.1- Definition of Reference Time-series and Model Calibration Criteria

V.1.1- Initial Reference data and reference criteria for calibration and Time-series

The initial conditions corresponding to the piezometric status calculated in 1950, represent a steady state. Over all **supply boundaries**, the conditions of imposed potential arre transformed into conditions of imposed flow, equal to the one calculated over the model during the initial steady state.

As for the reference period to adopt for the calibration of the model in a transient state, there was an attempt in a first phase to conduct the calibration over the 1950-1981 period, then to validate the model over the remaining period 1982-2000. Unfortunately, this protocol soon appeared to be difficult to apply, due to the following reasons:

- **Flowing quantities:** at the end of the 70's, they represented hardly 1/3 of present flowing rates, and the highest acceleration of flows was recorded between 1980 and 1995, for the IC as well as for the CT (see. fig. 56). It would certainly have been prejudicial if the model had been set over this acceleration in particular.
- **Piezometric levels:** It is starting from the 80's that we observe the highest densification of level measures, namely in Tunisia and Libya. As for Algeria, it is precisely during the 90's that the most important Sahara inventories were conducted: with regard to the scarcity of level measures previously recorded, these inventories provided complementary data required for the constitution of piezometric series.

V.1.2- Structural Parameters Calibration initialization

The distribution maps of the storage coefficients initial values are determined as follows:

- Areas where the aquifer is free are determined on the basis of the IC and CT geological formations emergence maps, as well as by « subtraction » between the aquifer ceiling level and the piezometric surface level. This last calculation, conducted through automatic cartography, provides results shown in fig. 42 et 43. A porosity ranging between **8%** and **20%** is initially attributed to these areas, in coherence with distributions calculated by previous models (ERESS, GEOMATH, GEFLI).
- In areas where the aquifer is captive, values obtained by the models preceding the NWSAS have been taken as a reference:
  - **CT Aquifer**: initial storage coefficient equal to 10^{-3} in Libya, and an average of $2x10^{-3}$ elsewhere except in the northern region of Algerian Chotts where it equals 5x10.
  - **IC Aquifer:** it ranges between $4x10^{-4}$ in the northern region of Algerian Chotts and 10^{-3} in the southern sector of the Algerian-Tunisian domain. It equals 10^{-4} in Libya but in the sector of Ghadames where it has a value of 10^{-3}
  - **Turonian Aquifer:** a homogeneous value of $1.5x10^{-4}$ is adopted in the beginning for the whole domain.

V.1.3- Calibration Criteria Transient state

It is first the good restitution of the series of reference time series levels. Calculated draw-downs (level variations) and those observed in corresponding control points were compared. The calibration criteria also included the good restitution of series pertaining to flows measures at the level of outlets: Sources of the Djerid and Nefzaoua, Ain Tawargha and Kaam, foggaras flows.

V.2- Knowledge Rate of abstraction time-series

V.2.1- Exploitation of Drillings in Algeria, Tunisia and Libya

The NWSAS data base reports on foggaras individual histories (nearly 3200 exploited or having been exploited deep wells) histories that are obviously not reproduced in this report. Libya constitutes a singular example, as flowing was not conducted individually at the level of foggaras, but rather at groups of pumping operations. This sometimes results in a high concentration of pumping (and hence drawdowns) in some singular points, in spite of the scattering of groups in sub-groups which dimension does not exceed the model elementary cell.

V.2.2- Out Flows of Sources and Foggaras

Tab.19 presents the evolution, over the 1950-2000 period of flows from sources located in the Djerid and Nefzaoua in Tunisia, as well as that in Ain Tawargha in Libya.

As for evolutions of flows from foggaras, the last inventories conducted by the ANRH in 1998 show significant variations (reductions) of flows from foggaras. Indeed, all active foggaras today total up a surveyed flow of 2.7m^3/S, while the inventory conducted in 1960, cited by ERESS, stated a total flow of 3.6 m^3/s. This evolution represents a general reduction of 25%.

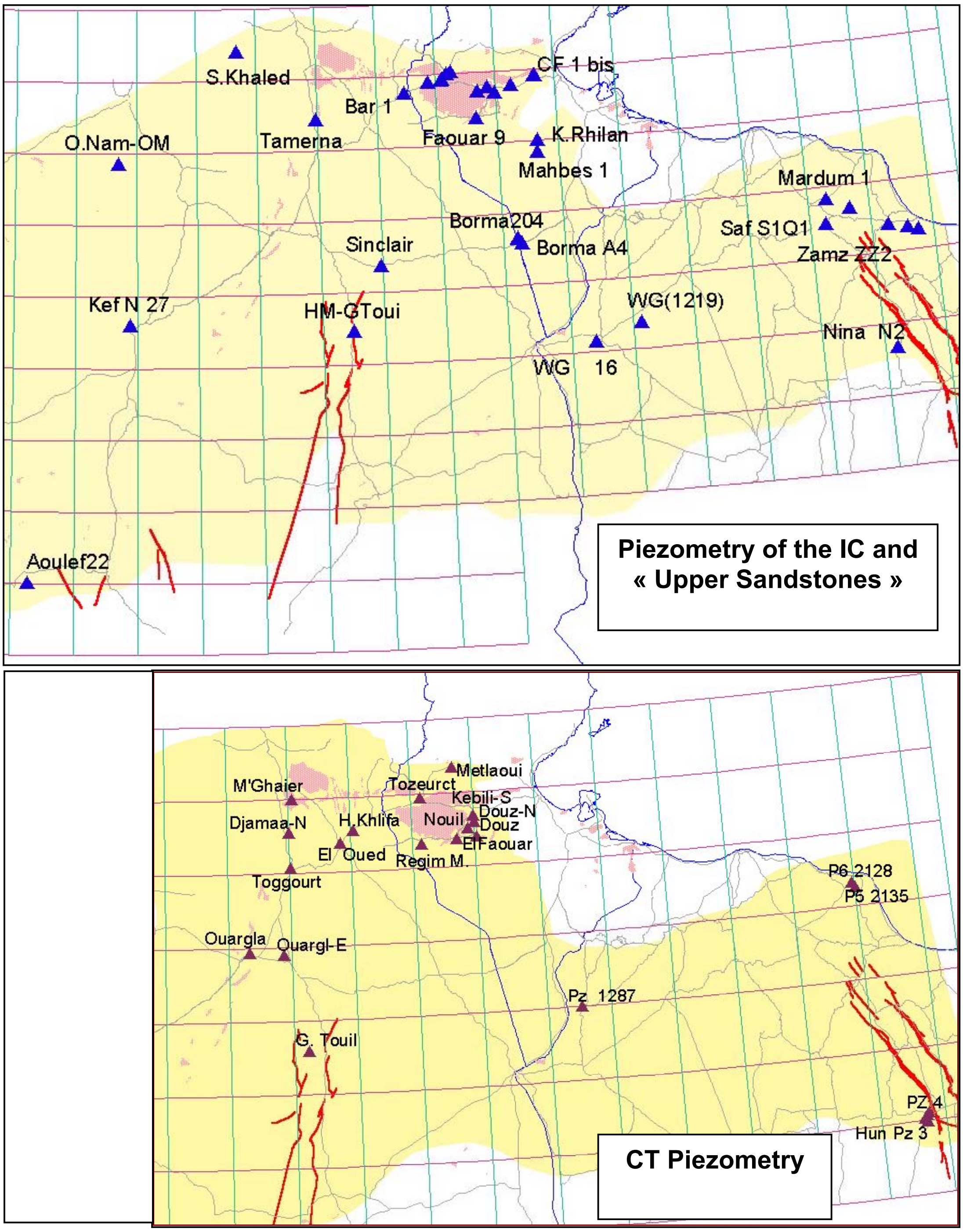
Table 19: Sources Flow-rates observed during the 1950-2000 period (l/s)

	1950	1960	1970	1980	1990	2000
Tunisia Sources	2.02	1.76	1.52	0.76	0.02	0.01
Ain Tawargha	2.13	2.06	2.00	1.87	1.83	1.77
Foggaras	3.6					2.7

V.3- Time-series of reference piezometric levels

The reconstituted piezometric levels, and namely those selected to evaluate the calibration of the model, are presented with details in the Annexe [Annex 8]. The part related to the calibration of the model in a transient state developed further refers thereto. The situation map of control points selected for the evaluation of the calibration is presented in fig. 86.

Fig. 86: Piezometries selected for the transient state calibration of the CI, « Upper sandstones » and CT



V.4. Calibration in Transient State

V.4.1- Adjustment of Model Parameters

The main modifications conducted during the calibration, namely concerning the passage from initial storage coefficients to those selected (see. fig. 87 and 88) are summarized below:

- Reduction of the storage coefficient of the CI's free aquifer from 0.2 to 0.05 in Adrar region (South West), reflecting a piezometric lowering from 1 to 4.5 m (Aoulef piezometry) an that the model could not restore.
- Adoption of a weak value for the IC's S ($4x10^{-4}$) at the foot of the Saharan Atlas to retsore the lowering observed at the level of the piezometry of Mehéguène. This low value (characteristic of the captive aquifer) is coherent with the burying of the Continental Intercalaire, under the Cenomanien.
- High reduction of S in the Djerid and Chott Fedjej to restore drawdowns observed in these regions.
- Adoption of S strong values for the CT and the Turonian in the Libyan sector, in the North East, mainly in the upstream sector of Tawergha. This modification proved to be necessary to obtain a flow calculated in Ain Tawergha in coherence with the value surveyed in 2000.
- Reduction of S of the CT free aquifer to range between 10^{-2} to $8x10^{-2}$, the initial values reaching 0.15 in Nefzaoua are high and resulted in the under-estimation of the aquifer drawdown.
- Increase of the CT's S in the Hun sector in a range of $2x10^{-3}$ to $7x10^{-3}$ to reduce the excessive calculated draw-down reaching one hundred meters in 2000 while the piezometers J3 and Pz 3, Pz4 and Pz5 reflect an average 30 m draw-down between 1974 and 1990. This modification has not been sufficient to improve piezometric results, the CT transmissivity has therefore been increased to $3x10^{-2}$ m^2/s in this area. This high values is compatible with those calculated by GEOMATH.

V.4.2- Evaluation of Calibration in the Transient State:

V.4.2.1. Restoration of Piezometric Time-series

V.4.2.1.1. Continental Intercalaire in Algeria (fig.90)

The piezometric evolutions in the following eight points have been selected to serve as final criteria for the transient state calibration:

→ Kef n°27; → Sinclair; → Gassi Touil-Nezla ; → Tamerna

→ Bou Aroua; → Oued Mehéguène ; → Sidi Khaled ; → Aoulef 22

V.4.2.1.2. Continental Intercalaire in Tunisia (fig.89)

The selected reference points are:

→ El Borma A4 ; → El Borma 204 ; → Ksar Ghilane ; → Mahbes1

→ Chott Fedjaj CF1bis ; → Bhaier CI9 ; → Mansoura CI9 ; → EL Faouar 9

V.2.2.1.3. Continental Intercalaire in Libya (fig.91)

The CI Libyan network includes the points

→ Sawfujin SIQ1; → Nina N2 ; → Mardum 1; → Zamzam ZZ2 ;

→ Tawurgha 3.83 ; → Bay el Kebir BAK3 ; → Ghadames MW1219 ; → Ghadames WG16

V.2.2.1.4. Upper Sandstone Aquifer (fig.92)

→ Tozeur1 ; → Tozeur2 ; → Degache3 ; → Nefta CI1 ;

→ Nefta CI2 ; EL Hamma CI1bis ; → EL Hamma CI2.

V.2.2.1.5. Complexe terminal in Algeria, Tunisia and Libya

Fig 93 to 95 show the piezometric restorations after calibration thr model. Points selected as control points (or ynthesis Curves of Piezometers Groups) for the CT transient regime are:

- In Algeria:

→ Djemaa Nord ; → M'Raier ; → Gassi Touil ; → Hassi Khlifa

→ EL Oued ; → Toggourt ; → Ouargla ; → Ouargla Est .

- In Tunisia:

→ Rejim Maatoug ; → Metlaoui ; → Tozeur ; → El Faouar

→ Douz Tarfaiet ; → Nouil ; → Douz EL Hsay ; → Kebili Sud

- In Libya:

→ PZ3, PZ4, PZ5, J3 in the sector of Soknah - Hun
→ Zamzam P5 2135 ; → Zamzam P6 2128.

V.4.3- Restitution of out Flows of Sources

The good restoration of the flow of sources ; Sources in Tunisia, Ain Tawargha, Foggaras in Adrar, also constitute an appreciation criteria for the calibration of the Model, that can be evaluated for the study of the following table:

Table 20: Restitution of source flow rates by the Model (m^3/s)

Tunisian source					Aïn Tawergha		Foggaras	
year	Djerid	Nefzaoua	Tot. calculated	measured	calculated	measured	calculated	measured
1950	1.550	0.468	2.018	2.018	1.995	2.127	3.598	3.600
1955	1.554	0.460	2.014		1.996	2.095	3.598	
1960	1.531	0.446	1.976	1.764	1.997	2.063	3.603	
1965	1.509	0.441	1.949		1.997	2.032	3.618	
1970	1.424	0.418	1.842	1.521	1.996	2.000	3.608	
1975	1.219	0.374	1.593		1.989	1.902	3.618	
1980	1.021	0.298	1.318	0.764	1.964	1.873	3.634	
1985	0.668	0.214	0.882		1.876	1.841	3.582	
1990	0.167	0.084	0.251	0.020	1.750	1.832	3.495	
1995	0.074	0.000	0.074	0.010	1.663	1.810	3.334	
2000	0.012	0.000	0.012		1.613	1.775	3.151	2.700

VI- CALIBRATION RÉSULTS IN TRANSIENT STATE

VI.1- Distribution of Storage Coefficients

In the Complexe terminal

The S storage coefficient after calibration ranges between 10^{-3} and 7 10^{-3} in a captive aquifer and from 0.01 to 0.08 in a free aquifer. In a captive aquifer, the lowest values are in the north of the Chotts (5 10^{-4}). In the Djerid, S equals 10^{-3}. It averages $5x10^{-3}$ in the valley of Oued Rhir. In Libya, it ranges between 10^{-3} and 0.01. High values are shown at the level of the Hun sector and in the Gulf of Syrta, while low value are recorded in Hamada Al Hamra. In the Hun sector, S ranges between 2 10^{-3} and 7 10^{-3}. By the outcrops of Tunisia, (Dahar, most southern regions, Draa Djarid), S varies from 0.02 to 0.025. It equals 0.08 near the emergence of Djebel Nafoussa. At the level of the “Western Grand Erg”, S equals 0.025. In Gassi Touil the model reflect a value of 0.002 to 0.01. In the Atlas Piedmont and over Mzab heights, la S value equals 0.025. It varies between $2x10^{-3}$ and 0.03 in Nefzaoua.

In the Turonien

The storage coefficient of the captive aquifer equals 10^{-6} in the Algerian-Tunisian domain. In Libya, it equals 1.5 10^{-4} over all the domain except in the Hun Sector (10^{-3}) and the Syrta basin (6 10^{-3}). By the Dahar outcrops and the North of Libya where the aquifer is free, S equal 0.08.

In the Continental Intercalaire (fig. 88)

The captive storage coefficient averages 10^{-3} in the exploitation areas of Ouargla, El Oued and Ghadames. It is low in the Tunisian territory. It ranges between 10^{-5} and $2x10^{-5}$ in the Djerid and the caCThing fields of Fedjej. It equals 5 10-5 in Nefzaoua and in the most southern regions. In Libya, the low values are obtained in the Hun sector (10^{-5}). The storage coefficient is also low in the northern region of Tunisian and Algerian chotts (10^{-5}). In the south of the Saharan Atlas, it equals 4 10^{-4}). In Hamada Al Hamra, it is calculated at 10^{-4}. In a free aquifer, the values adjusted on the model range between 0.001 to 0.2. the highest values are obtained on Tinrhert plateau. The low values are recorded at the foot of Dahar. It euqlas to 0.05 in the regions of Adrar, Gourara and Timimoun ; and to 0.08 in Djebel Nafoussa. It ranges between 0.07 and 0.1 in the western Grand Erg. In the upper sandstones, the storage coefficient is uniform and equals 10^{-5}.

Fig. 87 : CT – Storage Coefficients after calibration

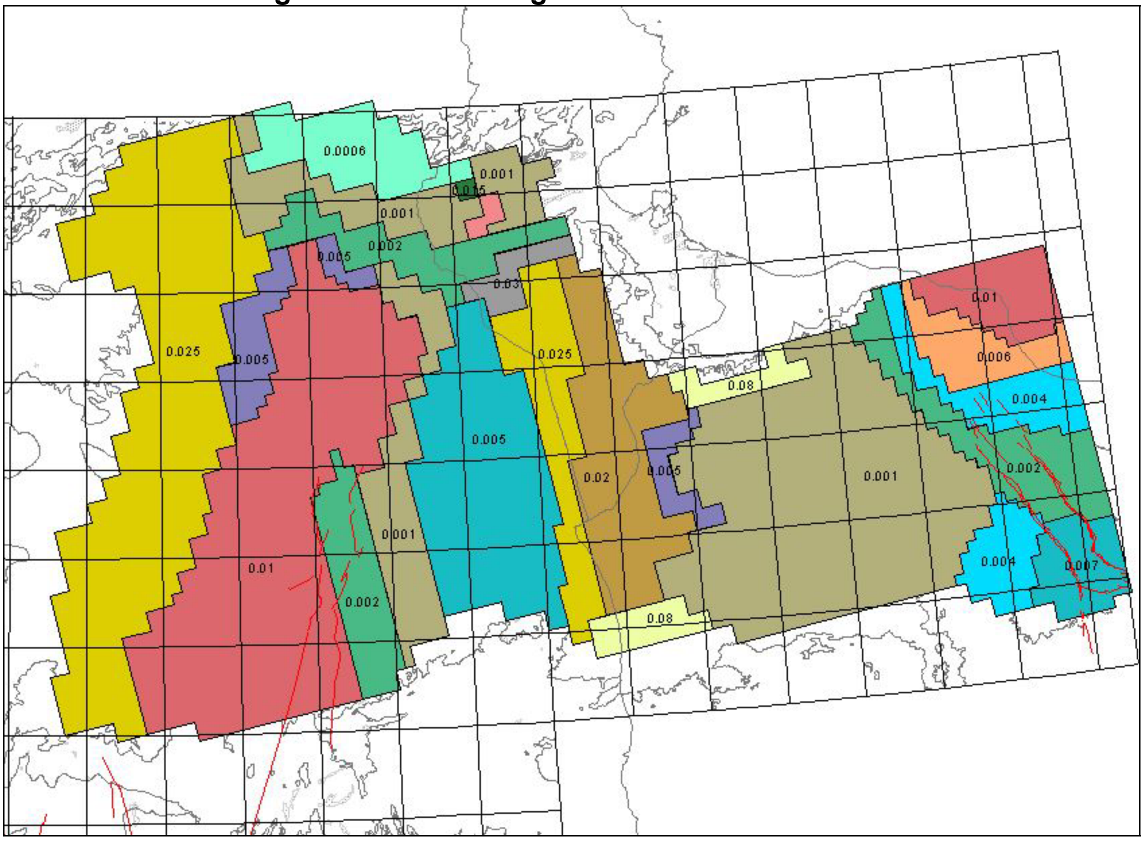


Fig. 88: CI – Storage Coefficients after calibration

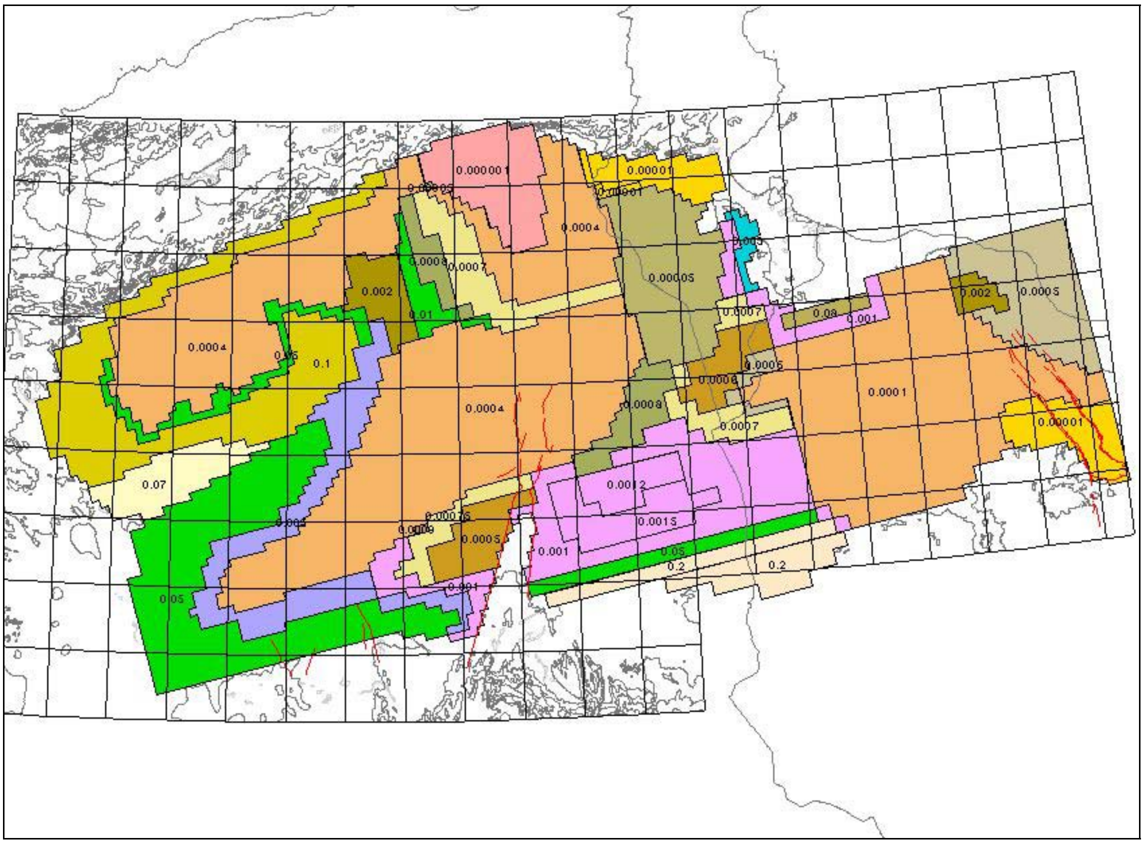


Fig. 89: IC - Tunisia

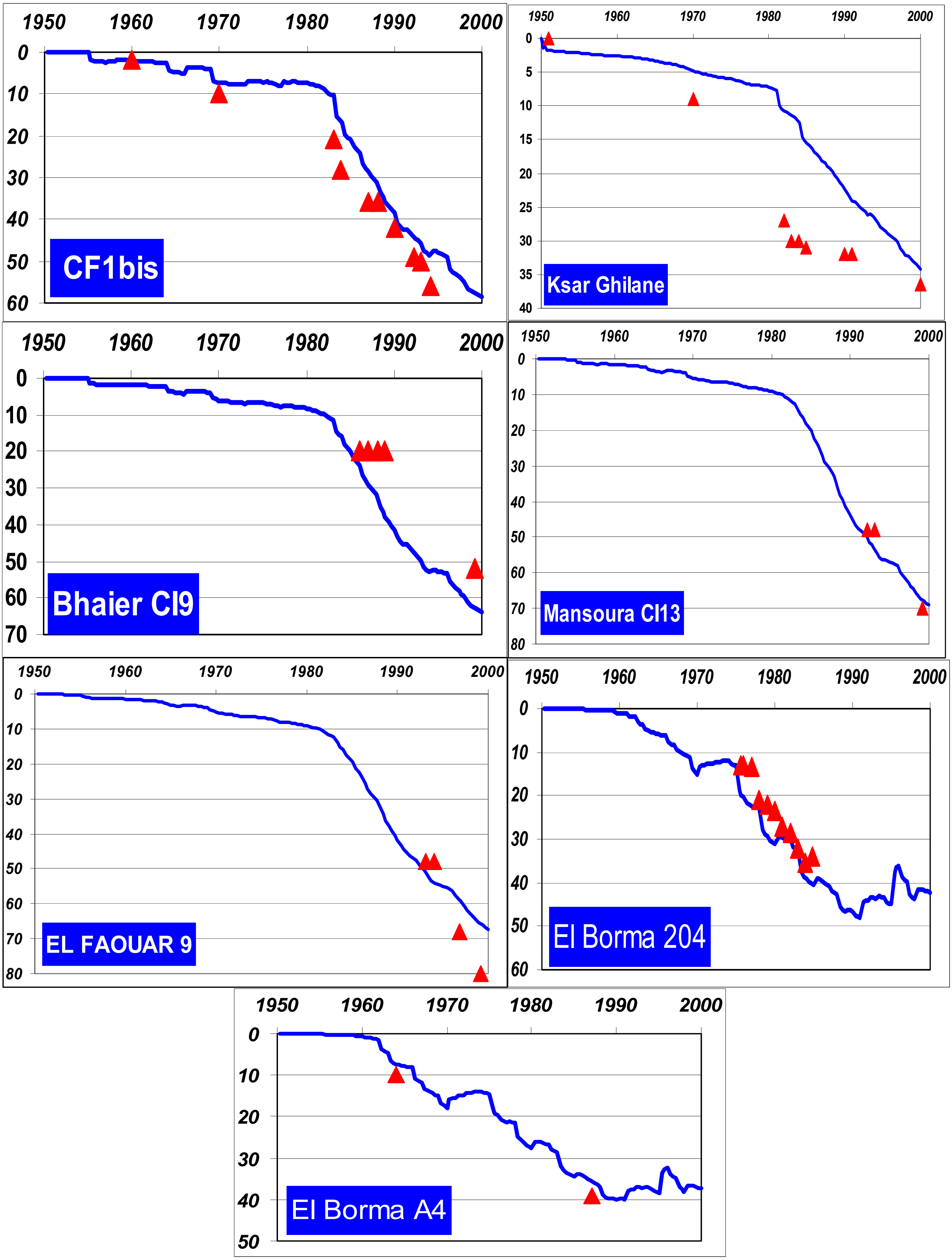


Fig. 90: CI - Algeria

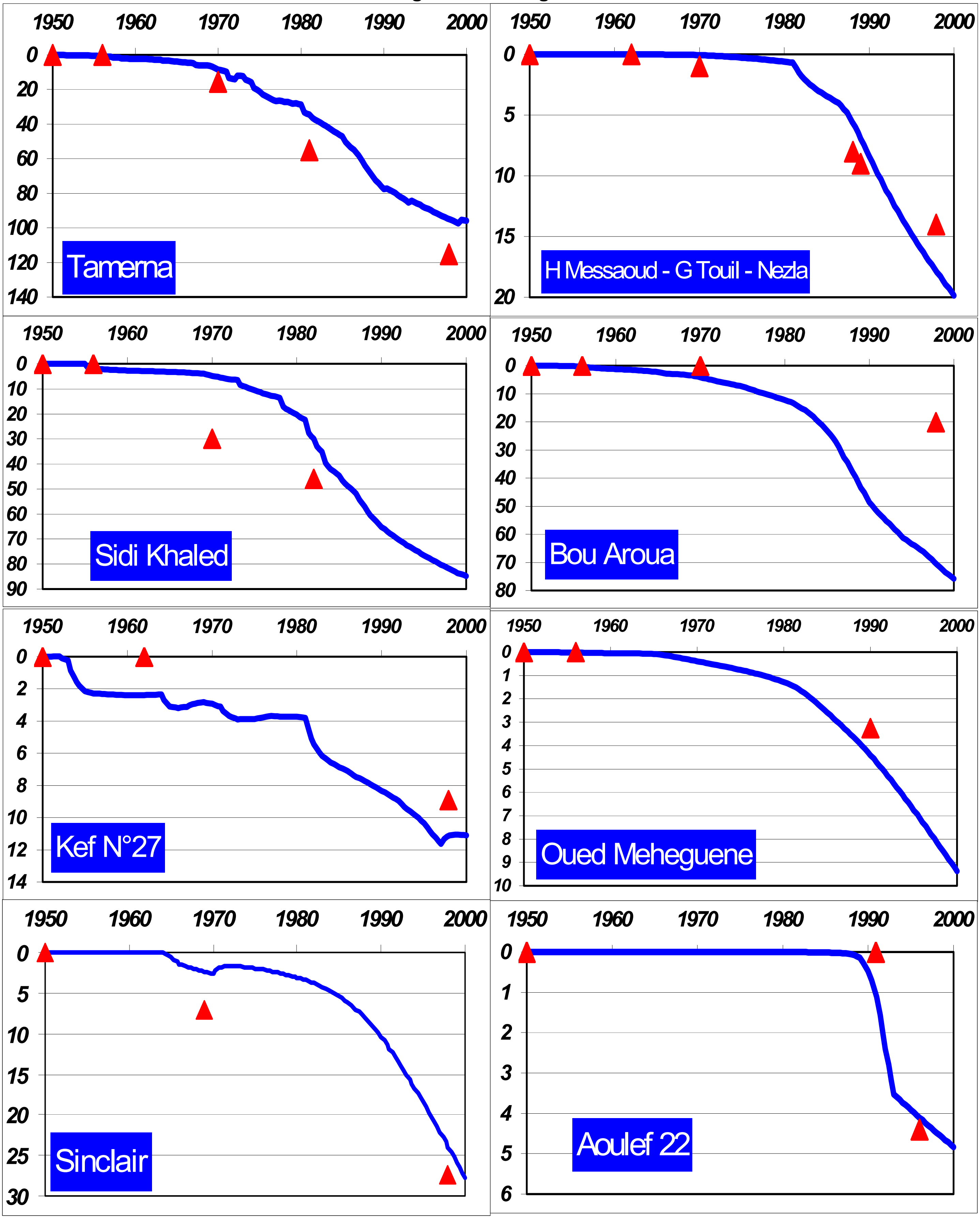


Fig. 91: CI - Libya

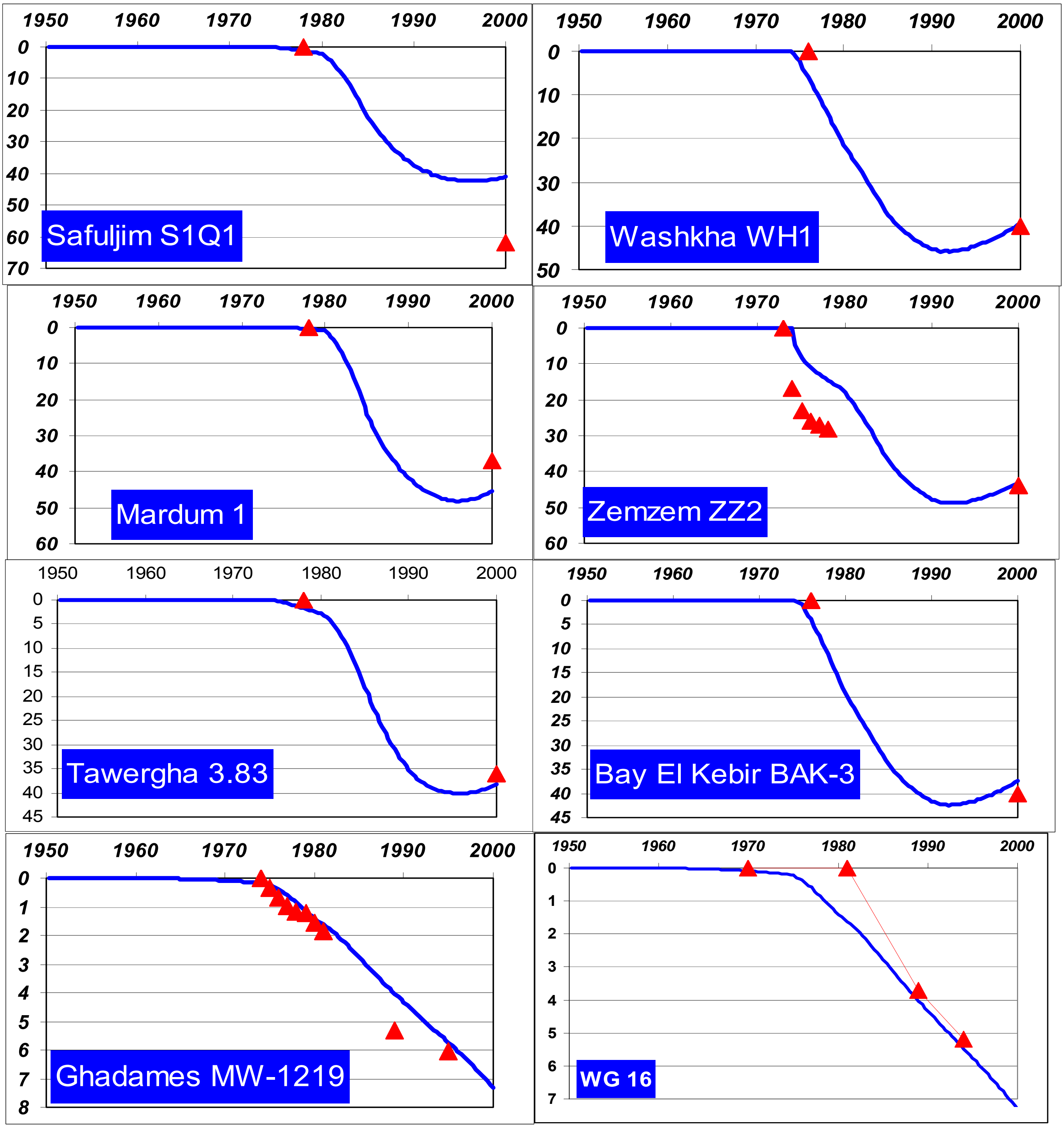


Fig. 92: Upper sandtones

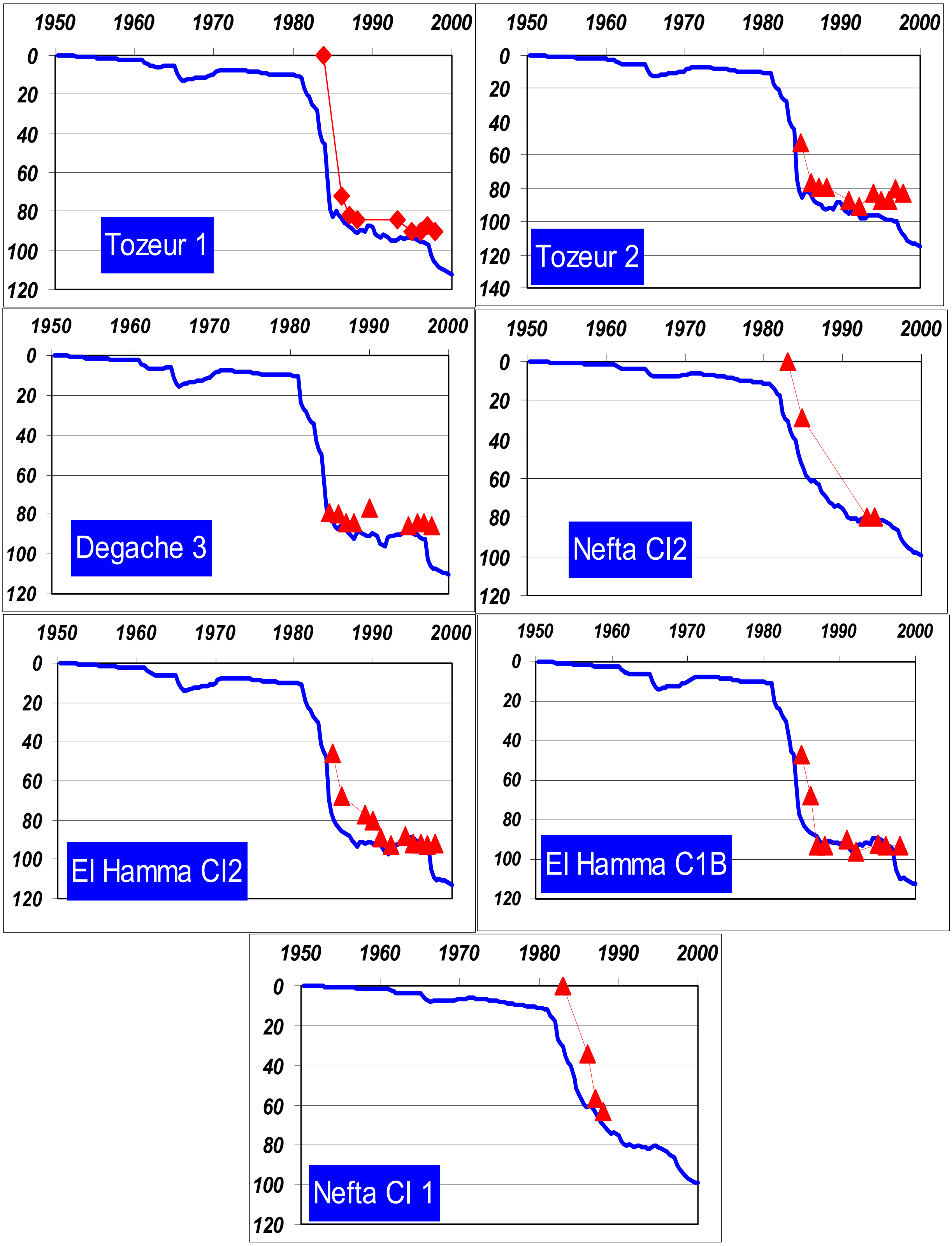


Fig. 93 : CT - Tunisa

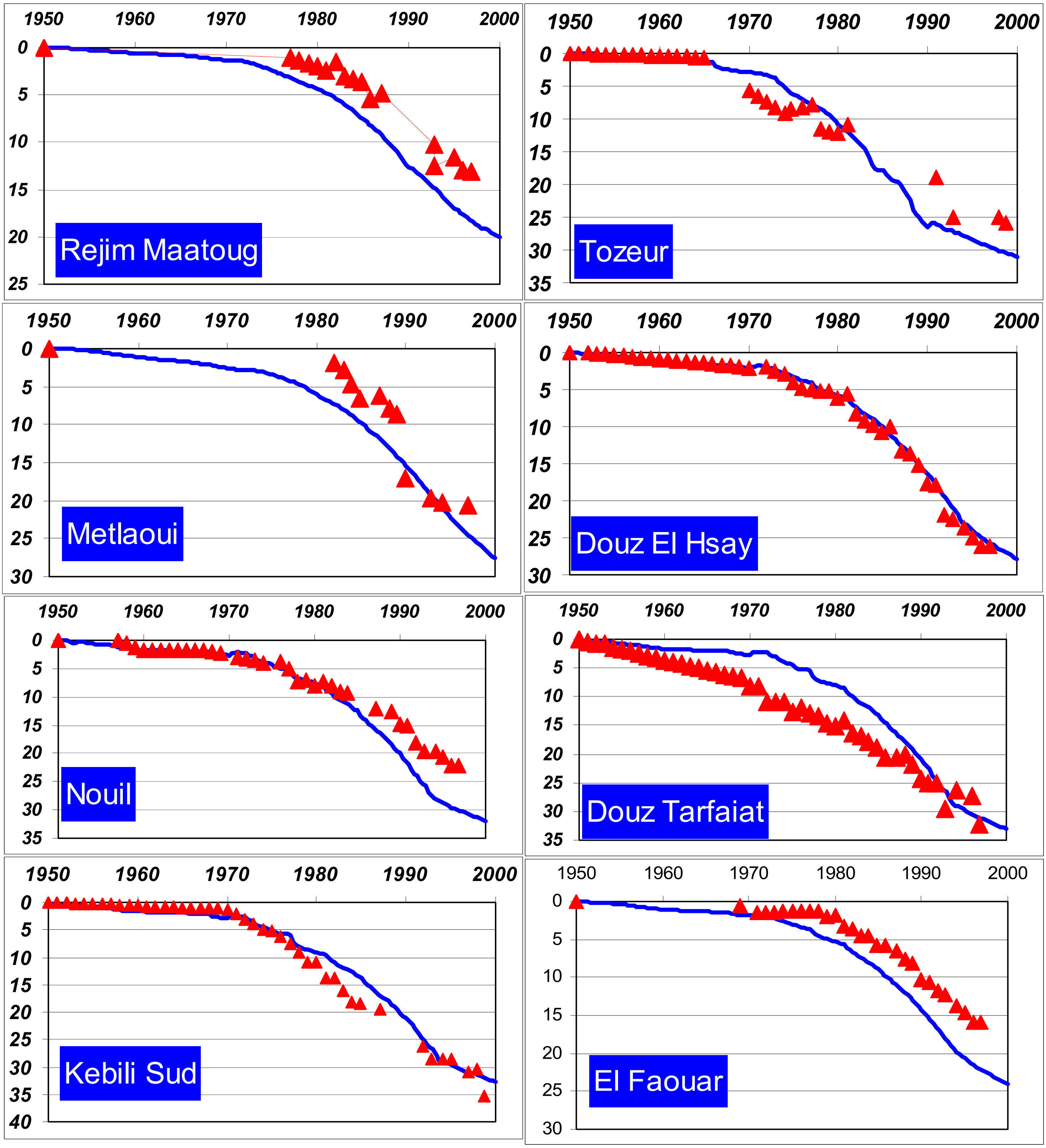


Fig. 94: CT - Algeria

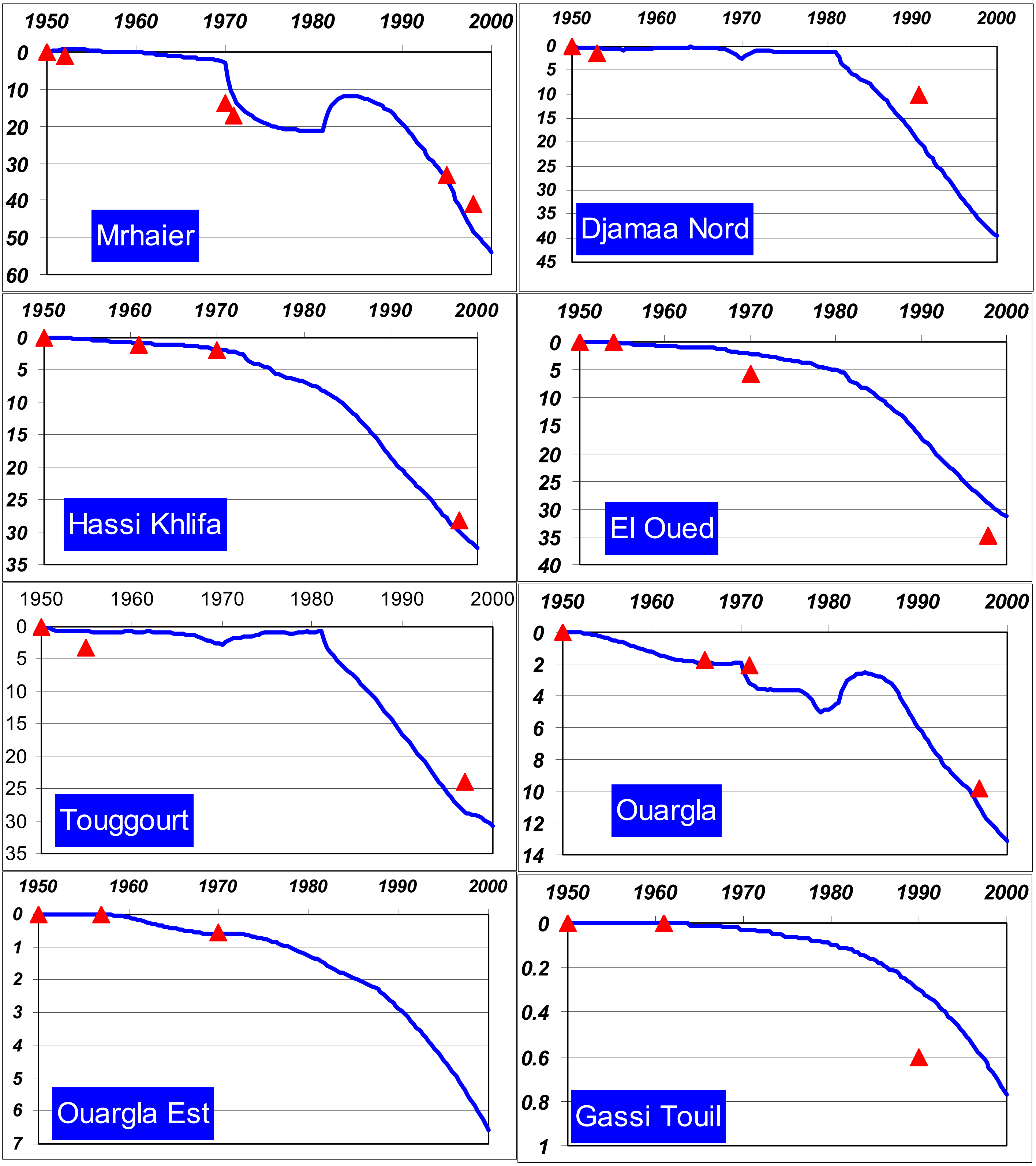
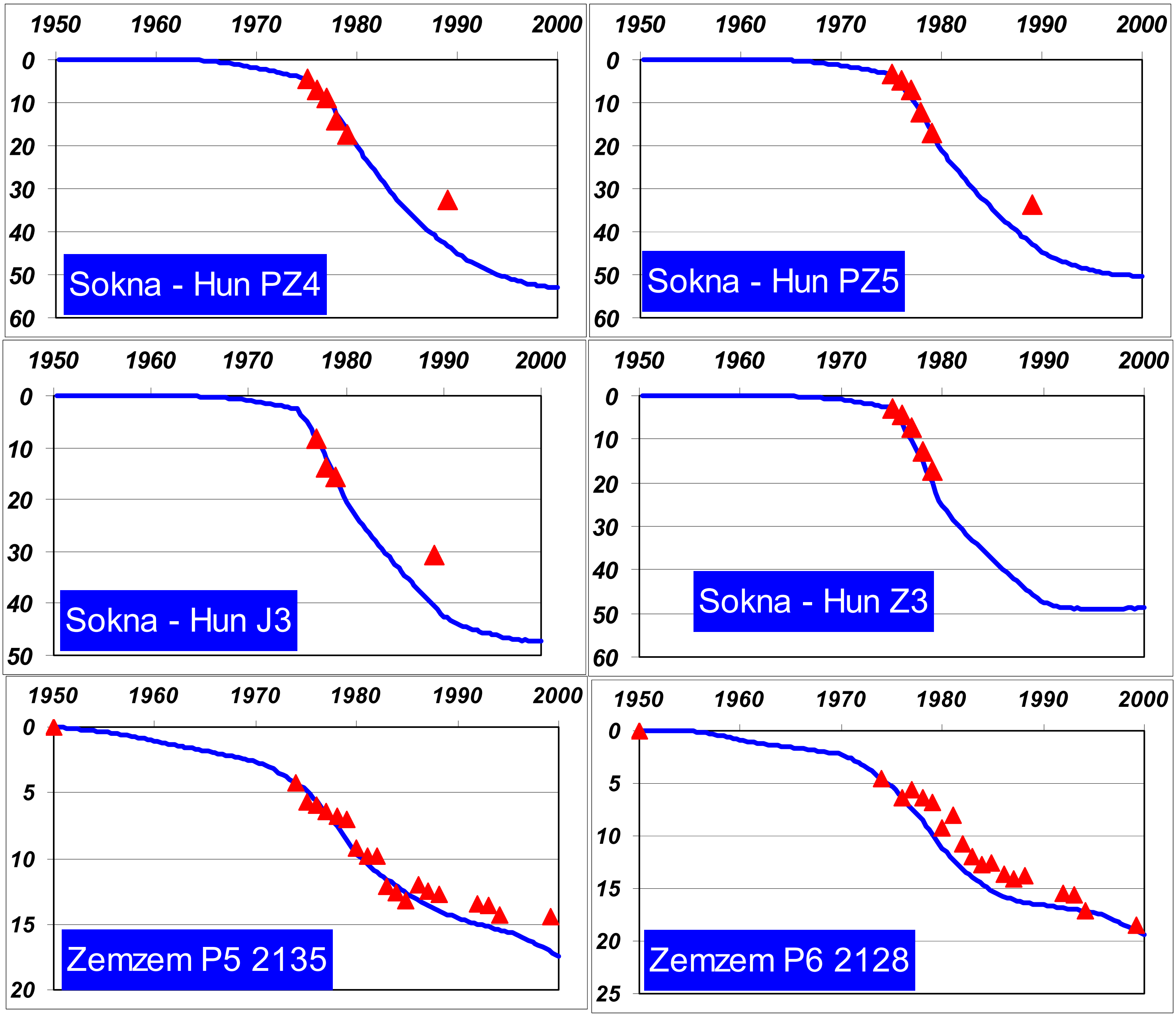
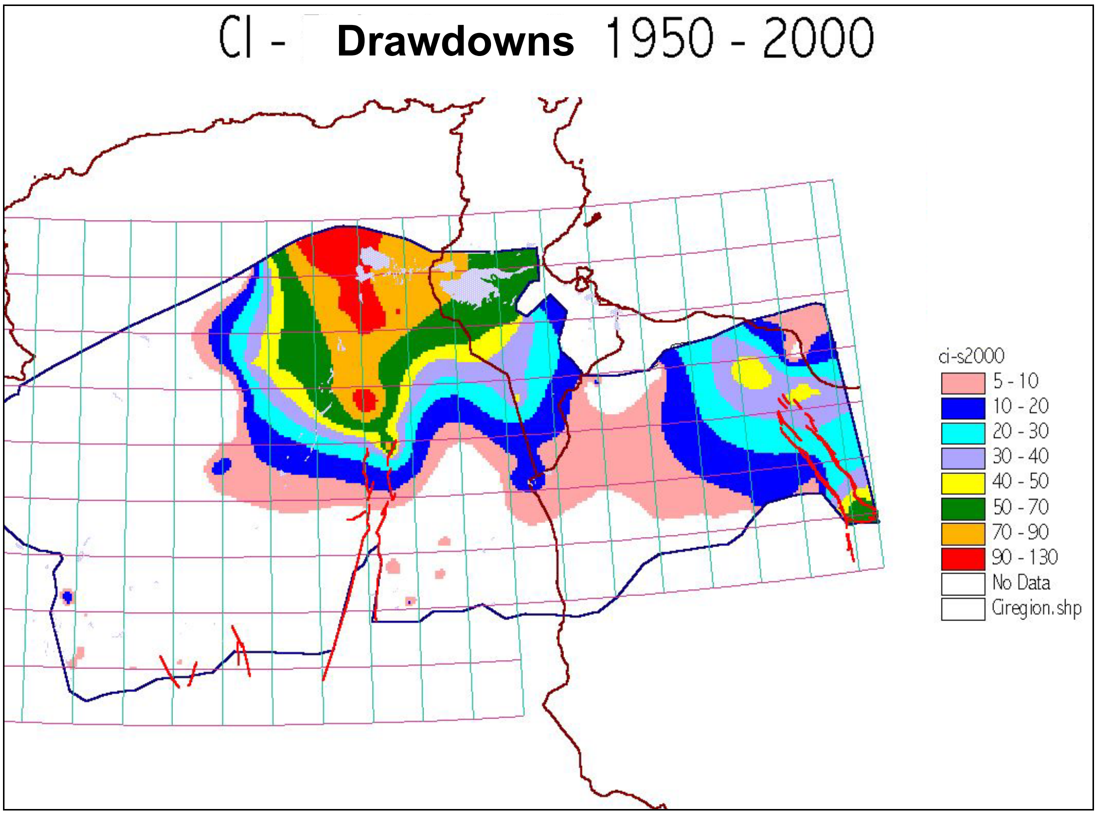


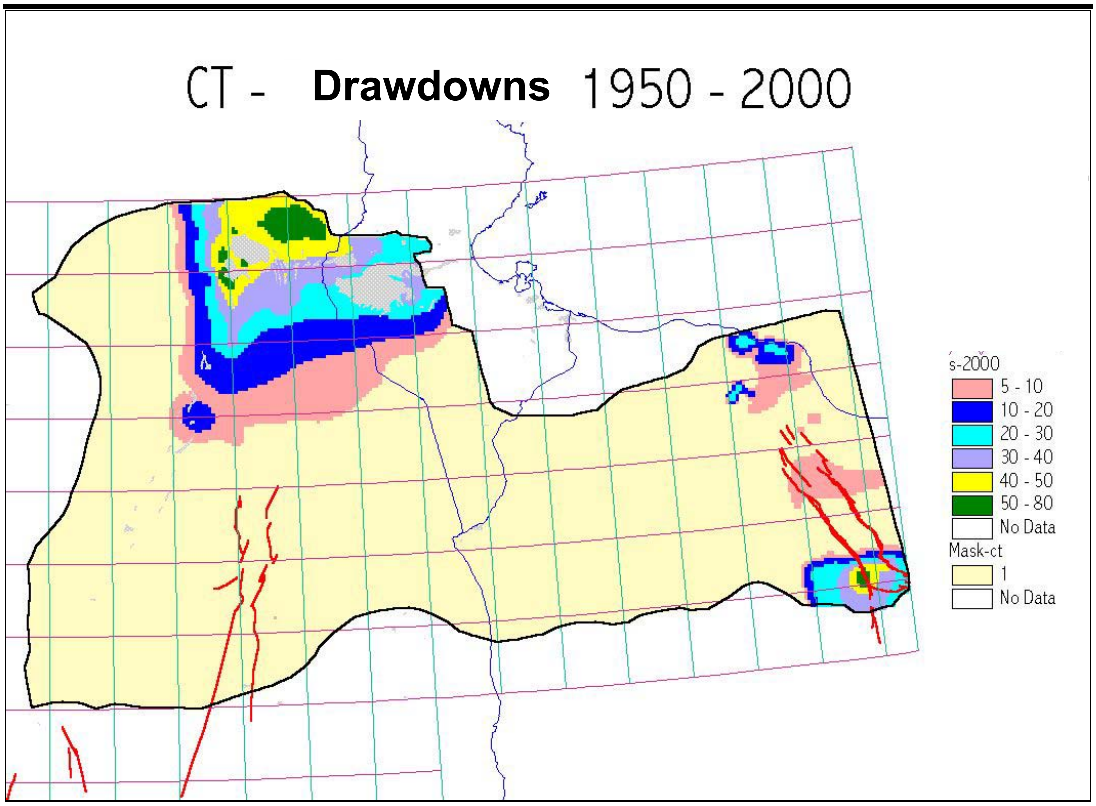
Fig. 95: CT - Libya



VI.2- Map of Drawdowns 1950-2000

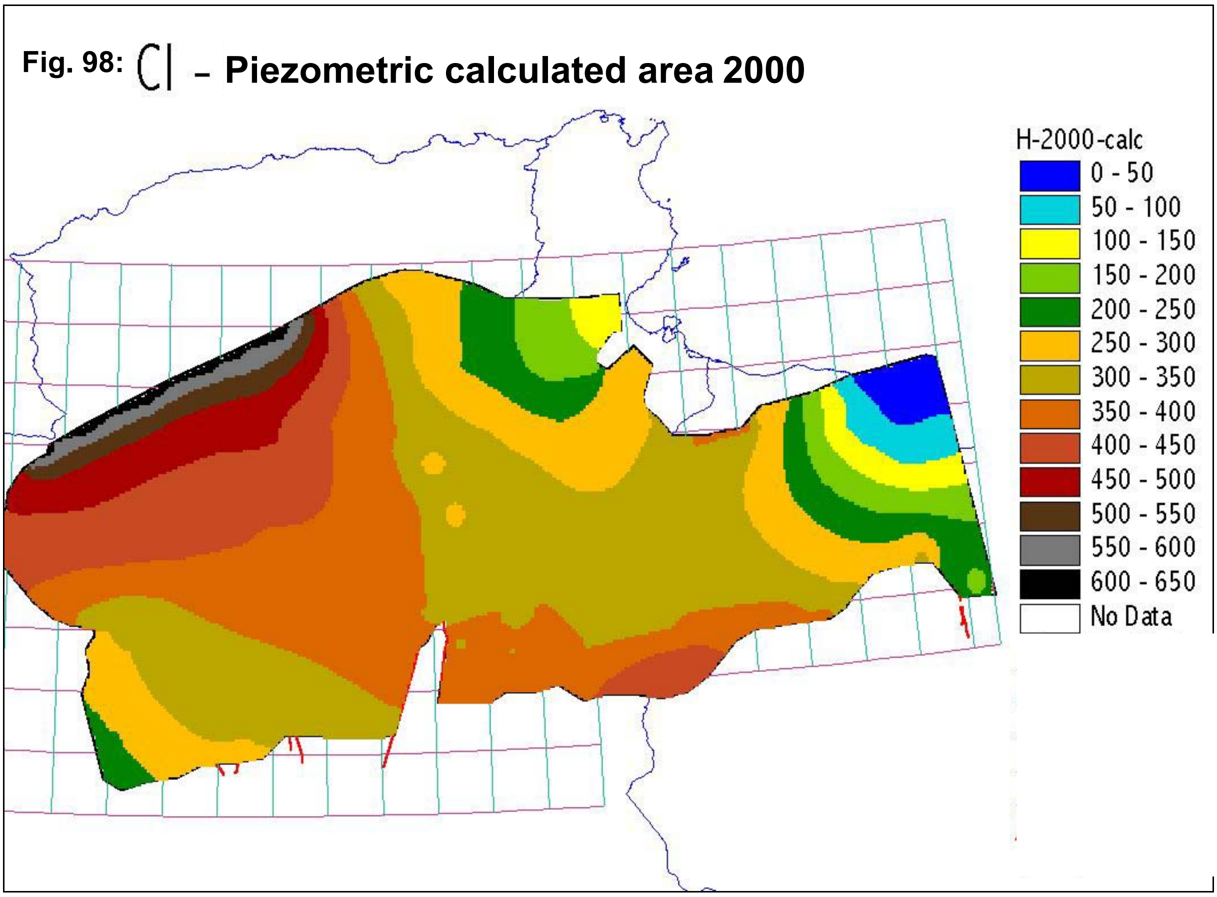
Maps shown in fig 96 & 97 well report on the spatial distribution of draw-downs calculated by the model, respectively at the IC and the CT.





VI.3- Piezometric Maps calculated in 2000

The important calculated (and observed) draw-downs may induce important modifications to te hydro-dynamic regime of the aquifer systems with regard to the situation known in a balanced regime, and namely concerning the Complexe terminal, and more exchanges between the CT and the Algerian Tunisian Chotts. This is the reason why a particular interest has been given to the study of the calculated piezometric map of the Complexe terminal in 2000, represented in Fig. 99 with focus on the Chotts in fig. 100.



The isopiezic curves show that the flows main lines are preserved, towards the Algerian and Tunisian Chotts and the Gulf of Syrta. Nonetheless, we note the appearance of an artificial outlet in the south of Hun Graben: very sharp ddraw-downs induced by the important flowing in a sector blocked between two water tight boundaries. On the other hand, the flow is very influenced by the pumoing in the Djerid, Nefzaoua and the valley of Oued Rhir. The isopiezic curve 50 m initially presented in the form of two independent curves respectively centered in the Algerian and Tunisian Chotts, has widened towards the South to include the whole Chott region.

Considering the excessive draw-down in this sector (that may correspond to a CT piezometry lower than the level of the Chotts), that may result in theinversion of the flows, the piezometry calculated in 2000 has been compared the level of the Chotts (fig. 100-b). We note a very clear evolution between 1950 and 2000: in Tunisia, the whole Nefzaoua and the Djerid, where the aquifer was clearly artesian in 1950 (fig.100-a), show today, under the effect of 25 m generalized draw-downs, piezometric levels right equal to the level of Chott Djerid. In the future, this situation will get worse, unless flowing is reduced, whih seems a hard thing to achieve now. In Algeria, the situation is even more worrying in Chott Merouane where the CT piezometry is already under the level of the Chott, on a « standby » situation.

CT – **Piezometric calculated area 2000**

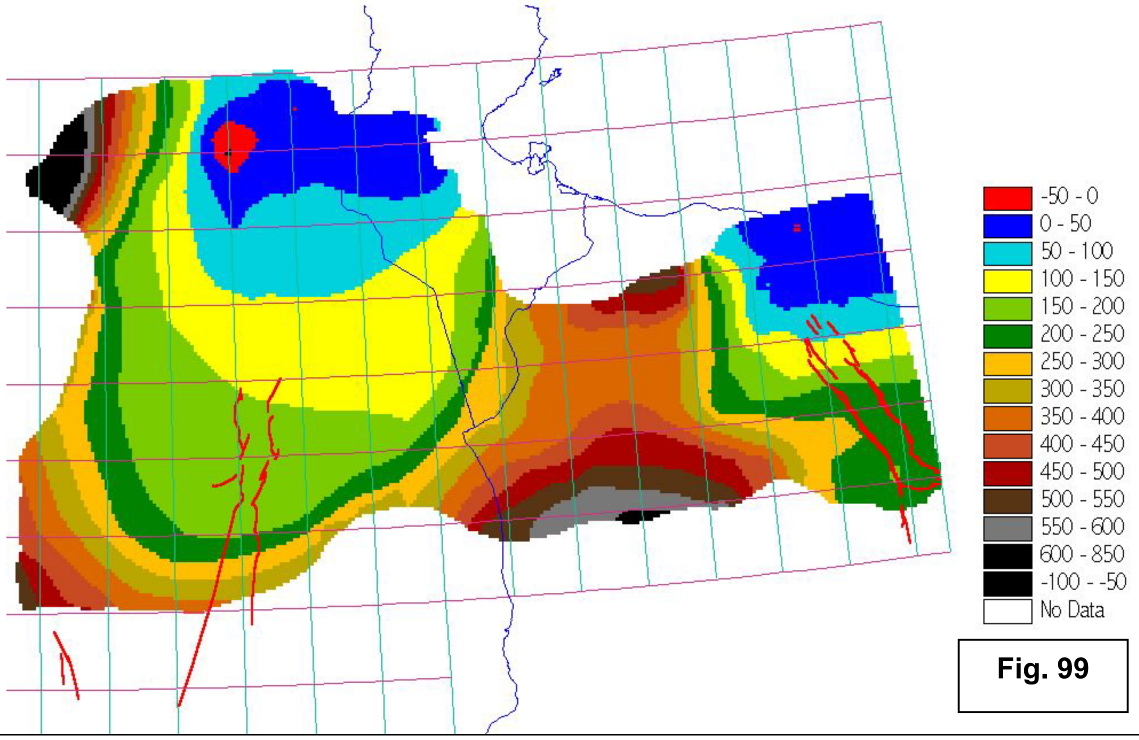


Fig. 99

VI.4- Water balance 2000

Table 20 describes the 2000 balance calculated for all the NWSAS. We can note some interesting indications:

- The sum of the system recharges (including the COD input through deep percolation) is 30.3m^3/s, which represents 43% of all flows made through drilling (70.1m^3/s).
- All contributions of reserves (« input through draw-down ») amount to 46.4m^3/s and represent 66% of flowing through drillings.
- When reading the above, and after studying the evolution of draw-downs over time (fig. 89 à 95), we can already predict that draw-downs will continue to rise, even if we decided to block pumping at its current level[26]. The amplitude of this increase, in terms of space and time, still needs to be determined. This calculation will in fact constitute the object of the Zero Simulation, the first to consider on the Model!

On the other hand, and when comparing statements of 1950 and 2000, we can note that the flow of the Tunisian Outlet reflects a decrease of about 52 %. We shall also note the very high reduction of CT outlets towards Chotts and Sebkhas: they sum up 2.2 m^3/s in 2000 against 8.8 m^3/s in 1950.

This evolution (certainly expected due to shown flowing and observed draw-downs) constitutes, it continues, the prelude of major and probably irreversible perturbations in the region of the Chotts.

[26] Unless flowing is drastically decreased, which is very well shown in the CI in Libya from 1990 to 2000 and the clear rise of piezometres in Washka, Zamzam, Mardum, Tawargha and Bay el Kabir .

CT - **Piezometric level compared to the chotts - 1950**

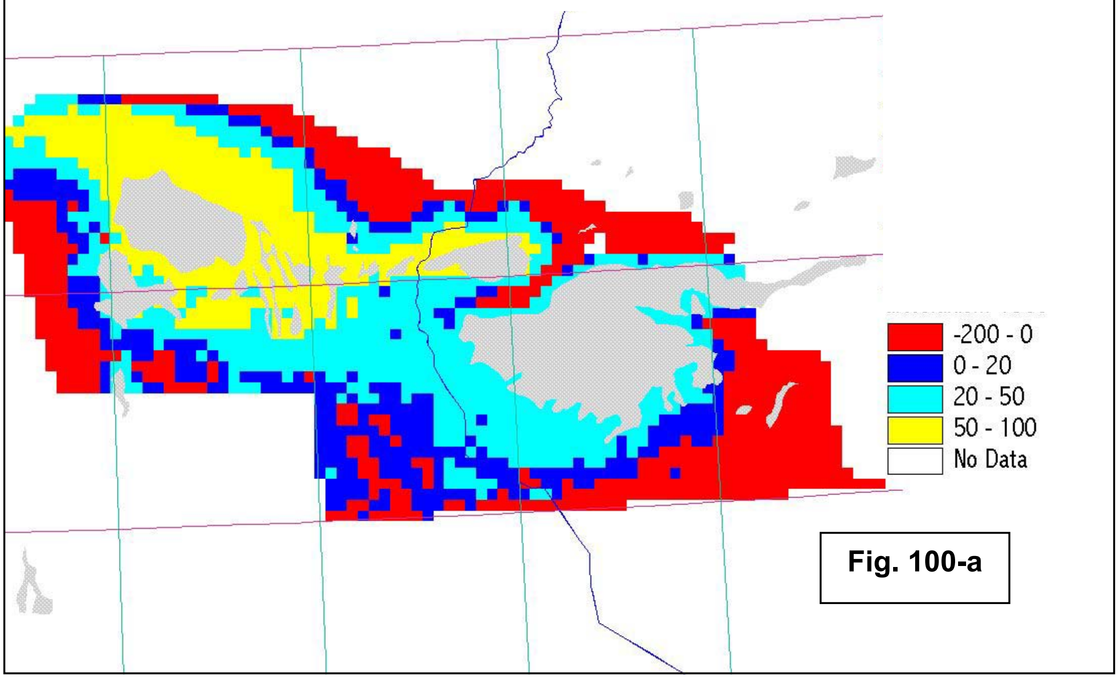


Fig. 100-a

CT - **Piezometric level compared to the chotts - 2000**

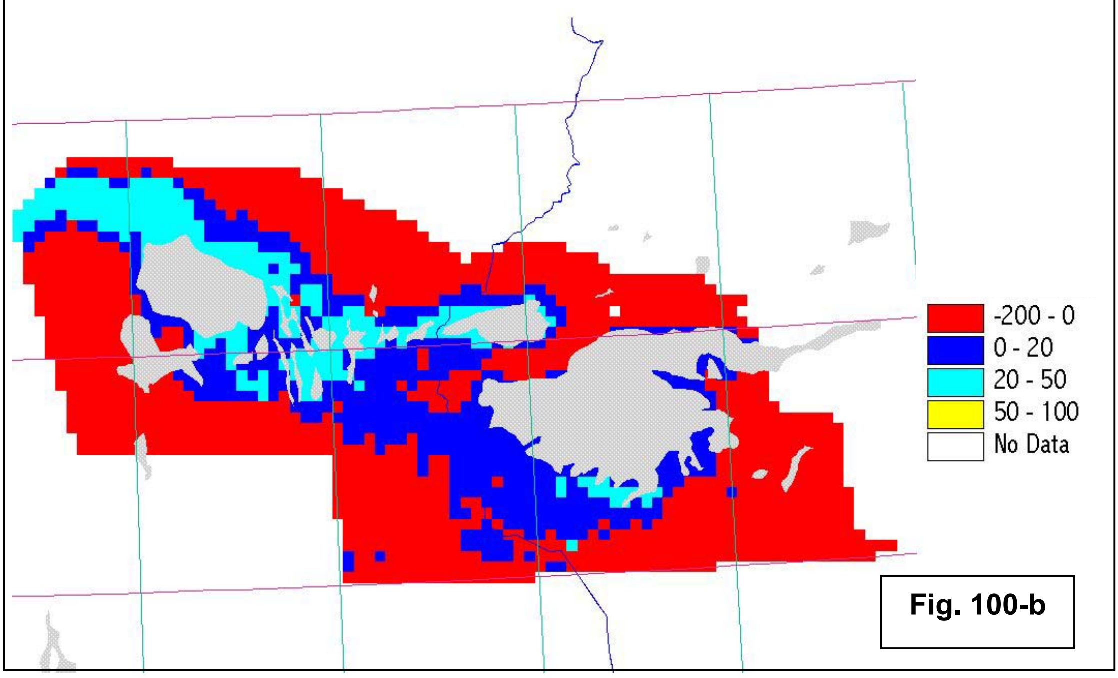


Fig. 100-b

Tableau 21: NWSAS water balance in 1950 and 2000

Complexe Terminal	1950	2000
Inputs (m^3/s)		
Supply	**18.2**	**18.2**
Turonian Leakage	**5.4**	**6.9**
Contribution of reserves	**0.0**	**24.9**
Total of Inputs	**23.6**	**50**
Outputs (m^3/s)		
Pumping	**7.5**	**42.8**
Algeria	*5.9*	*20.9*
Tunisia	*1.2*	*14.5*
Libya	*0.4*	*7.4*
Turonian Leakage	**2.4**	**2.7**
Ain Tawargha Source	**2.0**	**1.6**
Chotts in Algeria-Tunisia	**7.4**	**1.6**
Sebkha Mjezem-Tawargha	**0.2**	**0.2**
Gulf of Syrte	**0.6**	**0.6**
Ain Kaam	**0.3**	**0.1**
Sources of Nefzaoua Djrerid	**2.0**	**0.0**
Sebkhas Algeria	**1.2**	**0.4**
Total of Outputs	**23.6**	**50**

Continental Intercalaire	1950	2000
Inputs (m^3/s)		
Supply	**9.4**	**9.4**
Turonian Leakage	**0.5**	**0.8**
Upper sandstone Leakage	**0.0**	**0.0**
Apport Cambro-Ordovicien	**2.0**	**2.7**
Eastern Boundarye	**0.0**	**0.0**
Contribution of reserves	**0.0**	**21.5**
Total of Inputs	**11.9**	**34.4**
Outputs (m^3/s)		
Pumping	**0.5**	**26.8**
Algéria		*21.3*
Tunisia		*2.2*
Libya		*3.3*
Turonian Leakage	**3.3**	**1.7**
Upper sandstone leakage	**0.4**	**0.5**
Saoura & S.Timimoun	**0.2**	**0.2**
Foggaras	**3.6**	**3.1**
Tunisian Outlet	**3.1**	**1.5**
Gulfe of Syrta	**0.8**	**0.6**
Total of Outputs	**11.9**	**34.4**

Upper Sandtones	1950	2000
Inputs (m^3/s)		
Tur. Leakage	**0**	**0**
IC Leakage	**0.4**	**0.5**
Reserves	**0**	**0**
Total of Inputs	***0.4***	***0.5***
Outputs (m^3/s)		
Pumping	**0**	**0.46**
Tur. Leakage	**0.15**	**0.04**
IC Leakage	**0**	**0**
Chott Fedjej	**0.26**	**0**
Total of Outputs	***0.4***	***0.5***

PART III

PREDICTIVE SIMULATIONS

Chapter I: DEFINITION AND PERFORMING THE EXPLORATORY SIMULATIONS

I- DEFINITION OF EXPLORATORY SIMULATIONS

The purpose of this first section is to define conditions for the execution of a number of exploratory simulations aimed at the assessment of NWSAS capacity to perform, at the hydraulic plan, water resprings development objectives defined by experts working on future demands, i.e. A.SALEM (April 2001) concerning Algeria, O.M. SALEM (April 2001) for Libya and M.S. BACHTA (June 2001) regarding Tunisia. In order to do so, it is necessary to:

- Define every selected development scenario or plan, namely with regard to the year 2000, in terms of additional exploitation spatially distributed, and execution planning, for each of NWSAS aquifers. Every scenario or plan shall be subject to simulation.
- Define results expected from said simulations.
- Define simulation calculation conditions: initial status, forecast time-frame, temporal variation of flow rate, boundary conditions.

Calculation conditions

The purpose of exploratory simulations is precisely to explore the system possibilities, up to its ultimate boundaries: the aim at this stage is to determine the boundary of resprings development, and due to uncertainties prevailing at the level of hydro-geological parameters as well as at the level of social and economic factors, and likely to generate very illusionary precisions in terms of working hypothesis and all the more so of results, it seems interesting to conduct calculations over a period that can be:

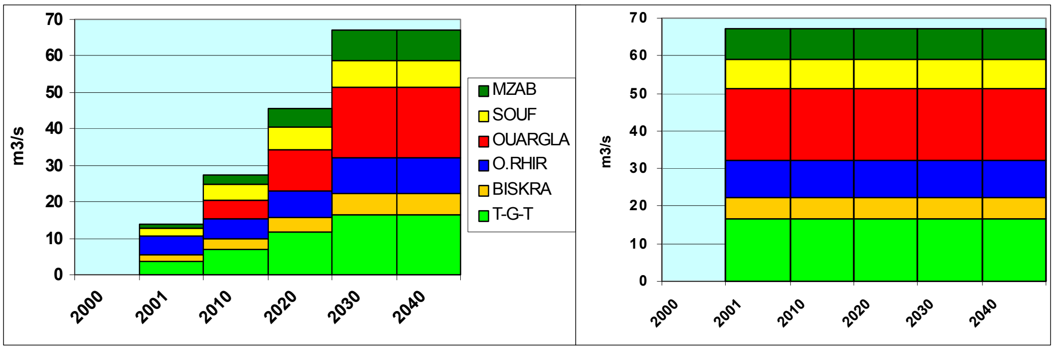
- Long enough so that impulsions with effects we are planning to measure could reach all their scope and have as lasting impacts as possible in the space;
- Not too long in order not to exceed the tool significance boundaries with regard to reasons of uncertainties mentioned above, and also with regard to the length of records having served for the calibration of the model.

A fifty year long simulation period therefore seems reasonable: *the exploratory simulations will be carried out over 50 years, the reference initial status being the system status in 2000, as reconstituted by the model.*

The tool used for this calculation is naturally the one which corresponds to the last version of the wedging of NWSAS model.

For the Aquifer system to be explored until its most extreme reactions and capacities, and for the sake of “durability”, we shall simulate a constant flow throughout the whole calculation period [01/01/2001 to 31/12/2050] and this flow will represent the maximal flow considered for subject plan or scenario. In order to clarify this protocol, we will anticipate on what follows, and consider as an example the low hypothesis in Algeria, presented in Table 2. This scenario suggests, for each province, a regular additional exploitation growth until 2030 (see left part of the drawing below). The corresponding exploratory simulation will consider that the maximal additional flows, expected for the time-frame 2030, are applied since 2001 and will remain constant until 2050 (see right part of the drawing). We thereby introduce a an additional forcing level to the system, with the effect of slightly amplifying the scenario’s expected effects.

Fig. 101: Simulation with graded flows and simulation with constant flows



Expected results

The following result will be associated with each of the simulated development plans or scenarios:

- The 2000-2050 drawdown map calculated all over the considered aquifer,
- The drawdown evolution curves in terms of time (2000 to 2050), plotted in a specific number of core-drills, on the basis of one core-drill per large hydraulic region, or by large exploitation area,
- The main terms of 2050 statement, and namely the flow calculated at the level of the three main outlets: Ain Tawargha, Foggaras, the Tunisian outlet.
- An evaluation, in terms of additional drawdowns, of the impact of simulated scenario in each of the neighbouring countries likely to be influenced,
- The depth map of 2050 Piezometric levels calculated with regard to the ground,
- The NP depth map under the surface of the Algerian Tunisian Chotts, that we can translate in terms of risk intensity (potential salinization).

The reference scenario: keep the present state or zero simulation

This scenario (certainly not probable but necessary to simulate if we want to compare and make a reliable appreciation, between the effects of all various envisaged development scenarios), would be to keep constant the abstractions surveyed in 2000 and calculate the system corresponding evolution throughout the next 50 years.

Scenarios for Algeria

Concerning Algeria, A. SALEM (April 2001) developed two scenarios for the development of water resprings that can be summarized as follows:

- The Forecast year is 2030
- The need for drinking water is related to demographic growth, the population of the region being 2.5 M inhabitants in 2005 is expected to be 5.3 M Inhabitants in 2030. The current consumption standards currently adopted are 100 to 200 l/d/capita depending on the site of the community, and 80 l/d/c for scattered housing, with a growth rate of 1% per year after 2000. The high hypothesis suggests to keep the present loss rate in the networks (**50%)** while the low hypothesis considers a decrease in that rate to **20%**. That is respectively and in average in 2030:
    - 243 l/d/cap. For the low hypothesis [= 88 m^3 /year/cap]→ additional Q= 8.8m^3 /sec
    - 300 l/d/cap for the high hypothesis [= 110 m^3/year/cap] → additional Q = 12.5m^3/sec

- the need of the oil industry is estimated at **290Mm^3** in 2000, with a growth of **5Mm^3/year**, or an additional exploitation in 2030 = 4.75m3/sec whatever the hypothesis is.
- The Agriculture provisional needs suggest:
  - First the fulfilling of current deficit and the restoration of existing palm groves, which requires the mobilizing of **13.9 m^3/sec since 2001**
  - The exploitation of new irrigated perimeters at an average of **2000 ha/year** for the low hypothesis and **4000 ha/year** for the high hypothesis [distributed throughout the basin].

This represents, respectively for each of both hypotheses (**including the filling of deficits**), additional irrigation exploitations for the time-frame **2030** equal to: **53.5 m^3/sec** and **89. m^3/sec**.

Table 22: Low and High Hypotheses in Algeria

Additional Exploitation/2000, per Aquifer _ Time-frame_2030 _ m^3/sec			
HYDRAULIC REGION		**Low H.**	**High H**
GOURARA-TOUAT-TIDIKELT	CI	16.6	29.0
	CT		
	TOTAL	16.6	29.0
BISKRA	CI	1.1	1.4
	CT	-	-
	TOTAL	1.1	1.4
O.RHIR	CI	6.0	7.0
	CT	3.8	4.3
	TOTAL	9.8	11.3
OUARGLA	CI	2.0	4.0
	CT	17.3	29.5
	TOTAL	19.3	33.5
SOUF	CI	2.5	3.9
	CT	5.0	8.0
	TOTAL	7.5	11.9
MZAB	CI	8.2	14.3
	CT		
	TOTAL	8.2	14.3
TASSILI	CI	0.0	0.0
	CT		
	TOTAL	0	0
	Total CI	**36.4**	**59.6**
	Total CT	**26.1**	**41.8**
	Big Total	**62.5**	**101.4**

- By the time-frame 2030, the **Global Additional Demand** [Agriculture + drinking water + Oil Industry, calculated with regard to 2000] will then amount to:
  - → **67. m^3/sec for the low hypothesis**
  - → **106. m^3/sec for the high hypothesis**
- Inside each large hydraulic region, the identification of points for the **implementation of new exploitation operations** can be made on the basis of preliminary cartographic works of the possible extension areas of the Sahara irrigation regions, shown in the report prepared by A. Khadhraoui in October 2001 [« Irrigated Areas in the Northern Sahara: Current Status and Extension Possibilities »][1].

[1] For the localization of these extension areas, as well as simulated flows for each region and aquifer, see the document « Definition and Execution Exploratory Simulations » OSS, Nov 2001 »

- As for the ZIBANS region (Biskra), we supposed that all **additional abstraction operations** from the CT were **assigned to the Tolga aquifer**, isolated from the NWSAS system[2]. These operations are not represented on the NWSAS Model: This explains the absence of additional abstraction in the table presented above.

Scenarios for Tunisia

The report prepared by M.S BACHTA (June 2001) suggests the following evolutions:

- Forecast time-frame = 2020
- Domestic demand: it depends on the population increasing from 0.38Million inhabitants (0,38M/cap) in 2000 to **0.6M cap in 2020**. The consumption standards are provided on the basis of = **100 l/d/cap** including constant losses or **36.5m^3/year/cap**, which represents an additional demand of: 0.22M/cap x 36.5 = **8 Millions m^3/year in 2020**. [255.l/sec].
- Tourism: Demand increases from **1.5 to 2.8 M**, or an evolution of 1.3M = (or 40 l/s in the time-frame 2020).
- Industries: No additional demand is expected.
- Agriculture: the financial incentives granting water economy will result in the decrease of irrigation water demand from **450 Mm^3/year in 2000** to the level of **400 Mm^3/year in the time-frame 2015**. Along with this, we expect the creation of a number of new irrigated perimeters:

→ 2000 ha in Regim Maatoug ; → 2000 ha in Nefta ; → 1000 ha in Gabes and Tataouine

M.S BACHTA considers that economies achieved through the improvement of irrigation methods represent a [« profit » of 50 Mm3/year in 2015] will gradually compensate the additional demand of said new perimeters, whose development will be gradual throughout the same period, to be final by time-frame 2015. Such an estimate can be true if the water demand of these new perimeters can be limited to 10 000 m3/year/ha through water economy appropriate measures. In these conditions, the result of additional agricultural demand will be strictly nil between 2000 and 2020. Such a scenario is naturally valid throughout Tunisia, but less if the spatial and temporal evolutions of additional abstraction (more or less) can be determined.

Finally, and concerning exploratory simulations, the scenario proposed by M.S.BACHTA for Tunisia agrees with the scenario « Keep the present state, or Zero Simulation ». [At this level, additional domestic and tourism demand seems minor, and in any case can be absorbed by uncertainties related to existing abstraction, namely agricultural].

Scenarios for Lybia

The document prepared by O.M.SALEM, related to the study area [Present water exploitation and future demand in Hamada El Hamra Sub-Basin, Apr 2001] is based on the following data:

- Forecast time-frame: 2030

[2] When constructing and wedging the Model (Spring 2001) , we did not have inventories conducted in the Province of Biskra. We then had, with regard to ERESS and the RAB Project, only few new data regarding this region. This is the reason why, after considering the integration of Eocene limestone aquifers in NWSAS Multi-aquifer system (see. Report on Conceptual Model, OSS, July 2000), we finally used, in the northern region of Algerian Chotts, a representation of the Complexe terminal similar to the one adopted by the ERESS Model, where the aquifer of Tolga Eocene limestone were not explicitly represented (see. NWSAS: Construction and Wedging of the Model, Phase Report, OSS, May 2001). When drafting this report, Biskra inventories were analysed by ANRH and NWSAS teams, and their results have not yet been published.

- Population in 2000 = 1.0 M inh → in 2030, increases to **2.32 M inh**
- Additional domestic demand by time-frame 2030 = **113 M m^3/year**
- Additional industrial demand by time-frame 2030 = **7 M m^3/year**
- Additional Agricultural demand by time-frame 2030 **= 720 M m^3/year**

→ **Additionnal** TOTAL demand by time-frame 2030 = **840 M m^3/year** ; or **# 27. m^3/sec**

The contribution of **GMRP**[3] to the needs of Hamada El Hamra basin in 2030 is estimated at **300 Mm^3/year**. There will then be a **Deficit of 540 M m^3/year by time-frame 2030**. One of the considered scenarios assumes the **reduction of deficit through the increase of the exploitation of basin aquifers** according to quantities pumped every year.

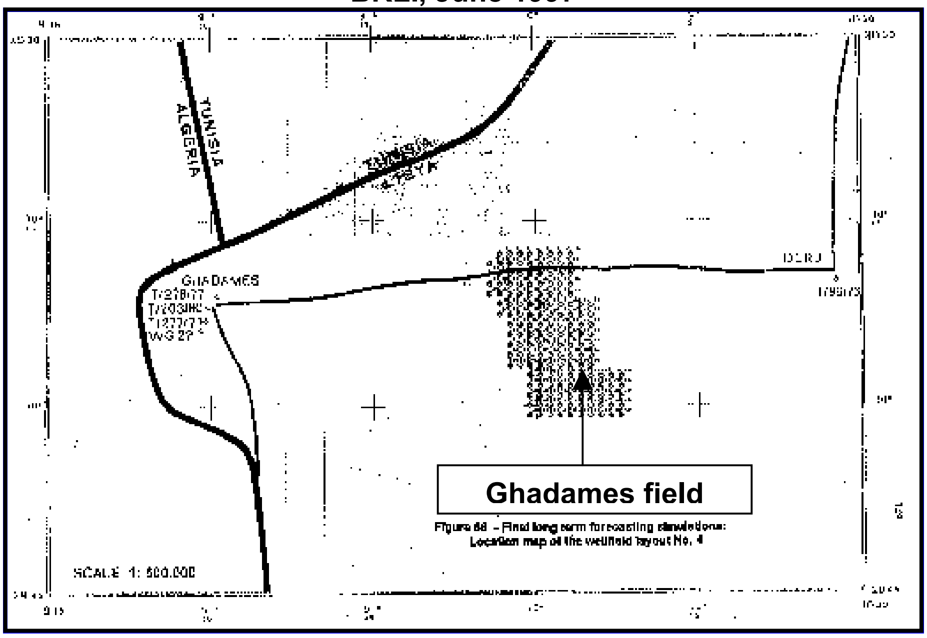
Conditions for the realization of this scenario, called «**Deficit Reduction Scenario in 2030** », as well as obtained results are shown in the third part of the report called « **Definition and Execution of Provisional Simulations** ».

Exploratory Simulations in Libya

The exploratory simulations shown hereafter concern the following programs:

- The pumping field planned in the region of Ghadames-Derj, corresponding to GMRP last phase, where an additional flow of 90 Mm^3/year will be exploited [BRLi, 1997]. The localization of the catching field is presented in Fig. 102. At the level of exploratory simulations, and as discussed above, a pumping at this regime will start in 2001.

Fig.102: Situation of the Catching Ghadames field ; BRLI, June 1997

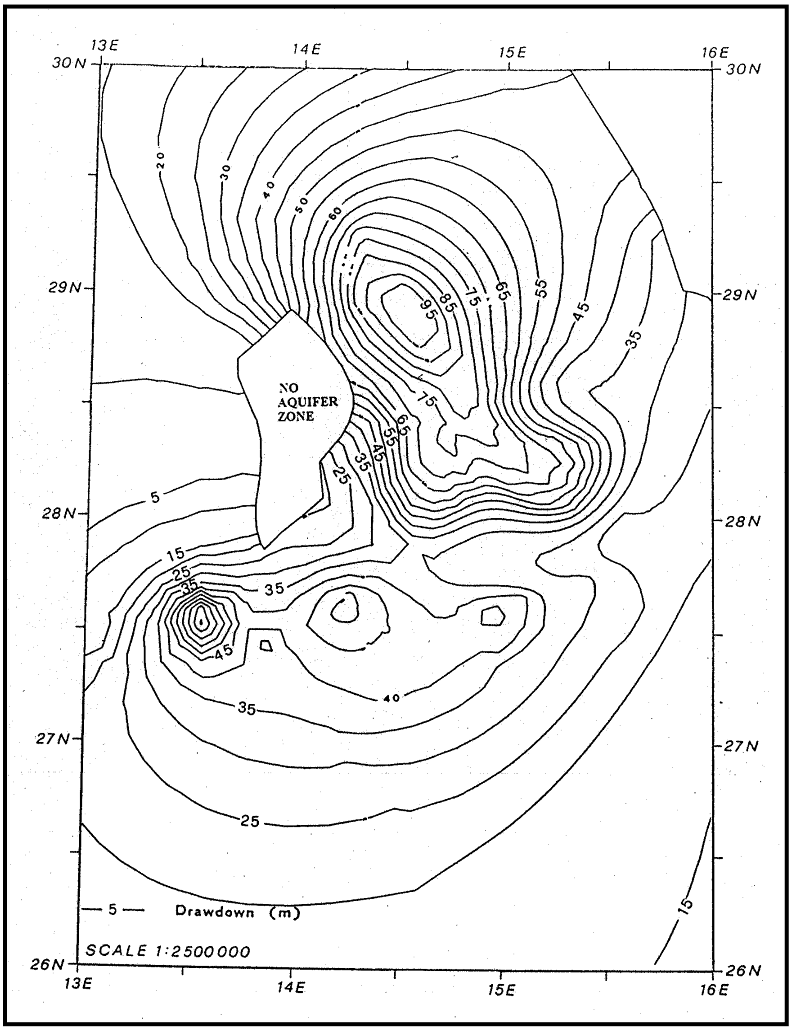


- The Catching Field of Djebel Hassaounah, where abstraction will start at a normal pace of **2.Mm^3/day**, [SPLAJ-GMRP, Brown & Root, final report, simulation N°6, GEOMATH, Dec.1994], hence a total flow of almost **23.m^3/sec**, through pumping at the large Cambro-Ordovician sandstone aquifer. This aquifer is not explicitly represented in our model, but we drew it since the beginning in an indirect way through a cell aquifer whose levels are imposed with the possibility of a temporal variation. Fig. 103, reproduced on the basis of GEOMATH documents, represents the drawdowns in the Cambro-Ordovician aquifer, calculated by Geomath Model in the time-frame 2046 at the end of a 50 year long calculation. This drawdown map will be used to determine the piezometric levels to

[3] Great Man Made River Project.

impose to the Cambro-Ordovician of NWSAS Model starting from 2001 according to the regime convention adopted for all exploratory simulations.

Fig. 103: Third Aquifer Unit – Calculated drawdown (m)
(in the project area exceeding 2046)
[simulation n°6]
GEOMATH, 1994



Summary of Exploratory Simulations

Finally, all Exploratory Simulations to conduct during this first phase of NWSAS study can be summarized as follows:

1. Keep the present state (2000 exploitation flows) or « Zero simulation », corresponding to Tunisia initial hypothesis
2. Algeria: Low hypothesis
3. Algeria: High hypothesis
4. Libya: Ghadames field.
5. Libya: Impact of pumping operations in Jebel Hassaouna

The following table 22 presents the Pumping Flows to show on NWSAS Model for each simulation:

Table 23: Summary of Exploratory Simulations

Scenario	CI Drills m^3/s	CT Drills m^3/s	Total NWSAS Drills m^3/s
Zero simulation			
Algeria [1]	**21.2**	**20.9**	**42.1**
Libya [2]	**3.4**	**7.4**	**10.8**
Tunisia [3] *Upper sandstone included in the CI*	**2.7**	**14.5**	**17.2**
Total ZERO-SIM	**27.3**	**42.8**	**70.1**
Additional Flows			
Algeria_Low Hypothesis [4]	36.4	26.1	62.5
Algeria_High Hypothesis [5]	59.6	41.8	101.4
Libya_Ghadames field [6]	2.9	0.0	2.9
Libya_Jbel Hassaouna	0.0	0.0	0.0
Total of simulated flow rates			
Total low hypothesis = [1]+[2]+[3]+[4]	63.7	68.9	**132.6**
Total high hypothesis = [1]+[2]+[3]+[5]	86.9	84.6	**171.5**
Total Ghadames field_Libya = [1]+[2]+[3]+[6]	30.2	42.8	**72.9**

II- RESULTS OF EXPLORATORY SIMULATIONS

II.1- Maintenance of current situation: ZERO SCENARIO

It is necessary first to be able to forecast the system status for the time-frame 2050 in case we decided to maintain all NWSAS flows at their 2000 level.

This simulation constitutes the unavoidable reference to be able to *estimate the effect of any additional abstraction* that may be considered from the system: the evaluation of Provisional Simulations results can be efficiently made only with reference to results obtained from zero reference.

By maintaining the 2000 abstraction constant, we calculate the evolution of the system until time-frame 2050. The simulation of maintaining 2000 abstraction rates [values shown in year 2000 Model] over a long period of time, will help to test the Model forecasting capacity. This simulation allows the assessment of the long term impact [over time-frame 2050] of holding NWSAS abstraction at their current level: impacts in terms of additional drawdowns and reduction of the flow from natural outlets.

Table 24: Flow rates of the Zero Scenario

Flows of DEEP WELLS _ 2000_shown on Model _ m^3/s				
Aquifer /Country	**Algeria**	**Tunisia**	**Libya**	***Total***
C.I	21.2	2.2	3.4	26.8
S.G	0	0.5	0	0.5
M.C	20.9	14.5	7.4	42.8
Total	42.1	17.2	10.8	***70.1***

II.1.1- Results in terms of Piezometric and Drawdowns Levels 2050

In what follows and throughout this document, the drawdown values are calculated with reference to the Piezometric levels restored by the Model in 2000.

The following figures successively show:

- Map of piezometric levels in 2050 at the CI (fig.104)
- Map of drawdowns in 2050 at the CI (fig.105)
- Map of Artesian areas at the CI in 2050 (fig. 106)
- Map of piezometric levels in 2050 at the CT (fig.107)
- Map of Drawdowns in 2050 at the CT (fig.108)
- Map of N.P Depths at the CT in 2050 with regard to the Chotts level (fig. 109).

Marginal Continental

CI – Zero Scenario - Piezometry

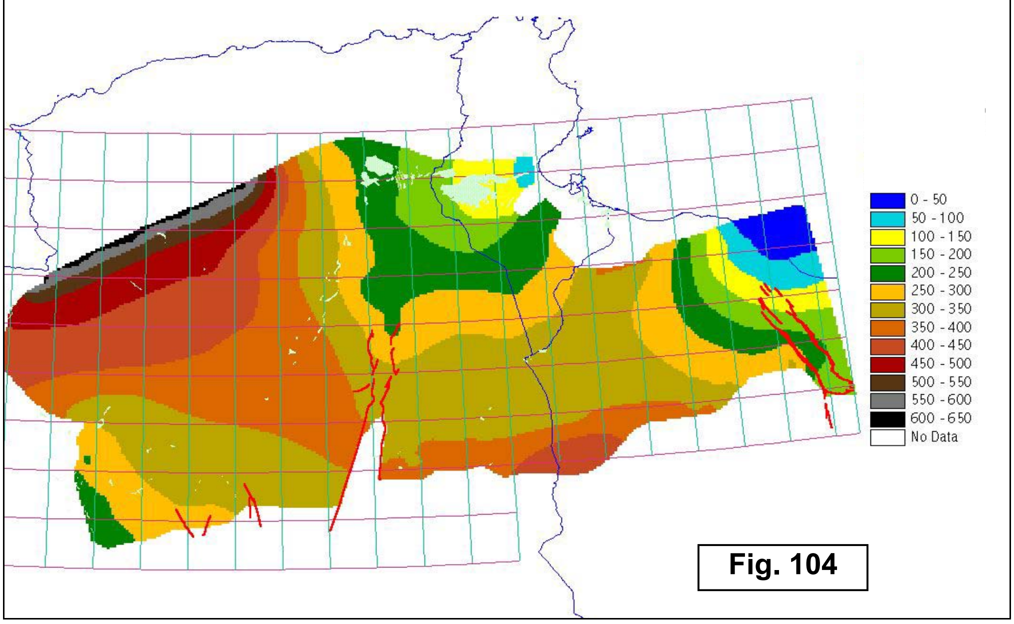


Fig. 104

Zero Scenario – Drawdowns 2050

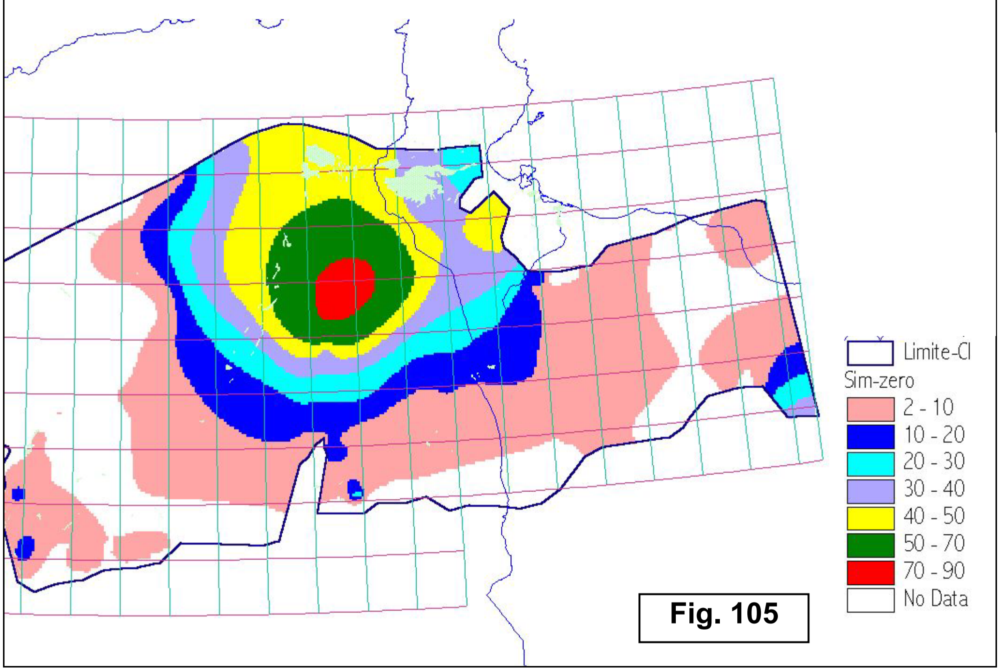


Fig. 105

Complexe Terminal

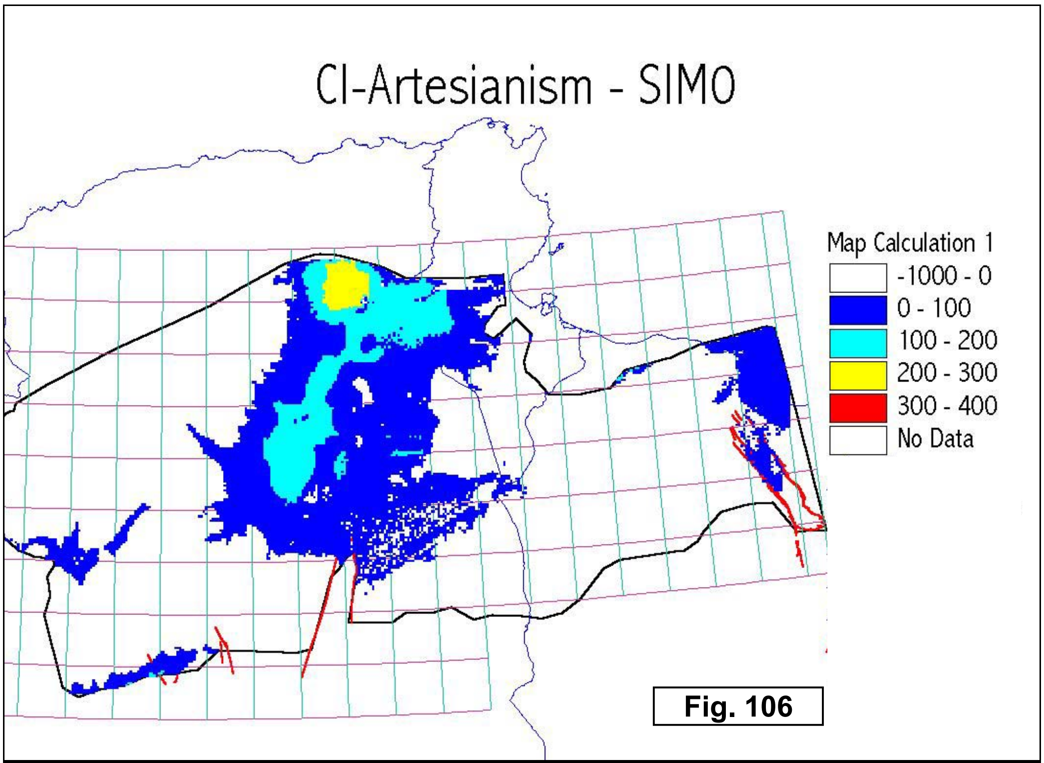


Fig. 106

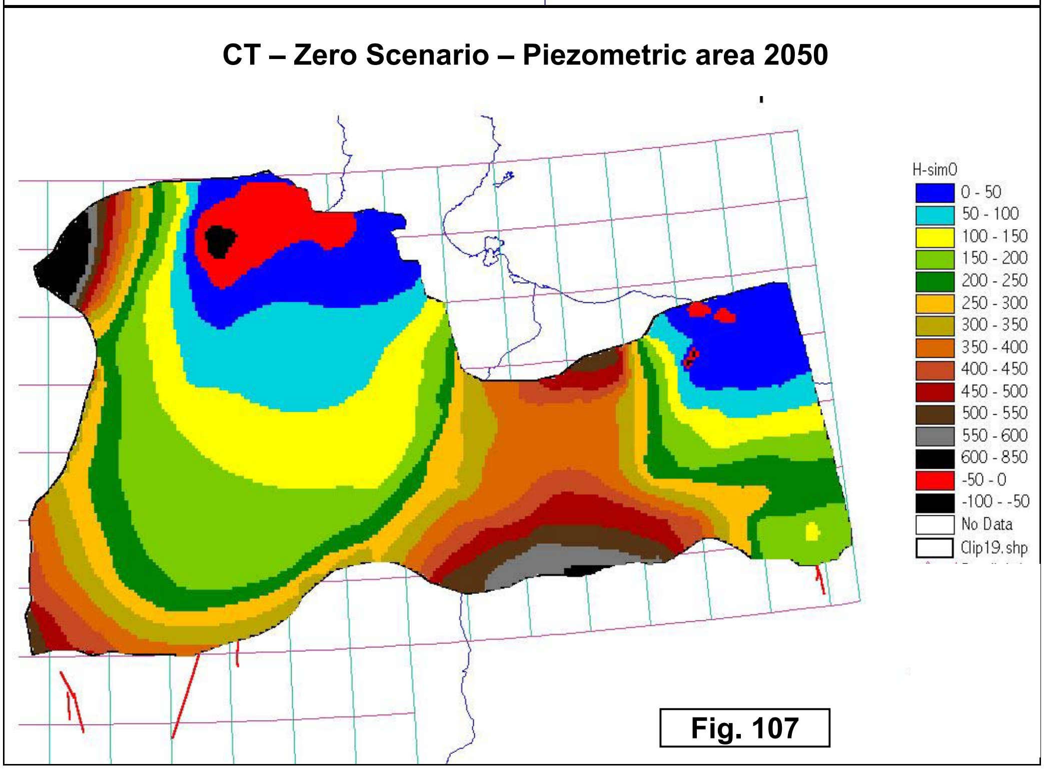


Fig. 107

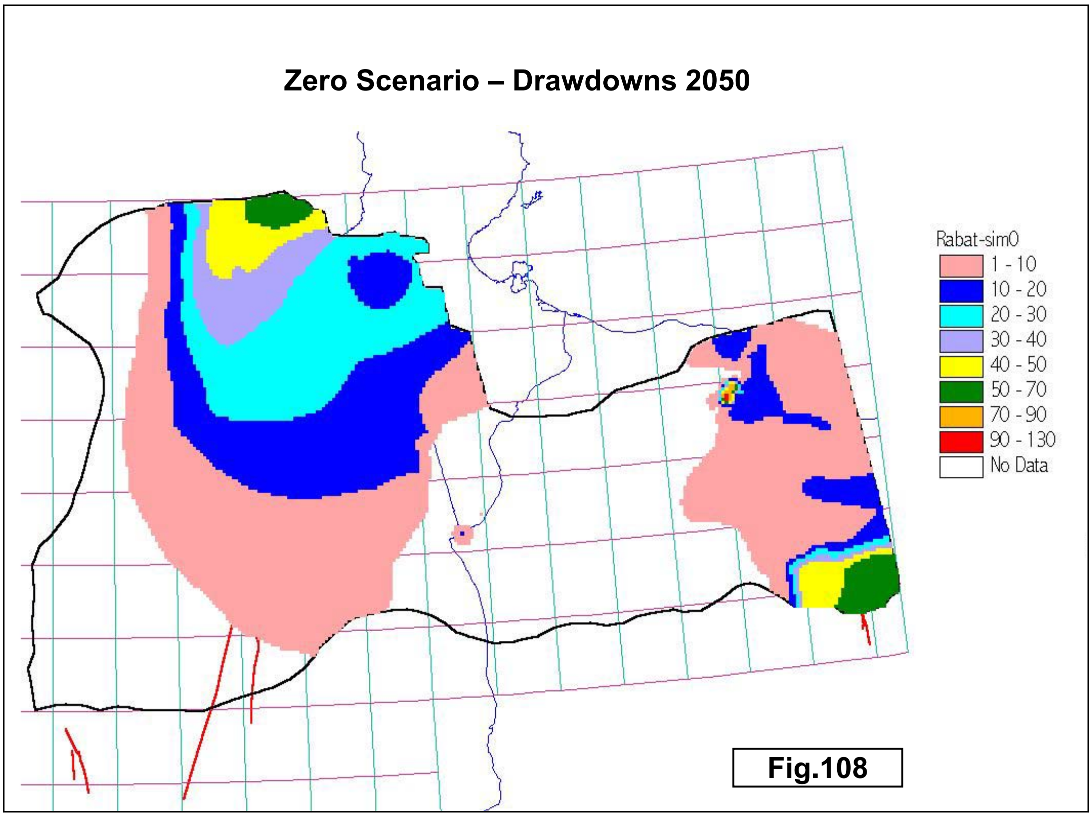


Fig.108

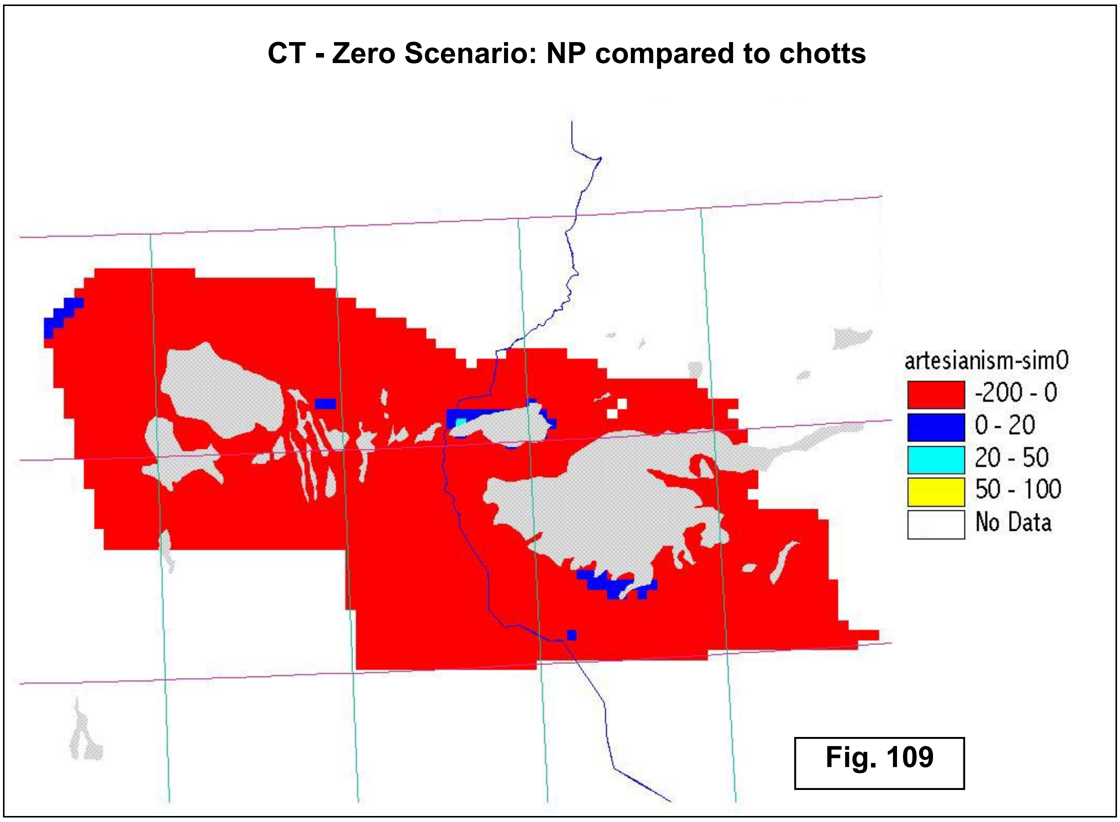


Fig. 109

II.1.2- Results in terms of water balance calculated in 2050

Table 25: Result in terms of water balance calculated 2050

Marginal Continental								
	1950	**2000**	**SIM-0**			**1950**	**2000**	**SIM-0**
Inputs (m^3/s)					**Outputs (m^3/s)**			
Recharge	9.4	9.4	9.4		Pumping	0.5	26.8	26.8
Of which: Saharan-Atlas	*7.5*	*7.5*	*7.5*		*Of which: Algeria*	0.5	21.2	21.2
South-Libya	*0.3*	*0.3*	*0.3*		*Tunisia*	0.0	2.2	2.2
Neffoussa	*1.1*	*1.1*	*1.1*		*Libya*	0.0	3.4	3.4
Dahar	*0.5*	*0.5*	*0.5*		Turonian Leakage	3.4	1.7	1.9
					Upper sandstone Leakage	0.4	0.5	0.5
Turonian Leakage	0.5	0.8	0.7		Saoura & S.Timimoun	0.2	0.2	0.2
Upper sandstone Leakage	0.0	0.0	0.0		Foggaras	3.60	3.15	1.95
Cambro-Ordovician	2.0	2.7	3.0		Tunisian Outlet	3.1	1.54	0.94
Eastern Boundary Input	0	0.003	0.008		Syrta bay	0.9	0.6	0.6
Contribution of reserves	0.0	21.5	19.8		Eastern Boundary	0.005	0	0
Total Inputs	**12.0**	**34.4**	**32.9**		**Total Outputs**	12.0	34.4	32.9

Complexe Terminal								
Inputs (m^3/s)	**1950**	**2000**	**SIM-0**		**Outputs (m^3/s)**	1950	2000	SIM-0
Recharge	18.2	18.2	18.2		Pumping	7.5	42.8	42.8
Of which: Saharan Atlas	3.8	3.8	3.8		*Of which: Algeria*	5.7	20.9	20.9
South western Boundary	6.0	6.0	6.0		*Tunisia*	1.3	14.5	14.5
South Lybia	1.0	1.0	1.0		*Libya*	0.5	7.4	7.4
Nefoussa	0.6	0.6	0.6		Turonian Leakage	2.4	2.7	2.8
Dahar	6.1	6.1	6.1		Ain Tawargha Spring	2.0	1.6	1.3
North of Chotts	0.7	0.7	0.7		Algerian Tunisian Chotts	7.3	1.6	0.0
Turonian Leakage	5.4	6.9	7.2		Sebkha Mjezem-Tawargha	0.2	0.2	0.2
Of which: Algeria	1.3	1.3	1.4		Syrta Bay	0.6	0.6	0.5
Tunisia	0.3	0.2	0.2		Ain Kaam	0.3	0.1	0.0
Libya	3.8	5.3	5.6		Nefzaoua Djrerid Springs	2.1	0.0	0.0
Contribution of reserves	0.0	24.9	22.1		Algerian Sebkhas	1.2	0.4	0.0
Total Inputs	23.6	50.	47.5		**Total Outputs**	23.6	50.	47.5

Upper Sandstone - 2050	**SIM-0**
Outputs (m^3/s)	
Turonian Leakage	0
CI Leakage	0.47
Contribution of reserves	0
Total Inputs	0.47
Outputs (m^3/s)	
Total Outputs	0.47
Pumping	0.46
Turonian Leakage	0.01
Chott Fedjej	0

III- ALGERIA: HIGH WATER HYPOTHESIS

III.1- Simulated Abstraction and their Localization

Table 26: Simulated abstraction and their location

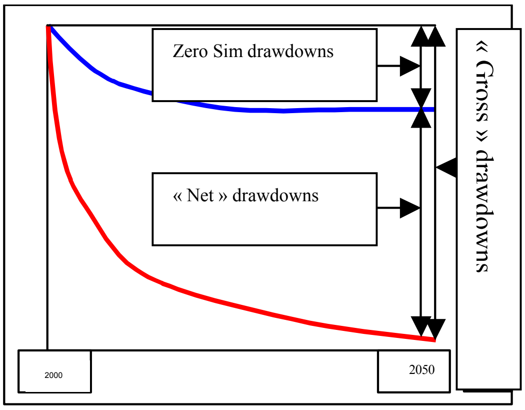
Algeria _ High Hypothesis	
CI _ Additional Q _ m3/s	
TOUAT-GOURARA-TIDIKELT	29.0
BISKRA	1.4
OUED RHIR	7.0
OUARGLA	4.0
SOUF	3.9
MZAB	14.3
TASSILI	0.0
Total	**59.6**

Algeria _ High Hypothesis	
CT _ Additional Q- _ m3/s	
O.RHIR	4.3
OUARGLA	10
H.MESSAOUD-G.TOUIL	19.5
SOUF	8.0
TOTAL	**41.8**

III.2- Results in terms of Drawdowns and Levels

Gross Drawdowns Vs. Net Draw-Dawns

If in a given point and at a given time, s_0 refers the drawdown calculated in this point and at this time during the zero simulation, s_b refers to <u>the gross drawdown</u> or drawdown in this point and at the same time calculated during the high hypothesis, then s_n, as $sn = s_b - s_0$, will refer to the <u>net drawdown</u> in the same point and at the same time corresponding to the same simulation during the high hypothesis



The following figures respectively show:

- The drawdown map in 2050 at the CI after deducing drawdowns of Simulation Zero (fig.110) and that we will call **« net drawdowns »** (see box)
- Map of Piezometric levels calculated in 2050 at the CI (fig. 111)
- Map of Piezometric levels calculated in 2050 at the CT (fig. 112)
- Map of net drawdowns in 2050 at the CT (fig. 113)
- Drawdowns of Zero Scenario in the upper sandstones (fig. 114)
- Map of gross Drawdowns of the high hypothesis in the upper sandstones (fig. 115)
- Map of net drawdowns in the high hypothesis in the upper sandstones (fig. 116)

Marginal Continental

CI - High Hypothesis: Drawdowns 2050

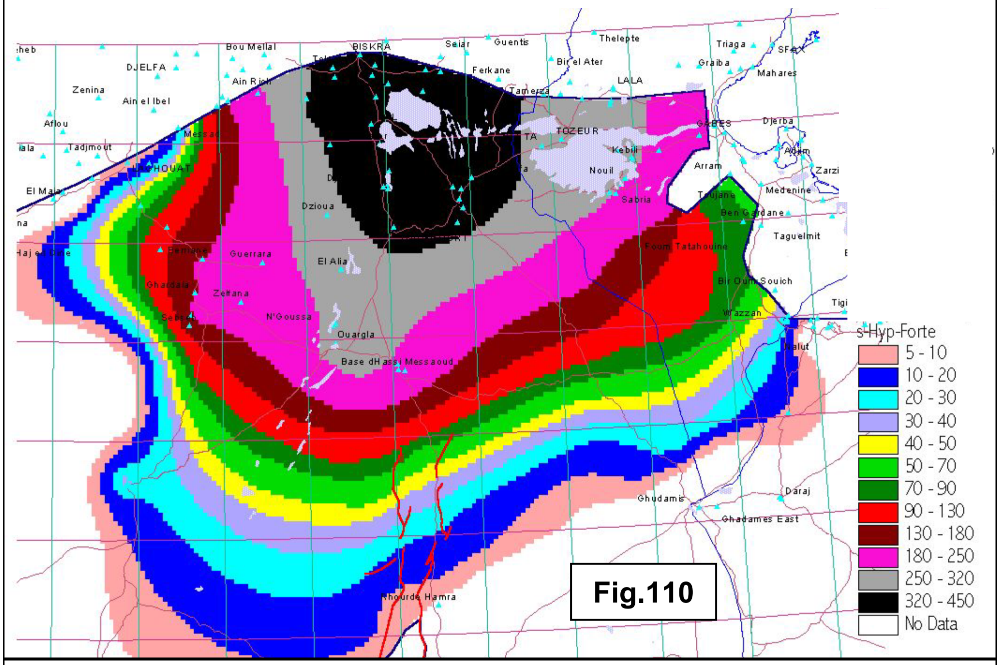


Fig.110

High Hypothesis – piezometric area 2050

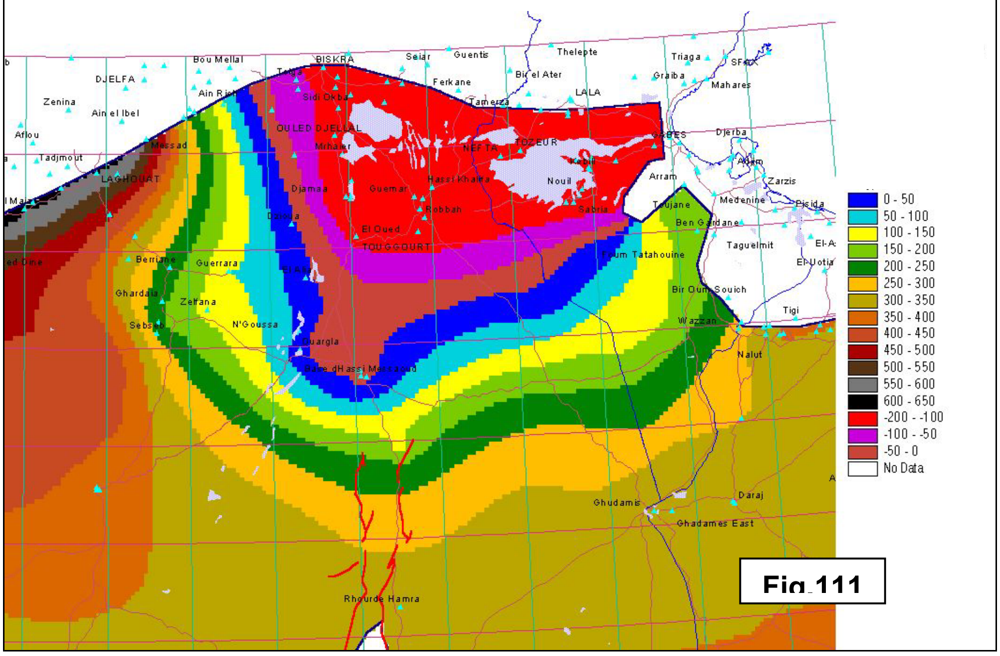


Fig.111

Complexe Terminal

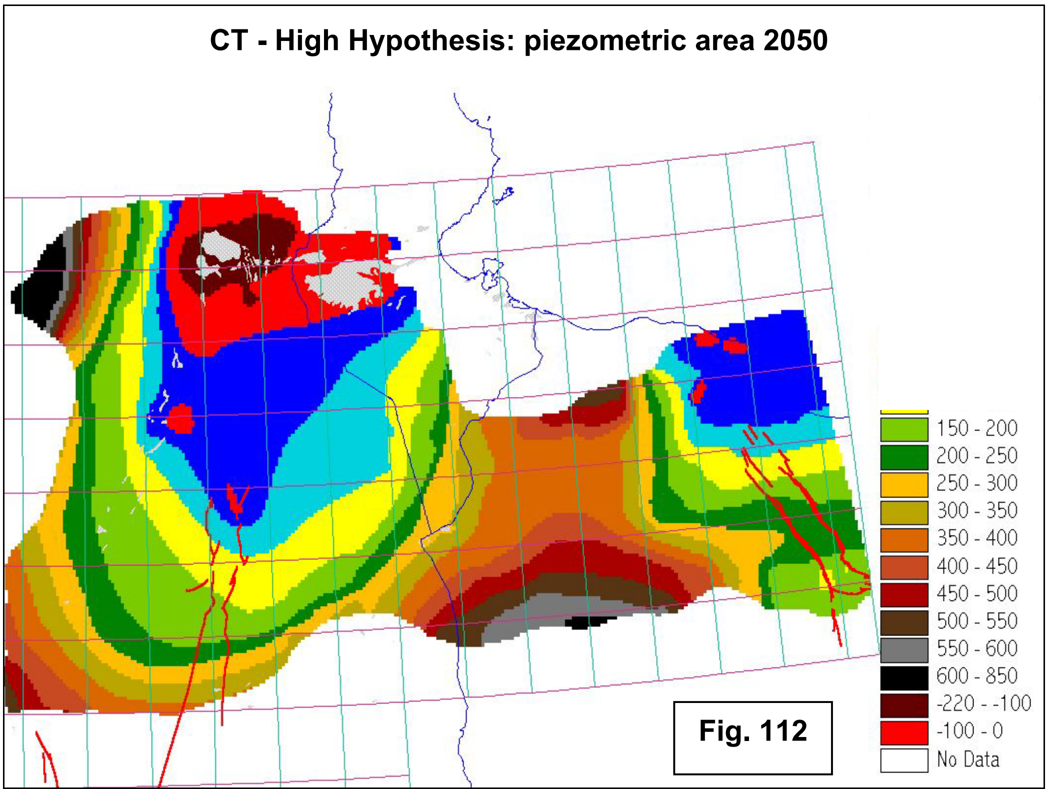


Fig. 112

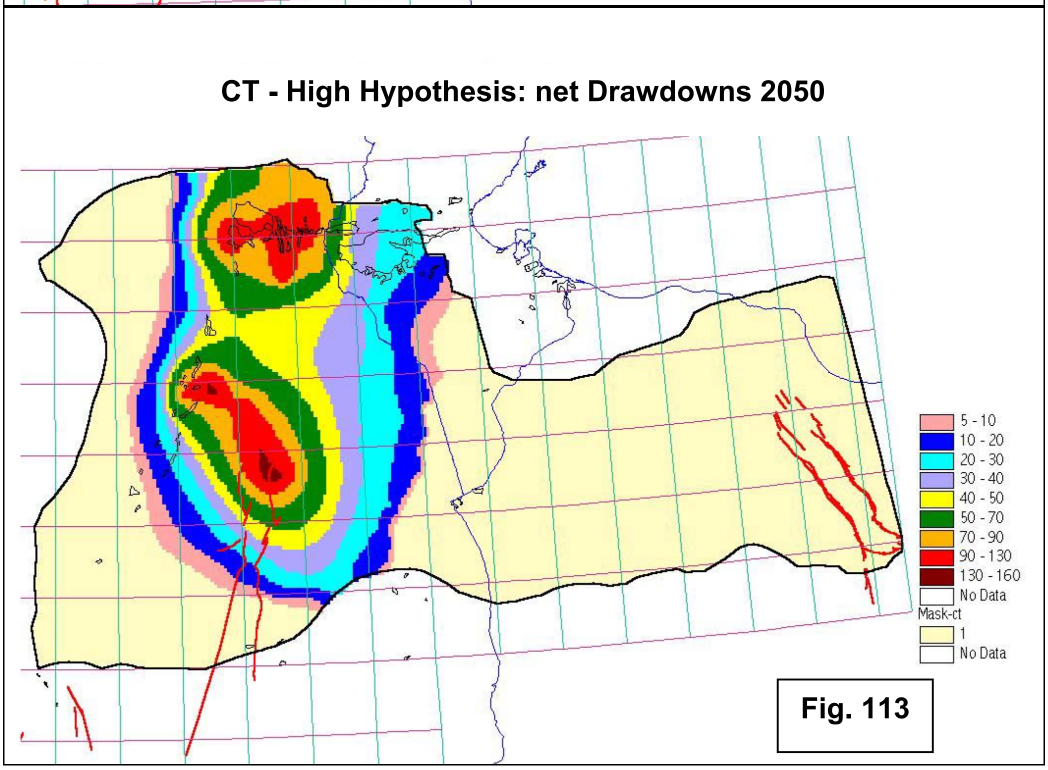


Fig. 113

Upper Sandstone

Upper Sandstone: Drawdowns 2050 Simulation zero

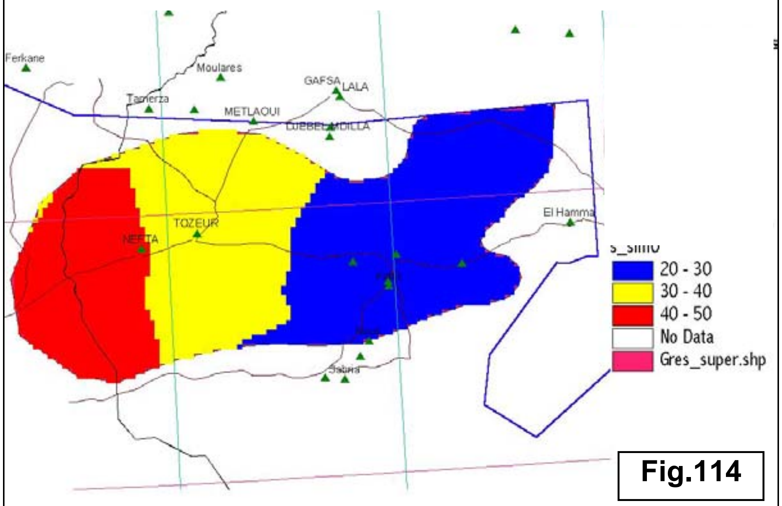


Fig.114

Algeria High Hypothesis: Total Drawdowns Upper Sandstone

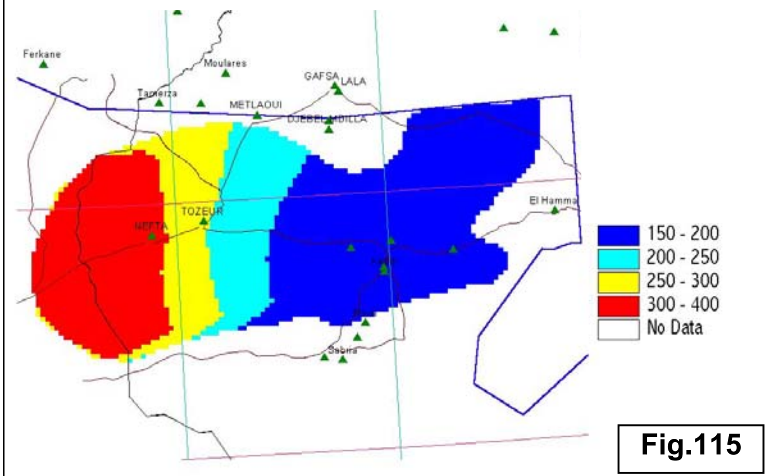


Fig.115

Algeria High Hypothesis: Net Drawdowns 2050 Upper Sandstone

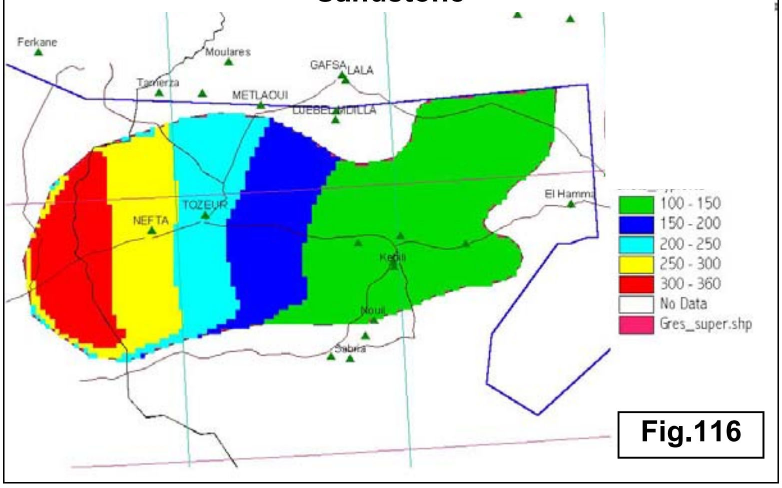


Fig.116

IV- ALGERIA: LOW HYPOTHESIS

IV.1- Reminder of Simulated Abstraction

Table 27: Reminder of simulated abstraction

Algeria _ Low Hypothesis	
CI _Additional Q- _ m3/s	
TOUAT-GOURARA-TIDIKELT	16.6
BISKRA	1.1
OUED RHIR	6.0
OUARGLA	2.0
SOUF	2.5
MZAB	8.2
TASSILI	0.0
TOTAL	36.4

Algeria _ LOW Hypothesis	
CT _ Additional Q- _ m3/s	
O.RHIR	3.8
OUARGLA	5
H.MESSAOUD-G.TOUIL	12.3
SOUF	5.0
TOTAL	26.1

IV.2- Results obtained in terms of levels and drawdowns

The following figures show results obtained in the form of:

- Map of net drawdowns in 2050 at the CI (fig.117)
- Map of Piezometric levels in 2050 at the CI (fig. 118)
- Map of net drawdowns in 2050 at the CT (fig. 119)
- Map of NP Depths at the CT in 2050 under the level of Chotts (fig.120)

Continental Intercalaire

CI – Low Hypothesis: Drawdowns 2050

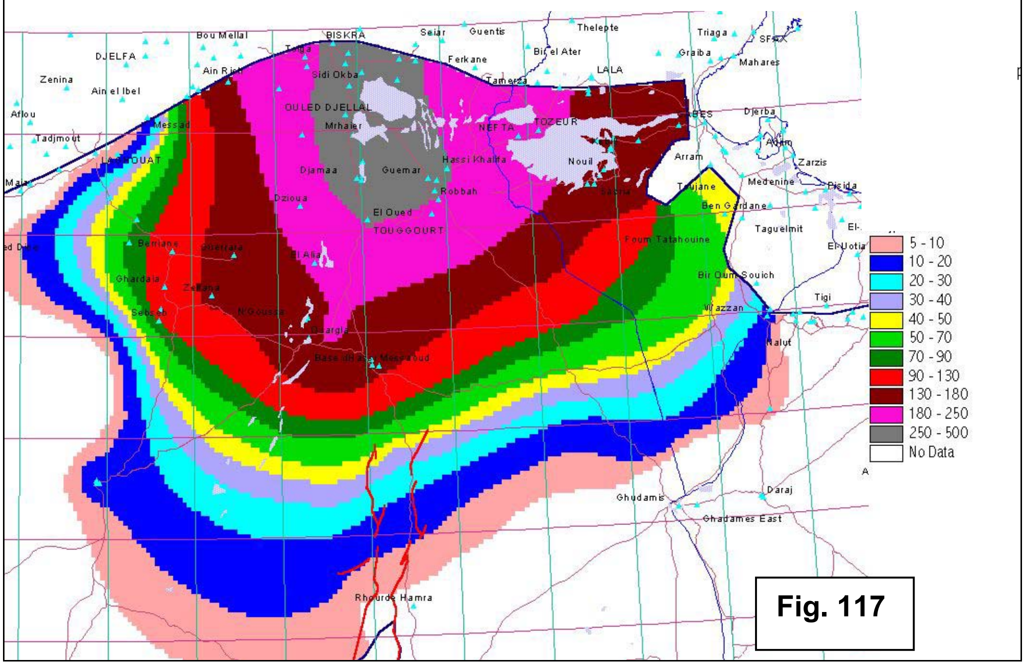


Fig. 117

CI - Low Hypothesis: piezometric area 2050

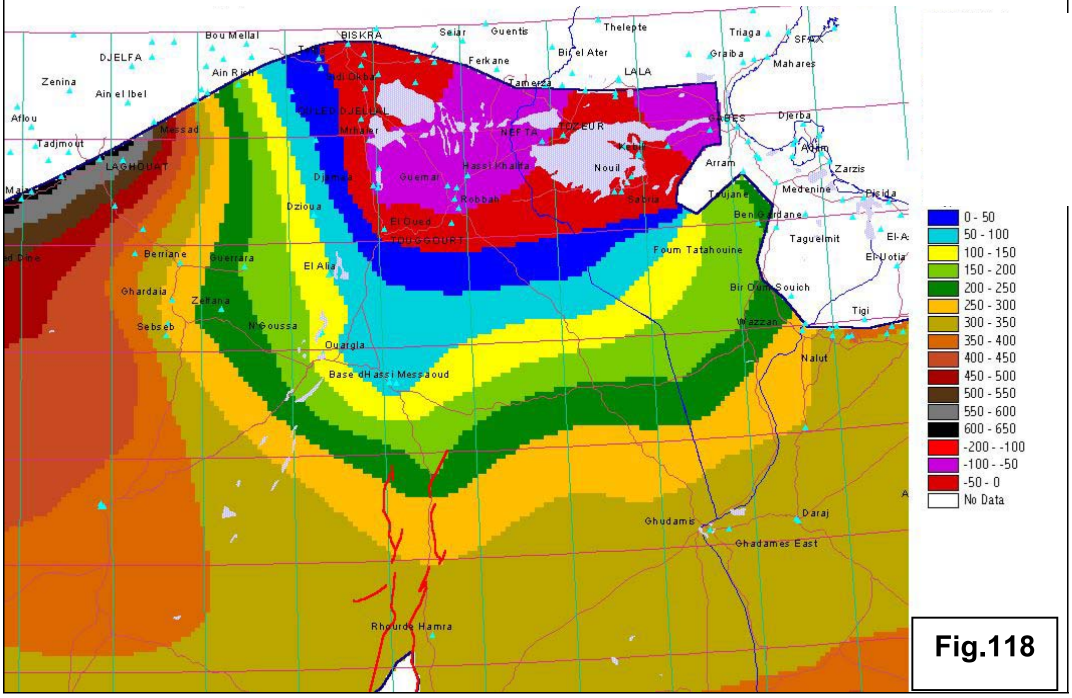


Fig.118

Complexe Terminal

CT – Low Hypothesis: net Drawdowns 2050

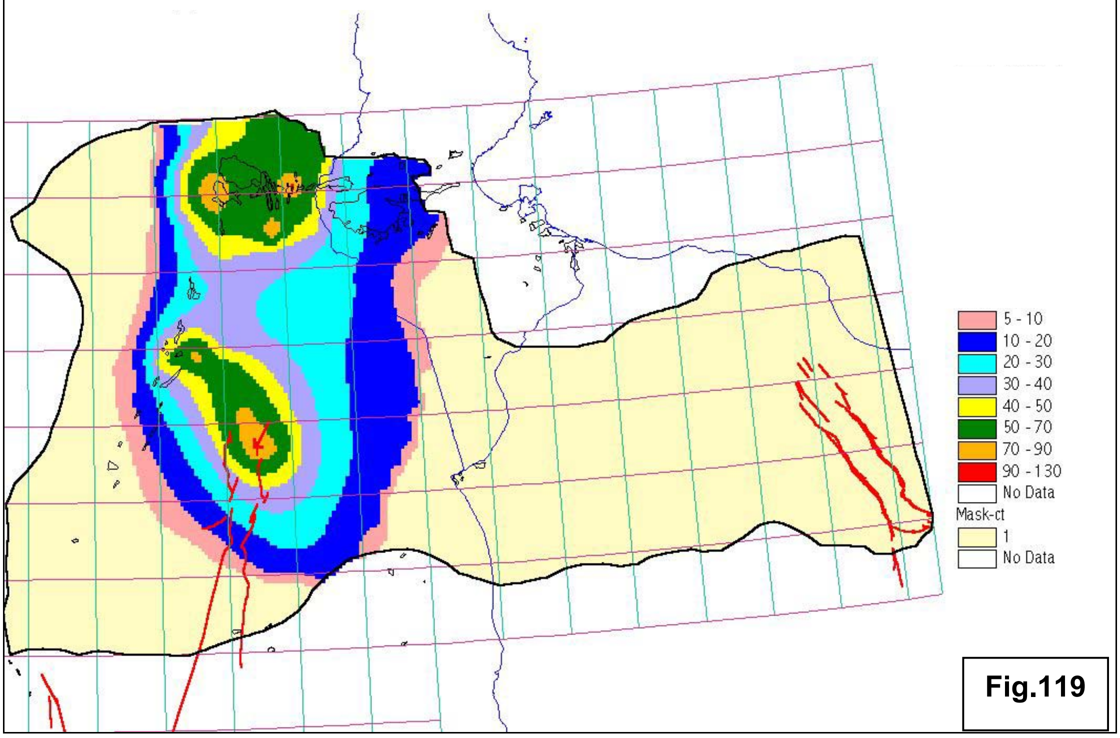


Fig.119

CT - Low Hypothesis: NP 2050 under level of Chotts

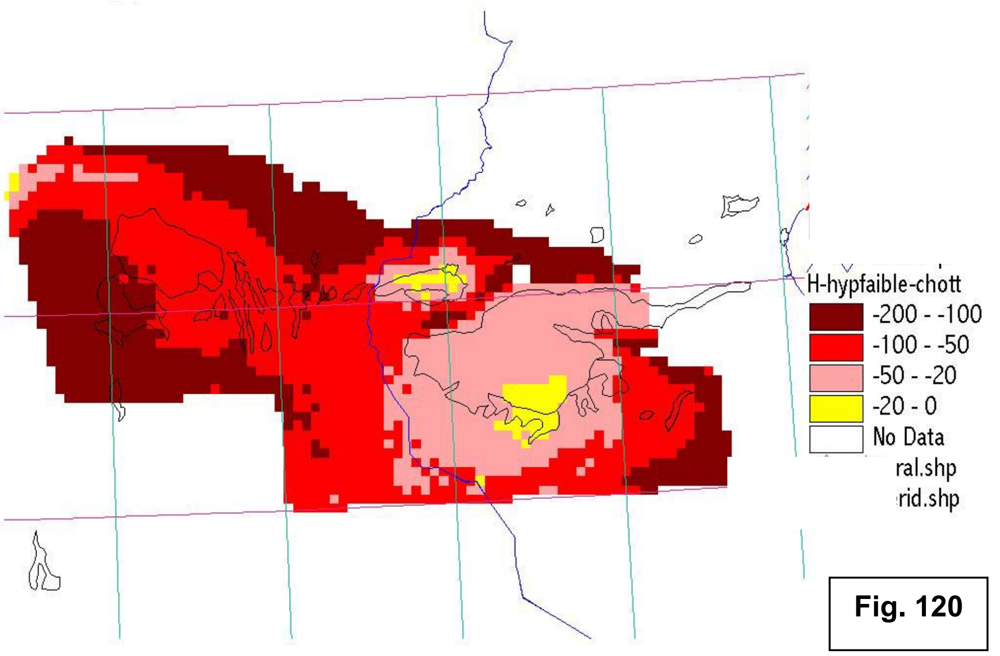


Fig. 120

V- LIBYA: GHADAMES FIELD

This simulation represents the continuous pumping of a flow of **2.85m^3/s** at the catching field of Ghadames-Derj (Marginal Continental) from 2001 to 2050.

The net drawdowns (specific impact on Ghadames field, with no consideration of effects of keeping to the existing) are presented hereafter (fig. 121).

Scenario of Ghadames field – net drawdowns 2050

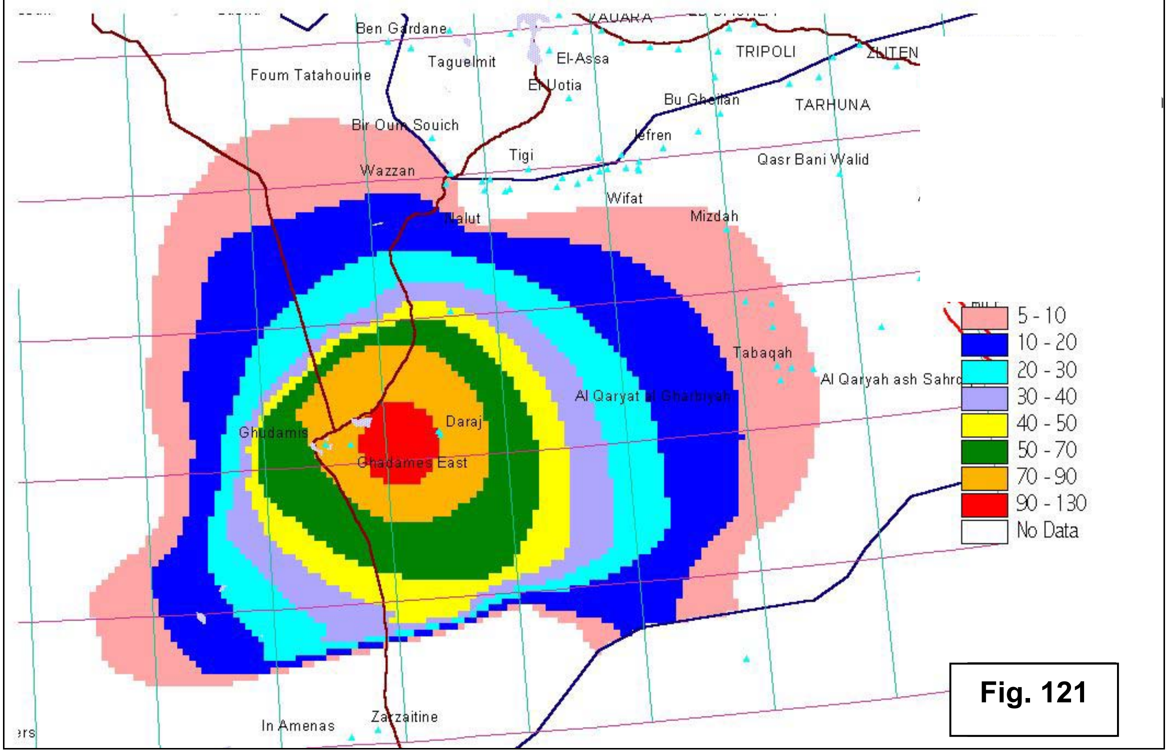


Fig. 121

VI- LIBYA: DJ. HASSAOUNA FIELD

Drawdowns calculated by GEOMATH (fig.103 &122) were used to determine the potentials of the Cambro-Ordovician aquifer, constantly imposed from 2001 to 2050.

Calculated results, net drawdowns at the CI calculated in 2050, (specific impact on the catching field of Dj. Hassaouna, with no consideration on effects of keeping to the existing) are presented hereafter (fig 123).

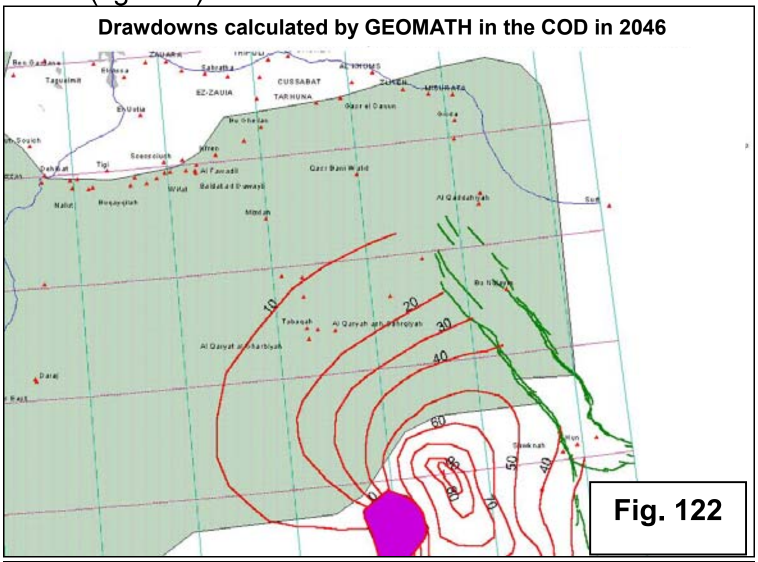


Fig. 122

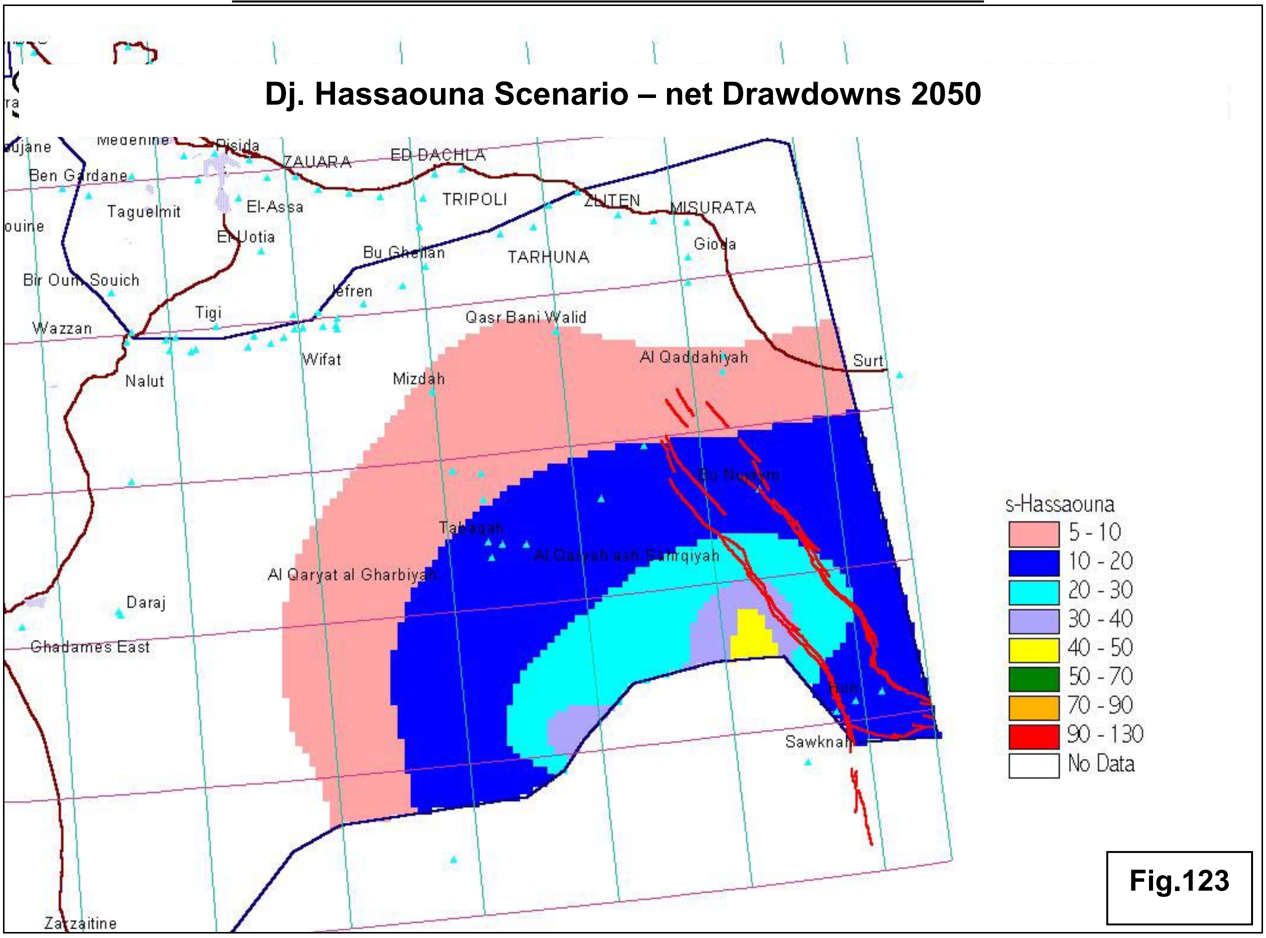


Fig.123

VII- DRAWDOWN TEMPORAL EVOLUTION

Fig. 124 to 128 show the drawdown curves calculated between 2000 and 2050. The selected core-wells were used to wedge the Model in a transient regime and represent large hydraulic regions with homogeneous behaviour, regions highly prompted by simulations, or still subject to important external influences. They are:

For the CI: Wadi Rhir (Tamerna), the Tunisian outlet (CF), Ghadames Basin (WG),

For the CT: Wadi Rhir (Mghaier), Djerid (Tozeur).

- BLUE → Zero Simulation
- RED → Algeria, High Hypothesis
- GREEN → Algeria, Low Hypothesis
- BROWN → Ghadames field, in Libya

VII.1- Continental Intercalaire – KIKLAH

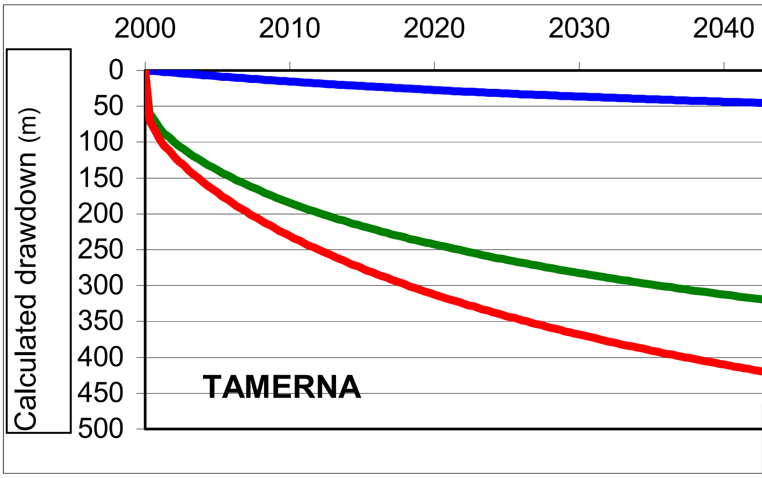


Fig. 124

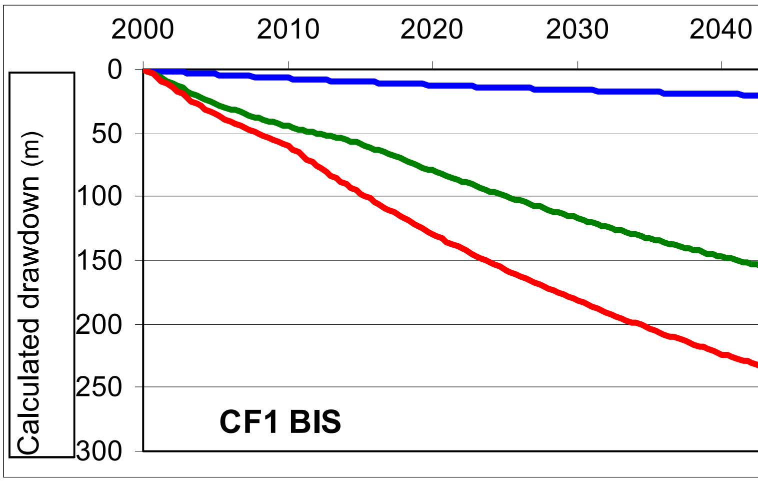


Fig. 125

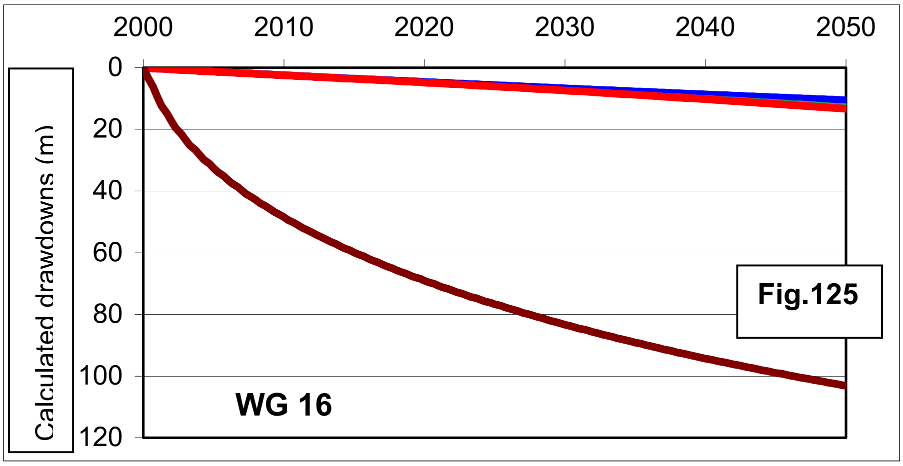


Fig.125

VII.2- Complexe Terminal

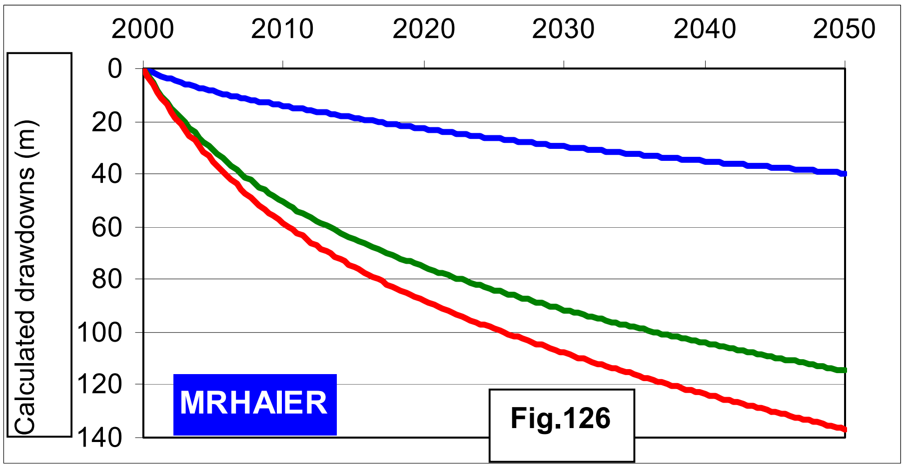


Fig.126

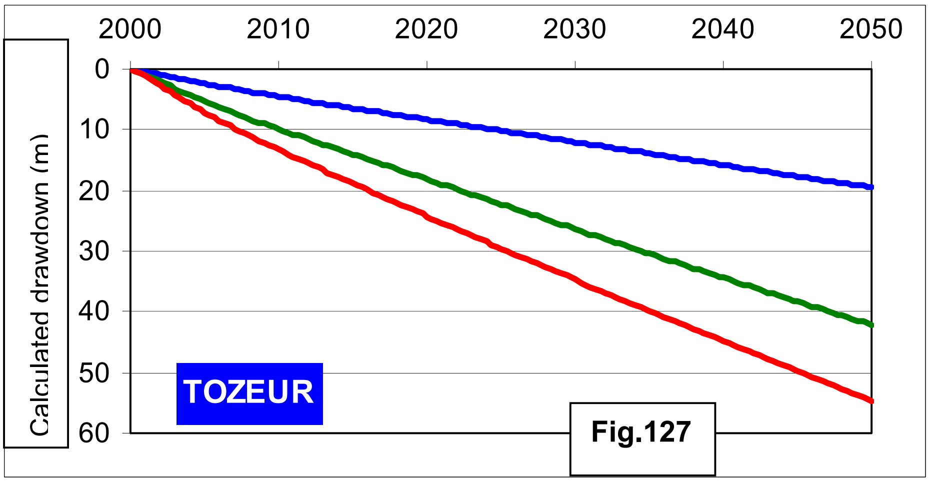


Fig.127

VIII- WATER BALANCE TIME-FRAME 2050

Budgets calculated for 2050 for each of the simulations conducted are presented hereafter and for each of NWSAS aquifers: CT, CI and Grès Supérieurs. In order to help the reader to follow the evolution of the different budget terms and throughout time, there should be reminded, in the first columns of every table, the system water budgets respectively calculated at the initial status in 1950 and at their current rate in 2000.

In the last table, we show the evolution, for each of the simulations and since 1950, of the flow of the three main natural outlets of the Saharan basin:

- Tawargha spring,
- The Tunisian outlet,
- The Foggaras.

Table 28: Evolution of the flow rates of the three main natural outlets of the Saharan basin since 1950

CT Simulations Water budget 2050 m3/s	Initial status 1950	Current Status 2000	Zero Simulation	Algeria low Hypoth.	Algeria high Hypoth.	Libya Hassaouna	Libya Ghadames
Inputs (m^3/s)							
Supply	18.2	18.2	18.2	18.2	18.2	18.2	18.2
Turonian Leakage	5.4	6.9	7.2	7.2	7.4	7.0	7.1
Contribution or reserves	0	24.9	22.1	48.3	64.0	22.4	22.3
Total Inputs	*23.6*	*50.*	*47.5*	*73.8*	*89.6*	*47.6*	*47.6*
Outputs (m^3/s)							
Pumping	7.5	42.8	42.8	68.8	84.6	42.8	42.8
Turonian Leakage	2.4	2.7	2.8	3.0	3.1	2.9	2.9
Springs & Sebkhas	13.7	4.5	1.9	1.9	1.9	1.9	1.9
Total Outputs	*23.6*	*50.*	*47.5*	*73.7*	*89.6*	*47.6*	*47.6*

CI Simulations_ Statement 2050 m3/s	1950	2000	Zero Simul.	Low Hypo	High Hypo	Dj Hassa	Libya Ghad
Inputs (m^3/s)							
Supply	9.4	9.4	9.4	9.4	9.4	9.4	9.4
Turonian Leakage	0.5	0.8	0.7	0.8	0.8	0.9	1.0
Upper sandstone G.sup	0	0	0.0	0.0	0.05	0.0	0.0
COD Contribution	2.0	2.7	3.0	3.0	3.0	2.3	3.1
Contr. Reserves	0	21.5	19.8	53.7	76.5	19.9	22.2
Eastern boundary	0	0.003	0.008	0.008	0.008	0.009	0.008
Total Inputs	*12.0*	*34.4*	*32.9*	*66.9*	*89.8*	*32.5*	*35.7*
Outputs (m^3/s)							
Pumping	0.5	26.8	26.8	63.2	86.4	26.8	29.7
Tur Leakage	3.4	1.7	1.9	1.9	1.9	1.6	1.9
Upper sandstone leakage	0.4	0.5	0.5	0.2	0.1	0.5	0.5
-Sebkhas springs	7.7	5.4	3.7	1.6	1.4	3.6	3.6
To COD	0	0	0	0.01	0.01	0.02	0
Total Outputs	***12.0***	***34.4***	***32.9***	***66.9***	***89.8***	***32.5***	***35.7***

Upper sandstone Water budget 2050 m^3/s	1950	2000	Zero Sim	Low Hypo.	High Hypo	Libya Hassa	Libya Ghad
Inputs (m^3/s)							
Tur. Leakage	0	0	0	0.3	0.4	0	0
CI Leakage	0.4	0.5	0.5	0.2	0.1	0.5	0.5
Reserves	0	0	0	0	0	0	0
Total Inputs	***0.4***	***0.5***	***0.5***	***0.5***	***0.5***	***0.5***	***0.5***
Outputs (m^3/s)							
Pumping	0	0.46	0.46	0.46	0.46	0.46	0.46
Tur Leakage	0.15	0.04	0.01	0	0	0.01	0.01
CI Leakage	0	0	0	0	0.05	0	0
Chott Fedjej	0.26	0	0.0	0.0	0	0.0	0.0
Total Outputs	***0.4***	***0.5***	***0.5***	***0.5***	***0.5***	***0.5***	***0.5***

IX- SIMULATIONS RESULTS ANALYSIS

IX.1- Effects of proceeding with the present situation

IX.1.1- At the Continental Intercalaire

The simple holding of current abstraction rates would result by **the time-frame 2050 in important drawdowns (**measured with reference to 2000 levels**) in the most southern part of the Algerian Sahara, higher than 40 m over an area of about 200.000 Km^2**, approximately centralized on the axis El Oued-Hassi Messaoud. Elsewhere in Algeria and namely in CI emergence areas, drawdowns remain limited, particularly in Adrar Province where the maximum is about **15 m** in Touat.

In Tunisia, drawdowns are everywhere superior to 20m. They exceed **40m** in the sector of Ksar Ghilane and are about **25m** around Chott Fedjej.

In Libya, drawdowns are almost 25m over a 100 km x 300 Km band surrounding major exploitation centres: Bani Walid, Wadi Zamzam, Wadi Ninah, Sufajin. Elsewhere, calculated drawdowns average 10 m overall Hamada El Hamra.

The determination of piezometric levels depth (fig.106) shows that artesianism boundaries calculated in 2050 are not very different from current boundaries: the loss of artesianism is limited to the sectors of El Borma and Ghadames. We should note that in these areas located in dipping regions (0m depth regions), our results depend very much on the altimetric accuracy of the field digital Model we are using, as well as of course on the precision of the piezometric level calculations of our own model: the latter can be evaluated by the « setting discrepancies » admitted on the system initial piezometric situation, calculated by the model in 1950.

IX.1.2- On the Aquifer Upper Sandstone

The 2050 drawdowns range between 20m on the east (in the vicinity of Chott Fedjej) to **50m at the western boundary of the aquifer.**

IX.1.3- At the Complexe Terminal

In Algeria, the 2050 drawdowns exceed 30m in all the valley of Oued R'hir in the north of Toggourt; they reach 60 m in the North of the Chotts.

In Tunisia, drawdowns range between 20 and 30 m in all the Dejrid and Nefzaoua. In Libya the drawdowns maximal rates (about 60 m) can be found in the South East, around the communities of Soknah, Hammam and Ferian.

On the other hand, the map of Piezometric levels and that of NP depths with respect to the ground, clearly indicate, when compared to the present situation, the *total disappearance of all forms of artesianism in the Algerian-Tunisian Chott region*. We can even note that the chotts of Merouane and Melrhir are totally « suspended » over the CT piezometric surface, and the same can be found in Tunisia, in the Djerid as well as in Nefzaoua, with all that this particular situation so far unknown in the region implies in terms of « re-supply » risks of the CT aquifer by waters from the Chott.

Concerning this possible phenomenon, we do not know more today than several years ago. In fact, if there is a possible spring for a major salt contamination in the CT aquifer, it may mainly be generated by the Tunisian and Algerian Chotts.

An accurate modelling of the links between the CT aquifer and the chotts requires a fine analysis and a full consideration to the mechanisms regulating exchanges between these two units.

This analysis, which has not yet been addressed at the local and regional scales, obviously cannot yet be seriously developed at the level of NWSAS. In our model, the link is made through a simple vertical permeability, and the transfer of materials will be instantaneous if it can be activated.

In practice, the current version of NWSAS model does not provide for links between the CT and the Chott when the latter is dewatered. In fact, some salinity records available in NWSAS database and the arrangement of corresponding deep drills around the chotts do not lead to the conclusion that increases recorded can be the result of salt inputs from the Chotts.

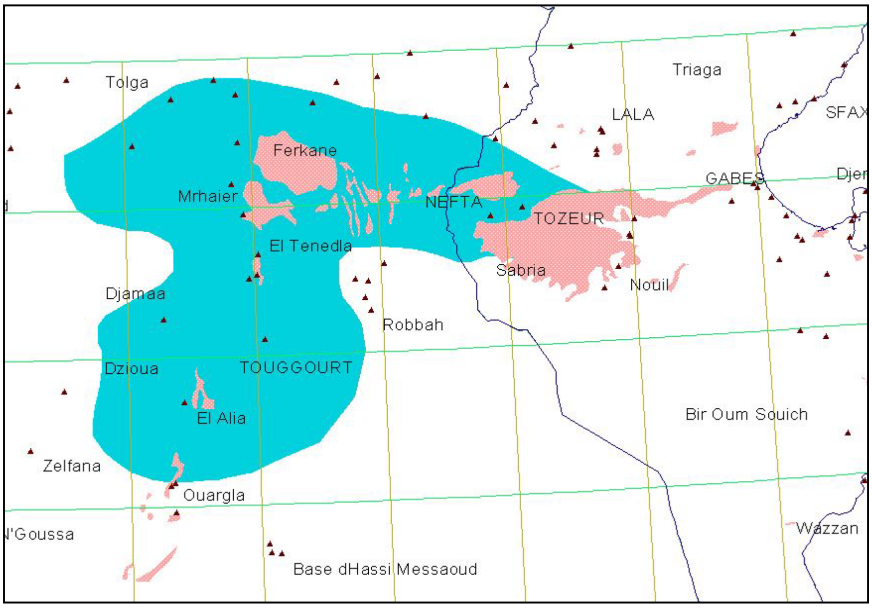
In fact, we do not have yet scientifically validated observations that can efficiently describe relations and flows between the Chotts and the CT aquifer. These two entities are also generally not directly connected.

Indeed, in Algeria, the chotts area corresponds to a collapsing area where impermeable formations of the evaporitic Eocene are developed. (cf. fig. 59 and 129).

In Tunisia, the CT formations lie very deep below Chott Djerid, the latter having been the seat of high MioPliocene subsidence; but this series sharply bevels around the Chotts, and preferential communications, in both ways, would not be excluded namely in the South East in Nefzaoua, and in the North towards the sector Djerid.

In fact, important flows from the CT aquifer towards the Chotts can be limited to a simple hydrodynamic speculation, highly induced by the regional piezometry, if there were no « ajouns » in Chott Djerid, whose important flow initially evaluated between 3 and 5 m3/s can only be generated by the CT aquifer.

fig. 129:Extension boundary of Evaporitic Eocene under the MioPliocene (according to Bel and Demargne)



Concerning the CI aquifers, the Chotts represent a major risk, as important drawdowns in the water table in the vicinity of the Chotts can induce the arrival of over-salty contents and hence result in irreversible degradation of water resprings.

The Model can serve to calculate with accuracy the time when a possible recharge of the aquifer by the Chott can take place. The first indicator enabling the evaluation of such a risk is provided by the position of the piezometric level of the aquifer relatively at the level of the Chott.

**fig. 130: Artesian springs of Chott Djerid, « Aiouns »,
photo by Berkaloff, (in M. Gosselin, 1952)**

Fig. 100-a, 100-b and 109 (NP depths calculated under the ground) show very well the evolution reconstituted over the last 50 years and **the foreseeable evolution of this indicator over the next 50 years.**

While in 2000, there was still a considerable artesianism area namely on the southern shore of Chott Djerid and in the North of Meherir (fig. 100-b), in 2050, artesianism has totally disappeared from the region of the Chotts, and we can even observe (fig. 109) that there are sectors like Kebili peninsula, Nefzaoua, Djerid, Chotts Merouane and Melrhir which seem to be seriously threatened as the CT aquifer PL is systematically below the level of the Chotts.

From the point of view of salt contamination risks, these sectors are already highly exposed, without even the addition of any new abstraction: ***the simple continuation of current abstraction risks constitutes a major possible danger.***

In Libya, artesianism decreased but has not completely disappeared. There still remains for 2050 some islands and namely in the coastal zone constituting the most exposed area to the flows inversion risks.

IX.2- Effects of the High Hypothesis in Algeria

IX.2.1- At the Continental Intercalaire

If we consider « net »[4] drawdowns calculated in 2050, we can note **extremely high** values around the main catching fields: Ghardaia, Oued Rhir, El Oued, Ouargla, where they range between **300 to 400m**. In Adrar, net drawdowns exceed **50m**, namely in Touat and Tidikelt, which will certainly have an impact on the flow of Foggaras.

The map of NP depths under the ground (fig. 131) shows a total disappearance of artesianism in the Albian aquifer in the Lower Algerian Sahara. A limited cavity of artesianism still persists over half of the Province of Ouargla as well as in Tidikelt. Elsewhere and in all the valley of Oued Rhir, pumping depths range between 100m and 300m.

[4] Calculated after deducing drawdowns corresponding to zero simulation

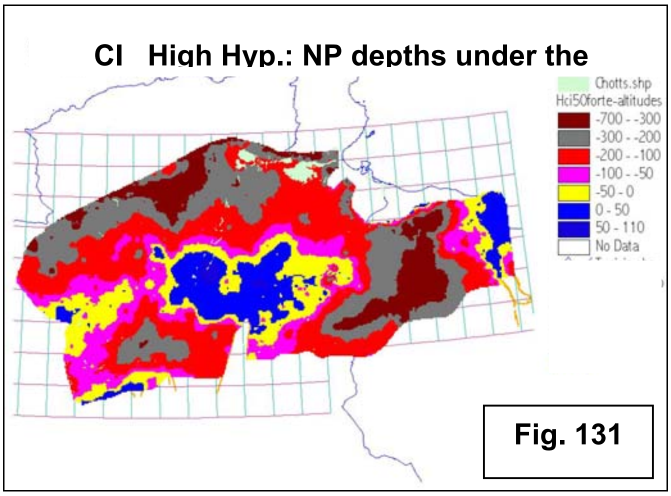


Fig. 131

If Libya is almost not affected by this scenario, Tunisia on the contrary is very much influenced (in terms of net drawdowns, see fig.110) by the realization of such a hypothesis:

→ **Drawdowns between 200 and 300 m** in the sectors of the main catching areas
→ **Pumping depths from 100 to 300 m** in the main exploitation areas
→ **General disappearance of all forms of artesianism**
→ **Total disappearance of the Tunisian outlet**

IX.2.2- On the Aquifer Upper sandstone

Calculated gross drawdowns are considerable: they range between **150m on the East to 400 m on the West**. As for **net drawdowns**, reflecting the scenario proper influence, they range between **100m to 350m**.

IX.2.3- At the Complexe Terminal

In Algeria, this scenario induces important additional drawdowns (or, better, net drawdowns), namely around the most intense additional abstraction fields located in:

- Oued Rhir [4m^3/s] and Souf in the North [10m^3/s]
- Ouargla [10m^3/s] and Hassi Messaoud-Gassi Touil in the South [19,5m^3/s]

Additional drawdowns calculated there range between **70 and 150 m**.
In Libya, this scenario has no incidence. But in Tunisia, impacts are considerable

- Additional drawdowns amounting to **50m in the Djerid and 20 to 40m in Nefzaoua**
- All the Chotts (Djerid and Rharsa) are in a recharge position with regard to the CT aquifer, and level differences average **50m**.

This level difference, which constitutes the main risk indicator, is by far more elevated in Algeria where it exceeds 100 m under Chotts Melrhir and Merouane and reaches 200m in Mghaier and Djamaâ.

IX.3- Effects of the Low Hypothesis in Algeria

IX.3.1- At the Continental Intercalaire

In Algeria, compared to the high hypothesis, **drawdowns are slightly less spread** in terms of space and amplitude, but remain very important: about **300m in El Oued-Biskra as « gross » and 250m as « net »**. Artesiansism has also disappeared from all Lower Sahara as pumping depths there amount to 100m.

In Tunisia, artesianism has totally disappeared and drawdowns range between 100m and 200m in the main catching fields. As for **the Tunisian outlet, it is totally dry.**

IX.3.2- At the Complexe Terminal:

Drawdowns are still very high, be they in Algeria or, in terms of their impact, in Tunisia. Chotts are everywhere in a possible recharge position with regard to CT aquifer: **the level difference** amounts to **100m** under Chotts Melrhir and Merouane and **ranges between 20 and 60 m under Chotts Rharsa and Djerid**.

IX.4- Effects of the « Ghadames field » scenario

On the CT, drawdowns induced by this simulation are not important. As for the Continental Intercalaire level, calculated net drawdowns are about **100m** in the catching field of Ghadamès-Derj. They gradually decrease as they get farther **until they practically disappear in a 200 to 300 km radius**. **All the most southern part of Tunisia is affected by** Ghadames flows: induced drawdowns range between 10m (at about 200km in the North of the catching field) to 80 m in Borj el Khadhra. **In the region of Debdeb in Algeria, induced drawdowns are about 60 m**.

IX.5- Effects of the « Dj. Hassaouna field » scenario

At the CT, net drawdowns induced by the catchments of Dj. Hassaouna are limited, showing a maximum rate of 10 to 20 m in the centre of the Hun graben.

At the IC, the influence of Dj. Hassaouna is limited to the basin of Hamada El Hamra and does not reach the Algerian and Tunisian borders. In Libya, calculated drawdowns form a gascap surrounding the catching field, with a maximum of **50m in the South**.

CHAPTER II: MINIATURIZATION OF THE MODEL FOR THE RESERVOIR INVESTIGATION

I- THE REASON FOR A MINIATURE MODEL?

The execution of exploratory simulations and the analysis of obtained results have explicitly highlighted a number of nuisances and « **risks** » threatening the water respring at the level of its development.

Any intention to continue the exploitation of more CI and CT aquifers requires from know on a perfect awareness of how to minimize and manage these risks. Among these risks one can cite:

- Disappearance of artesianism
- Heights of excessive pumping operations
- Drying of the Tunisian outlet
- Drying of Foggaras
- Exaggerated drawdown interferences between countries
- Potential recharge by the Chotts

The results of the « high hypothesis » and the « low hypothesis » have also demonstrated the boundaries of the « **pure hypothesis** » approach in the definition of the NWSAS development strategy. The high hypothesis as well as the low one, which initially seemed to “frame” the choice of decision makers and foreseeable solutions, would have, with regard to such results, devastating consequences on the future of NWSAS. This is the reason why decision was made to look for another processing procedure to define acceptable solutions.

The **simulation** techniques enable decision makers to choose, among various scenarios for the development of underground water resprings, forecast and simulated by the model, the most appropriate solution, responding to initially formulated criteria. In this type of approach, the system parameters (transmissivity, storage coefficient, and boundary conditions) as well as pumping flows are known: the piezometric levels and the outlets flows are calculated by the model. The pumping flows defined by their intensity and their position are the « ***decision variables*** ». The analysis of the results of each realized simulation serves to guide the choice of the decision maker.

But the number of foreseeable solutions is high:

- This is the case when the respring development plans are not established with accuracy,
- Or when several concurrent supply springs are available,
- Or also when precise boundaries in terms of encountered risks (“ the constraints”) could be fixed and that the multiplicity of these constraints could be established,
- Or finally when we assign to the simulation model an investigation objective of the production capacities of the aquifer reservoir, with no consideration to water resprings,

The simulation becomes fastidious and it would be better to resort to **optimisation** techniques. In this case, the state variables (piezometric levels, outlet flows) are unknown, but the decision variable (intensity of flows and their locations) is also not known. We look for decision variables that can help find, among foreseeable solutions, the optimal solution that verifies choice criteria. The latter defining the “objective” function.

There may be several objective functions:

If we refer by **f** to the objective function and **q** to the decision variable, the optimisation problem can be formulated by:

Minimize (or maximize): $f = \sum_{j=1}^{n} q_j$

Under the constraints: $\sum_{j=1}^{n} a_{ij} * q_j \geq b_i$ i=1,2, …, n

The coeffiicients $\mathbf{a_{ij}}$ and $\mathbf{b_i}$ are data while q_j are unknown decision variables. The coefficients coefficients a_{ij} inform about the aquifer response following to a modification made to executed flows. We call them « **influence coefficients**[5] ». The coupling of these two approaches: (simulation and optimisation) is made by means of these coefficients. In fact, the latter are determined on the basis of the simulation model.

The influence coefficients include the same quantity of information of the models they derive from. They can be used whether to formulate optimisation problems, or to miniaturize[6] a simulation model, or even to realize a combination of these two possibilities. This last approach: **a coupling miniaturisation-optimisation**, has been preferred in what follows to continue the exploitation of CI and CT aquifers.

[5] P. Hubert: *Eaupuscule*, an introduction to water management, Ellipses, 1984
[6] P. Hubert et J. Leon: Miniaturisation of underground flows models; c.r. symp. Coblence; UNESCO-IAH ; vol.2, pp 829-841; 1983

II- INFLUENCE FUNCTIONS AND INFLUENCE COEFFICIENTS

Unitary grade and influence function

Starting from a given state of the aquifer [on December 31, 2000 fixed in advance by NWSAS: the end date of the reference transient history state calculated by the model] we apply in an i cell a flow equal to the flow unity and maintained in a constant status throughout the simulation period [or until 31/12/2050] and we calculate the drawdown in each of the model cells (see. fig.132). This calculation can be repeated for all cells. This will yield an influence matrix to n^2 if n is the total number of the model cells. This matrix is systematic, based on the flows reciprocity principle in the underground environment [$a_{ij} = a_{ji}$].

Considering $a_{ij}(t)$ the drawdown induced in d day, and at t time, by the abstraction unitary grade, if the flows linearity hypothesis can be applied (this is made in a catching aquifer far from non linear boundary conditions), the drawdown (r) provoked in j by any pumping Q_i made in i is equal to:

$$r_{ij}(t)=a_{ij}(t)Q_i$$

The knowledge of a_{ij} coefficients is then enough to determine drawdowns (or poiezometric levels) corresponding to any distribution of pumping within the aquifer system.

The definition of each a_{ij} function requires a simulation on the model, whose duration is 50 years ; which represents a mass of manipulations. All model cells (several dozens of thousands) not bound to be more or less pumping cells, nor in areas where it is neither necessary nor useful to hold accurate information concerning drawdowns, it seems more appropriate and efficient to boundary calculations strictly to the cells that will on the one hand, serve one day for the execution of pumping, and on the other observe their effects. This way, we can yield influence coefficient matrices with a “visual dimension”, that can be handled and whose reactions can be immediately measured, on a very simple programmed, calculating machine, or on the screen of a micro-computer.

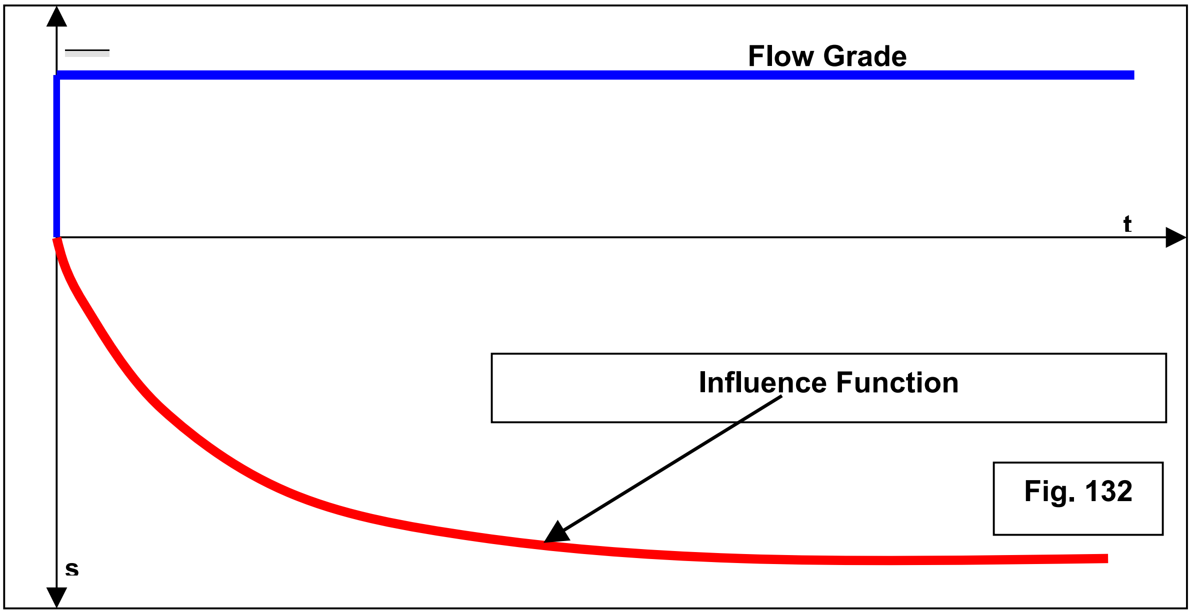


Fig. 132

III- PROPERTIES, HYPOTHESES AND APPROXIMATIONS

III.1 - Conditions and Calculation Time-Frame

All calculations are induced over a period of 50 years ranging between January 1st, 2001 and December 31st, 2050. During this period, we will calculate in each of selected cells to be "**core cells**", an Influence Function by imposing a constant pumping flow, equal to the "rated **flow", in respectively each of selected cells, to constitute NWSAS "well** cells".

We fixed the pumping rated flow to 10 m^3/s, a certainly high value, but which enables to obtain significant drawdown values at a certain distance from the well (see fig. 133) with regard to the size of the aquifer system and distances to take in account in terms of influence.

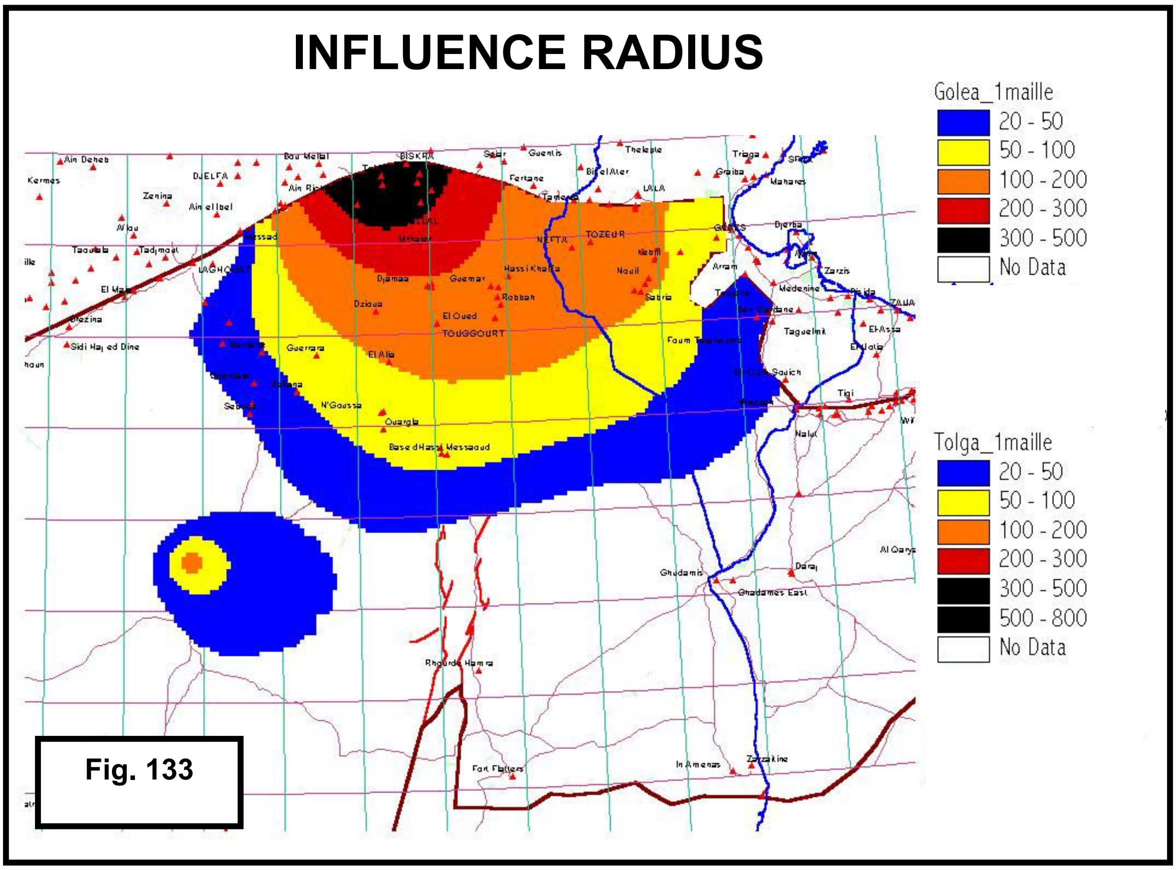


Fig. 133

Fig. 134: Influence radius in the CI - Kiklah

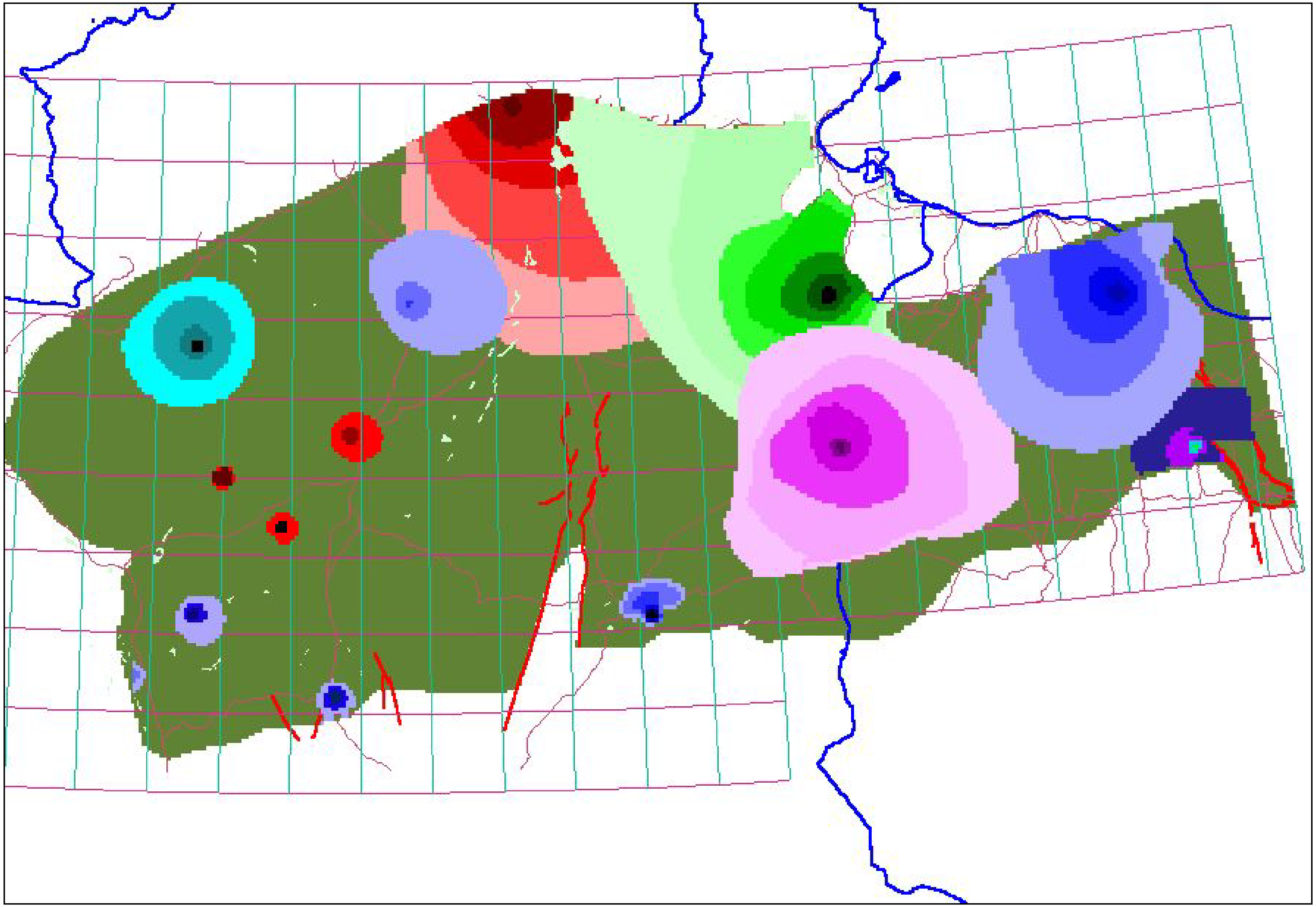
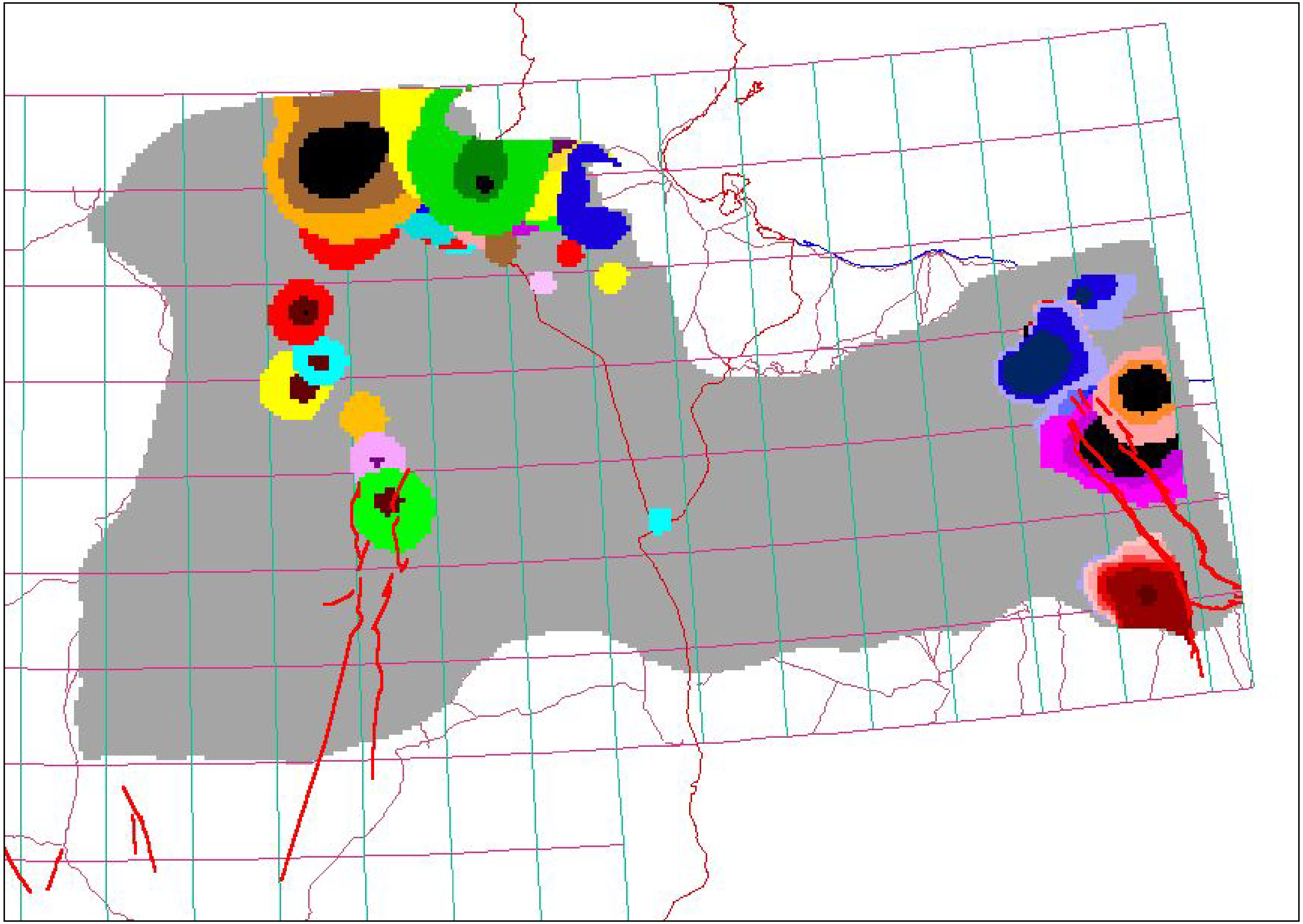


Fig. 135: INFLUENCE RADIUS in the Complexe Terminal



III.2- Flows Linear progressions

The flows general equation in the multi-aquifer, which constitutes the NWSAS Mathematical Model, is provided by the following expression:

$$\frac{\partial}{\partial x}\left(T_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(T_y\frac{\partial h}{\partial y}\right)+q_H+q_B=S\frac{\partial h}{\partial t}+q$$

$$q_B=K_v\frac{H_B-H_C}{e_B}$$

$$q_H=K_v\frac{H_H-H_C}{e_H}$$

where:

T_x is the aquifer transmissivity according to Ox
T_y is the aquifer transmissivity according to Oy
q_H is the leakage to the top specific flow
q_B is the leakage to the bottom specific flow
h is the hydraulic charge in the aquifer
H_H is the hydraulic charge in the upper aquifer
H_B is the hydraulic charge in the lower aquifer
Kv is the vertical permeability in the semi-permeable aquifer

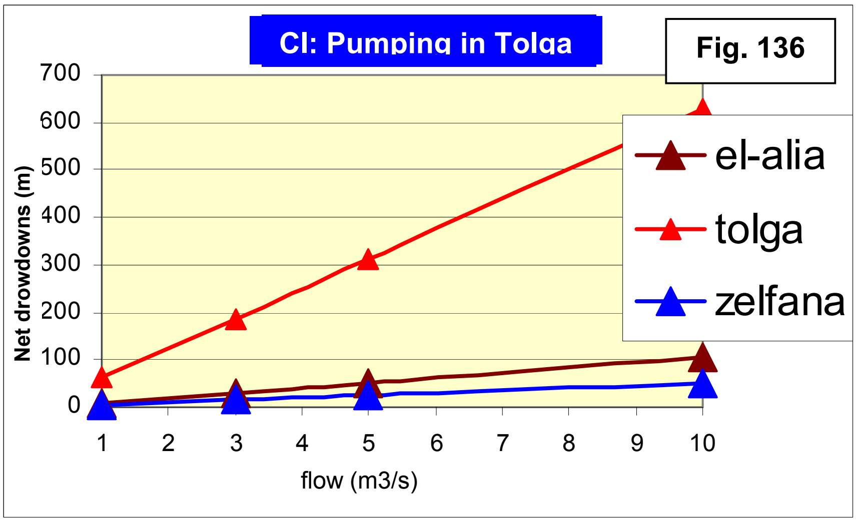
The multi-aquifer equation is linear, and this linearity authorizes the use of the « ***superposition principle*** », which states that:

- If h1 is a particular solution of the equation, and h2 is another particular solution, then h1 + h2 will also be another solution of the equation, with conditions appropriate to the boundaries of the domain.

- And, in general, any linear combination with constant coefficients: $h = \alpha h_1 + \beta h_2 + ... + \gamma h_n$, of solutions h_1, h_2 … h_n, will also be a solution for this equation. We can then determine new solutions by combining known solutions.

- On the other hand, we can superpose drawdowns due to a multi-well system. Similarly, and still due to the equation linearity, and the additionality of solutions, ***if a pumping*** $\lambda.q$ ***corresponds to a drawdown, then a drawdown will correspond to a drawdown.***

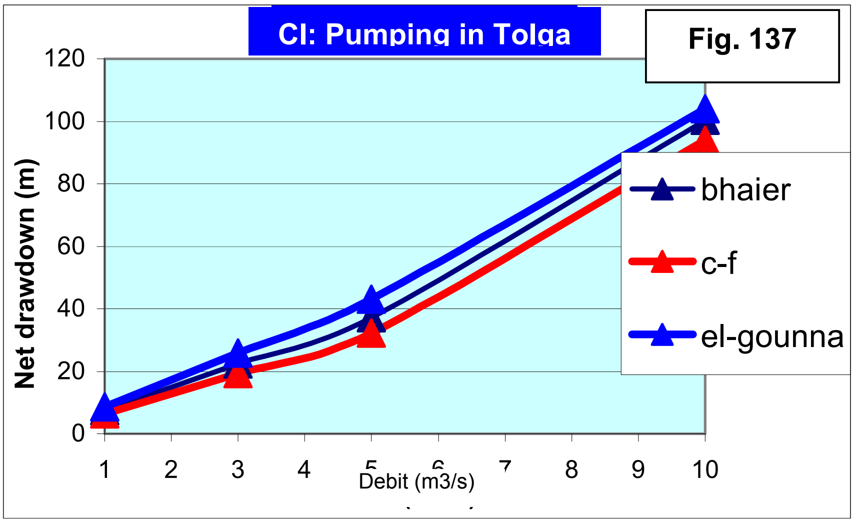
This last property is obviously **fundamental to validate the miniaturisation of the NWSAS Model**. It has been verified on the simulation Model, on the pumping example in Tolga, with pumping flows of respectively $10m^3/s$, $5m^3/s$, $3m^3/s$, and 1m3/s. Fig. 136 helps indeed to observe the proportionality of drawdowns with regard to flows.



Nonetheless, **this property is not verified next to a « Drain » condition with an imposed level**, namely when the drain is « dewatered”. This dewatering marks in fact the abrupt passage, at the level of the drain, from an “imposed level” drain to a disconnected regime. (equivalent to a nil flow).

It is therefore natural that such a condition can result in high non linear ties in its immediate vicinity, and in the passage between two regimes. This can be verified in the example of reactions in the region of Chott Fejej, where the Tunisian outlet is characterized by a drain condition (still in the case of pumping at the level of Tolga: fig. 137).

However, and with regard to the very local character of these non linear ties, limited in the vicinity of Chott Fedjej and in the foggaras for the CI, in Ain Tawargha and in the Chotts for the CT, we will later assume the linearity hypothesis over all NWSAS domain.



III.3- Aspects Influence Functions

Fig. 138 shows the trend of some influence functions, for a pumping in Chott Fejej. In fig. 139 where time is represented on a logarithmic scale, we can realize that the pseudo-stabilization of drawdowns shown in fig. 138 was only due to the representation of the axis abscissa on an arithmetic scale.

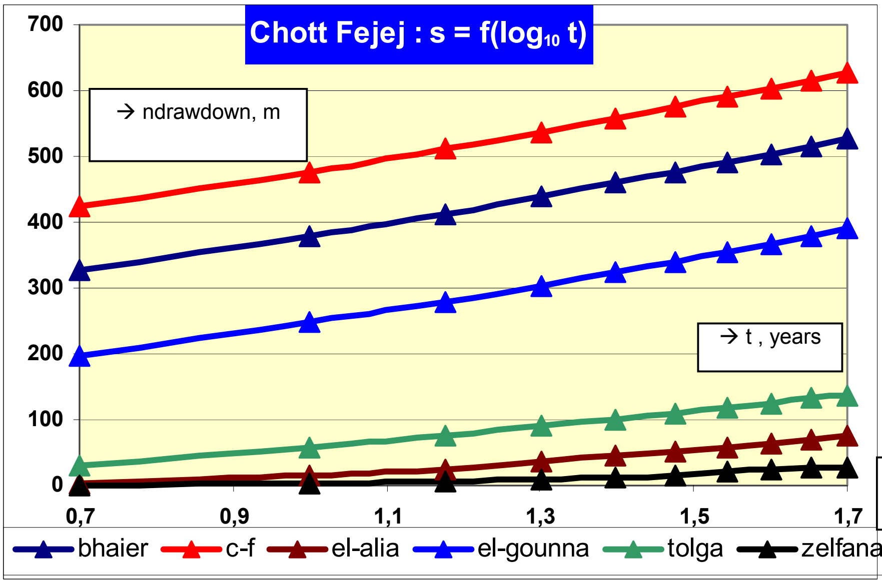


Fig. 138

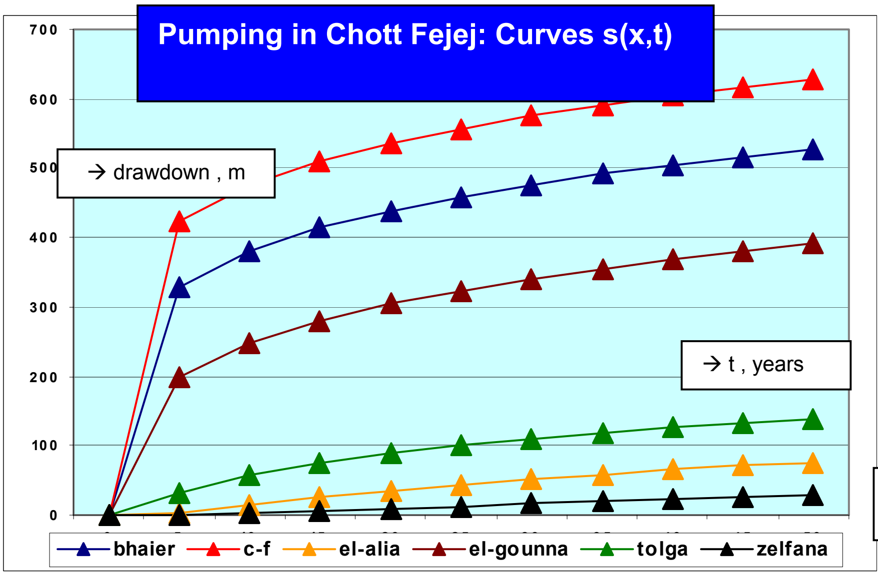


Fig. 139

III.4- Concentrated pumping Vs. distributed

At the end of the first obtained results, the drawdown values calculated in the center of some cells with the selected rated flow of **$10m^3/s$** (namely where hydraulic parameters are not favorable) seemed excessive to us. The 2000 flows displayed on each of the model cells were revised, to note that, in practice, the maximum values per cell for the CI (with the exception of Libyan drills temporarily gathered in “Pumping groups”) average 400 l/s.

Concerning the CT, the above observation remains valid, only in Nefzaoua where we have very elevated values yielded by the union of «**manual drilling groups** ».

In any case, we noted that the rated flow of **10m3/s** will be, in practice, not concentrated in the middle of the cell of a single pumping but distributed over a group of neighbor cells, on the basis of **400 l/s** per unit, or a group of 25 cells (see. fig. 140). In such conditions, the few realized calculations show that the drawdown in the central cell will be limited to **approximately 40% on average**[7] of what would be if the total flow were concentrated there (fig. 141).

[7] To report on the calculations, this value is 30% in EL Golea and 50% in Tolga.

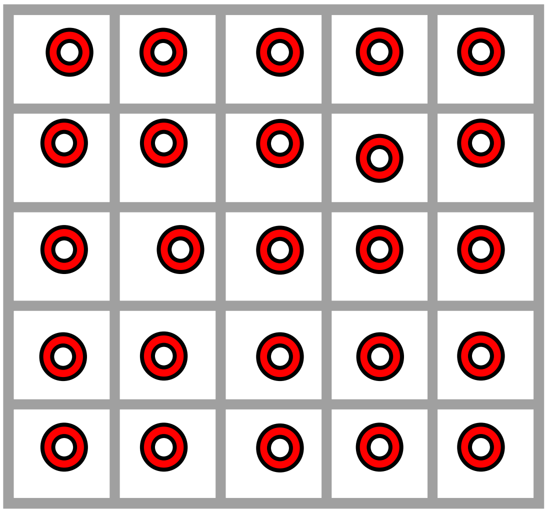


Fig. 140

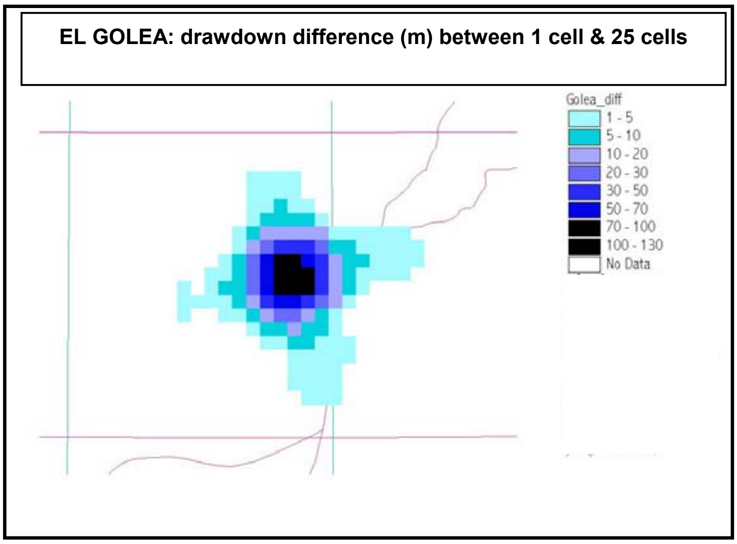


Fig. 141

III.5- Constant pumping Vs gradually varied

As conducted for the execution of exploratory simulations and for the aquifer system to be explored to its most extreme capacities, and with a perspective of « sustainability », a simulation of the constant flow has been made over all the calculation period, ranging between January 1st, 2001 to December 31, 2050. We hence introduce an additional forcing level of the system, which has the effect of amplifying the expected impacts of the displayed flow. We can assess this amplification by noting the evolution throughout time of drawdown values obtained at a constant flow. We can then observe that, in the pumped cell, 80% of the total drawdown over 50 years will be reached from the tenth year and that this proportion naturally diminishes as one gets farther from the pumping cell. (fig.142 et 143).

Fig. 142: ZELFANA: Fractions in % of 2050 net drawdown calculated for each of the 5 decades 2000-2050

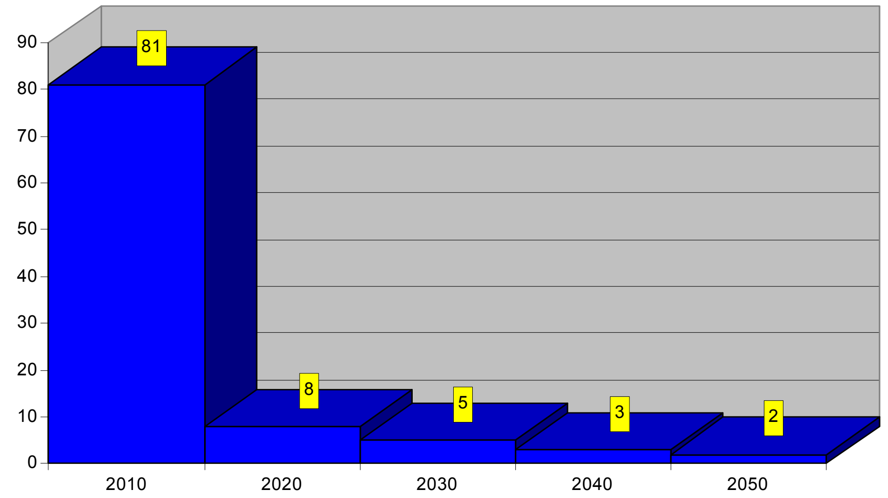
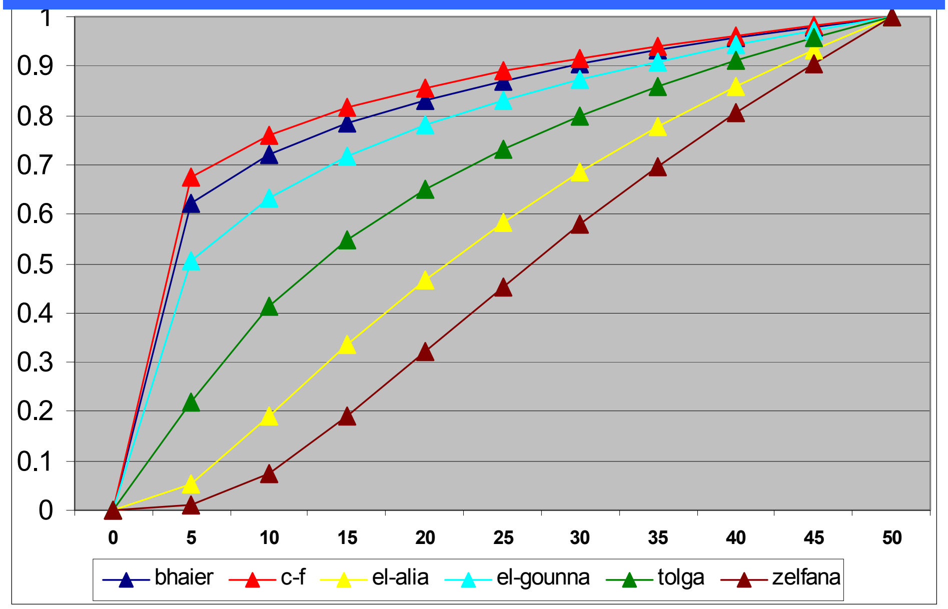


Fig. 143: Pumping in CF: Time Evolution of the drawdown % over 50 years



IV- MATRIX OF INFLUENCE COEFFICIENTS

IV.1- Identification of well fields and scope of the problem

The principle adopted based on the results of exploratory simulations **was then to free oneself from the search for development scenarios with no direct relation to the aquifer properties, solely founded on forecasts of water needs, and on the contrary to look for the construction of scenarios with a « hydraulic » base founded on NWSAS production capacities, in sites as close to each other as possible, areas where the present or future needs will have better chances to be highly expressive,** without giving up the opportunity to explore favorable sectors that may be far away from possible demand sites but that can prove to be appropriate for export.

The first phase of such a process will naturally be to make the inventory in the two main aquifers of all possible pumping sites. This inventory can be conducted country by country.

Table 29: Inventory of possible pumping sites in Algeria

CI			CT	
	1	titaf	1	Hassi-messaoud-nord
	2	Akabli	2	Hassi-messaoud
	3	timimoun	3	Gassi-touil
	4	in-salah	4	Ouargla
ADRAR-MENIA	5	el-golea	5	N'goussa
	6	fort-flatters	6	El-alia
DEBDEB	7	Deb-deb	7	Taleb-el-arbi
	8	Ouled-djellal	8	M'ghaier
	9	Tolga	9	El-oued
	10	El-oued	10	Douar-el-maa
	11	Djemaa	11	Ben-geucha
	12	M'ghaier	12	Djemaa
	13	Taleb-el-arbi		
	14	Ben Guecha		
OUED RHIR - EL OUED	15	Douar El Ma		
	16	Sebseb		
	17	Guerrara		
GHARDAIA	18	Zelfana		
	19	El-alia		
	20	N'goussa		
	21	Ouargla		
OUARGLA	22	Hassi-Mess-nord		
	23	Timimoun-2		
	24	Erg-occ-1		
	25	Oued-seggeur		
	26	Tiberrhamine		
	27	Ain-guettara		
	28	Erg-occ-2		
	29	Erg-occ-3		
WESTERN ERG	30	Oued-el-gharbi		

Fourty two (42) possible pumping sites have been surveyed in **Algeria by the ANRH, 30 in the CI and 12 in the CT**, most of which correspond to agricultural development areas used during the exploratory simulations, but other potential sites have been identified, namely those related to the « Erg Occidental», which declared objective was to investigate for the first time the production capacities of the CI in this sector apparently « remote » from any present precise demand and bound for export, if the model results prove to be favorable: the important extension that NWSAS Model operated towards these last regions allows a consideration of such an alternative.

Table 30: Inventory of pumping sites in Tunisia

CI				CT	
C. FEJEJ	1	C-F		1	Dhafria
	2	Bhaier		2	Segdoud
NEFZAOUA	3	Sabria		3	Segui
	4	El-gounna		4	Htam
	5	Ghoumrassen		5	Bir-roumi
Far-South	6	Bordj-Bourguiba		6	Tozeur
	7	Bir-zar		7	R-maatoug
	8	Tiaret		8	Zaafrane
	9	Borj-el-khadra		9	Djemna
DJERID	10	Hazoua		10	Tembain
	11	Degache-Hamma		11	El-ouar
	12	PIK		12	Bordj-el-khadra

Twenty-four (24) possible catching sites could be identified by the DGRE: 12 in the CI and 12 in the TC .

Table 31: Inventory of possible pumping sites in Libya

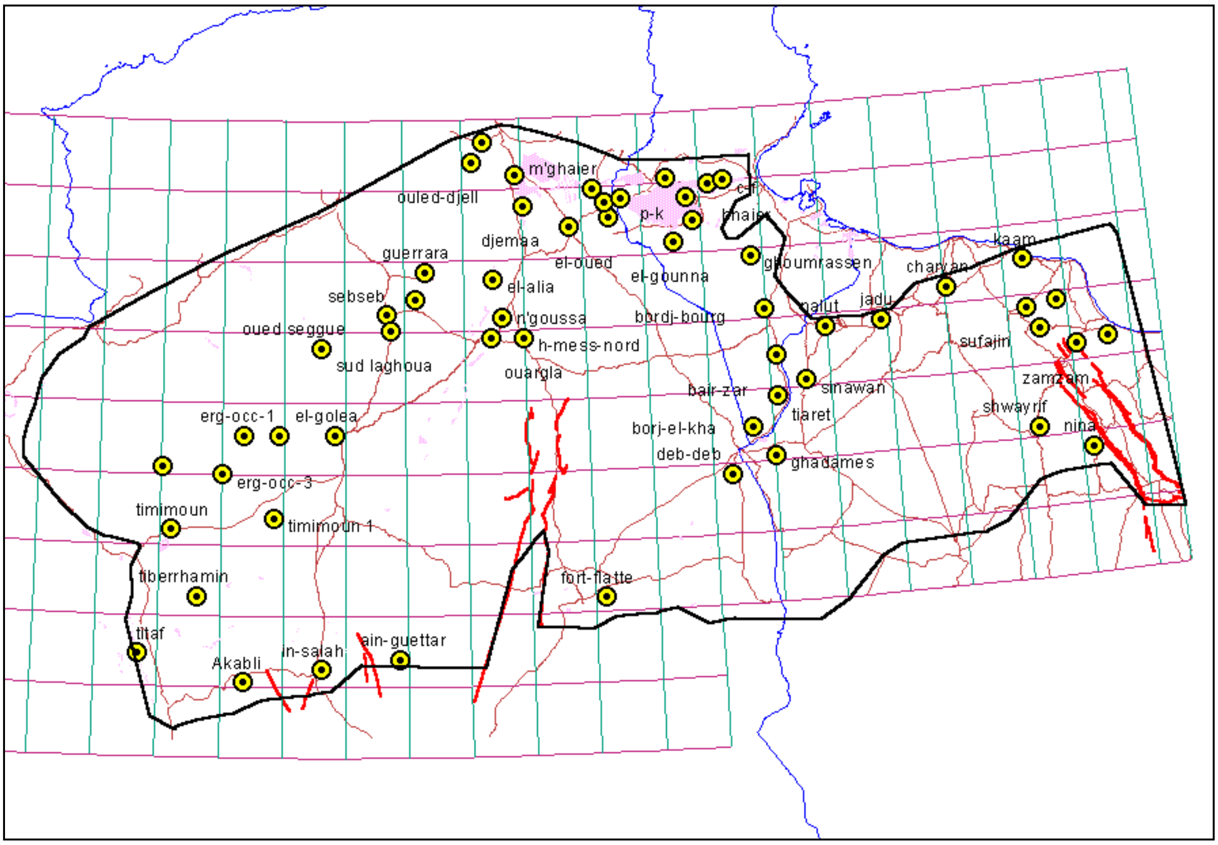
CI				CT	
Eastern Basin	1	nina		1	ferjan
	2	shwayrif		2	hammam
	3	zamzam		3	abou-njaim
	4	washkha		4	zamzam
	5	sufajin		5	washkha
	6	beni-walid		6	beni-walid
	7	kaam		7	maymoun
	8	mardum		8	kararim
NEFUSA	9	jadu		9	Soknah
	10	gharyan		10	Waddan
	11	Nalut			
GHADAMES	12	Sinawan			
	13	Ghadames			

Twenty three (23) sites were identified in Libya: 13 in the CI and 10 in the CT, corresponding to site groups presently exploited and surveyed by GWA.

IV.2- Coefficient Matrix and discharge drawdowns converter

Eighty nine (89) of possible pumping sites in total have been identified all over NWSAS domain: **55 in the CI** (fig. 144) and **34 in the CT** (fig.145). Each site would be subject to a “unitary” simulation on the digital model, which aims at calculating over a 50 year long period starting from 2001, the drawdown function or influence function in each of the core-wells, the closest of which can be grouped to simplify the representation of pumping sites.

Fig. 144: Pumping sites in the CI



For each of these two aquifers, the extent of the influence coefficients matrix became very important and namely for the CI where we obtain a 55x55 aquifer size, which is impossible to display on a computer screen.

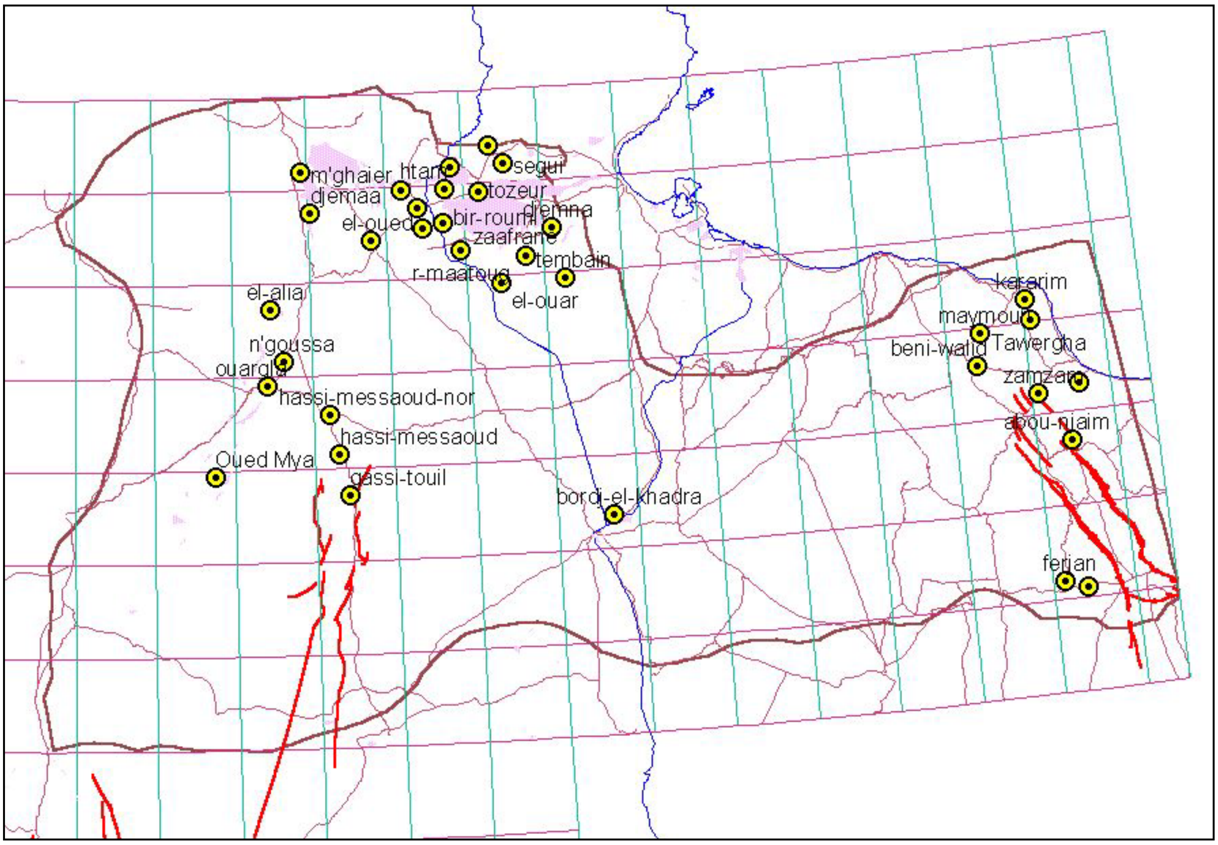
However, the object of miniaturizing the mode is precisely to build in a calculation table sheet, a ***drawdown- flow converter*** in the same format as problem influence coefficients, related to the matrix coefficients and using the latter to calculate drawdowns corresponding to the pumping flows displayed on the converter, based on the slow superposition converter.

These flows can be modified according to the operator's wish, who can immediately have corresponding drawdown values as calculated.

One of the main advantages of the converter is its ***interactivity***: the operator must than have ***on the same screen the problem's data and results.*** With a regular screen, the ease in handling starts to considerably decrease when we obtain 25 column-tables (cf. fig. 146).

This is why the problem was broken down into three parts: first a ***micro-model*** per country and per aquifer, including borders core-wells to assess cross-borders interferences. Which serves in a first phase to look for a number of « acceptable » configurations, then in a second phase to compare the latter with a converter gathering all fields « interfering » with NWSAS, and which gathers on the one hand those of the Algerian lower Sahara, Tunisia and the Ghadames basin for the CI (fig. 146), and on the other all the Chott basin for the CT.

Fig.145: Pumping sites in the CT



V- OBJECTIVES AND CONSTRAINTS OF NWSAS EXPLOITATION

V.1- Objectives: Maximise Production and Preserve the Respring

Considering the conditions of the Saharan climate, the NWSAS formations are poorly supplied: about **1 billion m^3/year** in total, mainly filtering through the piedmonts of the Saharan Atlas in Algeria, as well as in Dahar and Dj. Nefoussa in Tunisia and Libya.

However, the extension of the system and the thickness of aquifers have favored the accumulation of considerable reserves, though with a concerning quality in some areas: salt in these regions constitutes a risk that must be managed with full awareness.

The question is then to know up the extent to which Saharan aquifers can be prompted, certainly well beyond their present recharge rate, through drawing from accumulated reserves, **with the perspective of a sustainable development**.

The past evolution of this exploitation indicates staggering growth rates over the last twenty years. If this evolution, also shared by all three countries, continues at this pace, there will certainly be good reason to worry about the future of Saharan regions, where we have already recorded signs of the degradation of resprings: **very important drawdowns of the aquifer, likely to bring about soon an irreversible salinization of the Complexe Terminal aquifer at a water budget with the Tunisian-Algerian Chotts.**

Such an evolution could be very highly confirmed by results of the first exploratory simulations conducted on NWSAS digital model and namely through the simulation of the "**high hypothesis**" and "**low hypothesis**" scenarios. **The three countries** concerned by the future of the system are therefore necessarily called upon, in the short term, to have some kind of concerted management of the Saharan Basin.

How to ensure the maximum of water abstractions for the best development of the region without threatening the status of the water respring ? And how to formulate the "**best**" exploitation scheme in relation to this ?

The NWSAS Micro-Model has precisely been developed to achieve this.

It is first necessary to make the inventory of all risks facing the respring and determine the constraints that we must observe to minimize such risks. This requires the quantification of the risks, which means modeling them.

Fig. 146: Flows-Draw downs converter in CI interferences area

Fichier Edition Affichage Insertion Format Outils Données Fenêtre ?

	Ouled-djellal	El-oued	Djemaa	M'ghaier	Taleb-el-larbi	Sebseb	Guerrara	Zelfana	El-alia	N'goussa	Ouargla	H-Mess-nord	Deb-deb	C-F	Bhaier	Sabria	El-gounna	Ghoumrassen	Bordj-Bourguiba	Bir-zar	Tiaret	Borj-el-khadra	Hazoua	Deguache-hamma	PIK	Nalut	Sinawan	Ghadames	Rabattemnt-Total	Hauteur pompage	Etat	Contr-Rabt
POMPAGES	0.0	0.0	0.0	0.0	0.0	5.0	0.0	2.0	1.0	0.5	0.5	0.5	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	1.0	0.0	0.0	0.0	0.0	0.0	3.0	17.0			
Ouled-djellal	0	0	0	0	0	14	0	10	10	4	3	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	46	-42	Artésien	
Tolga	0	0	0	0	0	13	0	10	10	4	3	3	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	45	-108	Artésien	
El-oued	0	0	0	0	0	10	0	8	10	4	3	4	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	43	-83	Artésien	
Ben-guecha	0	0	0	0	0	9	0	7	8	3	2	3	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	36	-130	Artésien	
Djemaa	0	0	0	0	0	14	0	10	12	5	4	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	51	-163	Artésien	<=10
M'ghaier	0	0	0	0	0	13	0	10	11	4	3	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	47	-197	Artésien	<=13
Taleb-el-larbi	0	0	0	0	0	8	0	6	8	3	2	3	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	34	-92	Artésien	
Douar-el-maa	0	0	0	0	0	8	0	6	8	3	2	3	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	34	-95	Artésien	
Sebseb	0	0	0	0	0	45	0	16	4	2	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	71	147	0	
Guerrara	0	0	0	0	0	30	0	23	10	4	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	98	0	
Zelfana	0	0	0	0	0	41	0	21	8	4	4	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	80	80	0	
El-alia	0	0	0	0	0	21	0	16	18	9	6	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	78	-26	Artésien	
N'goussa	0	0	0	0	0	21	0	15	17	12	12	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	90	-25	Artésien	
Ouargla	0	0	0	0	0	22	0	15	13	12	11	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	85	-21	Artésien	
H-Mess-nord	0	0	0	0	0	17	0	12	13	12	12	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	86	4	0	
Deb-deb	0	0	0	0	0	0	0	0	0	0	0	0	45	0	0	0	0	0	0	2	15	23	0	0	0	0	0	66	151	141	0	
C-F	0	0	0	0	0	4	0	3	4	1	1	1	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0	1	19	-62	Artésien	
Bhaier	0	0	0	0	0	4	0	3	4	2	1	2	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	1	21	-68	Artésien	
Sabria	0	0	0	0	0	5	0	4	5	2	1	2	1	0	0	0	0	0	0	2	1	1	0	0	0	0	0	1	24	-76	Artésien	
El-gounna	0	0	0	0	0	5	0	4	5	2	2	2	1	0	0	0	0	0	0	3	2	1	0	0	0	0	0	2	27	-49	Artésien	
Ghoumrassen	0	0	0	0	0	2	0	1	2	1	1	1	1	0	0	0	0	0	0	6	4	2	0	0	0	0	0	3	24	69	0	
Bordj-Bourguiba	0	0	0	0	0	1	0	1	2	1	0	1	3	0	0	0	0	0	0	11	7	3	0	0	0	0	0	7	37	88	0	
Bir-Zar	0	0	0	0	0	0	0	0	1	0	0	0	10	0	0	0	0	0	0	26	22	9	0	0	0	0	0	22	92	154	0	
iaret	0	0	0	0	0	0	0	0	0	0	0	0	29	0	0	0	0	0	0	11	101	27	0	0	0	0	0	66	235	291	0	
orj-el-khadra	0	0	0	0	0	0	0	0	0	0	0	0	46	0	0	0	0	0	0	5	27	25	0	0	0	0	0	85	190	174	0	
Hazoua	0	0	0	0	0	8	0	6	8	3	2	3	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	1	37	-57	Artésien	< 50
Deguache	0	0	0	0	0	4	0	3	5	2	1	2	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	20	31	0	< 50
PIK	0	0	0	0	0	3	0	2	3	1	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	13	-89	Artésien	< 50
Nalut	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	3	281	0	
Sinawan	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	13	30	15	0	0	0	0	0	41	117	237	0	
Ghadames	0	0	0	0	0	0	0	0	0	0	0	0	44		0	0	0	0	0	4	22	28	0	0	0	0	0	65	163	154	0	
Total Algerie				11.5		Total Tunisie			2.5		Total Libye			3.0		Débit exutoire tunisien (m3/s)												0.50				

Erg-Occidental / Coef2 / TUNISIE / ALGERIE / Alg+Tun+Lib / Coeff / initiale

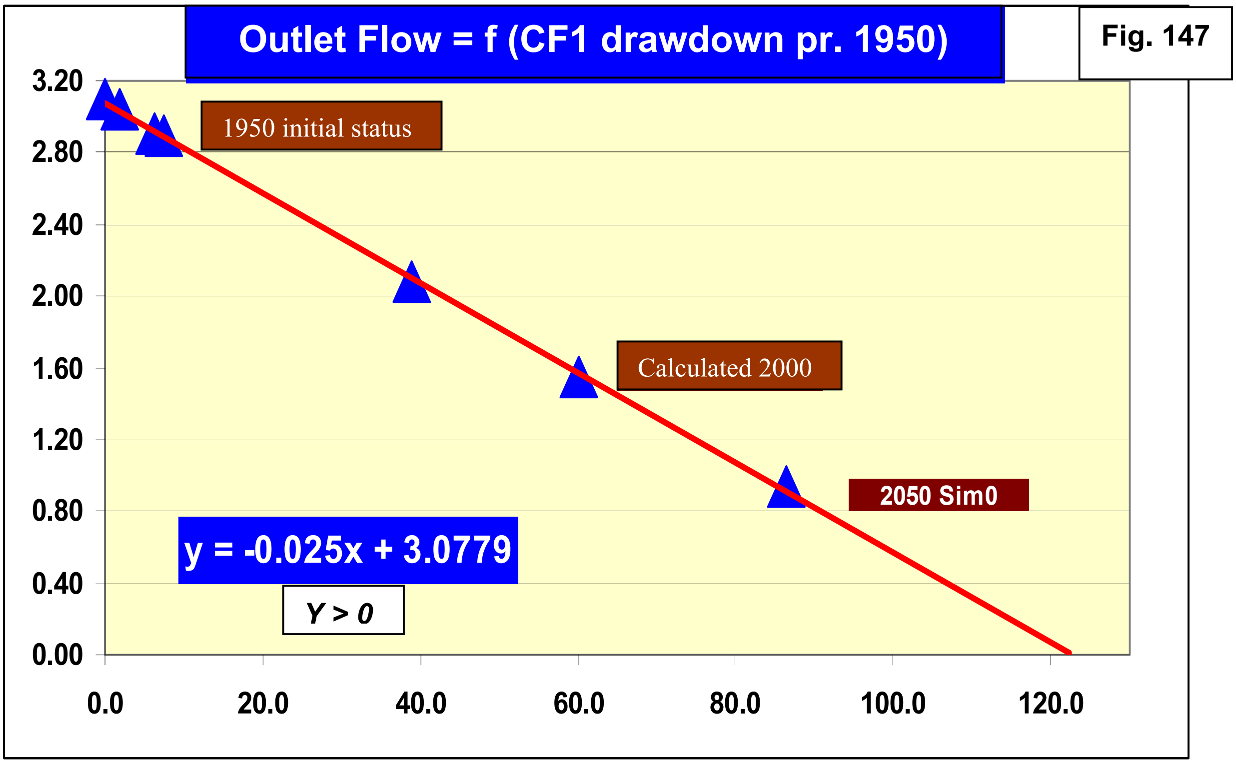
V.2- Constraints and Risks Management

Let us first recall the major risks that may face the present and future exploitation of NWSAS and all the more so its intensification:

- Disappearance of artesianism
- Excessive heights of pumping
- Drying of the Tunisian outlet
- Drying of Foggaras
- Exaggerated drawdown interferences between countries
- A possible recharge by the Chotts

It is then necessary now to quantify as much as possible these risks in order to determine constraints that must be recorded.

V.2.1- the conservation « Tunisian Outlet »



The « flow-drawdown » function of the Tunisian Outlet (TO) was constructed by points on the location of CF1 drill, using results of calculations made on the model, namely in a steady state in 1950 then in a transient regime in 2050, as well as on some calculated intermediate status.

All points are perfectly aligned on a straight line reflecting the proper behaviour of a linear reservoir, whose flow is proportional to the charge. **This function enables the forcasting[8] of situations posterior to 2000**.

The corresponding point by the time-frame 2050 of the zero simulation is important to underline. Let us remember that the flow corresponding to the Tunisian outlet, calculated by

[8] This is a « rapid » forecast at the level of the micro-model.

the digital model, is estimated at **0.94 m3/s**. This flow will constitute the reference value for all future simulations concerning the CI development.

V.2.2- Algerian Foggaras

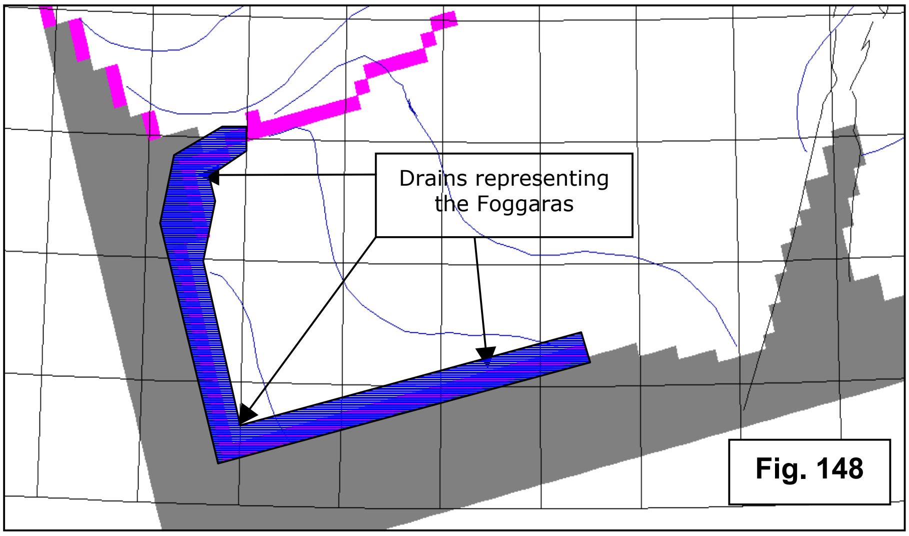


Fig. 148

The Foggaras constitute very dispersed emergences: we may estimate that 700 active foggaras cover a front of 700 linear kilometers ; or an average of one foggara/one kilometer!

This configuration does not facilitate the micro-modeling of the system, and it seems difficult to consider a simple relation connecting the total flow of foggaras to an average drawdown of the CI aquifer. The only way to assess the flow of foggaras is then simulation on a digital model.

V.2.3- Maintaining artesianism

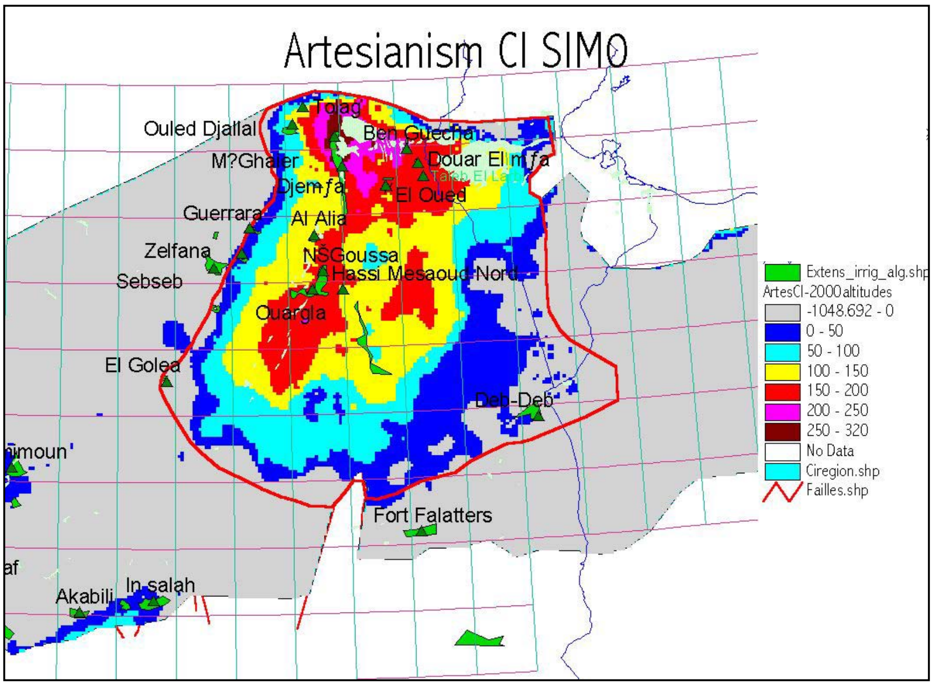


Fig.149 shows the move of the CI artesianism boundary between 2000 (surveyed in 1998) and the time-frame 2050 in a zero scenario. We can obviously not consider the preservation of artesianism everywhere ; but it seems very possible to maintain soil pressures on a one

hundred meter basis in all the valley of Oued Rhir with the condition of requiring **2050 drawdowns below 100 m**.

V.2.4- Decreasing pumping depters throughout the region

This constraint cannot be generalized everywhere at the same level. In fact, if in the valley of Oued Rhir it seems difficult to avoid artesianism, in other regions, in Dj. Nefusa for instance, heights of important pumping are already applied, it is true for drinking water supply projects. **It seems reasonable to boundary exploitations to regionalized pumping** (at the level of a set of cells of the digital model) **on the one hundred meter base.**

V.2.5- Protection of CT aquifer with regard to the Chotts

Concerning CT aquifers, the Chotts represent a major risk, as important drawdowns of the aquifer near the Chotts can induce the incoming of over-salty water and hence bring about an irreversible degradation of the water respring.

The digital model can be used to calculate with accuracy the time when a possible recharge of the aquifer can be made by the Chott.

The first indicator used to evaluate the possibility of such a risk is provided by the position of the water table piezometric level with regard to the level of the Chott.

Let us recall the results obtained by the zero scenario simulation, that is continuing the present situation:

« **While in 2000, there is still a considerable artesianism area, namely on the southern shore of Chott Djerid and the north of Melrhir, in 2050, artesianism will have totally disappeared from the region of the Chotts** and we may even observe that sectors like Kebili peninsula, Nefzaoua, Djerid, Chotts Merouane and Melrhir, will be seriously threatened as the NP of the CT aquifer will be systematically under the level of the Chotts. From the point of view of salt contamination, these sectors are already highly exposed and this, without adding any more abstraction: ***the simple continuation of the present abstraction pace constitutes already a major possible danger*** ».

In these very restrictive conditions, **it is necessary to minimize under the Chotts any additional drawdown when designing provisional simulations.**

V.2.6- Interferences Field

An examination of the spatial distribution of water points indicates in the CT, in the region of the Algerian-Tunisian Chotts, **an uncommon concentration of drills sealing a definitely common faith for the region of Oued Rhir, Souf, Djerid and Nefzaoua**.

We can note in this region that Algeria-Tunisia interferences will henceforth be determined by the necessity of ensuring a local protection against the Chotts.

In the CI, the regions of Oued Rhir, El Oued, the Chotts line and Nefzaoua form the same hydraulic province and are therefore **highly interdependent in terms of influences.**

Between the three NWSAS countries, Algeria, Tunisia, and Libya, **the only common interference field can be found in Ghadames Basin** from a broad point of view, in the CI, which includes the region of Debbab and the far southern Tunisian part.

CHAPTER III - PREDICTIVE SIMULATIONS

I- WORKSHOP HELD ON APRIL 1 & 2, 2002: CHOICE OF NWSAS EXPLOITATION SCENARIOS

Processing operations conducted on the micro-model during the Tunis workshop held on April 1 and 2, 2002, with the participation of General Managers of concerned institutions from all three countries, directed thoughts to a number of scenarios responding to development objectives while minimizing degradation risks by observing imposed constraints.

These scenarios, presented below in detail and summed up in the following table, will be simulated on the digital model which gives more complete results and will later enable the measurement of achievement of said objectives and the level of observance of the constraints.

Table 32: Additional abstraction in the Continental Intercalaire m^3/s

SCENARIO	CI-1	CI-2	CI-3	CI-4	CI-5	CI-6	CI-7	CI-8
ALGERIA	8.5		2	8.5	38.5	80		118.5
TUNISIA		2.2	1.4	2.2				2.2
LIBYA			2.9	3.6			5.2	8.35
Total	8.5	2.2	6.3	14.3	38.5	80	5.2	129.

Table 33: Additional Abstraction in the Complexe Terminal m^3/s

SCENARIO	CT-1	CT-2	CT-3	CT- 4	CT- 5
ALGERIA	14.7				14.7
TUNISIA		3.3			3.3
LIBYA			11.		11.
Algeria - OUED MYA				18.0	18.0
Total	14.7	3.3	11.	18.0	47.

While exchange through leakage between the CI and the CT can be considered insignificant [relatively to the budget main terms] in Algeria and Tunisia, there is nothing like that in Libya where exchanges between Mizda, Nalut and Kikla prevail in the Eastern Basin. Consequently, simulations [in terms of additional abstraction] exclusively concerning Algeria or Tunisia have been carried out independently of the last two CI and CT aquifers: this is the case of scenarios **CI-1, CI-2, CI-3, CI-4, CI-5, CI-6** and **CT-1, CT-2**.

On the other hand, scenarios where Libya is [in terms of additional abstraction] involved, were subject to joint simulations CI-CT, this is the case of scenarios CI**-7** coupled **with CT-4** and scenario **CI-8 coupled with CT-5**.

II- SIMULATION OF EXPLOITATION SCENARIOS ON THE DIGITAL MODEL: MAIN RESULTS

II.1- the Continental Intercalaire

Table 34: simulation 1: Algerian Lower Sahara

IC - 1 – additional flow rates			
Group	**Q m^3/s**	***Group***	**Q m^3/s**
Ouled-djellal	0.2	Zelfana	2.0
El-oued	0.2	El-alia	0.1
Djemaa	0.1	N'goussa	0.2
M'ghaier	0.2	Ouargla	0.2
Sebseb	2.0	H-Messaoud-nord	0.3
Guerrara	1.0	Deb-deb	2.0
Total		***8.5***	

The main directors presiding over the execution of this scenario are namely:

- Simulation of additional abstraction exclusively Algerian, so that the possible incidence on each of the two other countries can be assessed with accuracy
- Maximal racking while observing following constraints
- Preserve artesianism in all the valley of Oued Rhir and in El Oued
- Minimization of interferences on Tunisia in terms of drawdowns and reduction of the flow in the Tunisian outlet with reference to zero scenario
- Exploration of exploitation possibilities of the CI aquifer in the region of Debdab, which were not identified during the execution of exploratory simulations.

Once all calculations are made, the NWSAS water budget for the time-frame 2050, will be as follows:

Inouts (m^3/s)	Supply	Turonian Leakage Turonian	Upper Sandstone	Cambro-Ordovician input	Eastern Boundary	Contribution of reserves	Total of Inputs	**Outputs (m^3/s)**	Pumping	Turonian Leakage	Upper sandstone Leakage	Saoura & S.Timimoun	Foggaras	Tunisian Outlet	Gulf of Syrta	Total of Outputs
CI-1	9.4	0.8	0.0	3.0	0.0	27.7	40.9		35.3	1.9	0.4	0.2	1.95	0.60	0.6	40.9
CI-SIM-0	9.4	0.7	0.0	3.0	0.0	19.8	32.9		26.8	1.9	0.5	0.2	1.95	0.94	0.6	32.9

The results of this simulation are presented below in the form of 2050 « net » drawdowns map, a piezometric map and an artesianism map.

CI- Simulation n°1 – Net Drawdowns 2050

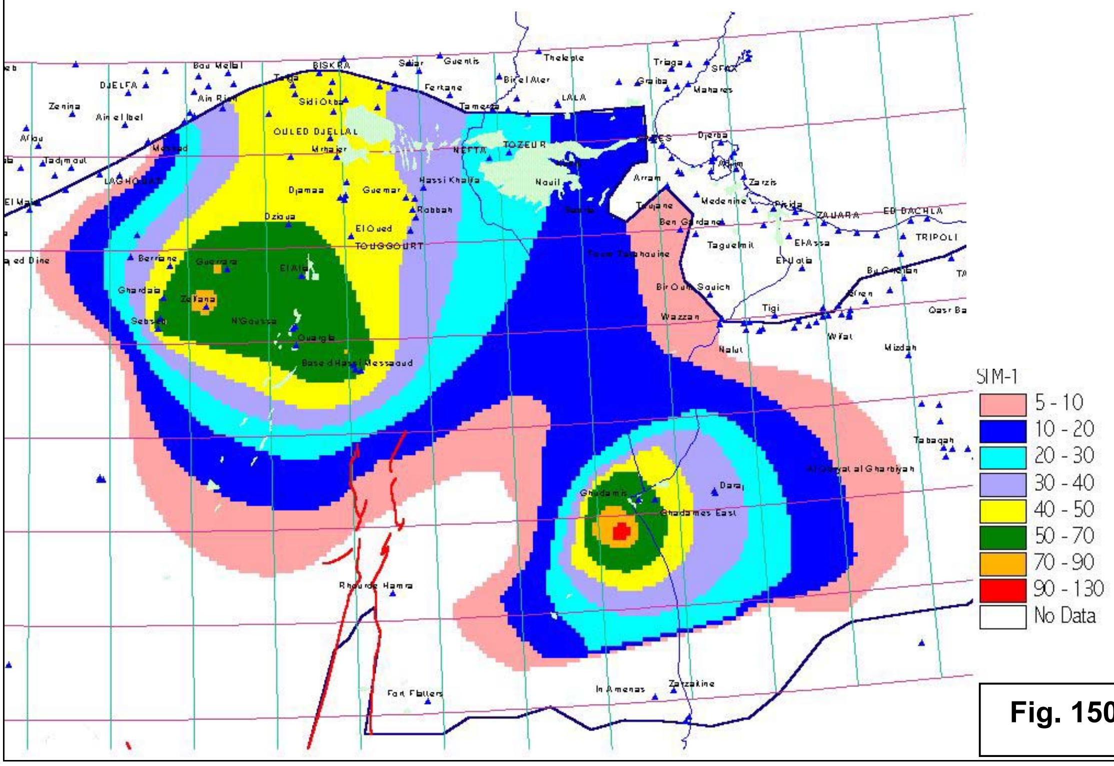


Fig. 150

CI- Simulation n°1 - Piezometric area 2050

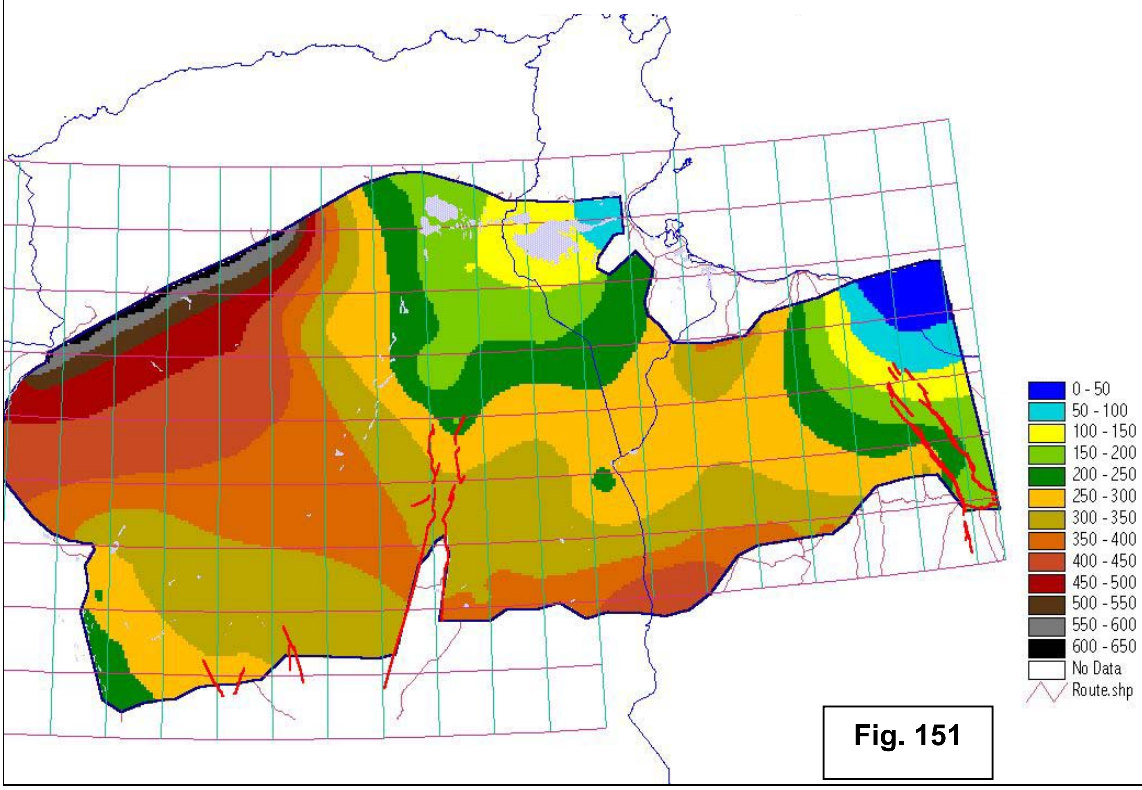


Fig. 151

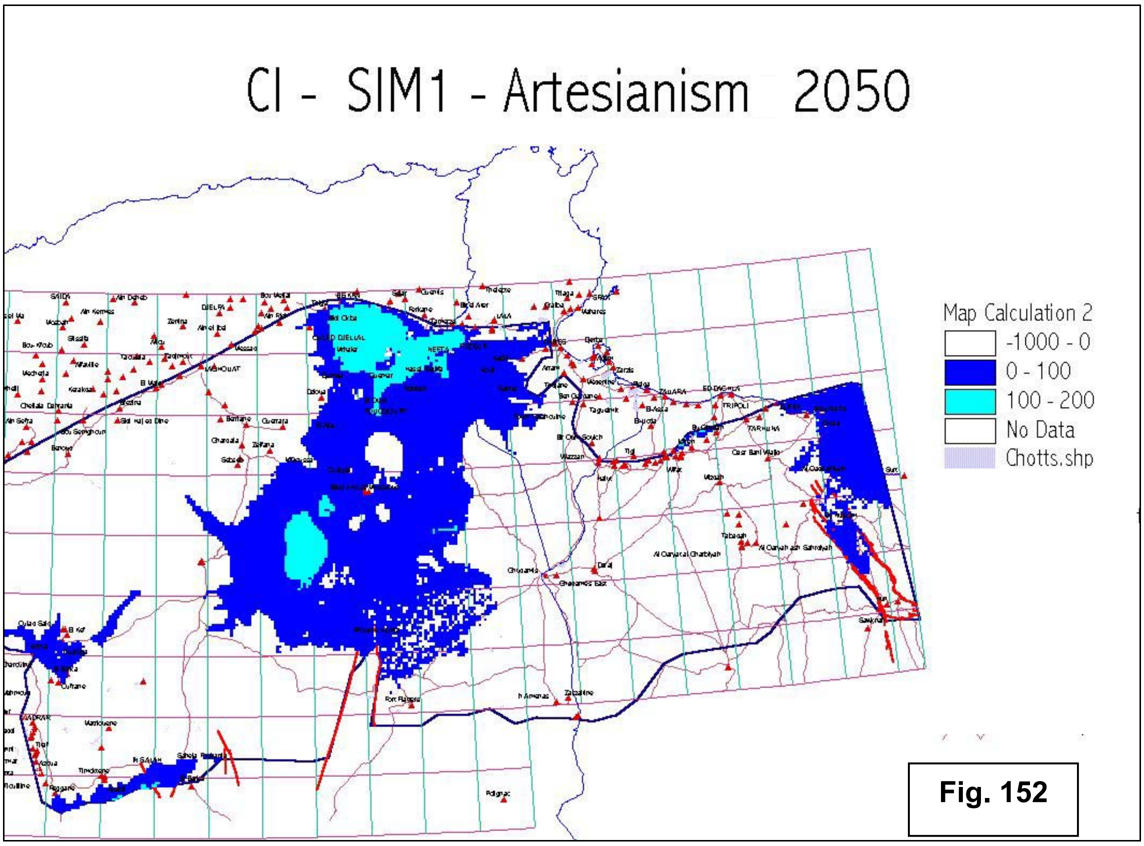


Fig. 152

Table 35: simulation 2: CI in Tunisia

CI - 2– Additional flows			
Group	**Q m^3/s**	***Group***	**Q m^3/s**
Chott Fejej	**0.2**	**Bordj-Bourguiba**	**0.2**
Hazoua	**0.3**	**Bir-zar**	**0.2**
Degache-hamma	**0.1**	**Tiaret**	**0.5**
PIK	**0.2**	**Borj-el-khadra**	**0.5**
Total		***2.2***	

The principles of this simulation are the following:

- Additional flows exclusively located in Tunisia so that we can measure the incidence on each of the two other countries
- Maximal racking while observing following constraints.
- Big distance from the field of Chott Fedjej in order to ensure the least influence on the flow of the Tunisian outlet
- Preserve artesianism by minimizing drawdowns

The water budget of this simulation is then as follows:

	Inputs (m^3/s)	Supply	Turonian Leakage Turonian	Upper Sandstone	Cambro-Ordovician input	Eastern Boundary	Contribution of reserves	Total of Inputs	Outputs (m^3/s)	Pumping	Turonian Leakage	Upper sandstone Leakage	Saoura & S.Timimoun	Foggaras	Tunisian Outlet	Gulf of Syrta	Total of Outputs
CI-2		9.4	0.8	0.0	3.0	0.0	21.4	34.6		29.	1.9	0.4	0.2	1.95	0.5	0.6	34.6
CI-SIM-0		9.4	0.7	0.0	3.0	0.0	19.8	32.9		26.8	1.9	0.5	0.2	1.95	0.94	0.6	32.9

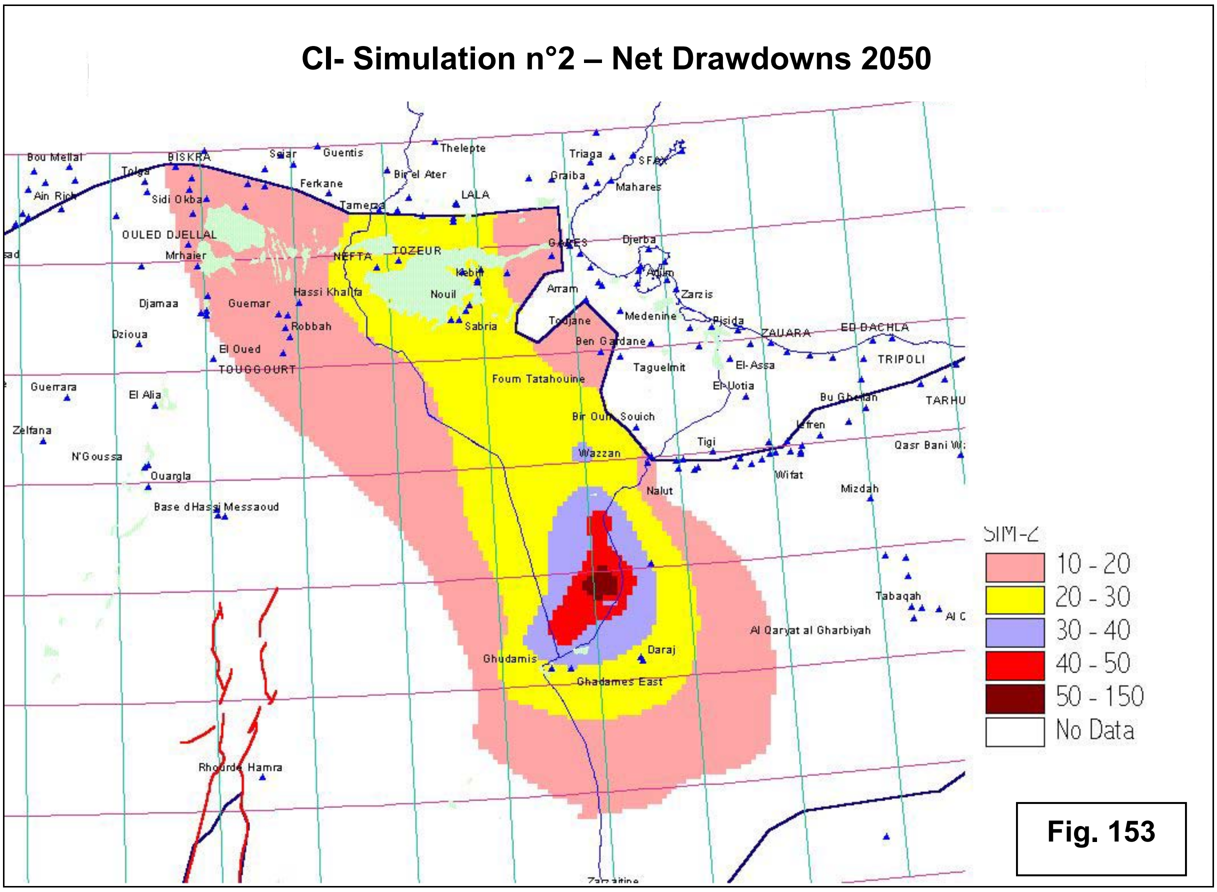


Table 36: simulation 3: Ghadames Basin

CI - 3– Additional flows			
Group	**Q m^3/s**	***Group***	**Q m^3/s**
Ghadames	**2.85**	**Bordj-Bourguiba**	**0.2**
Deb-deb	**2.0**	**Bir-zar**	**0.2**
Borj-el-khadra	**0.5**	**Tiaret**	**0.5**
Total		***6.3***	

The objective of this simulation is to measure the impact of a possible accumulation of all additional abstraction likely to be made in the Ghadames basin: the « Ghadames field » in

Libya, the Debdeb region in Algeria and the Tunisian far southern region, whose total in normal pace regime reaches 200 Millions m3/year.

The simulation water budget looks as follows:

	Inputs (m^3/s)	Supply	Leakage Turonian	Upper Sandstone	Cambro-Ordovician input	Eastern Boundary	Contribution of reserves	Total of Inputs	**Outputs (m^3/s)**	Pumping	Turonian Leakage	Upper sandstone Leakage	Saoura & S.Timimoun	Foggaras	Tunisian Outlet	Gulf of Syrta	Total of Outputs
CI-3		9.4	1.2	0.0	3.2	0.0	25.2	39.		33.1	1.9	0.4	0.2	1.95	0.84	0.6	39.
CI-SIM-0		9.4	0.7	0.0	3.0	0.0	19.8	32.9		26.8	1.9	0.5	0.2	1.95	0.94	0.6	32.9

CI- Simulation n°3 - Net Drawdowns 2050

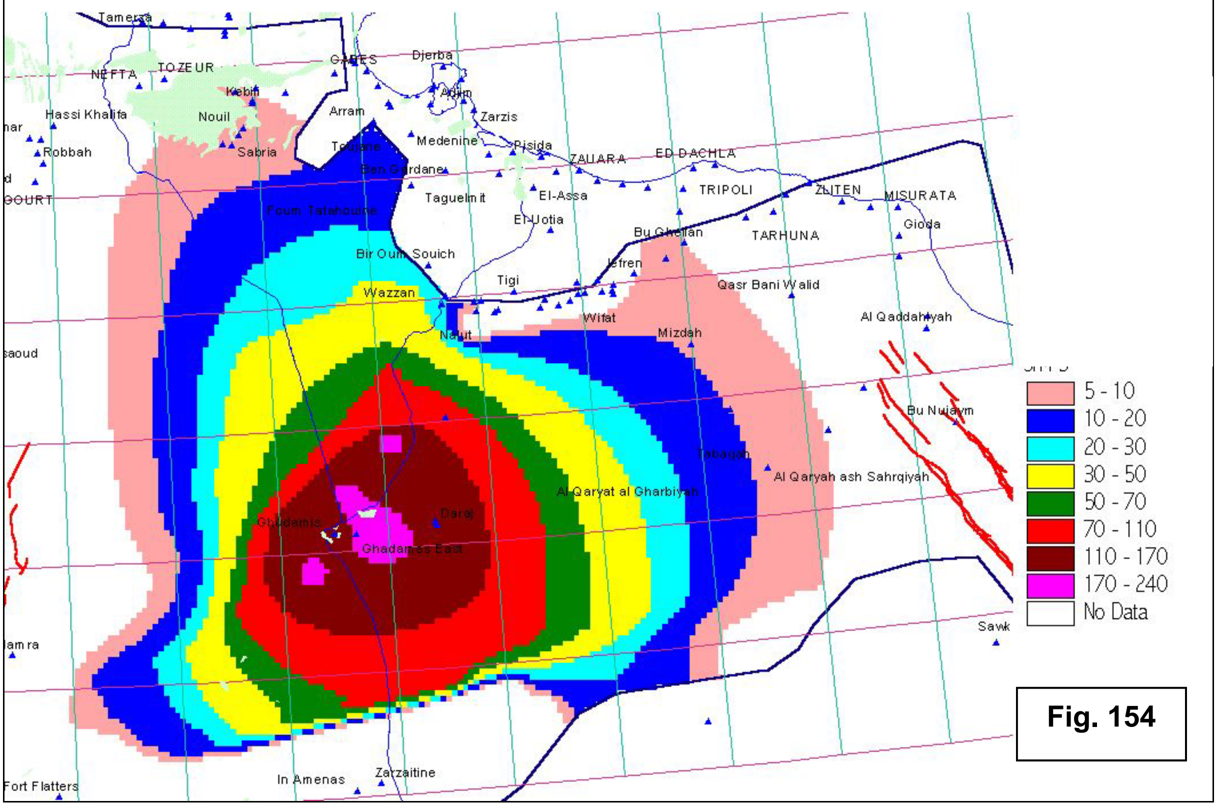


Fig. 154

Table 37: Simulation 4: CI over all the Central Basin

CI - 4 - Additional Abstraction			
Group	Q m^3/s	*Group*	Q m^3/s
Deb-deb	2.0	C-F	0.2
Ouled-djellal	0.2	Bordj-Bourguiba	0.2
El-oued	0.2	Bir-zar	0.2
Djemaa	0.1	Tiaret	0.5
M'ghaier	0.2	Borj-el-khadra	0.5
Sebseb	2.0	Hazoua	0.3
Guerrara	1.0	Degache-hamma	0.1
Zelfana	2.0	PIK	0.2
El-alia	0.1		
N'goussa	0.2	Ghadamis	3.10
Ouargla	0.2	Sinawan	0.02
H-Mess-nord	0.3	Nalut	0.52
Total		***14.3***	

This simulation gathers all additional abstraction from NWSAS central basin. It represents the union of simulations 1 and 2, complemented with the flows of the « Ghadames field » and other flows (Ghadames, Sinawen, Nalut) corresponding to the hypothesis of « reduction of 2030 deficits» in Libya (Cf. further Simulation CI7).

The water budget of this simulation is as follows:

	Inputs (m^3/s)	Supply	Turonian Leakage Turonian	Upper Sandstone	Cambro-Ordovician input	Eastern Boundary	Contribution of reserves	Total of Inputs	**Outputs (m^3/s)**	Pumping	Turonian Leakage	Upper sandstone Leakage	Saoura & S.Timimoun	Foggaras	Tunisian Outlet	Gulf of Syrta	Total of Outputs
CI-4		9.4	1.3	0.0	3.2	0.0	32.2	46.1		41.	1.9	0.4	0.1	1.95	0.13	0.6	46.1
CI-SIM-0		9.4	0.7	0.0	3.0	0.0	19.8	32.9		26.8	1.9	0.5	0.2	1.95	0.94	0.6	32.9

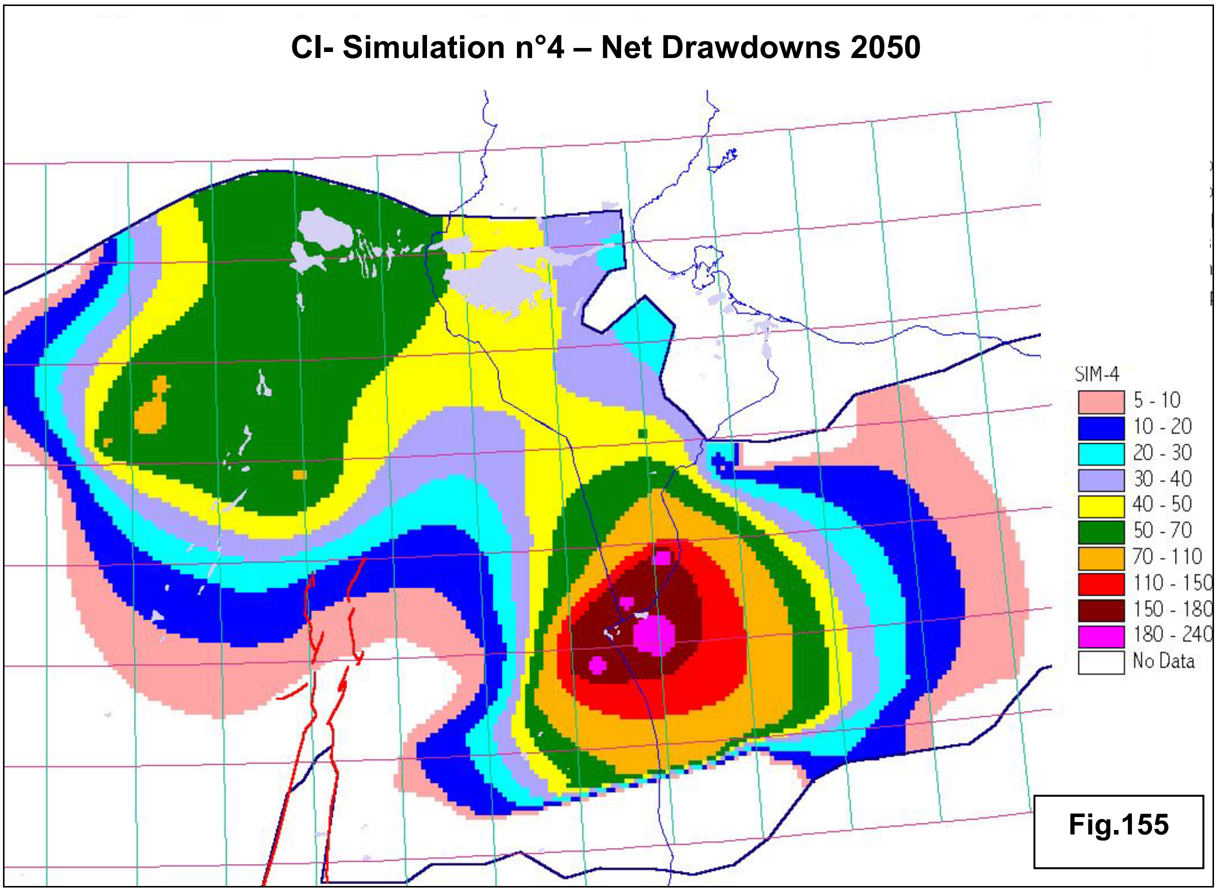


Fig.155

Table 38: Simulation 5: Algerian Lower Sahara and Adrar

CI - 5– Additional Flows			
Group	**Q m³/s**	***Group***	**Q m³/s**
Ouled-djellal	**0.2**	**Ouargla**	**0.2**
El-oued	**0.2**	**H-Messaoud-nord**	**0.3**
Djemaa	**0.1**	**Deb-deb**	**2.0**
M'ghaier	**0.2**	**titaf**	**5.0**
Sebseb	**2.0**	**Akabli**	**5.0**
Guerrara	**1.0**	**timimoun**	**5.0**
Zelfana	**2.0**	**in-salah**	**5.0**
El-alia	**0.1**	**el-golea**	**8.0**
N'goussa	**0.2**	**fort-flatters**	**2.0**
Total		***38.5***	

This is again a simulation abstraction exclusively in Algeria: to simulation n°1 we add all additional abstraction made in the province of Adrar (20 m^3/s), as well as important abstraction in El Goléa (8m^3/s) and Fort Flatters (2m^3/s). This scenario, resulting from a thorough investigation on the « micro-model », represents the maximum of what can still be abstracted in Algeria without causing major nuisances.

The water budget of this simulation is the following:

	Inputs (m^3/s)	Supply	Turonian Leakage Turonian	Upper Sandstone	Cambro-Ordovician input	Eastern Boundary	Contribution of reserves	Total of Inputs	Outputs (m^3/s)	Pumping	Turonian Leakage	Upper sandstone Leakage	Saoura & S.Timimoun	Foggaras	Tunisian Outlet	Gulf of Syrta	Total of Outputs
CI-5		9.4	0.8	0.0	3.0	0.0	57.0	70.2		65.3	1.8	0.4	0.2	1.32	0.59	0.6	70.2
CI-SIM-0		9.4	0.7	0.0	3.0	0.0	19.8	32.9		26.8	1.9	0.5	0.2	1.95	0.94	0.6	32.9

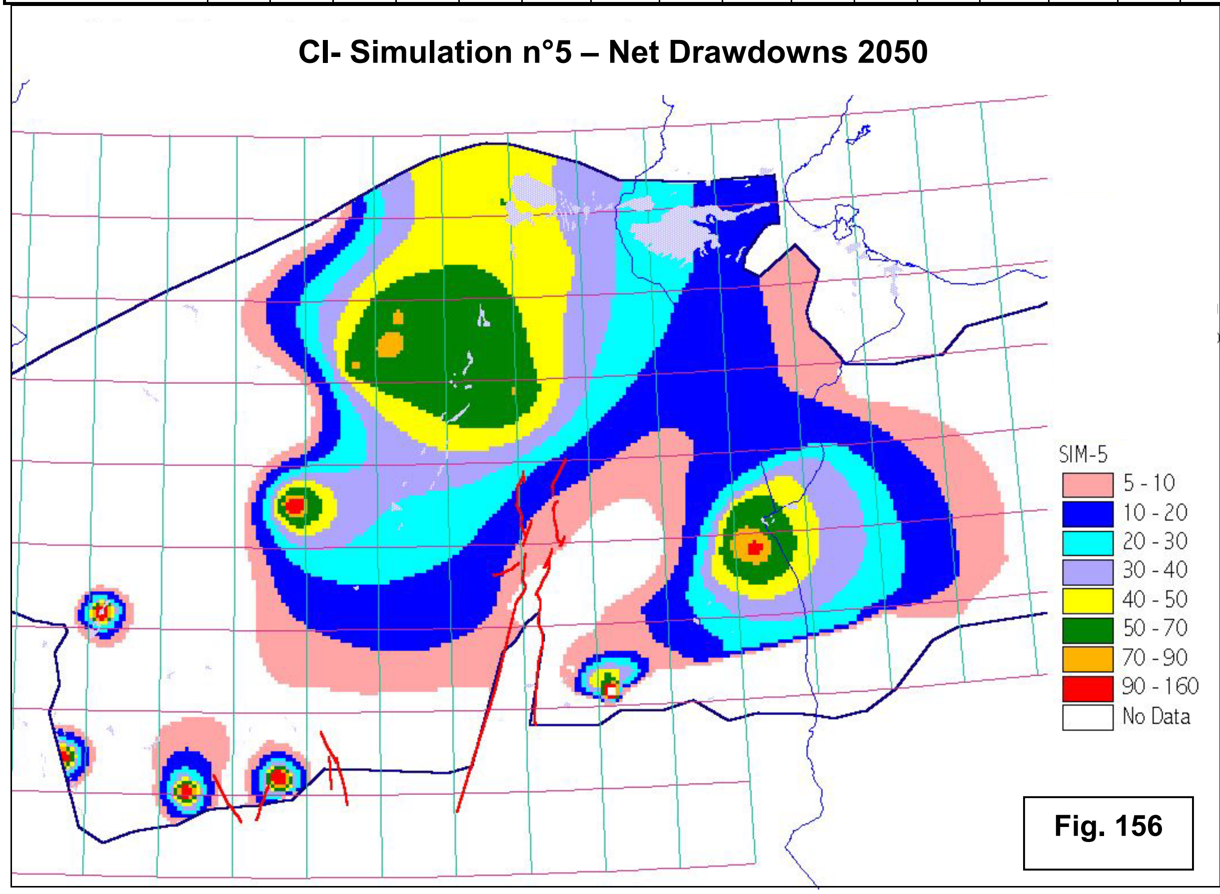


Fig. 156

With this simulation, we note the emergence of a particular phenomenon in newly explored sectors [Adrar, El Golea, Fort Flatters]: in spite of the intensity of shown flows [8 m^3/s, 5m^3/s] and the simulation duration, the drawdowns cones have very low lateral extensions and tend to « dig » in the same place. This phenomenon is specific to regions with poor diffusion capacity [T/S] which badly propagate disturbances. This also precisely corresponds to areas where the aquifer has an unconfined surface or at an immediate proximity, the essential portion of abstractions being drawn from the aquifer local reserves.

Table 39: Simulation 6: Exploitation of reserves of the Western Basin

CI - 6 – Additional Flow rates			
Group	**Q m³/s**	***Group***	**Q m³/s**
Western Erg- -1	**10**	**Tiberrhamine**	**10**
Western Erg- -2	**10**	**Timimoun-2**	**10**
Western Erg- -3	**10**	**Oued-el-gharbi**	**10**
Oued-seggeur	**10**	**Ain-guettara**	**10**
Total		***80.0***	

This simulation aims at exploring the « capacitive » properties of the Continental Intercalaire in its unconfined surface part, highlighting the « non diffusion » phenomenon of draw downs shown in simulation n°5 .

The purpose is to explore a region that is still not well known, but that we can reasonably hope it will considerably contribute by its huge reserves accumulated in the immense CI reservoir. The region of the Grand Western Erg (Grand Erg Occidental), lying on large areas where the CI aquifer has an unconfined surface, responds precisely to this definition. A simulation was made at 80m³/s (**2,5 billion m³/year**) spread over eight catching fields and on the basis of 10 m³/s each. Of course, these flows do not correspond to local needs: **this is a pure transfer scenario**.

The water budget of this simulation is as follows:

	Inputs (m³/s)	Supply	Turonian Leakage Turonian	Upper Sandstone	Cambro-Ordovician input	Eastern Boundary	Contribution of reserves	Total of Inputs	**Outputs (m³/s)**	Pumping	Turonian Leakage	Upper sandstone Leakage	Saoura & S.Timimoun	Foggaras	Tunisian Outlet	Gulf of Syrta	Total of Outputs
CI-6		9.4	0.7	0.0	3.0	0.008	99.6	112.7		106.8	1.9	0.5	0.2	1.78	0.94	0.6	112.7
CI-SIM-0		9.4	0.7	0.0	3.0	0.008	19.8	32.9		26.8	1.9	0.5	0.2	1.95	0.94	0.6	32.9

What seems interesting to note in this water budget, is the portion taken by the « contribution of reserves » in the total production, that we can express by the ratio "contribution of reserves/pumping". This ratio equals **74% for SIM0** and **93% for SIM-CI6**. But if we think in terms of flows superposition, we can note that between SIMO and SIM6, the growth of the contribution of reserves was **79.8m³/s** which represents **99.8% of additional pumping**, and which draw directly from the reserve.

CI- Simulation n°6 – Net Drawdowns 2050

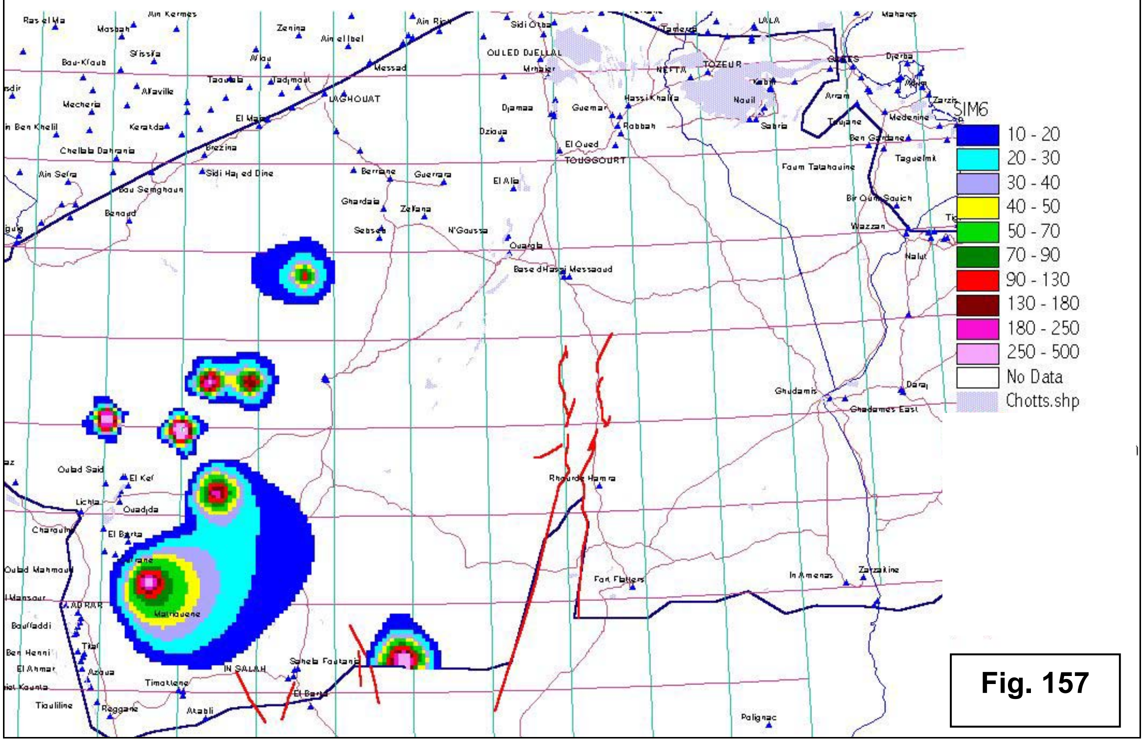


Fig. 157

In order to respond to all sectors' water needs, the NWSAS Libyan part will need, by the time-frame 2030, an additional quantity estimated at **840Mm^3/an**[9]. The contribution of GMRP to this need being estimated at **300Mm^3/year**, it is expected to resort to NWSAS aquifers to reduce 2030 deficits, hence an additional abstraction of (with reference to 2000) **540Mm^3/year** or **17. m^3/s**. In each of the pumping groups surveyed, this additional flow will be spread according to 2000 abstraction. This would represent a total of approximately **5.4 m^3/s in the CI** and **11 .6 m^3/s** in the CT.

Table 40: Simulation 7: Reduction of deficits in Libya

CI - 7 – Additional Flows			
Group	**Q m^3/s**	***Group***	**Q m^3/s**
Wadi Maymun	**0.16**	**Wadi Mardum**	**0.42**
Wadi Ninah	**0.41**	**Abu Njaym**	**0.10**
Wadi Sufajjin	**0.30**	**Ayn Tawurgha**	**0.31**
Wadi Zamzam	**0.80**	**Bani Walid**	**0.42**
Yafrin	**0.03**	**Bay al Kabir**	**0.26**
Zintan	**0.13**	**Buwayrat-al-Hasun**	**0.03**
Derj	**0.05**	**Gharyan**	**0.06**
Ghadamis	**0.22**	**Jadu**	**0.08**
Sinawan	**0.02**	**Mrah-Wishkah**	**0.33**
Nalut	**0.52**	**Waddan**	**0.63**
	Total	***5.2***	

[9] See « Definition and Conducting of Exploratory Simulations», doc. SASS-OSS , Nov. 2001

The water budget of this simulation is as follows:

	Einputs (m³/s)	Supply	Turonian Leakage Turonian	Upper Sandstone	Cambro-Ordovician input	Eastern Boundary	Contribution of reserves	Total of Inputs	Outputs (m³/s)	Pumping	Turonian Leakage	Upper sandstone Leakage	Saoura & S.Timimoun	Foggaras	Tunisian Outlet	Gulf of Syrta	Total of Outputs
CI-7		9.4	1.7	0.0	4.2	0.020	21.3	36.6		32.	0.8	0.5	0.2	1.95	0.93	0.26	36.6
CI-SIM-0		9.4	0.7	0.0	3.0	0.008	19.8	32.9		26.8	1.9	0.5	0.2	1.95	0.94	0.6	32.9

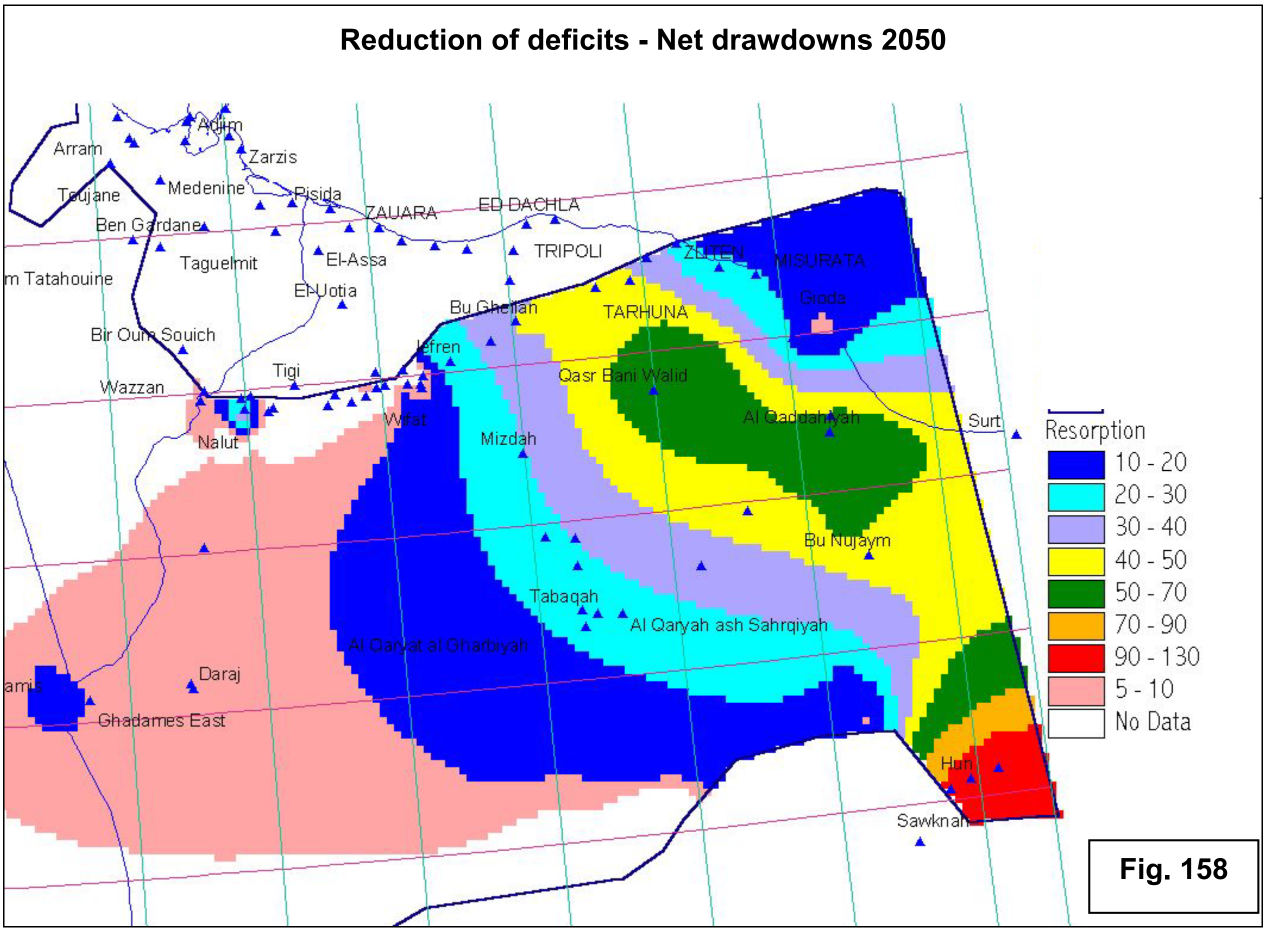


Fig. 158

Table 41: Simulation 8: Overall Exploitation of IC

CI - 8: CI Global Exploitation – Additional Flow rates								
Region	***Group***	***Q m^3/s***	***Region***	***Group***	***Q m^3/s***	***Region***	***Group***	***Q m^3/s***
ERG Occidental	**Timimoun-2**	***10***	**GHARDAIA**	**Sebseb**	***2.0***	**BASSIN ORIENTAL (Eastern Basin)**	**Abu Njaym**	***0.10***
	Erg-occ-1	***10***		**Guerrara**	***1.0***		**Ayn Tawurgha**	***0.31***
	Oued-seggeur	***10***		**Zelfana**	***2.0***		**Bani Walid**	***0.42***
	Tibrrhamine	***10***	**OUARGLA**	**El-alia**	***0.1***		**Bay al Kabir**	***0.26***
	Ain-guetera	***10***		**N'goussa**	***0.2***		**BuwayratHasun**	***0.03***
	Erg-occ-2	***10***		**Ouargla**	***0.2***		**Gharyan**	***0.06***
	Erg-occ-3	***10***		**H-Mess-nord**	***0.3***		**Jadu**	***0.08***
	Oued-el-gharbi	***10***	**C. FEJEJ**	**C-F**	***0.2***		**Mrah-Wishkah**	***0.33***
ADRAR-MENIA	**titaf**	***5.0***		**Bhaier**	***0.0***		**Waddan**	***0.63***
	Akabli	***5.0***	**EXT-SUD TUN**	**Bordj-Bourguiba**	***0.2***		**Wadi Mardum**	***0.42***
	timimoun	***5.0***		**Bir-zar**	***0.2***		**Wadi Maymun**	***0.16***
	in-salah	***5.0***		**Tiaret**	***0.5***		**Wadi Ninah**	***0.4 1***
	el-golea	***8.0***		**Borj-el-khadra**	***0.5***		**Wadi Sufajjin**	***0.30***
DEBDEB	**fort-flatters**	***2.0***	**JERID**	**Hazoua**	***0.3***		**Wadi Zamzam**	***0.80***
	Deb-deb	***2.0***		**Deguache-hamma**	***0.1***		**Yafrin**	***0.03***
OUED RHIR	**Ouled-djellal**	***0.2***		**PIK**	***0.2***		**Zintan**	***0.13***
	El-oued	***0.2***	**GHADAMES**	**Ghadamis**	***3.10***		**Derj**	***0.05***
	Djemaa	***0.1***		**Sinawan**	***0.02***	***TOTAL***	***129***	**m^3/s**
	M'ghaier	***0.2***		**Nalut**	***0.52***			

This scenario groups all additional flows simulated in Algeria, Tunisia and Libya. If we include current abstraction, this represents a production for all the CI of about **155 m^3/s**, or nearly **5. billion m^3/year**. By country, flows shown on the model are summarized in the following table:

Simulated Flow rates in (m^2/s)	***2000***	***SIM-8***	***total***
Algeria	21.2	118.5	139.8
Tunisia	2.2	2.2	4.4
Libya	3.4	8.3	11.6
Total	***26.8***	***129.***	***155.8***

The water budget of this simulation will then be as follows:

Inputs (m^3/s)	Supply	Turonian Leakage Turonian	Upper Sandstone	Cambro-Ordovician input	Eastern Boundary	Contribution of reserves	Total of Inputs	**Outputs (m^3/s)**	Pumping	Turonian Leakage	Upper sandstone Leakage	Saoura & S.Timimoun	Foggaras	Tunisian Outlet	Gulf of Syrta	Total of Outputs
CI-8	9.4	2.5	0.0	4.2	0.020	142.1	158.2		155.6	0.5	0.4	0.1	1.19	0.13	0.3	158.2
CI-SIM-0	9.4	0.7	0.0	3.0	0.008	19.8	32.9		26.8	1.9	0.5	0.2	1.95	0.94	0.6	32.9

CI - SIM8 - Net Darwdowns 2050

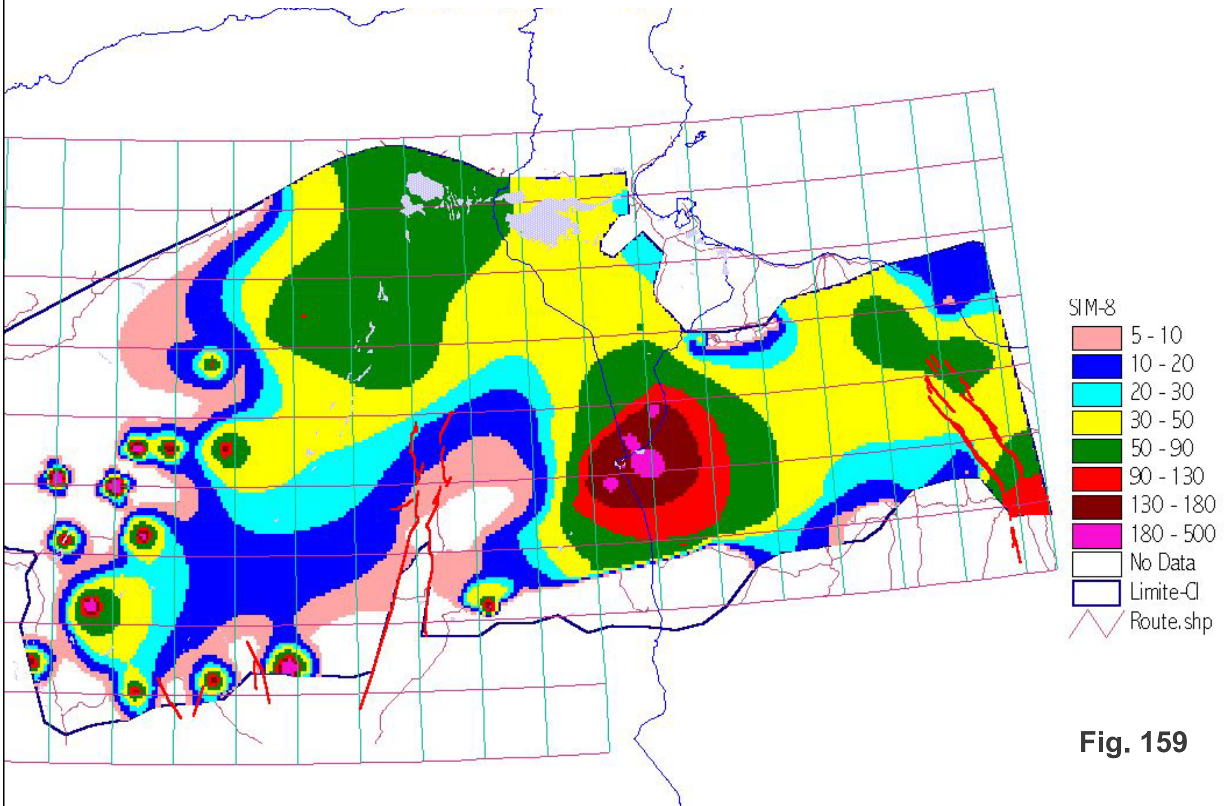


Fig. 159

CI - Simulation n° 8 - Artesianism in meters

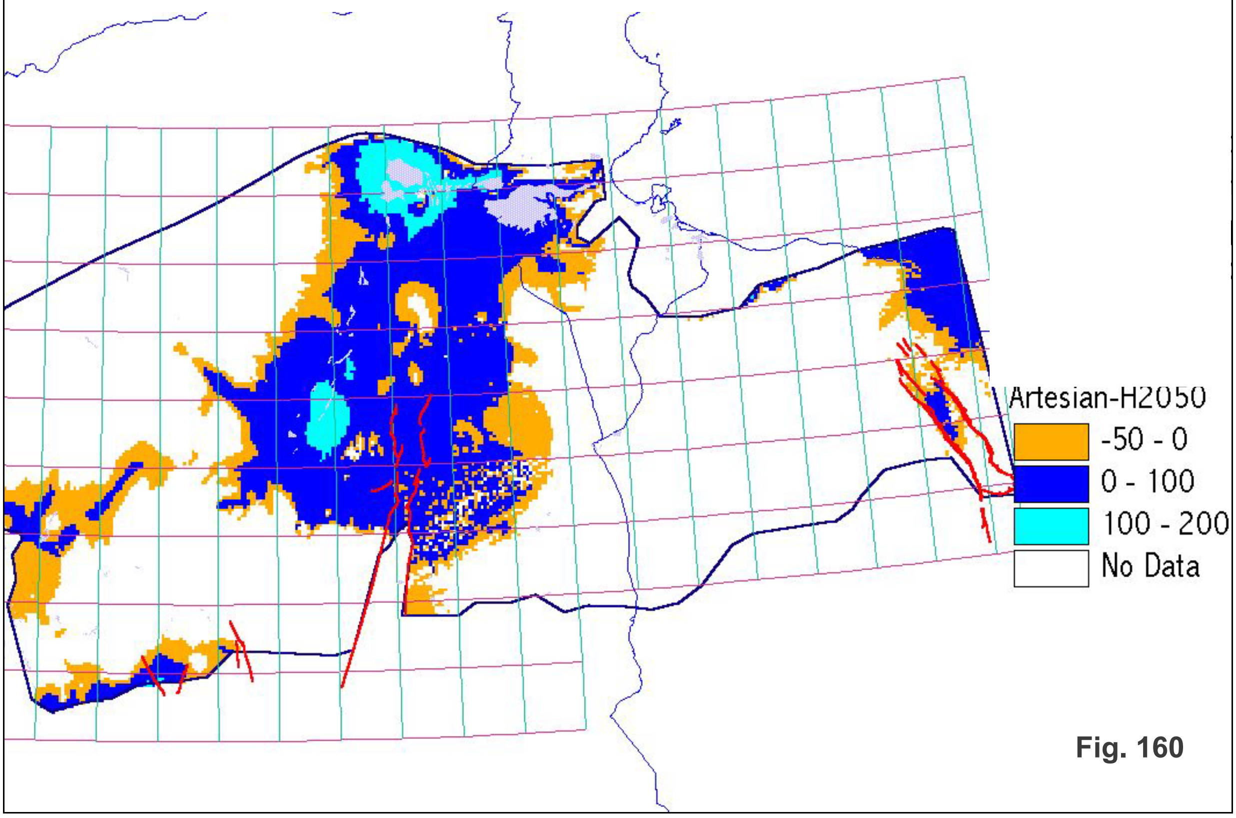


Fig. 160

Case of gradually varied pumping: CI-3 bis Simulation

In order to measure the real impact, on calculated drawdowns, of the amplification effect due to the imposition of a constant abstraction flow throughout the adopted simulation period (or 50 years from 2000 to 2050), a simulation was conducted again by staggering the pumping flows in a gradual way. For this exercise, simulation n°3 has been chosen [Ghadames Field ; Deb-Deb ; Tunisian far southern part]; this simulation, among other conducted ones, produces the most important NWSAS drawdowns in amplitude as well as in terms of regional extension.

The evolution of pumping flows follows the protocol drawn in fig.161: from 2000 to 2010, we maintain the same flow as 2000, then we equally distribute over the four following decades the additional flow that we want to simulate: the fourth portion starts in 2040, date when the final flow is imposed until 2050.

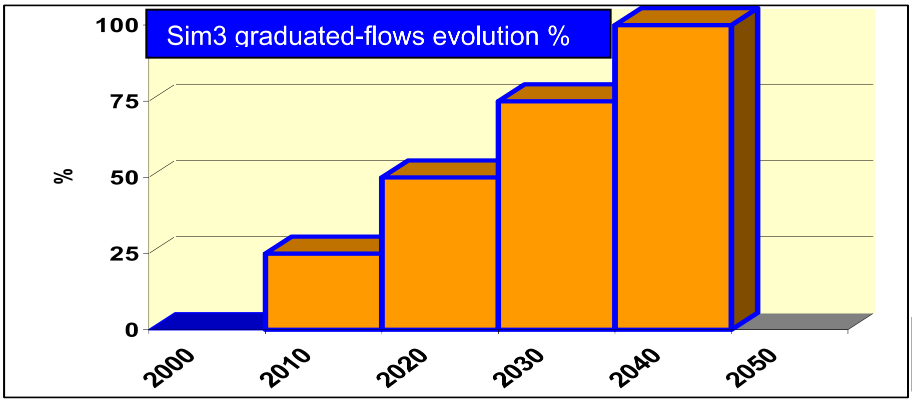


Fig. 161

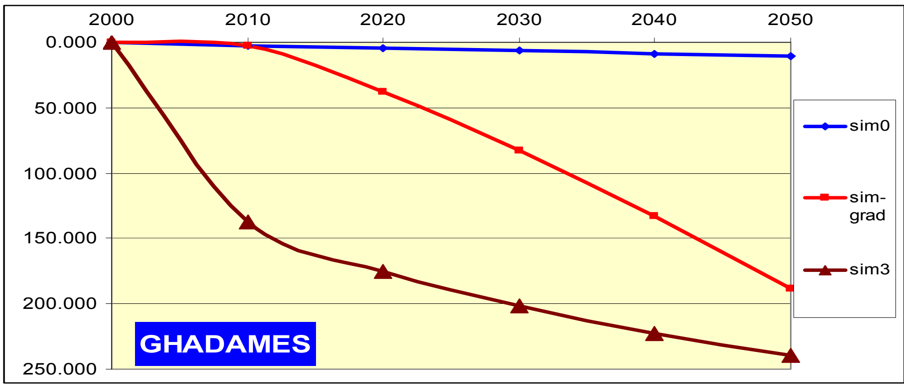


Fig. 162

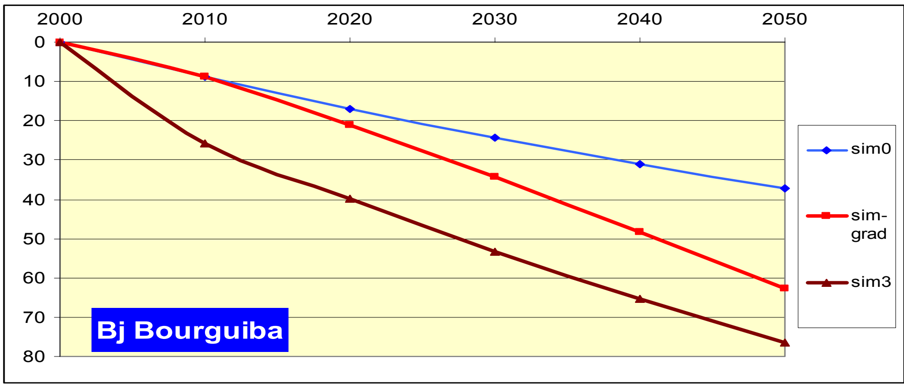


Fig.163

The evolution of drawdowns calculated in two points, the first in the middle of the catching field (Ghadames), the other at the periphery (Bj. Bourguiba), clearly shows that 10 years only of pumping at a given regime to reach drawdowns of **80%** [in the middle of the field **60%** at the periphery] of those calculated after 50 years at the same regime. This last result justifies the option taken to systematically simulate constant pumping flows throughout the simulation period.

II.2- The Complexe Terminal

Table 42: Simulation 1: Additional abstraction in Algeria

CT - 1 – Algeria – additional abstraction			
Group	***Q m^3/s***	***Group***	***Q m^3/s***
Hassi-messaoud	**3.0**	**Taleb-el-arbi**	**0.1**
Gassi-touil	**5.0**	**M'ghaier**	**0.1**
Hassi-messaoud-nord	**1.0**	**El-oued**	**0.1**
Ouargla	**1.0**	**Douar-el-ma**	**0.1**
N'goussa	**3.0**	**Ben-geucha**	**0.1**
El-alia	**1.0**	**Djemaa**	**0.2**
	Total	**14.7**	**m^3/s**

With regard to the risks identified near the Chotts, additional flows are set at their minima in Oued Rhir and El Oued and are related towards the south far away from the Chotts.

CT - Simulation N° 1 - Net drawdowns 2050

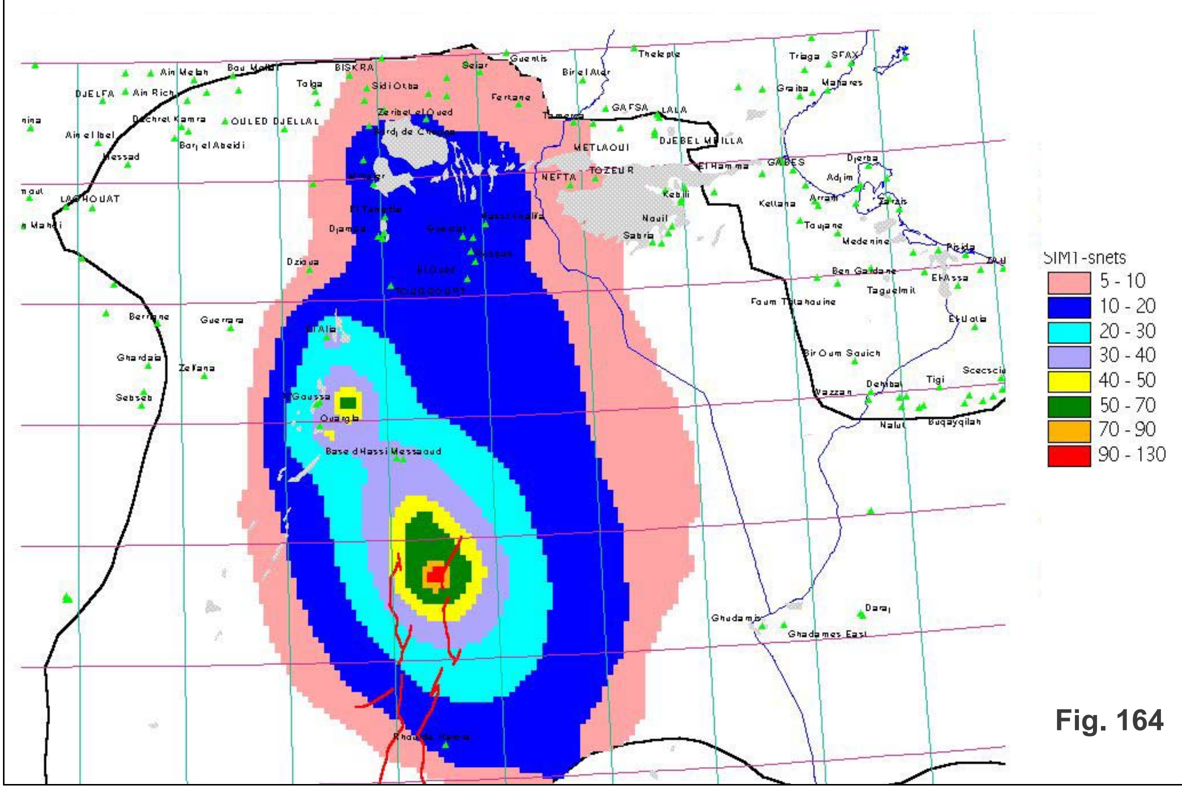


Fig. 164

The water budget of the simulation is written as follows:

Table 43: CT- 2: Tunisia– additional withdrawals

Group	*Q m³/s*	*Group*	*Q m³/s*
Dhafria	**0.2**	**R-maatoug**	**1.0**
Segdoud	**0.1**	**Zaafrane**	**0.5**
Htam	**0.1**	**Djemna**	**0.1**
Bir-roumi	**0.1**	**Tembain**	**0.5**
Bordj-el-khadra	**0.2**	**El-ouar**	**0.5**
	Total	**3.3**	**m³/s**

Simulation 2: Additional abstraction in Tunisia

The same concern, minimize additional flows around the Chotts, enabled the recognition of more remote regions such as Tembain or El Ouar (cf. localizations fig.14).

CT - Simulation N° 2 - Net drawdowns 2050

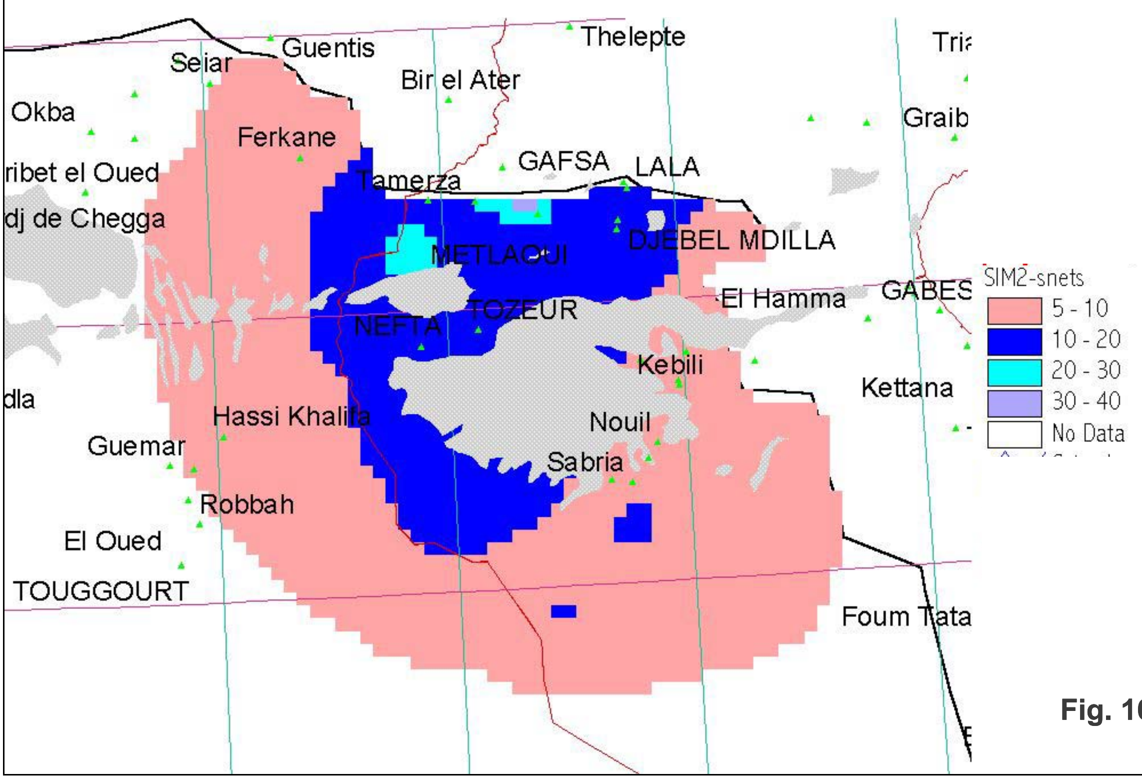


Fig. 165

The water budget of this simulation is:

CT	**Inputs (m³/s)**	Supply	Leakage Turonian	Upper Sandstone	Ordovician input	Eastern Boundary	Contribution of reserves	Total of Inputs	**Outputs (m³/s)**	Pumping	Turonian Leakage	sandstone Leakage	Saoura & S.Timimoun	Foggaras	Tunisian Outlet	Gulf of Syrta
SIM-1		18.2	7.3	36.7	62.2		57.5	2.8	1.3	0.0	0.1	0.5	0.0	0.0	0.0	62.2
SIM-0		18.2	7.2	22.1	47.5		42.8	2.8	1.3	0.0	0.1	0.5	0.0	0.0	0.0	47.5

Table 44: Simulation 3: Reduction of deficits in Libya

CT - 3 – Libya – additional flow rates					
Group	*Q m^3/s*	*Groupe*	*Q m3/s*	*Group*	*Q m^3/s*
As Sikt - Misratah	**0.5**	**Wadi Kaam Project**	**0.5**	**Mrah- Wishkah**	**0.2**
Bani Walid	**0.0**	**Suknah**	**1.5**	**Ferjan Project**	**0.8**
Dafniyah	**1.2**	**Tuminah**	**1.0**	**Hammam Project**	**1.6**
Hun	**0.35**	**Waddan**	**1.2**	**Wadi Sufajjin**	**0.25**
Kaam - Al Khums	**0.15**	**Wadi Majir**	**0.2**	**Wadi Zamzam**	**0.4**
Kararim	**0.3**	**Wadi Mardum**	**0.2**	**Zliten**	**0.6**
		Total	**11.**		**m^3/s**

Scenario of reduction of deficits - Net Drawdowns 2050

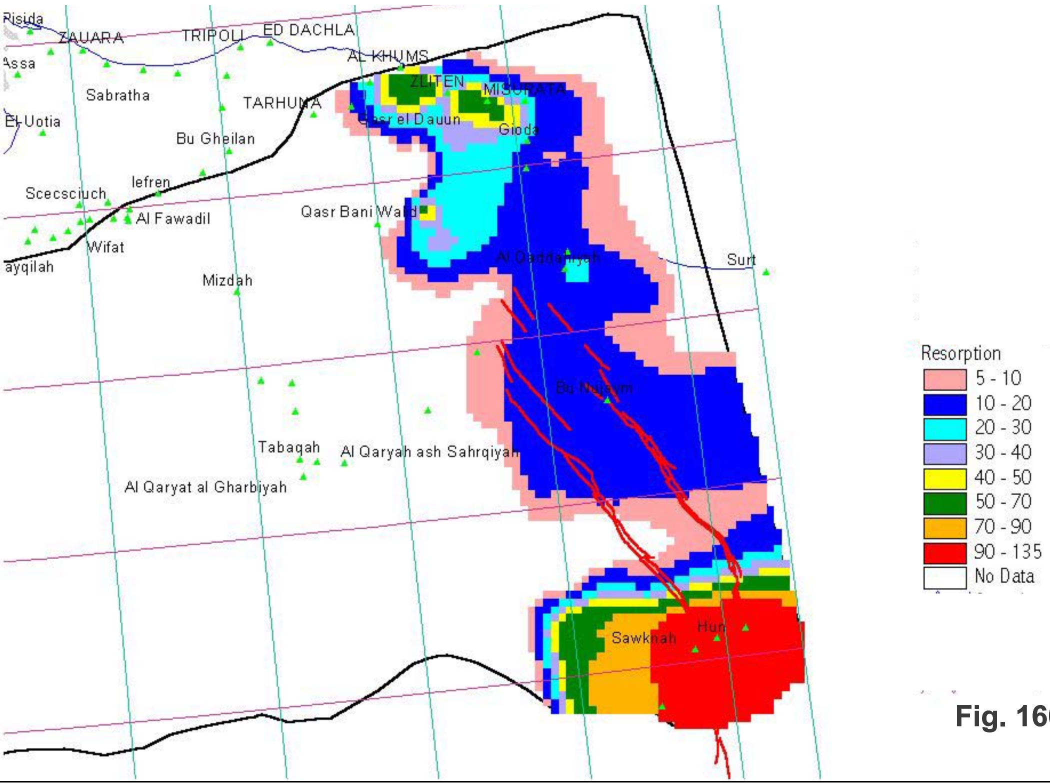


Fig. 166

The simulation water budget is:

CT	Inputs (m^3/s)	Supply	Turonian Leakage	Contribution of reserves	Total of Inputs	Outputs (m^3/s)	Pumping	Turonian Leakage	Ain Tawargha Spring	Chotts in Algéria-Tunisia	Sebkha Mjezem-Tawargha	Gulf of Syrta	Ain Kaam	Nefzaoua Djerid springs	Sebkhas in Algéria	Total of Outputs
CT-3		18.2	10.3	29.0	57.5		53.8	2.8	0.4	0.0	0.1	0.4	0.0	0.0	0.0	57.5
CT-SIM-0		18.2	7.2	22.1	47.5		42.8	2.8	1.3	0.0	0.1	0.5	0.0	0.0	0.0	47.3

Table 45: Simulation 4: Catching Field of Oued Mya

CT - 4: Algeria–Additional flow rates	
Group	*Q m^3/s*
Oued Mya	**18**

This simulation aims at investigating a region that has never been surveyed. Such an investigation became possible on the NWSAS Model. In fact, the CT has been extended to the South to outcrops boundaries, in order to better consider the important reserves represented by important volumes of aquifer not taken into account by ERESS. The catching field of Oued Mya has been selected for the following reasons:

- as far as possible from the region of the Chotts
- Exploit CT reserves in a very extended area of a free surface aquifer
- Profit from the favorable hydraulic conditions identified by the digital model: NP-2000 close to the ground or artesian, high T and S values.

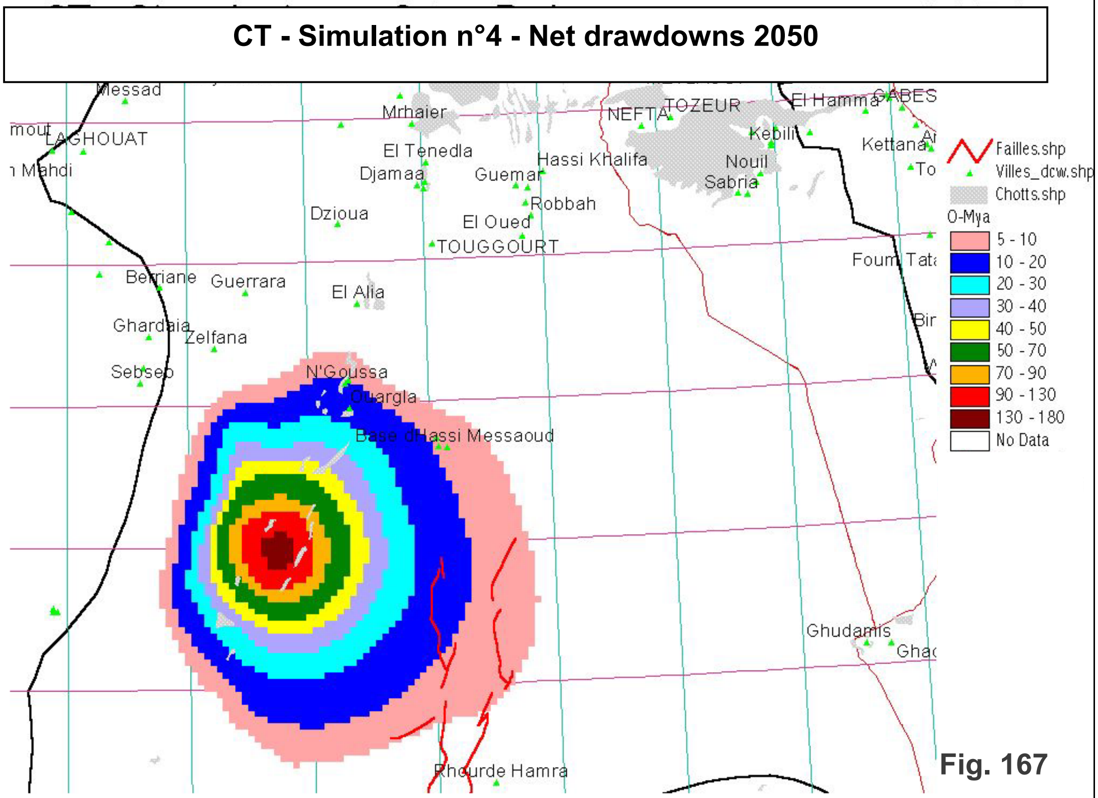


Fig. 167

CT	Inputs (m^3/s)	Supply	Turonian Leakage	Contribution of reserves	Total of Inputs	Outputs (m^3/s)	Pumping	Turonian Leakage	Ain Tawargha spring	Algerian-Tunisian Chotts	Sebkha Mjezem-Tawargha	Gulf of Syrta	Ain Kaam	Nefzaoua Djerid springs	Algerai Sebkhas	Total of outputs
SIM-4		18.2	7.3	40.0	65.5		60.8	2.7	1.3	0.0	0.1	0.5	0.0	0.0	0.0	65.5
SIM-0		18.2	7.2	22.1	47.5		42.8	2.8	1.3	0.0	0.1	0.5	0.0	0.0	0.0	47.5

Table 46: Simulation 5: Overal Exploitation of CT

CT- 5: CT Global Exploitation– Additional Flow rates								
ALGERIE	*Group*	*Q m^3/s*	TUNISIE	*Group*	*Q m^3/s*	LIBYE	*Group*	*Q m^3/s*
	Hassi-messaoud	**3.0**		**Dhafria**	**0.2**		**As Sikt - Misratah**	**0.5**
	Gassi-touil	**5.0**		**Segdoud**	**0.1**		**Bani Walid**	**0.**
	Hassi-messaoud-nord	**1.0**		**Htam**	**0.1**		**Dafniyah**	**1.2**
	Ouargla	**1.0**		**Bir-roumi**	**0.1**		**Hun**	**0.35**
	N'goussa	**3.0**		**Bordj-el-khadra**	**0.2**		**Kaam - Al Khums**	**0.15**
	El-alia	**1.0**		**R-maatoug**	**1.0**		**Kararim**	**0.3**
	Taleb-el-arbi	**0.1**		**Zaafrane**	**0.5**		**Projet Wadi Kaam**	**0.5**
	M'ghaier	**0.1**		**Djemna**	**0.1**		**Suknah**	**1.5**
	El-oued	**0.1**		**Tembain**	**0.5**		**Tuminah**	**1.0**
	Douar-el-ma	**0.1**		**El-ouar**	**0.5**		**Waddan**	**1.2**
	Ben-geucha	**0.1**		***Total***	***3.3***		**Wadi Majir**	**0.2**
	Djemaa	**0.2**					**Wadi Mardum**	**0.2**
	Oued Mya	**18.0**					**Mrah- Wishkah**	**0.2**
	Total	***32.7***					**Projet Ferjan**	**0.8**
							Projet Hammam	**1.6**
							Wadi Sufajjin	**0.2**
	Total Simulation:						**Wadi Zamzam**	**0.3**
							Zliten	**0.6**
	47.			***m^3/s***			***Total***	**11.**

This last simulation represents the sum of additional flow rates shown in all four previous simulations. If we add present abstraction, this will reflect a total simulated abstraction of **90 m^3/s [2.8 billion m^3/yer]**. Calculated by country, shown flows are presented in the following table:

Simulated flow rates	*2000*	*CT-5*	*total*
Algeria [y.c. O.Mya]	21	32.7	53.7
Tunisia	14.4	3.3	17.7
Libya	7.4	11.	18.4
Total	***42.8***	***47.***	***89.8***

The simulation water budget is as follows:

CT	**Inputs (m^3/s)**	Supply	Turonian Leakage	Contribution of reserves	Total of Inputs	**Outputs (m^3/s)**	Pumping	Turonian Leakage	Ain Tawargha spring	Algerian-Tunisian Chotts	Sebkha Mjezem-Tawargha	Gulf of Syrta	Ain Kaam	Nefzaoua Djerid springs	Algerai Sebkhas	Total of outputs
CT-5		18.2	11.1	64.8	94.1		89.8	3.4	0.4	0	0.1	0.4	0	0	0	94.1
CT-SIM-0		18.2	7.2	22.1	47.5		42.8	2.8	1.3	0.0	0.1	0.5	0.0	0.0	0.0	47.5

CT – Simulation n°5 – Net Drawdowns 2050

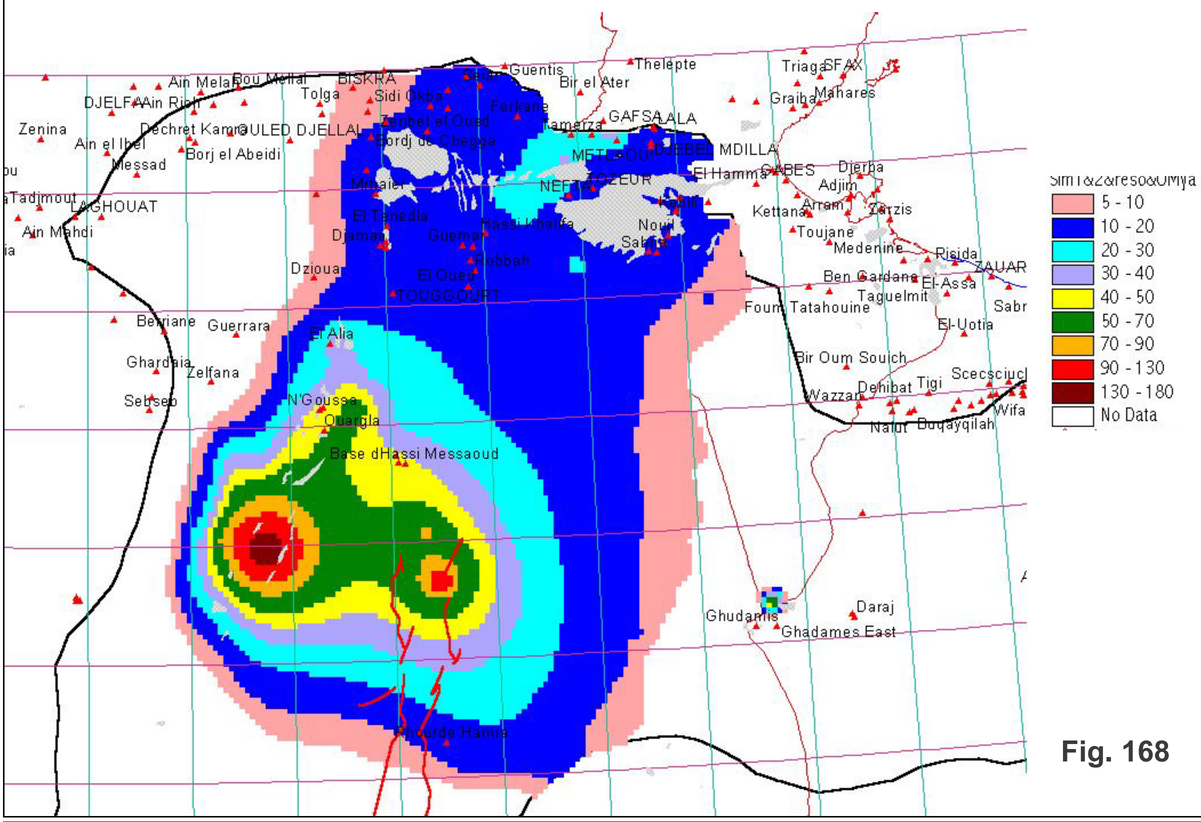


Fig. 168

CT – Simulation n°5 – Piezometric area 2050

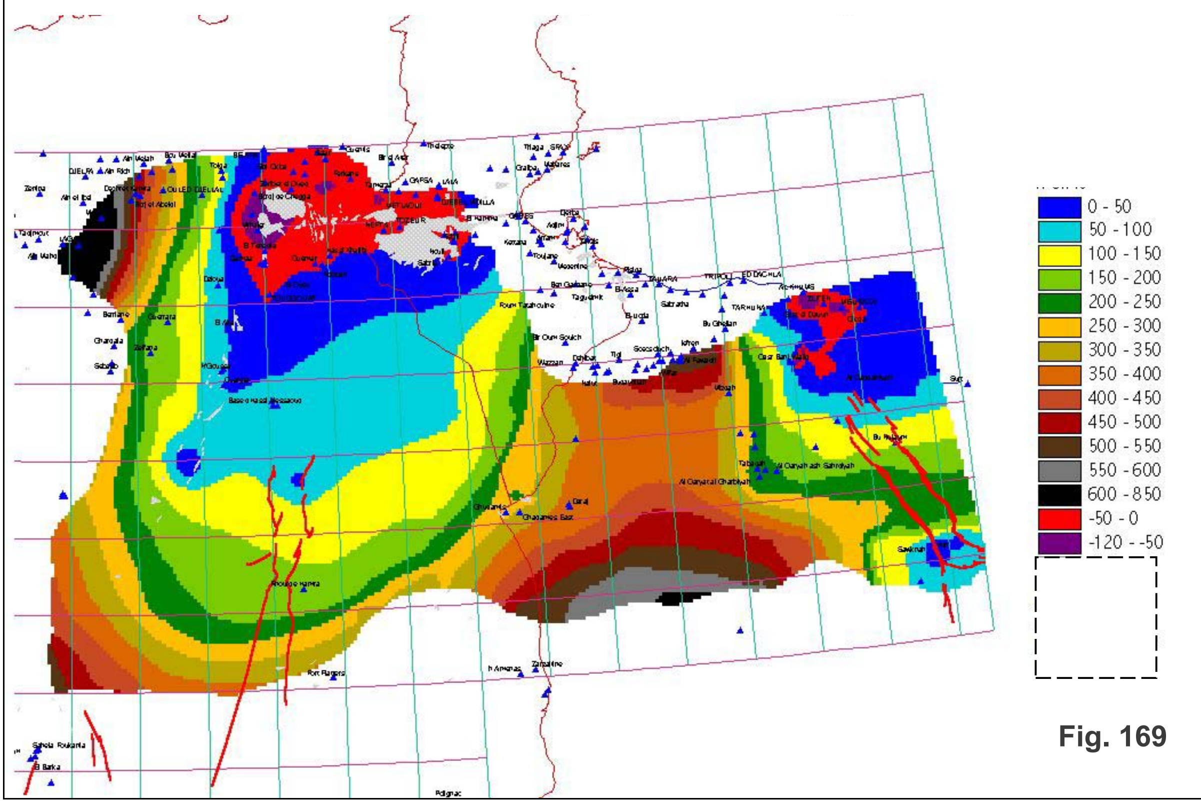


Fig. 169

Simulation N° 5: Piezometric level (reference: Chotts level) CI 2050

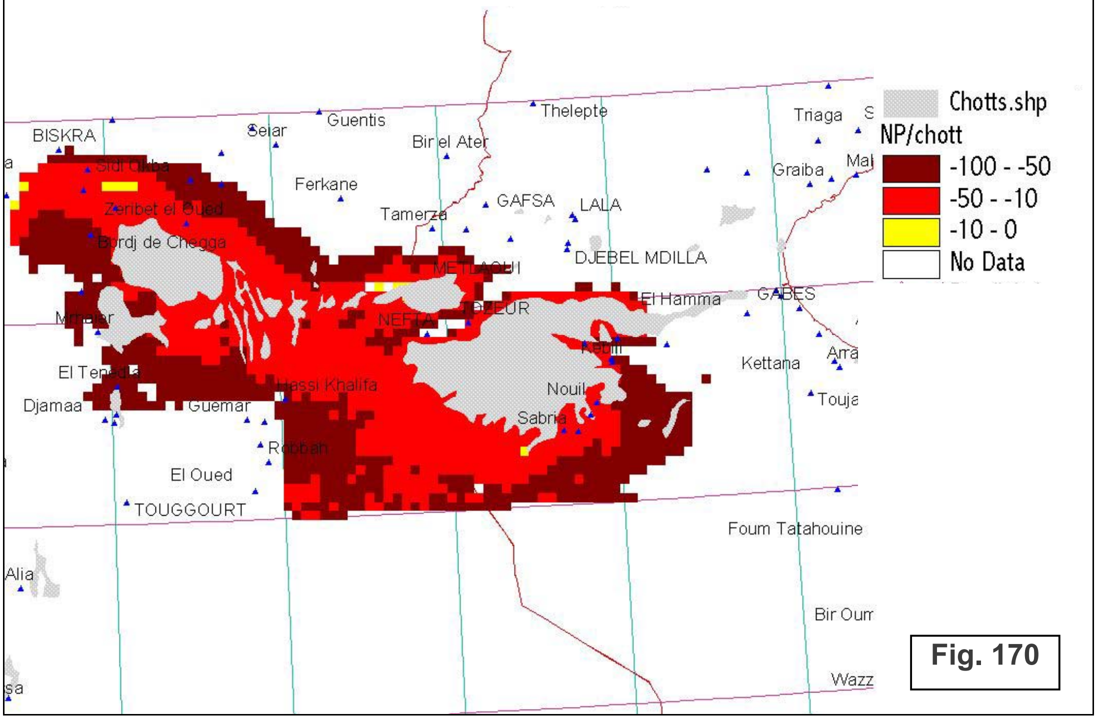


Fig. 170

III- ANALYSIS OF SIMULATIONS RESULTS

III.1- At the Continental Intercalaire

Simulation n°1 ; CI-1: The Algerian Lower Sahara

The results of provisional simulations can be compared and evaluated based on a number of indicators. For each of conducted simulations, the results obtained with regard to the following indicators are successively and systematically examined:

- ***At the level of net drawdowns***[10]

The net drawdowns reflect two very distinct cones: the most important one, ranging between amplitudes **50 and 70m**, forms a cap of almost **20000km^2** centered around the sectors of Zelfana-Ouargla ; the other cone corresponds to Deb-deb field, with a peak of 100 m at the level of the field itself.

- ***At the level of drawdowns interferences***

In Tunisia, the induced drawdown is **25m in Tozeur-Nefta**, in **12m in Chott Fejej**. In **Libya**, the influence of pumping in **Debdeb** is reflected by net drawdowns of about **40 to 50m** at the level of the **Ghadames field**, as is the case for **Tunisia's far southern region: 50m in Bj el Khadhra and 30 m in Tiaret**.

- ***At the level of outlet flows***

The impact of this simulation is strictly nil in the Foggaras, whose flow remains the same. As for the **Tunisian outlet**, its **2050 flow rate** increased to **0.6 m^3/s**, while it was **0.94 m^3/s in the case of zero scenario**.

- ***At the level of artesianism***

In Algeria, there is a **disappearance of artsianism in Hassi Messaoud.** It is true that we are in the heart of the most important drawdowns: that is **70 m of net drawdowns added to the 70 m already calculated for 2050** for zero scenario. Elsewhere, artesianism remains active throughout: **80m** in Ouargla, **50m** in Toggourt and El Oued, **180m** in Mghaier. In Tunisia, we still have **80m** in Tozeur and Sabria. In Libya, artesianism is still present in the Graben at the level of Abu Nujaym, amounting to **50m** and along the coast on the east of El Quaddahyah.

- ***At the level of the 2050 water budget***

When reading the water budget, and by comparing with the water budget of 2050 zero scenario, we can estimate that the flows of additional abstraction (**8.5 m^3/s**) come at rates of:

- **7.9 m^3/s** by the contribution of reserves (**or 93%**),
- **0.34 m^3/s** through recovery at the Tunisian outlet (**4%**),
- 0.2m^3/s through leakage (Turonian increasing and upper sandstone decreasing; or **2,5%**).

Simulation n°2 ; CI-2: CI in Tunisia

- ***At the level of net drawdowns***

The most important drawdowns, amounting to **130m**, can be ascertained in the most southern region, and particularly in the field of Tiaret. Elsewhere, net drawdowns are relatively low: **20m** in Nefzaoua and **15 m** in Chott Fedjej.

[10] Drawdowns of which were deduced those of the zero scenario calculated at the same period.

- ***At the level of drawdowns interferences***

In the northern part of the domain, influences on Algeria are low: **10m** in Biskra and Mghaier, **8m** in Toggourt, **13m** in El Oued, **22m** in Taleb El Arbi. In the southern part, pumping in Tunisia's most southern part induces a net drawdown of **25m** in Debdeb in Algeria and **30m** in Ghadames field in Libya.

- ***At the level of outlets flows***

The flow of Tunisian outlet is brought back to **0.5 m^3/s**, that is when compared to the zero scenario a reduction of **0.44 m^3/s** (47%) due only to additional flow rates simulated in Tunisia.

- ***At the level of artesianism***

With the exception of Tunisia's far southern region, induced drawdowns are low and have little incidence on artesianism.

- ***At the level of the 2050 water budget***

When compared to zero simulation, we can consider that the simulated additional flow (**2.2m^3/s**) comes: a) from reserves of CI aquifer (**1.6 m^3/s**) or **73%**, b) from the Tunisian outlet (**0.44 m^3/s**) or 20%, c) from the leakage at the Turonian (**0.1m^3/s**) and at upper sandstones (**0.1m^3/s**).

Simulation n°3 ; CI-3: GHADAMES Basin

- ***At the level of net drawdowns***

Far away from pumping fields, be they in the North or in the East, the disturbance is not highly spread: **3m** of additional drawdowns in **50 years** in Chott Fejej, El Oued as well as in Gasr Bani Walid (however at a distance of 450km !). But in the sector of simulated catching fields, expected drawdowns are relatively very high: about **180m to 200m** in Ghadames, Debdeb, Tiaret ; and the circle at **110m** of drawdowns covers a radius of 100km.

- ***At the level of drawdowns interferences***

This simulation does not allow the measurement of mutual influences, abstraction is simultaneously conducted in all three countries.

- ***At the level of the flows of outlets***

The Tunisian outlet passes to **0.84m^3/s**, or a drawdown of **0.1 m^3/s** (**10%**)

- ***At the level of artesianism***

We are far away from traditional artesianism regions, and induced drawdowns are insignificant.

- ***At the level of the 2050 water budget***

Additional flows (**6.3m^3/s**) are provided respectively by:

- The contribution of reserves (**5.4m^3/s**) or **86%**,
- The leakage of the Turonian (**0.5m^3/s**) or **8%**,
- The Cambro-Ordovician (**0.2m^3/s**) or **3%**,
- The Tunisian outlet (**0.1m^3/s**) or **1.5%**.

Simulation n°4 ; CI-4: CI in all the Central Basin

- ***At the level of net drawdowns***

This simulation corresponds, with few exceptions, to the accumulation of flows shown in the three previous simulations ; it is therefore natural and based on the superposition principle, that drawdowns represent the sum of the drawdowns of simulations 1, 2 and 3.

- ***At the level of interferences drawdowns***

All three countries contribute to pumping: there can then be no estimate of reciprocal effects.

- ***At the level of outlets flows***

The Tunisian outlet increases to 0.13m^3/s under the conjugated effect of Tunisian and Algerian abstraction.

- ***At the level of artesianism***

There is little difference with simulation n°1.

- ***At the level of the 2050 water budget***

The total flow of simulated pumping (14.3 m^3/s) is provided respectively by:

  - CI reserves (87%),
  - The Tunisian outlet (0.8m^3/s) or5.5%,
  - Turonian leakage (0.6m3/s) or 4%,
  - The Cambro Ordovician (0.2 m^3/s),
  - The leakage of upper sandstones (0.1m^3/s).

Simulation n°5 ; IC-5: The Algerian lower Sahara and Adrar

- ***At the level of net drawdowns***

This corresponds to simulation n°1 to which we added an abstraction in Fort Flatters, but also and particularly a high prompting of the Western basin in Adrar, In Salah and El Golea. All these new abstraction are located in (within or very close to) unconfined surface areas of the CI aquifer: drawdowns are concentrated in localized areas: very deep at their centre, (**150 m**) but spreading little by little (drawdowns drop to **10m** within 50km from the centre).

- ***At the level of drawdowns interferences***

Influences on Tunisia and Libya are very precisely the same as in simulation n°1.

- ***At the level of flows of outlets***

The flow of the Tunisian outlet remains similar to the one calculated in simulation n°1. Here, it is the flow rates of Foggaras that is influenced (little influence due to additional flow rates abstracted nearby) increasing to **1.32 m^3/s**, while it was **1.95m^3/s** in the zero scenario simulation.

- ***At the level of artesianism***

They are practically the same results as for simulation n°1.

- ***At the level of the 2050 water budget***

Additional flow rates simulated here are **38.5 m^3/s**. They come from:

  - the contribution of CI reserves (**37.2 m^3/s**) or **97%**,
  - the Foggaras (**0.63 m^3/s**) or 1.5%,
  - the Tunisian outlet (**0.35 m^3/s**),
  - the leakage:Turonian and upper sandstones (**0.2 m^3/s**).

Simulation n°6 ; IC-6: Exploitation of CI reserves in the "Grand Western Erg" (Grand Erg Occidental)

- ***At the level of net drawdowns***

This simulation confirms and consolidates the results of the previous simulation concerning CI drawdowns in the unconfined surface area:

  - Locally intense (**100 to 180m** in the centers, but that can reach very high values: up to **400 and 500m** in some sites. Such drawdowns are obviously neither acceptable nor foreseeable. Simulated flows, very concentrated at **10m^3/s** per catching fields, are clearly not adapted in these last cases, and it would be better to divide them in various pumping fields to reduce induced drawdowns).
  - Spreading very little laterally: **1m** in El Golea which is within a circle of 100km and almost nothing (**some cm**) in Hassi Messaoud and Ouargla after **50 years** of pumping.

- ***At the level of drawdowns interferences***

Influences on Tunisia and Libya are strictly nil by the time-frame 2050.

- ***At the level of outlets flows***

The flow of Foggaras dropped to 1.78 m^3/s , hence a decrease of 0.17 m^3/s compared to zero scenario.

- ***At the level of artesianism***

This simulation has no impact on artesianism.

- ***At the level of the 2050 water budget***

Additional abstraction (**80m^3/s**) are provided by:

  - the contribution of reserves (**79.8m^3/s**) or **99.75%**,
  - the decrease of Foggara's flow rate (**0.17m^3/s**) or **0.22%**.

Simulation n°7: Reduction of the 2030 deficits in Libya

- ***at the level of net drawdowns:***

Two sectors are considerably distinct:

  - Soknah-Hun in the south where net drawdowns reach **110m** [they were already **30 to 40m** for the zero scenario] ;
  - A line of **60m** extending between Bani Walid and Abu Nujaym. Elsewhere, we can note drawdowns of **20 to 25m** at the level of the coastline and drawdowns gradually decreasing toward the West as we get farther from catching fields.

- ***At the level of drawdowns interferences***

Influences on Algeria and Tunisia are limited to Tunisia's far southern region, and to the region of Debdeb: induced drawdowns range between **5 to 8 m.**

- ***At the level of outlets flows***

The percolation in the Gulf of Syrta drops from **0.6 m^3/s** in the zero scenario to **0.3 m^3/s** here. On the other hand, the flow of the spring of Ain Tawargha passes from **1.3 m^3/s** (zero scenario case) to **0.4 m^3/s**[11]

- ***At the level of artesianism***

An artesianism cavity at **30m** persists in the Graben ; elsewhere, artesianism disappeared. Nonetheless, CI aquifer remains very poorly artesian and its NP remains all over considerably above sea level.

- ***At the level of 2050 water budget***

Additional abstraction (**5.1 m^3/s**) come respectively from:

  - contribution of reserves (**1.5 m^3/s**) or **29%** ;
  - leakage of Turonian (**2.1 m^3/s**) or **41%** ;
  - the Cambro-Ordovician (**1.2 m^3/s**) or **24%** ; the remaining part comes from a reduction of the flow of outlets (Gulf of Syrta, Ain Tawargha). It should be noted that the input of the Eastern boundary [Potentials imposed through resistance, likely to simulate the input of the reservoir salty part] which was **0.008m^3/s** for the IC-SIM0, drops to **0.02m^3/s** in the case of the present simulation.

Simulation n°8 ; CI-8: CI Global Exploitation

- We find the union of drawdowns, flows at outlets and respective artesianism corresponding to simulations making up the SIM8, that is SIM2, SIM5, SIM6 and SIM7.
- **At the level of the 2050 water budget**: additional abstractions represent **129m^3/s**, of which **118.5 for Algeria**. These additional flow rates must come from:
  - The contribution of CI reserves (**122.3 m^3/s**) or nearly **95%** ;
  - The leakage of the Turonian (**3.2 m^3/s**) or **2%**;
  - the Cambro Ordovician (**1.2m^3/s**) or **1%** ;
  - the decrase in the flow rate of outlets (Ain Tawargha 0.4, Tunisian outlet 0.8, Gulf of Syrta 0.3, Foggaras 0.75 ; representing a total of **2.25m^3/s**) or **1.5%**.

III.2- At the Complexe Terminal

Simulation n°1 ; CT-1: additional flow rates in ALGERIA

The evaluation criteria of the results of provisional simulations slightly differ from those adopted for the CI. For every simulation conducted in the Complexe Terminal, we shall systematically examine obtained results with regard to the following criteria[12]:

- ***At the level of net drawdowns***

The maxima, ranging between 70 to 100 m, can be found within the field of Gassi Touil , where this simulation concentrated abstraction. Elsewhere, drawdowns are generally low, namely at the level of chotts Merouane and Melrhir, where they do not exceed 10 m .

- ***At the level of drawdowns interferences***

[11] Note that this is the result of « reduction » simulation conjugated with **CI-7 and CT-3**: when reducing the spring flow, we can attribute in a first analysis a weight equivalent to additional abstraction shown in each of the two aquifers.
[12] Except for Liby where the problem of Chotts does not exist in the same way as in Algeria-Tunisia.

The 5m curve almost follows the Tunisian border. Induced drawdowns amount to 7 m in Nefta, 5 m in Tozeur and 3 m in Kebili. As for the influence of this simulation on Libya, it is strictly nil.

- ***At the level of the position of the aquifer NP with regard to the Chotts***

The CT piezometric level is globally 10 m, lower than zero scenario at the level of Melrhir and Merouane, and 5m lower at the level of the Djerid ; but the zero scenario has been qualified as critical. With this simulation n°1, the situation becomes more serious, according to the Chotts criteria.

- ***At the level of the 2050 water budget***

Additional flow rates are 14.7 m3/s. They come from the CT reserves, 14.6 m3/s (or 99.3%) and from the Turonian through leakage, 0.1 m3/s (0.7%).

Simulation n°2: Additional abstraction in TUNISIA

- ***At the level of net drawdowns***

They amount to 25m in the North of Rharsa, 10m elsewhere under the Tunisian Chotts, and between 5 and 10m in all Nefzaoua region.

- ***At the level of drawdowns interferences***

The Algerian border globally describes the 10 m drawdown curve. The influence of Tunisian abstraction is 3m in El Oued, and 1m in Mghaier .

- ***At the level of the position of the aquifer NP with regard to the Chotts***

This position is at 10 m lower that that of the zero scenario.

- ***At the level of 2050 water water budget***

The additional flow is provided by CT reserves at a rate of more than 99%.

Simulation n°3: Reduction of Deficits in LIBYA

- ***At the level of net drawdowns***

We can note net drawdowns (to which we shall add those of the zero scenario) at a rate of 100m in Soknah and Waddan, and 10 to 20m along the Graben and 50m in the northern fields close by Al Khoms-Zliten coastline.

- ***At the level of drawdowns interferences***

No interference in Tunisia and Algeria.

- ***At the level of outlets flows***

The flow of Ain Tawargha drops from 1.3 (zero scenario) to 0.4 m^3/s[13] and leakage in the Gulf of Syrta decreases from 0.5 to 0.4 m^3/s.

- ***At the level of artesianism***

The catching fields of the coastal region [Al Khums, Zliten, Misurata] show particularly low piezomteric levels, reaching even levels lower than –50m on the coast-line.

- ***At the level of the 2050 water budget***

The additional flow is 11.6 m^3/s. it is mainly provided by:

  - The CT reserves: 6.9 m^3/s (59%),
  - the leakage of the Turonian: 3.8 m^3/s (32%). The remaining part obtains from the outlets flows.

[13] We have assumed that this drop is due for a half by the CI and also by a half by the CT (see SIM CI-7).

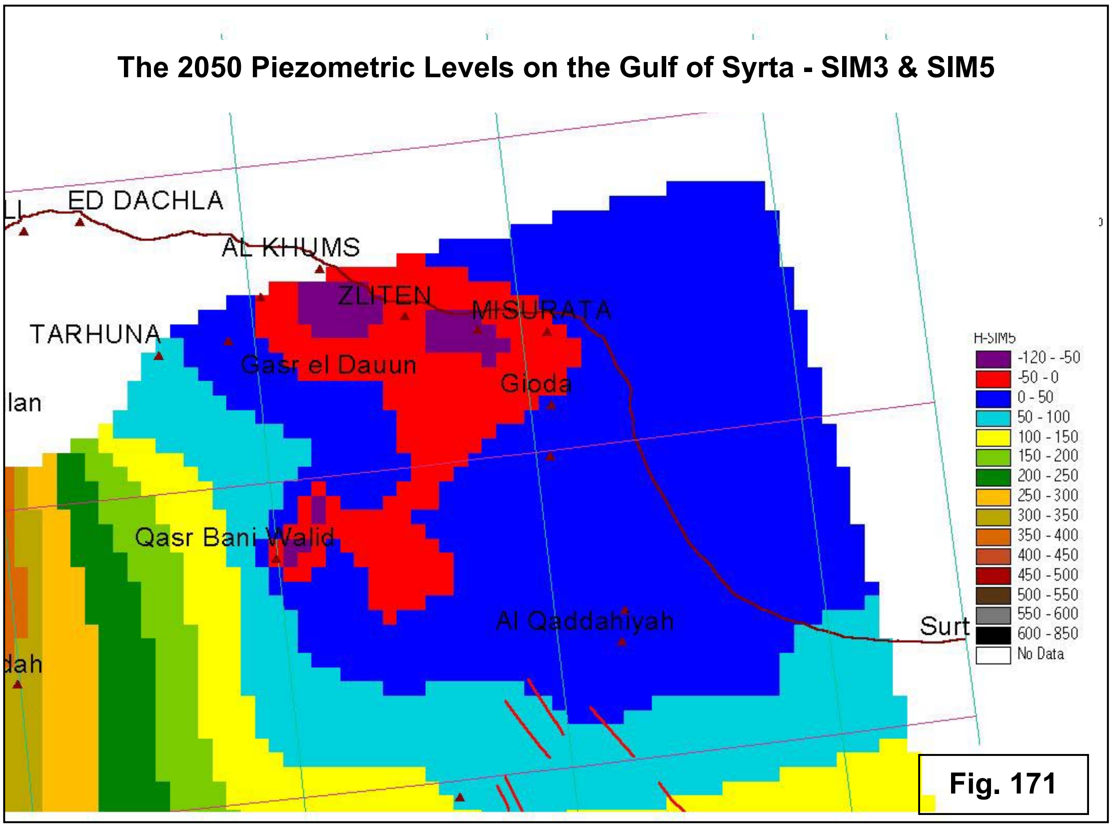


Fig. 171

Simulation n°4: the catching field of Oued MYA

- ***At the level of net drawdowns***

They are limited around the field, amounting to 150m at its center.

At the level of drawdowns interferences

No incidence on Tunisia and Libya.

- ***At the level of the position of the aquifer NP with regard to the Chotts***

Drawdowns induced by this simulation in the region of the Chotts are almost nil (10 to 20 cm). This scenario generates no change, with regard to the Chotts when compared to the zero scenario.

- ***At the level of the 2050 water budget***

Additional flows, or 18m^3/s, are provided by the CT reserves for 17.9 m3/s.

Simulation n°5: CT global exploitation

The simulated additional flow rates represent the sum of flows shown during the four previous simulations. Effects are globally equivalent to the sum of effects previously described. The most important are:

- 10 to 15 m of drawdowns under the Chotts, generating a sensitive and risky situation in spite of an almost full stabilization of abstraction in the region of the Chotts ;
- Piezometric levels at more than 50m below sea level on the Libyan coast-line, reflecting a real crisis situation ;
- Finally, at the level of the water budget, we note, with regard to abstracted volumes, the prevalence of the contribution of CT reserves.

PART IV

REPRESENTATIVITY OF NWSAS MODEL AND RESULTS ANALYSIS

PREAMBLE

At the end of the stages of design, construction and exploitation of the NWSAS Model, a number of uncertainties, shortfalls, and questions persists, be they at the level of hypothesis leading to the design of the Model determining parameters, or at the level of:

- The knowledge of the data entered,
- The nature and characteristics of conditions at adopted limits,
- The very structure of the Model

Removing these uncertainties will certainly contribute to further improving the representativeness of the model and the reliability of the results of all conducted simulations.

This note addresses the most important questions that one can raise today concerning the representation of the model, and its impact on obtained results, but also those which need to be further investigated, through scientific research or the consolidation of the data reliability.

I- TRANSMISSIVITIES AND OUTFLOW OF THE TUNISIAN OUTLET

The conjugation of the new configuration of CI in southern Tunisia [adjunction of the upper sandstones aquifer and absence of aquifer in Melab Mole] with transmissivities of the Tripoli Model, which represent more or less in Tunisia transmissivities of the ERESS Model, provided a first estimate of the flow rate of the Tunisian Outlet (ET) in the CI, that is 1. 8 m^3/s, a value that does nor comply with traditionally adopted estimates setting it to 3. 6 m^3/s.

Model of August 20, 2001 (M20-8): to yield such an increase, it was necessary to prepare a **power tube** with a width of about **100 km** connecting **Toggourt to El Hamma fault**, where the CI transmissivities amount to **2.** $\mathbf{10^{-2}\ m^2/s}$, increases of the highest transmissivities (up to ten times that of ERESS) being situated in the region of the Eastern Erg (ERG Oriental). The NWSAS is not the first to have to considerably increase transmissivities in this sector: GEOMATH (in BRL, 1997) was also bound to adopt for the same site high transmissivities (2. 10^{-2} m^2/s). With these modifications, the ET flow rate passes to **2. 75** $\mathbf{m^3/s}$.

Model of September 10, 2001 (M23-9): Readjustment of CI transmissivities field, which are 20 to 25% higher. The flow rate of the Tunisian Outlet increases to 3**. 3** $\mathbf{m^3/s}$.

Model of September 23, 2001 (M23-9): While ERESS map of transmissivities could rely on a lithosedimentolgical legacy (« useful » thickness and permeability values), the power tube of Toggourt-El Hamma does not correspond to this logic and is not based on any confirmed geological[1] legacy. Further to the debate resulting from the evaluation workshop held on September 17, 2001 and in the absence, in subject region, of recent values deduced from pumping tests, it was agreed to resort back to ERESS transmissivities. At the end of a permanent regime wedging, the Tunisian outlet flow rate amounted to 1. 9 m^3/s.

At this level of the study, we face a serious dilemma. We hold two Models: M10-9 and M23-9, very different in terms of the structure of the field of CI transmissivities, and showing very different ranges of transmissivity values, that can all be considered as wedged if we refer to:

- The piezometric measurements available at the control points , be they in permanent or transient regimes,
- The flow rate measurements known as the system natural outlets.

The long term behaviour of these two models is slightly different one from the other, namely in areas with important abstractions. It is therefore important to decide upon the “plausibility” of each of the models.

How can we decide on such plausibility ?

For this reason, we have two main criteria that we can consider constraints:

- The first has to do with the structure of transmissivities and with its geological legacy. It seems [and in spite of a preliminary intersection of the Chotts line with the corridor of high transmissivities values stated in M10-9 El Hamma-Tougourt **which needs to be further studied**] that, in the present status of our analysis, we shall, from this perspective, clearly prefer **M23-9**, which field of transmissivities complies with ERESS maps, which have not yet been denied by more recent data issued by test pumping operations.
- The second has to do with the flow rate value of the Tunisian outlet of the CI aquifer abstraction into the Djeffara. This is a constraint more difficult to apply: there is no precise evaluation of this flow rate, but rather a certain number of estimates described in the box below

[1] This corridor can represent the (necessary) continuation in Algeria of « the Chotts depression » highlighted by Tunisian geologists, a depression which is located precisely on the layout of the corridor.

SCG- BURGEAP (Dec. 1963)
. . . the value of the flow rate crossing the Tunisian outlet amounts to… **3. 2m^3/s**. This value is in harmony with the evaluation of the aquifers flow rate in the Gabes region.

GEOPETROLE (July 1964)
… before the creation of new racking units, … the flow rate of the Tunisian outlet is **4. 7m^3/s**…

M. BORELLI and R. ROUATBI (ERESS, 1970)
The flow rate exploited in the CT of Djeffara (natural and artificial outlets) is **4 m^3/s**. If we add sea losses, we can estimate the total dewatered flow rate from the North of Gabes to Zarzis at 5m3**/s**… direct inputs to Djeffara aquifer are estimated at **1. 5 m^3/s**… the deficit of the present balance of Djeffara aquifer equals **3. 5 m^3/s**. This is then the quantity that must be provided by CI aquifer.

FRANLAB (ERESS, Mars 1972)
- Calibration first phase ***_ Imperviousness of Medenine dome***:
… the flow rate available at the Tunisian outlet, with the best transmissivities (that of de Geopetrole), does not exceed **3 m^3/s** including the percolation in Chott Fedjej. The one obtained with the transmissivities of our study reaches, all things considered, the value of 1. 5 m^3/s. The flow rate obtained with SCG transmissivities was closer to this last value. The main lack of homogeneity between the three transmissivities maps can be found in the region of the Western Grand Erg (Grand Erg Occidental) between Hassi Messaoud and El Borma where Geopetrole transmissivities amount to 20 to 30 times ours …
- Second Calibration Phase ***_ Perviousness of Medenine dome***:
… FRANLAB underlined the possible non hydraulic tightness of Medenine dome (in spite of the disappearance of CI). …it was decided to impose a flow rate of 3. 5 m^3/s.

P. PALLAS (UNDP, 1984)
The proper supply of Djeffara is about **1m^3/s** . . . the total exploited in 1950 is **2. 4m^3/s**. Concerning the CI contribution, three values were tested, or respectively: **3. 6m^3/s**, **2. 7m^3/s** and **4. 5m^3/s** …However…the used transmissivities … tend to the hypothesis IC**=3. 6 m3/s**.

B. ABIDI (DGRE, October 2001)
El Hamma threshold is constituted by a 36 km long segment …based on piezomteric gradients deduced from 2000 measurements, over the threshold width, and on an average transmissivity estimated at **4. 10^{-2}m^2/s**, the flow rate crossing the threshold can today be estimated at **2. 3 m^3/s**.

All these works seem to converge towards the value of **3. 5 m^3/s** as constituting the flow rate of El Hamma threshold in the 1950's. this flow rate amounts today to **2 m^3/s**. It was then reasonable to reconsider the **M23-9** version of the Model, towards a more plausible version with regard to the two constraints stated above.

Model of September 30, 2001: the map of CI transmissivities of the M23-9 model, which is more or less similar to ERESS map and the Tripoli Model, is taken as it is, with the exception that on the catchments area of the Tunisian Outlet [or a limited circle quarter towards the south in Tougourt and Regim Maatoug], we consider increases in the transmissivities initial values amounting to 100%. This increase would be obviously necessary if we wanted that the flow rate of the Tunisian outlet be also considerably increased. Results of wedging this new model in a permanent regime , the **M30^{-9}**, show a flow rate at the Tunisian outlet in 1950 amounting to **3. 1 m^3/s**.

If we want to comment on the last model from the point of view of both constraints stated above, which are:

- The structure of the field of transmissivities ,
- The value of the flow rate of the Tunisian IC outlet,

The model issued on September 30, without fully satisfying them, seems to ***offer the best compromise***. It is this model which responds to the best to all criteria and constraints imposed to wedging; it is also the most appropriate to conduct the provisional simulations for the development of NWSAS water resources.

Fig. 172: Transmissivities of the Tripoli Model

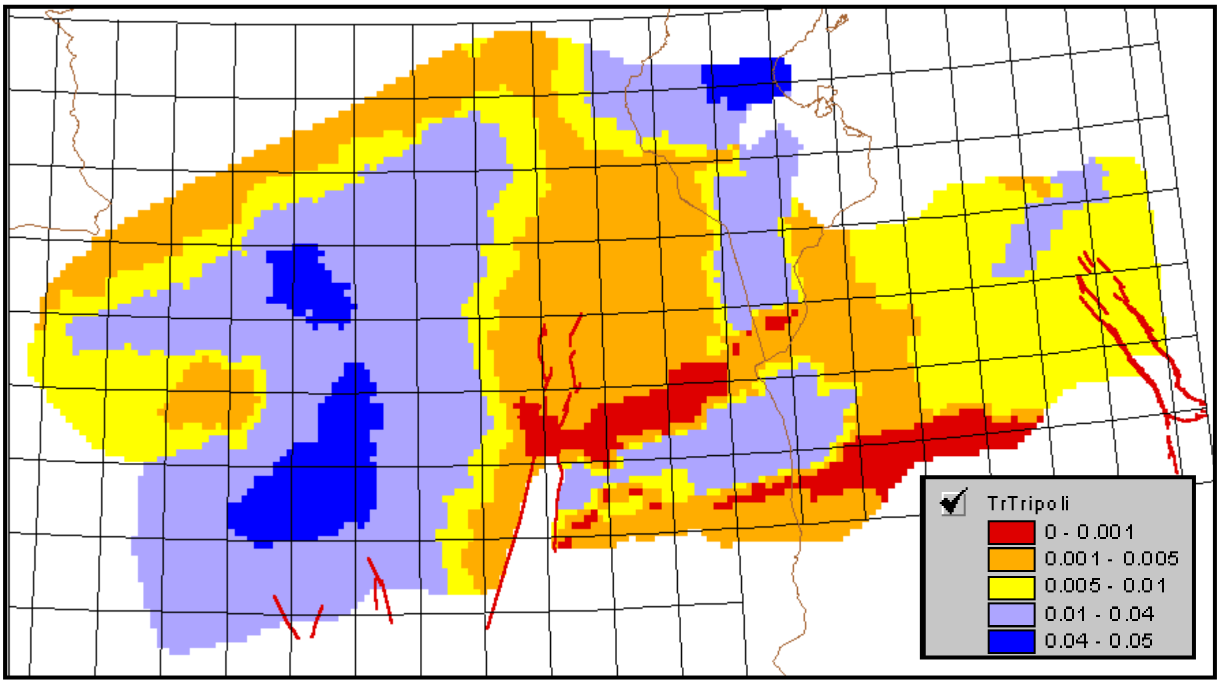


Fig. 173: Transmissivities of September 10 Model

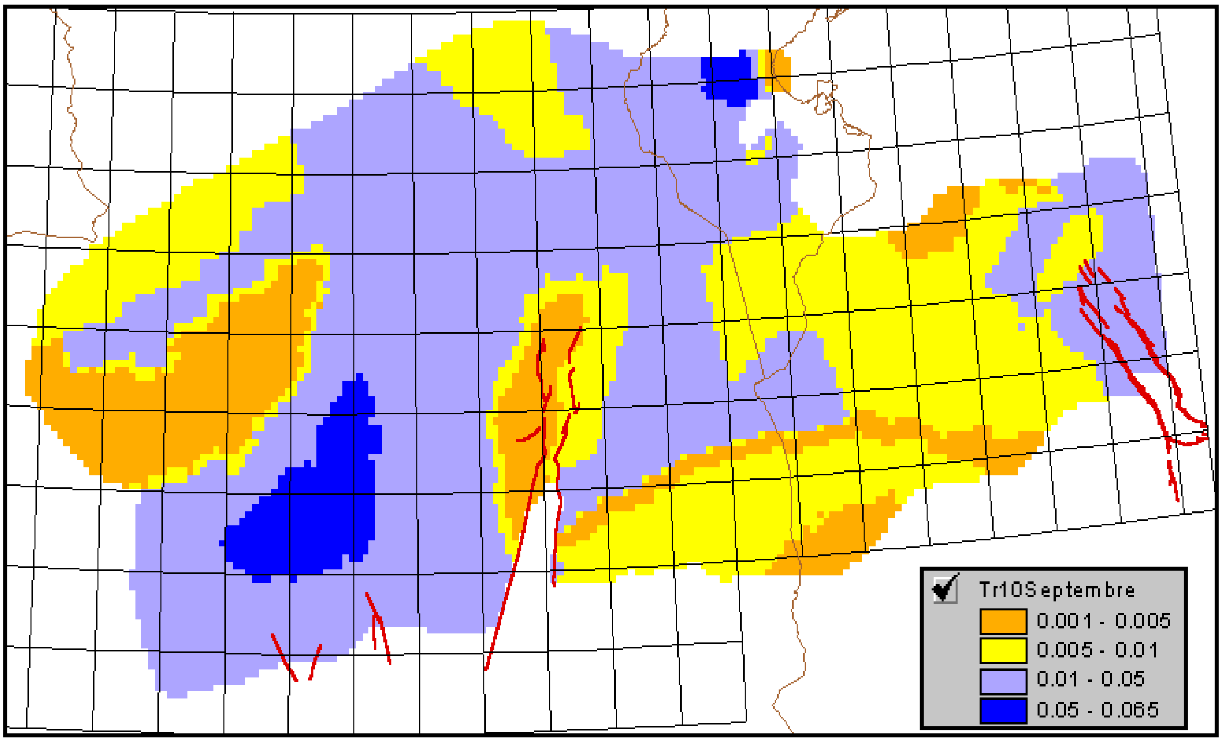
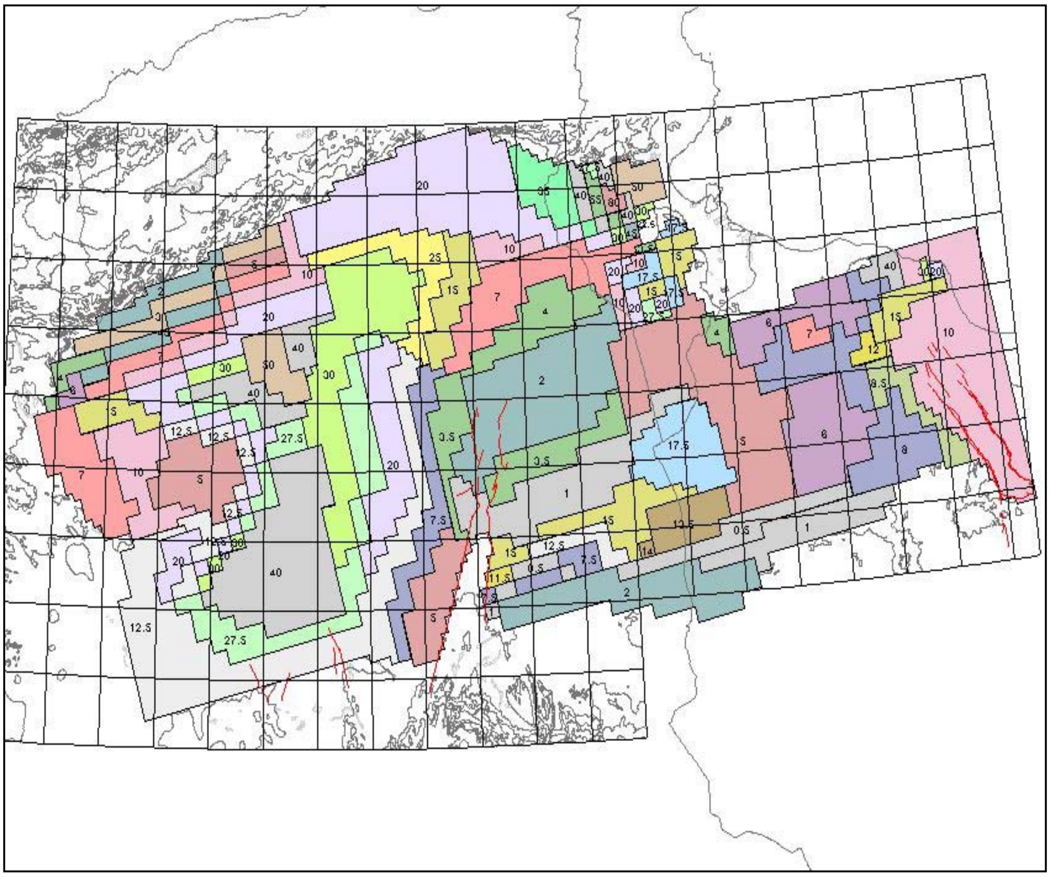


Fig. 174: Transmissivities of September 30 Model



II- STORAGE IN UNCONFINED AQUIFER

- In the ***August 20 Model***, the simulation providing for the holding of 2000 abstraction rates constant until 2050 clearly shows that the piezometric levels of the CT aquifer are « **maintained** » around the Chotts. Among other factors, this phenomenon can be due to an over-estimation of the storage coefficients adopted if unconfined surface areas. It is namely on the basis of this hypothesis that decision was made to design a new version of the Model where the wedging of level records in a transient regime shall provide for the possibility of a substantial decrease of storage coefficients in an **« unconfined aquifer** », namely in the sectors of the Complexe Terminal, where previous values were considered to be excessive in very wide areas, with no measurement or pumping test (especially in the Eastern "Grand Erg" Grand Erg Occidental).

This degree of additional unconfined dom adopted at this level of wedging is justified by the absence of reference values in these regions.

It is useful here to recall the criteria adopted by the ERESS model for the assignment of storage coefficient values in unconfined surface sectors (see the box below).

> « The nature of the aquifer reservoir led to the identification of two cases:
>
> - Rocks with inter-granular pore space … for which an average value of 150. 10^{-3} was adopted as a storage coefficient
> - Fissured rocks … for which a lower value was adopted, ranging between 100 and 150. 10^{-3} » [ERESS, plate 3: CT Aquifer, p37]"

- ***Model of September 10, 2001:*** it is marked especially by a substantial reduction of storage coefficients in the CT unconfined surface areas. This reduction, inspired by what has already been operated at the level of Adrar Intercalary Continental (see. Tripoli Model, BRL-Ecole des Mines Model, provisional simulations of the RAB-80 project), or a reduction bringing **S from 20% to 5%** to restore drawdowns (certainly low and sometimes insignificant) recorded in the sector.

Unfortunately, in the Complexe Terminal, we have:

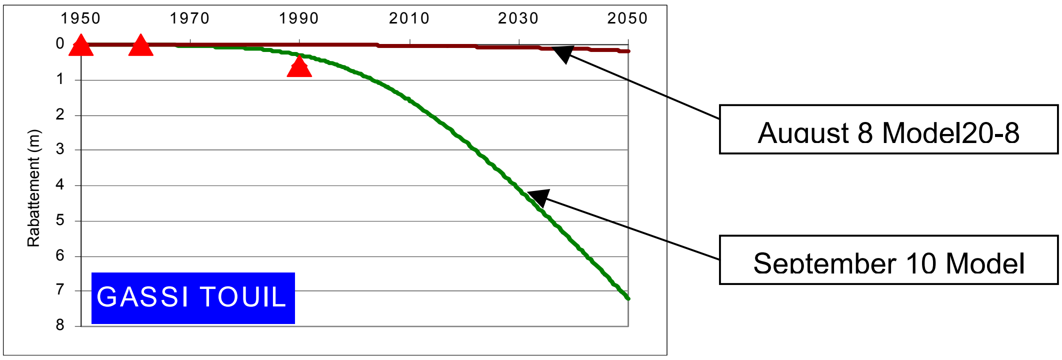
- Neither measured values of the storage coefficient in an unconfined surface,
- Nor control numbers in sufficient and reliable number which would have enabled, as was the case for CI, to consolidate the S values through wedging by basing them on historical drawdowns.

In the CT, the sole piezometric control point in an unconfined area can be found in Gassi-Touil: it is represented by a single post-1970 measurement, dated in 1990.

On the Tripoli Model, this point was very well wedged on the history of that time abstraction. Later, abstraction in all the sector of Gassi-Touil were brought back to zero at the end of reviewing flow rate records in Algeria conducted in **May 2001**. With these new records, it became almost impossible to find the reference drawdown (or 60 cm within 20 years) if we maintained the S real sizes in an unconfined aquifer adopted by ERESS (see box below).

On the other hand, if we considerably reduce these values → dropping from **$10x10^{-2}$ to $1x10^{-2}$** [which represents unconfined aquifer storage coefficients 10 times smaller in the sectors of Oued Mya–Gassi-Touil and southern Nefzaoua], we considerably get close to the reference drawdown (see. fig. below). This is the solution that was adopted.

Fig. 175: CT 1950-2050 drawdowns



III- EFFECT OF THE CAMBRO-ORDOVICIAN [COD]

The Cambro-Ordovician (COD) constitutes an immense reservoir related to IC in the basin South Eastern part. It was therefore essential to represent this layer in the model, especially that an important abstraction program planned in Jabal Hassawnah (Libya) must be simulated on the model to forecast long term effects.

The limits of the Cambro-Ordovician, (COD), are those adopted by GEOMATH cut out in the south at the correspondence with CI limits. COD/IC relations are regulated by the leakage all over the COD layer through "aquitards" constituted by Devonian and Carboniferous formations. There are however several areas where the CI directly lies on the COD, the semi-permeable layers of the average and upper Palaeozoic do not exist.

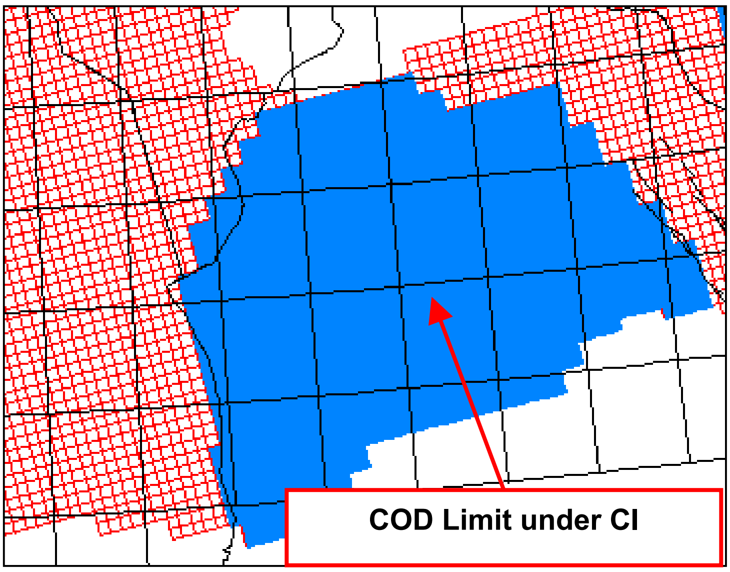
Table 47: Variation of some terms of NWSAS balance in Libya

Calculation Time-frame	**Simulation**	**Recharge Nefussa–Southern Libya**	**Pumping CI NWSAS m^3/s**	**Pumping CI-LIBYA m^3/s**	**Input of COD to IC m^3/s**
1950	Permanent wedging	1. 4	0. 5	0. 0	2. 0
2000	Transient wedging	1. 4	26. 8	3. 4	2. 7
2050	CI-SIM-0	1. 4	26. 8	3. 4	3. 0
2050	Dj. Hassaouna	1. 4	26. 8	3. 4	2. 3
2050	CI-7	1. 4	32. 0	8. 5	4. 2

At the present stage of the study, the representation mode of the Palaeozoic adopted for the Model seems valid (fixed imposed charge), but later, we should consider representing it by an active aquifer layer, namely because of:

- Its use to compensate one part of additional abstraction from the CI in Libya (see table below) ;
- The risk of decreasing this contribution under the effect of abstraction from DJ. Hassaouna.

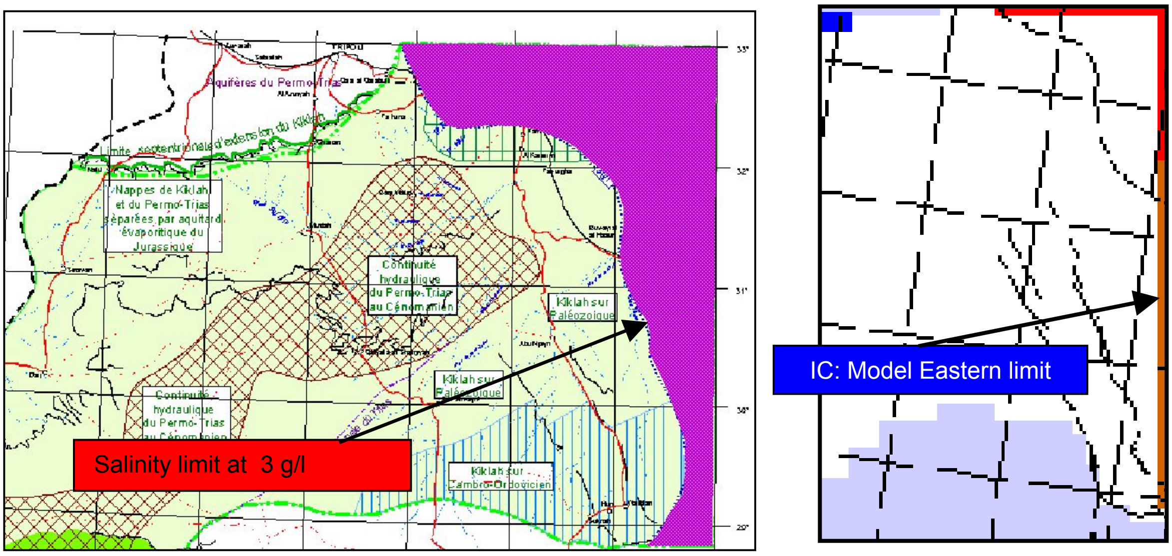
Fig. 176: Extension of the Cambro-Ordovician



IV- EASTERN BOUNDARY

The IC eastern limit is the only line in the model that is not natural. In fact, the Lower Cretaceous lower formations continue to the East of the Graben but show low transmissivities and a high salinity. There is therefore no clear hydraulic limit at this site. The model is limited by a condition of imposed potentials through a resistance. This formula authorized the estimate of CI exchanges with a salty eastern extension.

Fig. 177: Eastern Limit of the Intercalary Continental



The obtained results show first exchanges at the natural status extremely limited through this limit [**Input of 8 l/s**] due to a very bad connection with the imposed potential. This results from the wedging of transmissivities and piezometric heights very badly known on this limit.

Under simulation (see table below), this situation remains similar including in **2050** for the zero scenario. It is only for simulation **CI-7** for the reduction of deficits in Libya that the input flow rate of the salty water is brought to **20 l/s**, which certainly remains limited but shows anyway, a tendency for the activation of salty waters input under the effect of extensive exploitations.

As a conclusion, we would recommend **further investigations in this sector to better identify the distribution of piezometric heights, transmissivities and salinities.**

Horizon	Simulation	CI input through Eastern Limit m^3/s
1950	***Permanent***	0. 008
2000	***Transient***	0. 008
2050	***IC-SIM-0***	0. 008
2050	***IC-7***	0. 020

V- GULF OF SYRTE

Table 48: Percolation in the Gulf of Syrte m³/s

Horizon	Simulation	CT	CI	Total percol	Ain Tawargha
1950	Permanent	0. 6	0. 8	1. 4	2. 0
2000	Transient	0. 6	0. 6	1. 2	1. 6
2050	SIM0	0. 5	0. 6	1. 1	1. 3
2050	IC7 & CT3	0. 4	0. 26	0. 66	0. 4

The flow rate of Ain Tawargha passes from **1. 3** (zero scenario) to **0. 4 m³/s** for the scenario concerned by the reduction of deficits and, at the same time, leakage in the sea [IC+CT] drops from **1. 1 to** 0. 66 m3/s: the natural outlets lose in total **1. 33 m³/s** or nearly 60% of their flow rate provided for in the zero scenario.

If for the reduction scenario [**CI7 & CT3**] the Intercalary Continental continues in 2050 to receive a consistent recharge (**15 to 20 m**) on the coastline, this is not the same for the Complexe Terminal, whose piezometric level in **2000** is already Zero between Zliten and Misrata and which situation would be seriously prejudicial in the hypothesis of scenario **CT3** where the level would be–**70 m** on the coastline by the time frame 2050.

Such a catastrophic scenario fully justifies the fact that further investigations must be conducted for a more precise knowledge of hydrogeology particularly in the coastline area as well as close monitoring of this sector.

Fig. 178: Piezometric level of CI in 2050; Simulation CI-7

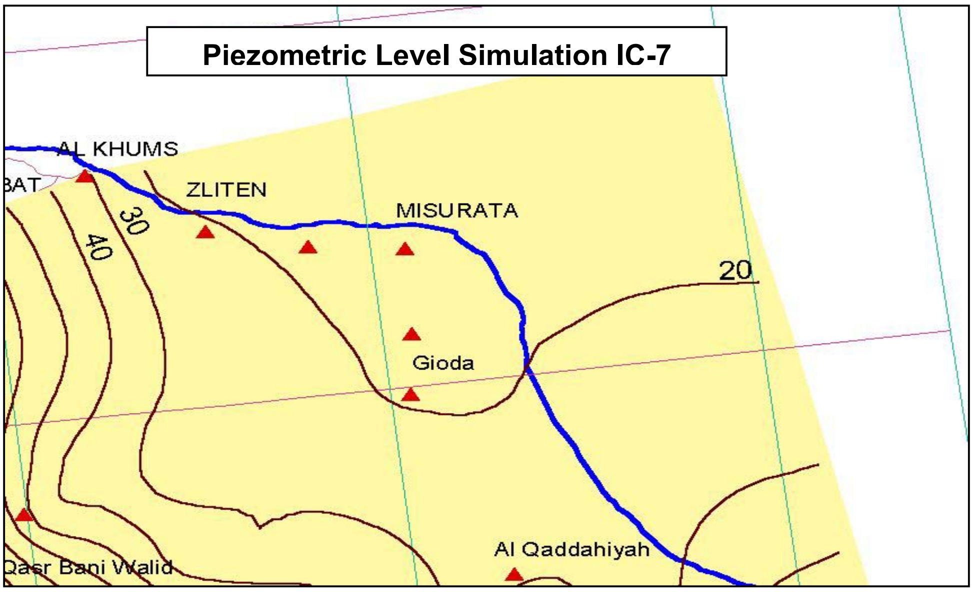


fig. 179: CT Piezometric Level 2000

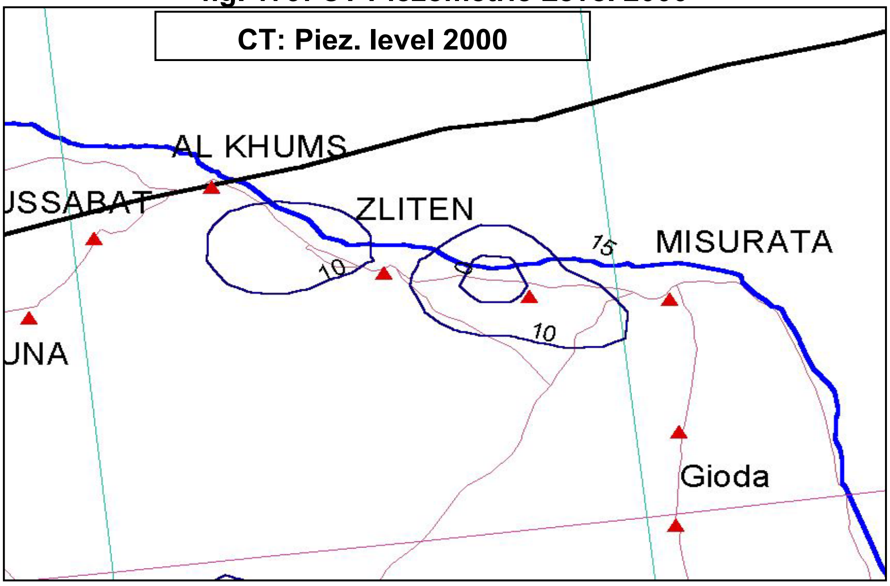


Fig. 180: CT Piezometry in 2050 ; zero scenario

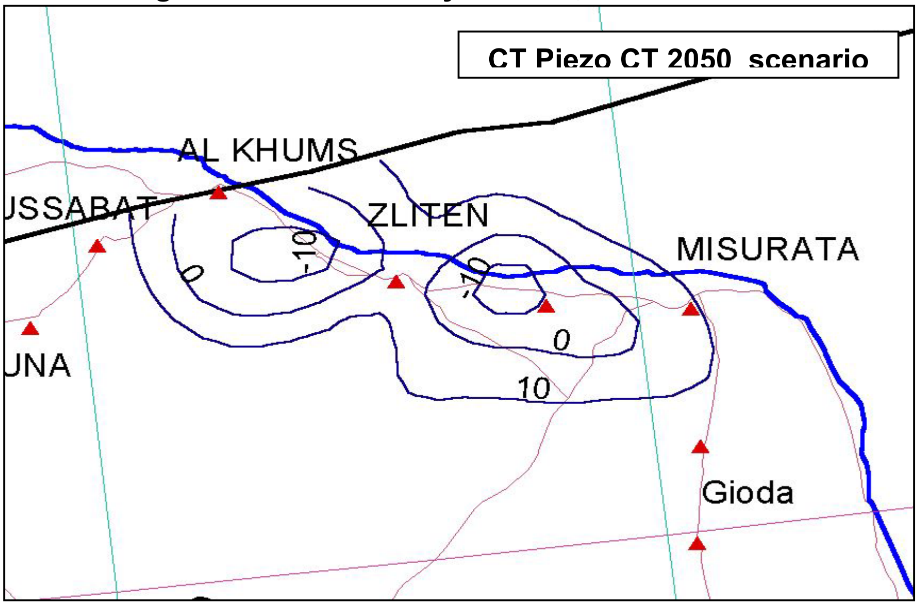
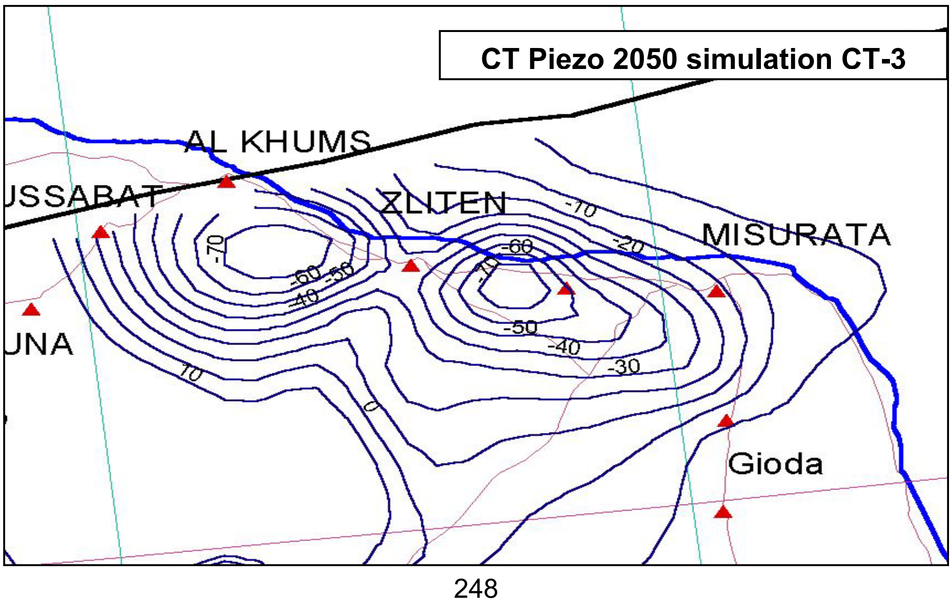


fig. 181: CT Piezometry 2050 ; simulation CT-3

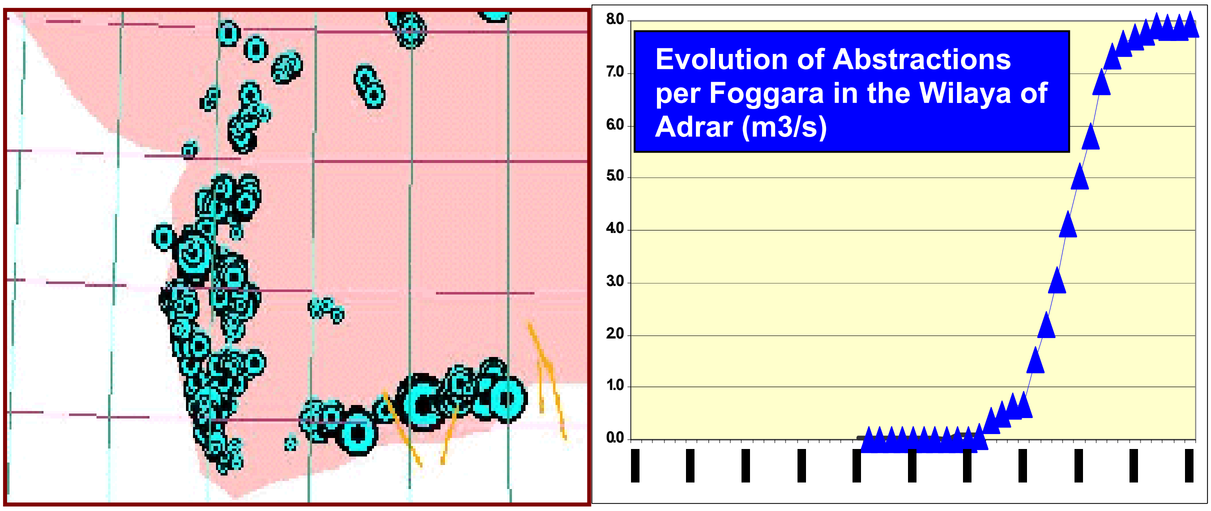


VI- FOGGARAS

The Foggaras of Gourara, Touat and Tidikelt constitute the main natural outlet of the Intercalary Continental aquifer. Their very precise survey represents a twofold challenge:

- With the explosion of drills in the region over the last twenty years (see map of the position of drills and the evolution chart of extracted flow rates), these outcrops will find it more and more difficult to bear competition and will disappear in the more or less long term. The accurate knowledge of their present regime will enable a better awareness of this evolution, by authorizing the adoption of reliable tools likely to forecast and hence anticipate future regimes;
- The foggaras constitute one of the most important "outlets", the sole visible outlet" and hence measurable" exit of the Intercalary Continental Model in Algeria.
  The wedging of the model in the region and its representativeness, depend on a good knowledge of the situation and of the present flow rate of foggaras, as well as on the quality of observation of past evolution.

Fig. 182: Evolution of abstraction in the Province of Adrar

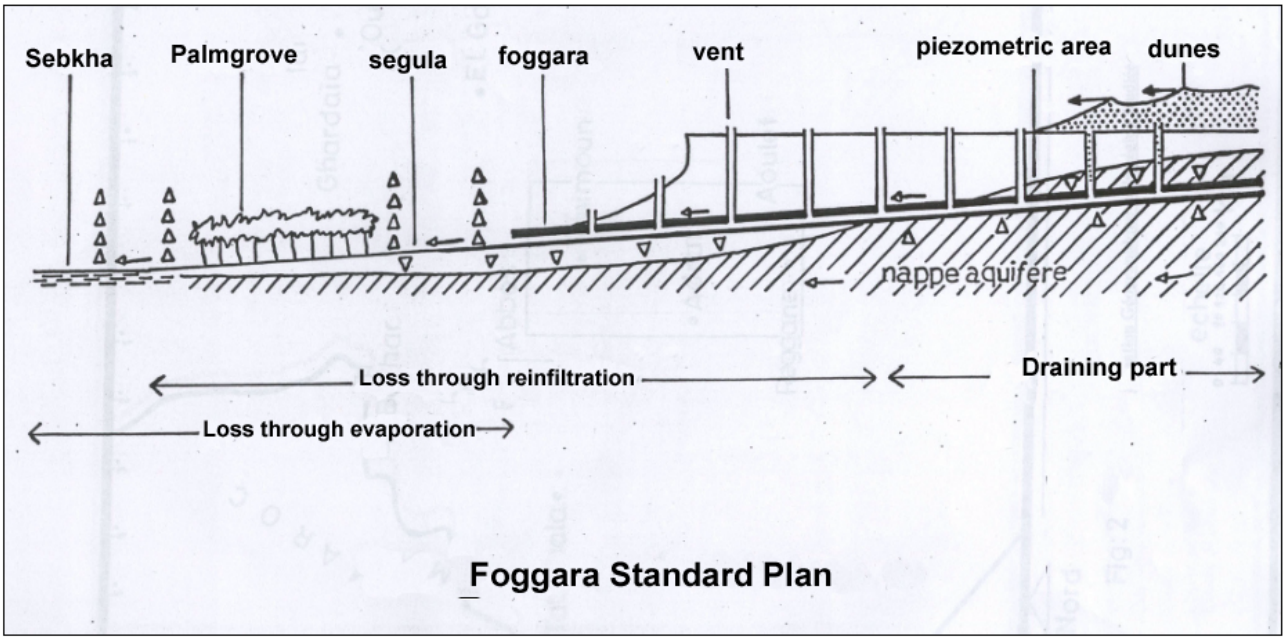


However, **at the scale of NWSAS study,** and the mesh units adopted for the model (12,5x12,5 km), there was no point to **stick to a fine hydro-geology of the foggaras, which remains to be done.**

The present representation of foggaras on the model, in the form of drains of **156 km^2**, is far from being satisfactory even if globally, the model correctly reflects the outcrops flow rates summed by large areas. But when copying the model, we must state that the historical estimates of the flow rate of foggaras (inventories of 1960 and 1998) provide global evolutions only: **there is no individual record per foggara, not even per group of foggaras or palm groves, which is detrimental to the fine modelling of the system.**

On the other hand, the **hundreds of active foggaras** are not related to **precise coordinates**. It is true that the emergence point constitutes just the visible part of a very complex and sometimes well extended underground drainage system (sometimes several kilometres), and that this emergent point can move after restoration works, **the fine hydrogeology of foggaras includes a very important topographic, cartographic and piezometric component.**

Fig. 183: Principle drawing of a Foggara



VII- CHOTTS

CT – Outlets (m^3/s)	1950	2000	SIM-0
Pumping	7. 5	42. 8	42. 8
Algeria-Tunisia Chotts	7. 3	1. 6	0. 0
Nefzaoua Djrerid Springs	2. 1	0. 0	0. 0
Algeria Sebkhas	1. 2	0. 4	0. 0

Let us recall the results yielded by the zero simulation: by the time frame 2050, **artesianism will have totally disappeared from the Algerian-Tunisian Chotts.** Chotts Merouane and Melrhir are « **suspended** » above the CT piezometric surface and there is the same in Tunisia be it in the Djerid, or in Nefzaoua, with all that this particular situation, unknown up to now, may imply in terms of « recharge » risks of the CT aquifer by the waters of the Chott…

A precise modeling of the links between the CT and the Chotts requires a fine analysis and a consideration of **the mechanisms which regulate exchanges between these two entities.** This analysis, which has not been yet done at the local and sub-regional levels, cannot obviously be seriously adopted now at the NWSAS scale. In our Model, the link is made through a simple vertical permeability and materials transfer will be instantaneous if they are activated.

In practice, the current version of NWSAS abandoned all types of direct connections between the CT and the Chott in case the latter is dewatered. In fact, the few salinity records available in the NWSAS database and the localization of corresponding drills around the Chotts cannot be used to conclude that the observed increases can be due to the arrival of salt from the Chott.

In fact, we do not hold yet validated observations that can describe with certainty relations and flow rates between the Chott and the CT aquifer. These two entities are also generally not directly connected.

Indeed, in Algeria, the area corresponds to a collapse region where impervious formations of the Evaporitic Eocene have developed.

In Tunisia, the CT formations lie very deep below Chott Djerid, the latter having been the seat of a strong MioPliocene subsidence; but this series rapidly bevels around the Chott, and preferential communications, in both ways, cannot be excluded, namely in the South East in Nefzaoua and in the North towards the sector of the Djerid. In reality, the important flow rates of the CT aquifer to the Chott, figured out by the Model, can be limited to a simple hydro-dynamic speculation, certainly highly boosted by regional piezometry, if there were no "ajouns" of Chott Djerid, whose important flow rate, initially estimated at 3 to 5 m^3/s, can come only from the CT layer.

With regard to CT aquifers, **the Chotts represent a major risk,** as important aquifer drawdowns near the chotts can result in the **arrival of over-salty waters and hence induce the irreversible degradation of the water respring.**

The model can precisely be used to calculate the time when a possible recharge of the aquifer by the Chott can take place.

The first indicator allowing for the evaluation of such a risk is provided by the position of the aquifer piezometric level with regard to the level of the Chott.

The evolution reconstituted over the last 50 years and the foreseeable evolution of this indicator over the next 50 years well indicate that sectors like **Kebili peninsula**, **Nefzaoua**,

Djerid, **Chotts Merouane** and **Melrhir**, **seem seriously threatened** as the PL of the CT aquifer is systematically below the level of the Chotts. As for the salt contamination risk, these sectors are already highly exposed and this without adding any new abstraction: ***the simple holding of the present abstraction pace constitutes a major possible danger.***

The few developments described above summarize adequately all the questions that we can raise today about the relations between the Chotts and the CT aquifer. All these questions reflect the modesty of our present knowledge of this phenomenon. **They justify the scope of investigations that need to be performed in the near future so that we would not be led in ten or twenty years, to remark on the same state of ignorance.**

In addition, these questions justify the urgency of an effective design of a system to monitor salinity in the region: the absence of significant records about the evolution of the CT salinity around the Chotts will be catastrophic if it continues.

VIII- RECHARGE OF AQUIFERS

One of the weak points of all the models conducted in the Sahara has been to address in a rather too quick a manner the **the issue of aquifer recharge**, when this issue is not completely neglected in favour of a hypothetical hidden-recharge.

After the developments, certainly still preliminary, of the first part of this report concerning the estimate, respectively of the flow rates in the oueds and the seepage capacities of « useful » geological outcrops, it is possible to compare the storage flow rates calculated by the model at the end of wedging in a permanent regime, with supply flow rate estimates at the same sites, by making the sum of:

- Direct seepages at the level of outcrops (selected hypothesis: seepage coefficient = 2% of the inter-annual average rainfall),
- Seepages from river floods (hypothesis: 30% of the average flow rate seepage).

CONTINENTAL INTERCALAIRE								
Mathematical Model		Outcrops infiltrations			Wadi infiltrations			
CI Model boundary	Calculated model (l/s)	Outcrops	Cinf=2% Mm3/year	L/s	Basin	Cinf=30% Mm3/year	L/s	Total Recharge L/s
Saharan Atlas	7540	Saharan Atlas s. s	100	3175	n. c Atlas Djedi	110	3492	6667
		GrD Erg Occi.	66	2095			0	2095
Dahar	450	Dahar	3	95	Dahar	0	0	95
Nafoussa	1130	Nafoussa	3	95		0	0	95
Tinhert and Adrar B. Drich	290	Tinhert and Adrar B. Drich	8	254			0	254
TOTAL	**9410**	**Total**		**5714**			**3492**	**9206**
COMPLEXE TERMINAL								
TC Model boundary	Calculated model (l/s)	Outcrops	Cinf=2% Mm3/year	L/s	Basin	Cinf=30% Mm3/year	L/s	Total Recharge L/s
Saharan Atlas	3775				O. Djedi	40	1270	1270
Dahar		Dahar Matmata	0. 4	13	Dahar	15	476	489
	6085		46					
Nafoussa	620	Tunisia-Lybia	46	1460			0	1460
Western boundary	2450			0			0	0
South-western boundary	980		9	286			0	286
		Mzab		0	Mzab	45	1429	1429
Tademait	2585	Tademait	11	349			0	349
Southern Lybia	1060	Southern Lybia	1	32			0	32
		Tinhert	16	508			0	508
North of Algerian Chotts	305		8	254			0	254
North of Tunisian Chotts	150	North of the Chotts		0	Aures-Gharsa	90	2857	2857
Calc. Eoceneous contribution	200	Calc. Eoceneous contribution		200			0	200
		Miopliocene, yc Grand Erg O	156	4952			0	4952
Total	**18200**	**Total**		**8054**			**6032**	**14086**

The previous table shows all obtained results. We can note that:

- With the selected hypothesis concerning seepage coefficients, the estimate of the hydrological recharge of the Intercalary Continental corresponds more or less to the one calculated by the digital model[2]. The rivers inputs represent **40%** of recharge, and direct seepage **60%**. The latter is however not reported at the outer limit of the aquifer, as is in the drawing adopted by NWSAS model, and we need to involve the seepage surface of the Western Grand Erg (Grand Erg Oiccidental) to be able to “complement” the balance.

- Concerning the Complexe Terminal, the issue is much more complicated:
  - First the supply total flow rate of all springs, represents only **75%** of the value calculated by the Model,
  - then, if the respective parts of the rivers and the direct seepage are the same as for the CI, that is **40% and 60%**, their regional distribution is very uneven. In the Aures for instance, the rivers “bring” **3. m^3/s** to the aquifer while the model calculates **300 l/s**[3] only.
  - In other limits, the model over-estimates, sometimes even drastically, the inputs: this is namely the case in Tademait (2500 vs 350 l/s), South Libya (1000 vs 30l/s), Mzab (3400 vs 1700l/s), Dahar-Nefussa (6600 vs 1400l/s). And it is the infiltrating surfaces of the MioPliocene (input of 5000 l/s) which bring figures close to the balance calculated by the Model.

[2] This result can be considered as an artefact as the selected direct seepage coefficient (2%) was precisely the one that would be used to recover recharge estimates for the CI and CT aquifers. Such a coefficient is not exaggerated at all and can be considered as reasonable even in the Sahara.

[3] With this particular point, there is the question of representation of Biskra Aquifer and the representativeness of the CT Model in this region.

IX- RESERVES OF THE WESTERN BASIN

The provisional scenarios simulated on the model showed serious exploitation possibilities of the reserves of the Western Grand Erg Basin (G. E. O), preferred reserve of the unconfined surface sectors of the Intercalary Continental. In order to assess the real capacities of the region to bear such an exploitation, a particular simulation was conducted specifically designed for this question. This simulation gathers scenario **IC-6** [80 m^3/s ; « exploitation of reserves of the G. E. O basin»], to which were added some flow rates of the scenario **CI-5** [**5m^3/s** in each of the sites of Akabli, Timimoun, Titaf, In Salah ; and 8m^3/s in El Golea] ; hence a total additional abstraction of **108 m^3/s** or **3,4 Milliards m^3/year**. Of course, this abstraction is included in scenario **CI-8** already simulated, but due to the specific weight of additional flow rates of the western basin [90% of Algeria abstraction and 84% of NWSAS at the IC], it was important to estimate:

- What would be the impacts of the Western Basin on the rest of NWSAS at the forecast time frame 2050 ?
- Given the importance of considered quantities and the exclusive participation of IC reserves in the production of these quantities, what would be their impact in the very long term (one century, two centuries), in the basin itself and in the other regions, even in other countries, knowing that Tunisia and Libya are at about 1000 km apart?

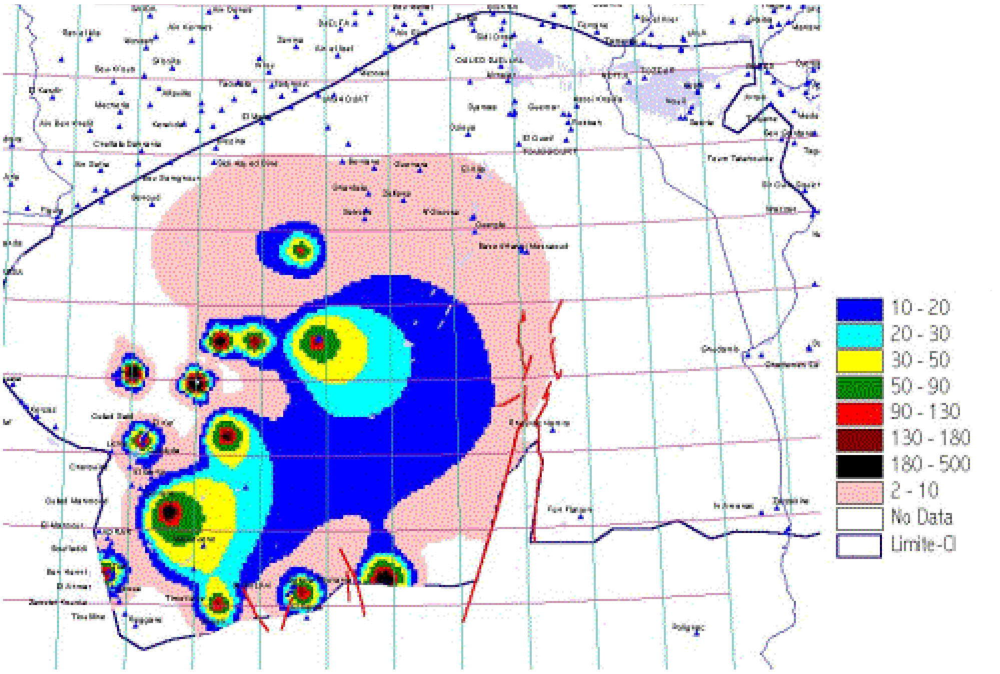
Water Budget of the Western Basin (m3/s)								
	1950		2000		2050		2200	
	input	output	input	output	input	output	input	Output
Recharge	3. 5		3. 5		3. 5		3. 5	
Unstorage			12. 7		120. 0		118. 8	
Horizontal exchange	0. 6			2. 2		3. 5		3. 4
Deep wells		0. 3		10. 7		118. 7		118. 7
Drains		3. 8		3. 3		1. 3		0. 2

The balance calculated for the time frames 2050 and 2200 and the **net drawdowns maps**, show the following observations:

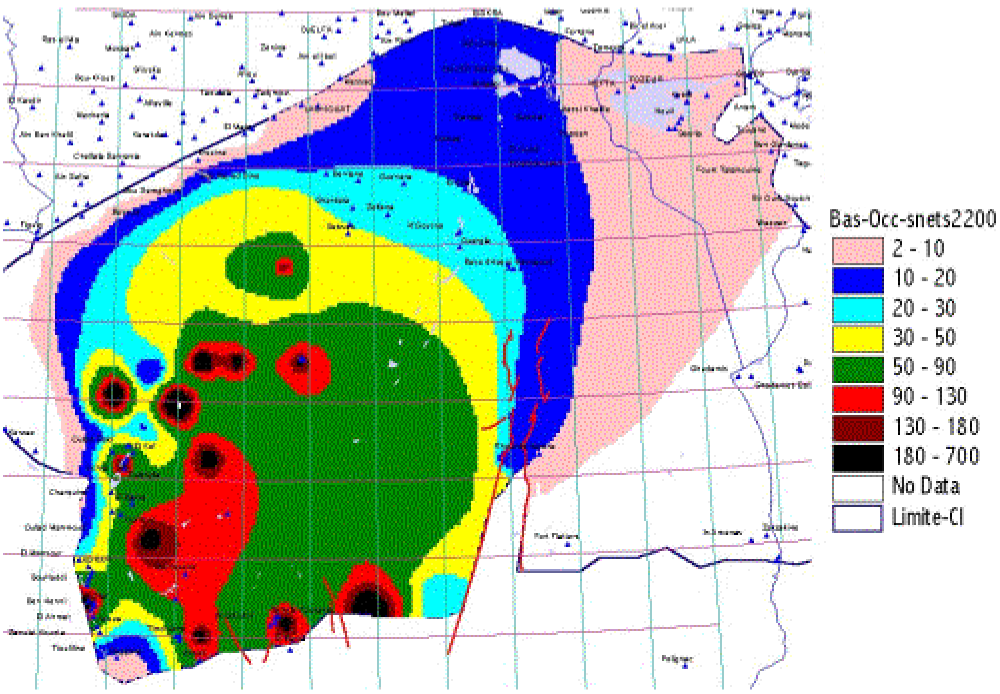
- The pumped flow rates are exclusively provided by the reduction of stocks of the aquifer reserves,
- The foggaras which will preserve some flow rate by 2050, will completely dry out by 2200,
- By the time frame 2050, drawdowns induced by additional abstraction (net drawdowns) will be limited to the region,
- In 2200, impacts on drawdowns will be clearly marked outside the region: 25m in Ouargla, 20m in Toggourt… and nearly 10m in Tunisia, at 1000km from the barycentre of abstraction.

Fig. 184: Impact of the Western Basin in 2050 and 2200.

Western Basin at 108 m3/s - Net drawdowns in 2050



Western Basin at 108 m3/s – Net drawdowns in 2200



X- COMPARISON OF MODELS

We can characterize the different versions of NWSAS Model by means of objective criteria that are the **model structural parameters**: Transmissivities and storage coefficients.

The distribution of transmissivities in a domain as wide as the NWSAS can be objectively and efficiently described by a single parameter: **the harmonic average of all transmissivities values.** This is shown in Tab. 1, with averages of the different versions of NWSAS Model, but **only for the Intercalary Continental** as the CT transmissivities have not been subject to changes since Tripoli wedging. It will be noted in this table that the **arithmetic average constitutes a less fair indicator** of the difference between both versions, while the harmonic average offers contrasted values from one version to the other.

Table 50 shows average storage coefficients [arithmetic averages] of the Complexe Terminal for the different versions of the Model.

Table 49: Average Transmissivities of the different versions of NWSAS Model in m^2/s

	MTRIPOLI	M20-8	M10-9	M30-9
Arithmetic Average	0.013	0.013	0.017	0.014
Harmonic Average	0.004	0.007	0.009	0.005

Table 50: Average storage coefficient of NWSAS Models

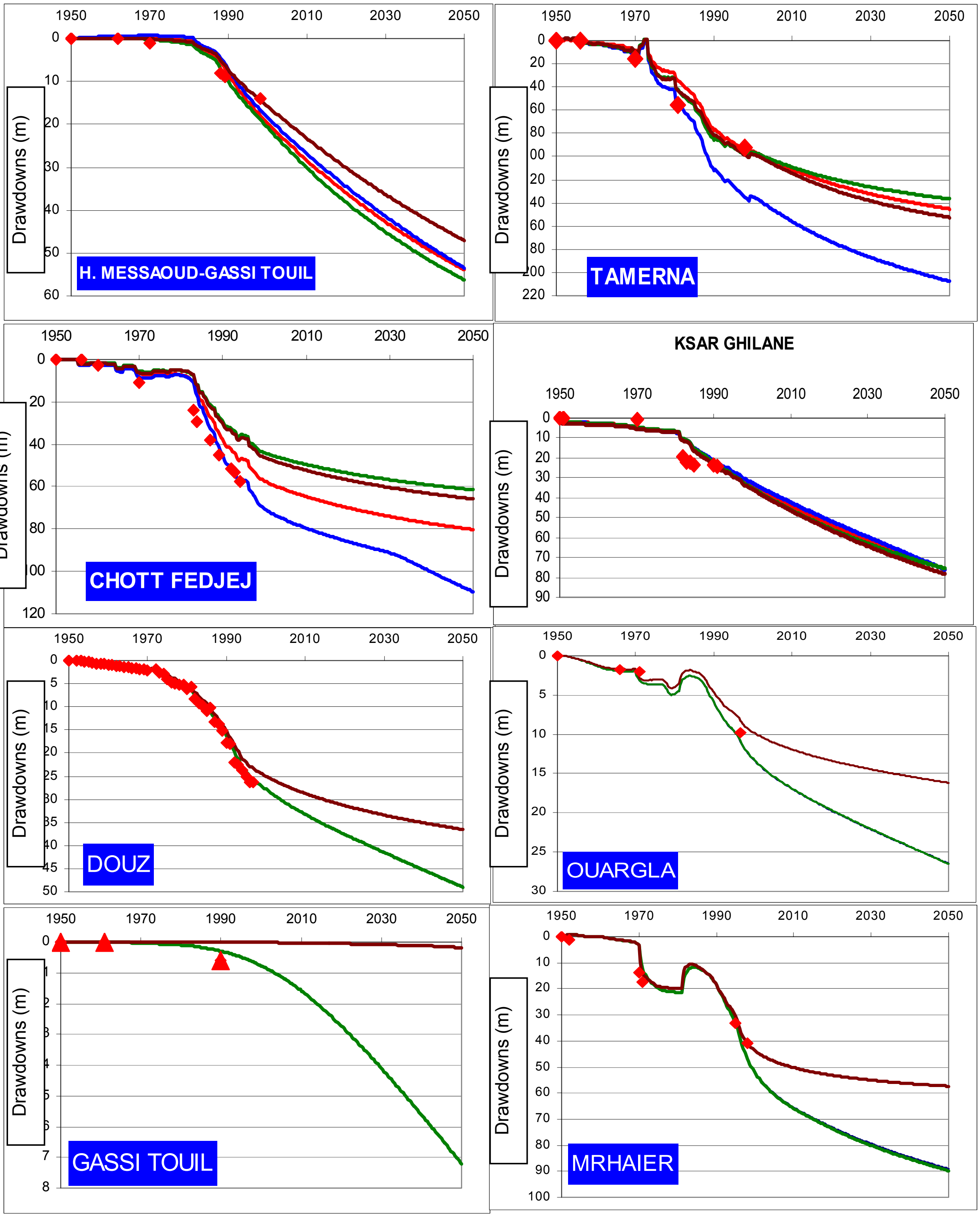
Version	**Average S (arithmetic average)**
TRIPOLI	2. 85 x 10^{-2}
M20-8	2. 85 x 10^{-2}
M10-9	1. 0 x 10^{-2}
M23-9	1. 0 x 10^{-2}
M30-9	1. 0 x 10^{-2}

XI- SENSITIVITY OF THE MODEL TO PARAMETERS

The different versions of the NWSAS Model can usefully serve the necessary study of sensibility to parameters that are determinant in the simulation. To assess such a sensitivity, the eight following figures [the first four in the CI, the last four in the CT] show drawdowns for 1950-2050 of the zero scenario calculated by the four last versions of the model [post-Tripoli: those which integrate the new design of the Tunisian Outlet]. These figures mainly express:

- the most pessimistic versions in terms of transmissivities (M23-9 and M30-9) yielding more severe CI drawdowns, namely in the pumping fields,
- sectors where CI transmissivities have not been modified (H. Messaoud, Ksar Ghilane) are unaffected by the change,
- the very important reductions of the storage coefficients of the CT unconfined aquifers in the CT have considerable impacts on drawdowns in areas where pumping fields are concentrated (Mghaier, Douz). These impacts are more obvious in unconfined surface areas (Gassi Touil).

fig. 185: Compared Responses of the different versions of NWSAS Model



Brown: August 20 version
Green: September 10 version
Blue: September 23 version
Red: September 30 version

XII- STORAGE IN "AQUITARDS"

Fluid Abstraction through an Aquitard

Between two aquifer layers separated by an "aquitard", the vertical flow rates through leakage are described by the equation:

$$\frac{\partial^2 h}{\partial z^2}=\frac{S_s}{K_v}\frac{\partial h}{\partial t} \qquad (1)$$

where S_s is the aquitard storage specific coefficient, K_v is its vertical permeability and $h=h(z,t)$ is the hydraulic charge, at t time and a point situated at a vertical distance z from the top of the aquitard.

When the system is initially balanced, if $H_0(t)$ is the hydraulic charge in the pumped aquifer and $H_1(t)$ the one in the adjacent aquifer, that H_0 is constant and $H_1=0$ for $t>0$, the equation solution is (1):

$$h(z,t)=H_0\left[1-\frac{z}{b}-\frac{2}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\sin\left(\frac{n\pi z}{b}\right)\exp\left(-n^2\alpha t\right)\right] \qquad (2)$$

where $\alpha=\dfrac{\pi^2 K_v}{S_s b^2}$; the vertical flow rate is written: $q=-K_v\dfrac{dh}{dz}$

(3)

where $$\frac{dh}{dz}(z,t)=-\frac{H_0}{b}\left[1+2\sum_{n=1}^{\infty}\cos\left(\frac{n\pi z}{b}\right)\exp(-n^2\alpha t)\right] \qquad (4)$$

At the level of the "aquitard" surrounding formations, we have:

$$\frac{dh}{dz}(0,t)=-\frac{H_0}{b}\left[1+2\sum_{n=1}^{\infty}\exp(-n^2\alpha t)\right] \qquad (5a)$$

$$\frac{dh}{dz}(b,t)=-\frac{H_0}{b}\left[1+2\sum_{n=1}^{\infty}(-1)^n\exp(-n^2\alpha t)\right] \qquad (5b)$$

In the case where $H_0=1$ and $b=1$, equations (5a) and (5b) respectively represent the water flow rate supplying the pumped aquifer and the one coming from the non pumped aquifer and pouring into the aquitard. The reaction of an aquitard following a sudden variation of the hydraulic charge in one of the two aquifers can be described by three phases:

- **Phase 1 of duration T_1** (fig. 2. a): the leakage flow rate pouring into the pumped aquifer comes from the reduction of stock of the aquitard. The aquitard can be considered as having an infinite thickness, the interaction between the two aquifers is insignificant. The hydraulic charge is given by:

$$h(z,t)=H_0\,\mathrm{erfc}\left(\frac{z}{\sqrt{\dfrac{4K_v t}{S_s}}}\right) \qquad (6)$$

and $$\frac{dh}{dz}(z,t)=-\frac{H_0}{\sqrt{\dfrac{\pi K_v t}{S_s}}}\exp\left(-\frac{z^2}{\dfrac{4K_v t}{S_s}}\right) \qquad (7)$$

for $\alpha t \leq T_1$ where αt is an adimensional variable describing time

- **Phase 2 extending until T_2** (fig. 2. b): the reaction of the aquitard spreads until the interface with the non pumped aquifer which starts to react. The interaction between the two aquifers starts to take place and the flow rate pouring into the pumped aquifer comes from at the same time the reduction in the stock of the aquitard and from the non pumped aquifer. We have

$$h(z,t)=H_0\left[1-\frac{z}{b}-\frac{2}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\sin\left(\frac{n\pi z}{b}\right)\exp\left(-n^2\alpha t\right)\right] \tag{8}$$

and $$\frac{dh}{dz}(z,t)=-\frac{H_0}{b}\left[1+2\sum_{n=1}^{\infty}\cos\left(\frac{n\pi z}{b}\right)\exp(-n^2\alpha t)\right] \tag{9}$$

for $T_1<\alpha t < T_2$

- **Phase 3** (fig. 2. c): the balance state is established in the aquitard. All the leakage flow rate towards the pumped aquifer comes from the non pumped aquifer. We have:

$$h(z,t)=H_0\left(1-\frac{z}{b}\right) \tag{10}$$

and $$\frac{dh}{dt}(z,t)=-\frac{H_0}{b} \tag{11}$$

for $\alpha t > T_2$

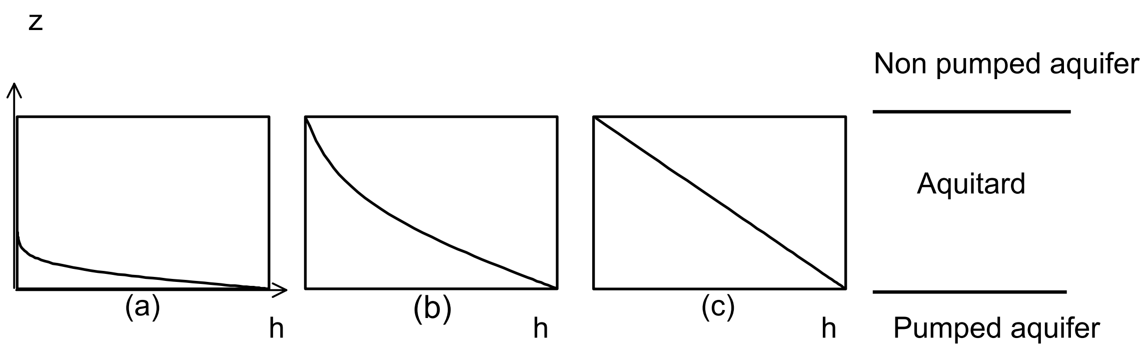


Fig. 186 – The different phases characterizing the aquitard reactions

The aquitard reaction functions in the three phases represent the aquitard reaction in a transient regime with regard to a balanced regime, and can be defined by:

$$g(z,t)=\frac{\left(\frac{dh}{dz}\right)_{i(i=1,2,3)}}{\left(\frac{dh}{dz}\right)_3} \tag{12}$$

By introducing adimentional parameters $\tau=\frac{\alpha t}{\pi^2}$ for time and $\chi=\frac{z}{b}$ for distance, the reaction functions for the three phases are therefore:

$$g_1(\chi,\tau,)=\frac{1}{\sqrt{\pi\tau}}\exp\left(-\frac{\chi^2}{4\tau}\right) \qquad \tau \le T_1' \tag{13a}$$

$$g_2(\chi,\tau)=1+2\sum_{n=1}^{\infty}\cos(n\pi\chi)\exp\left(-n^2\pi^2\tau\right) \qquad T_1' < \tau \le T_2' \tag{13b}$$

$$g_3(\chi,\tau)=1 \qquad \tau > T_2' \tag{13c}$$

with $T_1' = \frac{\alpha T_1}{\pi^2}$ and $T_2' = \frac{\alpha T_2}{\pi^2}$ respectively marking the beginning of the influence of one aquifer over the other and the starting of the permanent regime. (fig. 3). The permanent regime can be defined by the condition:

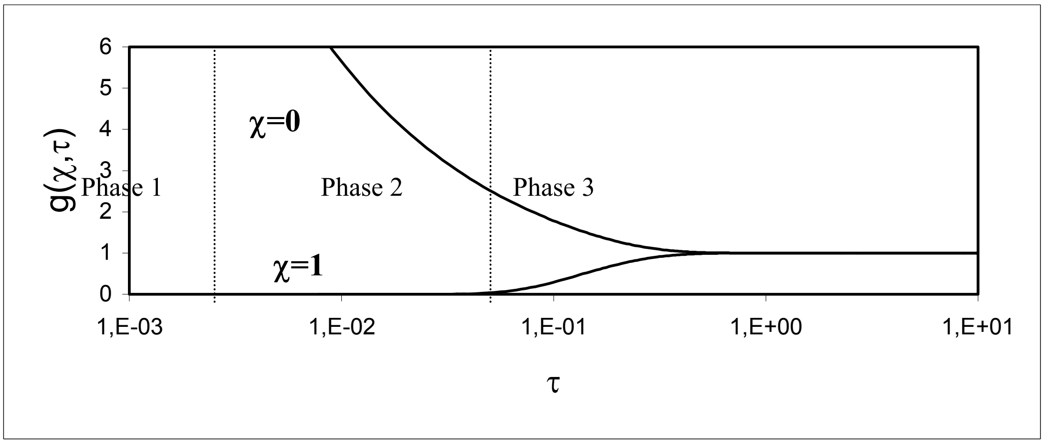
$$|g_2(1,\tau) - g_2(0,\tau)| \leq \varepsilon \qquad \tau \geq T_2' \tag{14}$$

ε is the admissible error on the aquitard behavioural approximation. In practice, we can adopt $\varepsilon=10^{-3}$ with regard to inaccuracies of the model related to the spatial discretisation. In this case, we obtain $T_2'=1$ et $T_1'=0.0316$, or:

$$t_2 = \frac{S_s b^2}{K_v} \tag{15a}$$

$$t_1 = 0.0316 \frac{S_s b^2}{K_v} \tag{15b}$$

Fig. 187: Aquitard Reaction Functions



The t_2 time depends on the physical characteristics of the semi-permeable layer. The design of an immediately permanent regime or of a very long transient differs from one aquitard to the other.

Application to NWSAS Multi-layer

Settlement Time of the Permanent Regime in NWSAS Aquitards

In MODFLOW RATE, the flow rate into aquitards is supposed to be permanent and flow rates through aquitards are calculated by the Darcy Law: $q = \frac{K_v}{b} \Delta H$

(19)

The reduction in the stocks of aquitards under the effect of a disruption in one of the two aquifers is neglected. To verify the validity of this hypothesis, we calculated the settlement time of a permanent regime in the system's different aquitards. The calculation of t_2 (cf. equation 15a) requires the knowledge of vertical permeability, the thickness and the specific storage coefficient. The vertical permeability results from the wedging of the model. The thickness is deduced from the geological database. The specific storage can be elevated for clayey formations or practically nil in case of non compressible layers like anhydrite. With reference to values mentioned in Saharan literature (UNESCO, 1972 ; GEOMATH, 1994), an intermediate value has been used, $S_s = 10^{-9}$ m^{-1} characterizing a heterogeneous formation including clay, sand, marl and anhydrite.

In the lagoon Senonian: t_2 is lower than 1 year in Libya and in all the lower Sahara located in the North of the 32nd parallel. In one third of SW, it ranges between 100 and 1000 years.

In the Cenomanian: t_2 is below 1 year in the domain of parallels 29°-32° and meridians 6°-16°, hence all Libya, Tunisia's most southern part, the Province of Illizi (Algeria) and one part of the province of Ouargla. Elsewhere, t_2 is more than 100 years and can reach extreme values as 3. million years in the North of Chott Rharsa. But we still have t_2 < 1 year in chott Fedjej and in the Kebili peninsula.

Fig. 188: Distribution of t_2 in the Lagoon Senonian

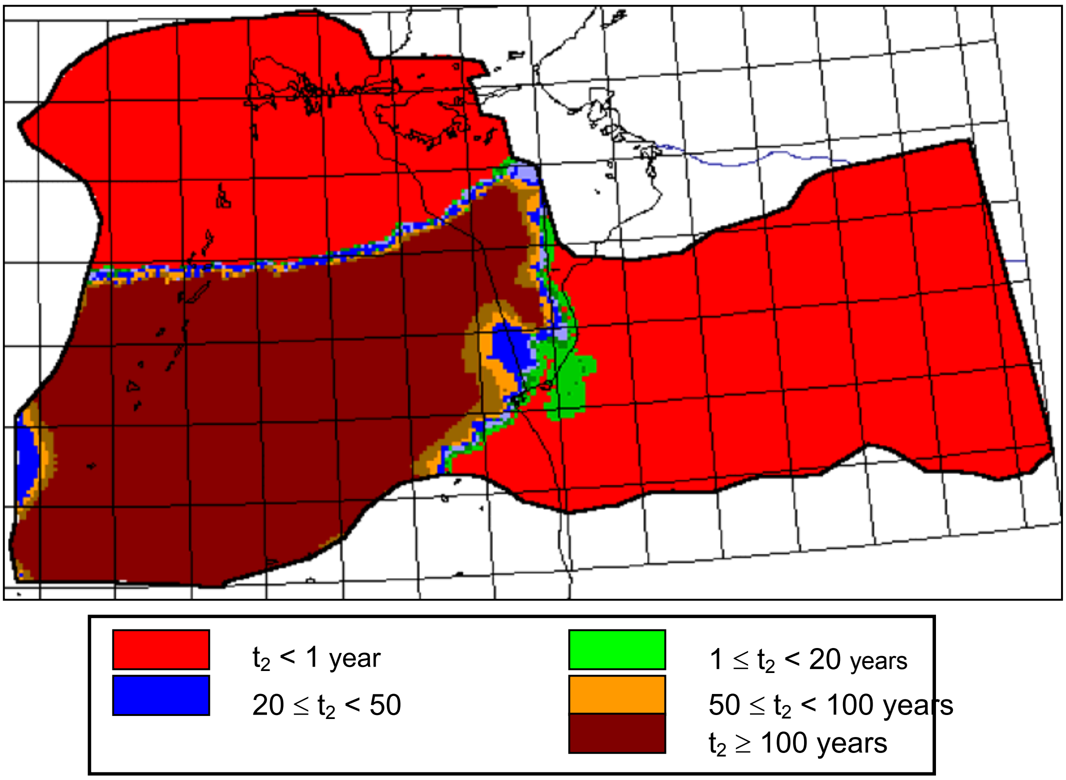
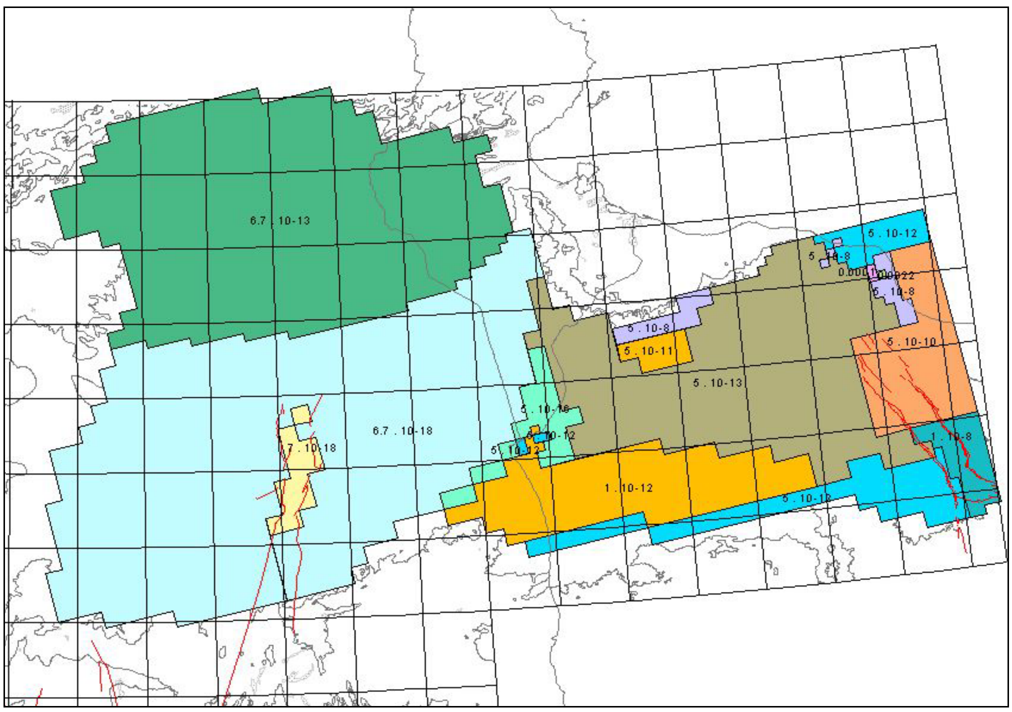


Fig. 189: Lagoon Senonian– Leakage Coefficients [s^{-1}]



CONCLUSIONS
&
RECOMMENDATIONS

CONCLUSIONS & RECOMMENDATIONS

CONCLUSIONS

The Objective of the Study of the North-Western Sahara Aquifer System was to build, for each of the two main aquifers : the Complexe Terminal and the Continental Intercalaire, a simulation digital model, the objective of the model being to « realize a coherent synthesis of data and information acquired about these aquifers, identify the water resource status in the North-Western Sahara, determine exploitable resources and design modalities for the management of these resources on the basis of development scenarios ». At the end of this study, whose works lasted from January 2000 until June 2002, the question is to know to which extent these objectives were achieved.

CI Model Vs. CT Model

When starting the NWSAS project, we were used to two traditions, two visions, two parallel conceptions of the Saharan hydrogeology:

- On the Tunisian-Algerian side, the thickness of semi-permeable separation formations, the very high charge difference between the two main layers, consolidated a well established tradition of a separated treatment of the CI and the CT, and models since Géopétrole in 1963 had been designed as independent single-layers;
- On the Libyan side, the separation layers between the aquifer formations are less thick, and since the first regional model of Idrotecneco in 1981, a multi-layer structure has been chosen.

In order to ensure a harmonious conjugation of hydro-geological visions in the three countries, the general design of the NWSAS Model had to abandon the duality, CI vs. CT adopted by ERESS, in favour of a Multi-layer representation, of which the design of a "Conceptual Model" has well demonstrated that it is the only one to bring together the hydro-geologies of Algeria-Tunisia with those of Libya. The representation of the "Saharan Multi-layer" enables the preservation of better simulation conditions in the long term, integrating the Turonian, the Palaeozoic, and taking in consideration leakage flow rates between the CI and the CT.

Synthesis of Acquired Knowledge

The cartographic representation of the flow rates constitutes the first level of hydrodynamic modelling. Such a map has not been drawn all over NWSAS domain, but representations covering parts of this territory are available, each contributing to the overall knowledge. In the framework of this project, it was necessary to build a piezometric map in order to present a coherent flow rates scheme throughout the basin. This map defines flow rates at their "natural" state, little or not influenced by pumping. As for the system general dynamics, the most significant piezometric evolutions have been gathered by homogeneous and representative geographical area :

- In the CI : Tamerna for the artesian basin with strong ground pressures, Kef n°27 for areas close to unconfined surface, Chott Fedjej for the vicinity of the Tunisian Outlet, the Djerid for very high drawdowns, the Ghadames Basin and the Graben;
- In the CT: in Tunisia, it was necessary to design a standard series, or « synthesis curve » by aggregating measurements available on each geographical sector.

The reconstitution of abstraction records was a difficult task with regard to the number of "active" water points, the length of the record time-periods and the diversity of counting methods, according to the country and successive teams.

Water balance and exploitable resources in the North-Western Sahara

The ERESS project defined the water resources of Saharan major aquifers : “with regard to the present and future geographical distribution of abstraction points, the water resources of an aquifer are the flow rate corresponding to a value and a growth in time, investments and operating admissible costs”. This “mining” approach of aquifer resources, considered of a “fossil” nature had to be updated. The exploratory simulations conducted on NWSAS model have in fact highlighted a number of nuisances and “risks” facing the water resource through its development. Any desire to continue the exploitation of more aquifers in the CI and the CT will require from now on to know, with full awareness, how to minimize and manage these risks, of which we may cite:

- Disappearance of artesianism ;
- Excessive pumping heights (depths);
- Drying of the Tunisian outlet;
- Drying of Foggaras;
- Important drawdown interferences between countries;
- Possible recharge by the Chotts.

The results of the « strong hypothesis » and the « weak hypothesis » have also proven the limits of the “pure simulation” approach in the definition of the NWSAS development strategy. The strong hypothesis as well as the weak one, which initially seemed to have to “frame” the choice of decision makers and foreseeable solutions, would have, with regard to these results, devastating consequences on the future of NWSAS. This is the reason why it was decided to seek out another way to jointly proceed to the definition of acceptable solutions, by means of a miniature model.

The principle adopted in the light of exploratory simulations results was to free oneself from the search of development scenarios with no direct relation to the aquifer properties, solely founded on forecasts of water demand, and to look instead for the *construction* of scenarios relying on a “hydraulic” base, *founded on the NWSAS production capacities and minimizing risks of identified nuisances*, in sites as close as possible to areas where present or future needs will have better chances to be greatly expressed, without missing opportunities to prospect favourable sectors that may be far away from possible demand areas, but that can prove to be pertinent for export. The first phase of such a process was to make the inventory, country by country, of all potential pumping sites.

How to ensure the maximum of water abstraction for a better development of the region, without the risk of damaging the state of this resource ? How to design the “best” exploitation planning with in regard ? NWSAS micro-model has in fact been developed for this reason. It was first necessary to make an inventory of encountered risks and determine constraints that need to be observed in order to reduce these risks. This required the quantification of the risks, which means their modelling. NWSAS digital model is precisely designed for such a function.

One of the results of the investigations carried out on this model have led to verifying that there exists the possibility of raising the NWSAS deep well exploitation, estimated at 2.2 billion m3 in 2000 [1.33 in Algeria, 0.55 in Tunisia, 0.34 in Libya], up to a level of 7.8 billion m3/year by the time-frame 2030, while observing as much as possible all constraints related to the risks of damaging the resource. Per country, this exploitation is divided as follows: 6.1 billion m3/year in Algeria, 0.72 billion m3/year in Tunisia, 0.95 billion m3/year in Libya. The possibility [this is in fact a hypothesis] to triple present abstraction will bring the NWSAS exploitation regime to a level representing eight times its renewable resources. Such an operation can obviously be possible only by drawing out of the system reserves.

RECOMMENDATIONS

For several reasons, related to the quantity and quality of available data, to the hypotheses and approximations adopted during the design, construction and setting of the model, a number of uncertainties and indecisions persist at the end of the study, which would have an impact on the reliability of obtained results, and that can gradually be removed thanks to new investigations that need to be carried out for a better knowledge of the system. The following points enumerate the most important uncertainties surveyed during the study and suggest some follow up ways. These ways naturally complement "obvious" recommendations, concerning the absolute necessity of a regular monitoring the evolution of abstraction rates, piezometric levels and salinity.

Transmissivities and flow rate of the Tunisian Outlet

If we were to judge the NWSAS Model from the point of view of the two constraints adopted for wedging:

- Geological legacy of the structure of the field of transmissivities ;
- Estimated value of the Tunisian outlet flow rate at the CI.

the adopted version [September 30 model], seems to *constitute the best compromise*. It is the most appropriate for the execution of provisional simulations. It is nonetheless necessary that NWSAS transmissivities and namely CI ones, must form the subject of several other new investigations, namely in the immense virgin areas represented by the two Grand Ergs: the Eastern and the Western.

Storage in an Unconfined Surface

Compared to previous models, the NWSAS Model is characterized by the substantial reduction of the storage coefficients in the CT unconfined surface areas. This reduction is inspired by what has been operated at the level of the Continental Intercalaire in the Adrar [reduction of 20% to 5%]. In the Complexe Terminal, one single piezometric control point in a free area can be found in Gassi-Touil : to get closer to the reference drawdown, we must substantially reduce S values in an unconfined aquifer dropping from $10x10^{-2}$ to $1x10^{-2}$. These new S values, though globally pessimistic, certainly need to be consolidated by other new investigations.

Impact of COD

The Cambro-Ordovician constitutes an immense reservoir related to the CI in the South eastern part of the basin. At the present phase of the study, the representation mode of the Palaeozoic adopted for the model seems valid (fixed imposed charge), but later it is necessary to consider representing it by an active aquifer layer, due to its contribution to compensate one part of CI additional abstraction in Libya, and the risk of reducing this contribution under the effects of abstraction at the level of DJ. Hassaouna.

Eastern Limit

The IC eastern limit is the only line in the model that is not natural. In fact, the aquifer formation of the Lower Cretaceous continue to the East of the Graben but show low transmissivities and a high salinity. There is therefore no clear hydraulic limit at this site. The model is limited by a condition of imposed potentials through a resistance. This formula authorized the estimate of CI exchanges with a salty eastern extension: these calculated exchanges remain insignificant though they show a tendency to activate salty water inputs under the effect of strong prompting. We would therefore recommend further investigations in this sector to better know the distribution of piezometric heights, transmissivities and salinity.

Gulf of Syrte

If for the deficit reduction scenario in Libya, [simulations IC7 & TC3] the Continental Intercalaire continues to profit in 2050 from a considerable charge in the coastline, it is very different for the Complexe Terminal, whose situation would be seriously prejudicial with a piezometric level of–70 m on the coastline ! Such a catastrophic scenario fully justifies more thorough investigations to have a more precise image of the littoral area hydrogeology as well as to conduct a close monitoring at this sector.

Foggaras

The Foggaras of Gourara, Touat and Tidikelt constitute the main natural outlet of the Continental Intercalaire aquifer. Their very precise survey represents a two-fold challenge:

- These outcrops will find it more and more difficult to bear competition and will disappear at more or less long terms. The accurate knowledge of their present regime will enable a better awareness of this evolution, by authorizing the adoption of reliable tools likely to forecast and hence anticipate future regimes;
- The foggaras constitute one of the most important "outlets", the sole visible outlet" and hence measurable" exit of the Continental Intercalaire Model in Algeria.

The wedging of the model in the region and its representativeness, depend on a good knowledge of the situation and of the present flow rate of foggaras, as well as on the quality of observation of past evolution. However, at the scale of NWSAS study, and the cells adopted for the model (12,5x12,5 km), there was no point to stick to a fine hydro-geology of the foggaras, which remains to be done. The present representation of foggaras on the model, in the form of drains of 156 km^2, is far from being satisfactory even if, globally, the model correctly reflects the outcrops flow rates summed by large areas. But when copying the model, we must state that the historical estimates of the flow rate of foggaras (inventories of 1960 and 1998) provide global evolutions only : there is no individual record per foggara, not even per group of foggaras or palm groves, which is detrimental to the fine modelling of the system.

On the other hand, the hundreds of active foggaras are not related to precise coordinates. It is true that the emergence point does constitute but the visible part of a very complex and sometimes well extended underground drainage system (sometimes several kilometres), and that this emergent point can move after restoration works, the fine hydrogeology of foggaras includes a very important topographic, cartographic and piezometric component.

The Chotts

A precise modelling of the links between the CT and the Chotts requires a fine analysis and a consideration of the mechanisms which regulate exchanges between these two entities.

In fact, we do not have yet validated scientific observations likely to describe with precision the relations and flow rates between the Chotts and the CT aquifer. In the model, the link is conducted through a simple vertical permeability, and materials transfers would be instantaneous if they could be activated. In practice, the final version of NWSAS model abandoned all direct connection between the CT and the Chott if the latter is dewatered. In fact, the few salinity records available in NSWAS database and the localization of corresponding deep wells around the Chotts do not clearly conclude that observed increases are due to the inflow rates of salt from the Chotts. This sums up some of the questions we may have concerning our present knowledge of this phenomenon. This also justifies the scope of research that must be soon conducted, so that we would not be, in ten or twenty years, in the same state of ignorance about the matter. These questions also justify the urgency of setting up an effective system to monitor salinity in the region: the absence of records on significant salinity evolutions at the CT around the Chotts would be catastrophic if it were to persist.

Recharge of Aquifers

One of the weak points of all models realized in the Sahara has been the neglecting of the aquifer recharge issue. It is now possible to compare supply flow rates calculated by the model, with estimates of supply flow rates at the same estimated sites, by making the sum of rainfall direct seepages through outcrops and rivers seepages. After examining obtained results, we can note that:

- The estimate of the hydrological recharge of the Continental Intercalaire Aquifer more or less corresponds to the one calculated by the digital model,
- Concerning the Complexe Terminal, the issue is much more complicated. First the supply total flow rate represents 75% only of the value calculated by the Model, then the regional distribution is very uneven. In the Aures for instance, the rivers "bring" 3.m^3/s to the aquifer while the model calculates 300 l/s[1] only. In other limits, the model over-estimates, sometimes even drastically, the inputs : this is namely the case in Tademait (2500 vs 350 l/s), South Libya (1000 vs 30l/s), Mzab (3400 vs 1700l/s), Dahar-Nefussa (6600 vs 1400l/s). And it is the infiltrating surfaces of the MioPliocene (input of 5000 l/s) which bring figures close to the balance calculated by the Model. As a conclusion, the model representativeness will be much better improved through a better awareness of the recharge mechanisms for the CI and the CT.

Reserves of the Western Basin

Provisional scenarios showed serious and possible exploitation possibilities of the reserves of the Western Basin, a privileged reserve of the unconfined surface sectors of the Continental Intercalaire. With regard to the specific weight of additional flow rates of the Western basin in the final simulations [90 % of abstractions in Algeria and 84% of CI NWSAS] , the importance of concerned quantities [3.5 billion m3] and the exclusive participation of CI reserves in the production of these quantities, it was important to be able to estimate impacts on the very long term, in the basin itself and in other regions, even in other countries, knowing that Tunisia and Libya are at about one thousand km apart.

The balance and drawdowns calculated at the time-frame 2200 show that :

- Foggaras will be completely dry,
- Drawdown influences are clearly marked outside the region : 25m in Ouargla and nearly 10 m in Tunisia.

Before thinking of implementing simulated abstraction, and with regard to the strong uncertainties of the model in the region of the Grand Western Erg [almost full ignorance of the field transmissivities and piezometric levels, see wedging of model in a permanent

[1] With this particular point, there is the question of representation of Biskra Aquifer and the representativeness of the CT Model in this region.

regime], it seems necessary to launch important investigations in the region, to better know the structure of aquifers, the distribution of piezometric levels, transmissivities and storage coefficients in an unconfined aquifer.

Deep Evaporation

The IC aquifer can be subject to considerable losses through evaporation in outcrop areas, where the aquifer is unconfined and close to the ground surface. In the Gourara-Touat-Tidikelt, the evaporation flow rates calculated by empirical formula reflect a continuous flow rate of 10 m^3/s, which seems very important. In fact, to evacuate such a flow rate, inputs at the CI aquifer must be doubled, through seeping into the Western Erg and in the Plateau of Tademait. Implications of this hypothesis have considerable consequences but do not contradict possible identified recharge areas. The further examination of this issue requires more investigation and a fine modelling of the CI western basin. As for the CT aquifer, it is not exempt from deep evaporations, mainly in the sector of Oued M’ya, subject in fact to a heavy exploitation scenario and which requires significant surveys.

ANNEXES

ANNEX 1
Reference piezometry of the Intercalary Continental (IC)

N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference	N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference
1	37H12	950995	361044	268		UNESCO (1972)	69	22-O6	421103	-385923	269	1960	UNESCO (1972)
2	EG1	1031790	284903	242	1962	UNESCO (1972)	70	TK105	240131	-386765	266	1970	UNESCO (1972)
3	5717	1140583	290513	310	1951	UNESCO (1972)	71	In Salah 1	481802	-375970	281	1956	UNESCO (1972)
4	DKA1	1102985	239218	301	1969	UNESCO (1972)	72	4N7	501089	-294859	346	1964	UNESCO (1972)
5	SP4-N	1159478	227457	307		UNESCO (1972)	73	A2	207672	-294619	265		UNESCO (1972)
6	5654	1190363	203664	312		UNESCO (1972)	74	Hassi Meraguene	203146	-277118	259	1969	UNESCO (1972)
7	2J14	1101379	178886	303	1966	UNESCO (1972)	75	Hassi en Nouss	203046	-221129	257		UNESCO (1972)
8	BZA1	1132894	179974	307	1966	UNESCO (1972)	76	OF101	241314	-235649	279	1970	UNESCO (1972)
9	6368	1210800	189529	306		UNESCO (1972)	77	TH5B	268092	-205743	300	1970	UNESCO (1972)
10	Mr a	1214838	177332	315	1961	UNESCO (1972)	78	Hassi Rhaba	256737	-178518	295	1969	UNESCO (1972)
11	6511	1224327	157716	317	1955	UNESCO (1972)	79	3N7	484109	-195838	358	1965	UNESCO (1972)
12	Sna	1168262	166169	315	1957	UNESCO (1972)	80	Me1	565105	-147602	367		UNESCO (1972)
13	EBA4	1121343	146090	318	1964	UNESCO (1972)	81	Oum Chen	489490	-149922	373		UNESCO (1972)
14	EBA7	1124451	120410	319	1968	UNESCO (1972)	82	Gouret Louazouaza	509429	-65770	388	1969	UNESCO (1972)
15	ZTA1	1139921	104990	316	1969	UNESCO (1972)	83	OS1	524659	-113537	381	1964	UNESCO (1972)
16	EZA1	1143531	94448	317	1970	UNESCO (1972)	84	Hassi Inkhal	457121	-96243	385		UNESCO (1972)
17	ECHA1	1145997	71251	342	1969	UNESCO (1972)	85	PN°8	426210	-88728	377		UNESCO (1972)
18	SBa	1167641	113925	312	1961	UNESCO (1972)	86	4M6	387470	-100183	364	1970	UNESCO (1972)
19	7000	1210657	77379	322		UNESCO (1972)	87	PN°4	364084	-132084	343		UNESCO (1972)
20	1K12	903063	81356	333	1969	UNESCO (1972)	88	PN°2	321604	-140198	327		UNESCO (1972)
21	Hassi Messaoud	819538	116525	375		UNESCO (1972)	89	T6	252469	-150896	280	1970	UNESCO (1972)

N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference	N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference
23	447J10	743948	148424	405		UNESCO (1972)	91	El Golea	508892	3033	401	1970	GEOMATH (1994)
24	480J10	753543	145583	403		UNESCO (1972)	92	C1-19	1208624	-246707	408	1970	GEOMATH (1994)
25	228I11	811534	277669	362		UNESCO (1972)	93	Ghadames	1151858	-44465	349	1970	GEOMATH (1994)
26	436I11	824763	288187	362	1959	UNESCO (1972)	94	T/96/76	1236279	-29915	331	1970	GEOMATH (1994)
27	437I11	823785	305674	357	1962	UNESCO (1972)	95	WG-9	1287223	9369	323	1970	GEOMATH (1994)
28	408H11	799982	315485	362	1956	UNESCO (1972)	96	WG-13	1252290	66113	319	1970	GEOMATH (1994)
29	42H10	768734	319822	362	1956	UNESCO (1972)	97	WG-16	1229001	80663	321	1970	GEOMATH (1994)
30	7I9	685741	291263	425	1954	UNESCO (1972)	98	T/41/81	1278489	166506	313	1970	GEOMATH (1994)
31	Guerrara	667395	245714	426		UNESCO (1972)	99	T/22/76	1252290	173781	312	1970	GEOMATH (1994)
32	Zelfana	647817	198074	426		UNESCO (1972)	100	W-23	1317789	118492	314	1970	GEOMATH (1994)
33	4K9	689117	86344	425	1960	UNESCO (1972)	101	C70-5	1346899	89392	304	1970	GEOMATH (1994)
34	16K8	561142	12444	407	1957	UNESCO (1972)	102	C70-8	1358543	76298	308	1970	GEOMATH (1994)
35	15K8	565770	56219	414	1958	UNESCO (1972)	103	T/11/81	1320700	-9546	315	1970	GEOMATH (1994)
36	1J8	592363	110996	422	1970	UNESCO (1972)	104	10/81	1457519	-3726	282	1970	GEOMATH (1994)
37	20J8	597050	147689	432	1956	UNESCO (1972)	105	158/70	1514285	22463	253	1970	GEOMATH (1994)
38	67J8	568205	163292	441	1958	UNESCO (1972)	106	213/76	1536118	64658	249	1970	GEOMATH (1994)
39	71J8	544403	171870	441	1958	UNESCO (1972)	107	29/83	1492452	128677	254	1970	GEOMATH (1994)
40	Metlili	592202	180143	443		UNESCO (1972)	108	22/87	1552129	128677	208	1970	GEOMATH (1994)
41	Ghardaia	592395	206804	445		UNESCO (1972)	109	B2	1566684	182511	177	1970	GEOMATH (1994)
42	20I7	534630	197187	460	1957	UNESCO (1972)	110	131/77	1412398	71933	291	1970	GEOMATH (1994)
43	Berriane	594191	240975	445		UNESCO (1972)	111	130/77	1400754	92302	297	1970	GEOMATH (1994)
44	124I8	550396	252712	449	1958	UNESCO (1972)	112	46/77	1426953	181056	320	1970	GEOMATH (1994)

N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference	N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference
45	8-9I7	495523	245617	481	1955	UNESCO (1972)	113	K12	1597250	154866	175	1970	GEOMATH (1994)
46	19I7	496560	221048	477	1957	UNESCO (1972)	114	5-82	1632183	96667	190	1970	GEOMATH (1994)
47	31K8	487035	66015	435	1961	UNESCO (1972)	115	208/76	1629272	-3726	279	1970	GEOMATH (1994)
N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference	N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference
49	5K4	215146	82629	495	1955	UNESCO (1972)	117	P21	1623450	240710	65.5	1973	GEFLI (1978)
50	1L14	1136168	-25121	335	1959	UNESCO (1972)	118	K6	1643827	197061	87.8	1973	GEFLI (1978)
51	2M14	1153310	-84554	345	1959	UNESCO (1972)	119	K10	1616172	191241	127.6	1973	GEFLI (1978)
52	5M14	1145284	-170011	353	1959	UNESCO (1972)	120	B3	1579784	188331	174.5	1973	GEFLI (1978)
53	3N14	1151601	-228695	383	1957	UNESCO (1972)	121	SOF5	1597250	160686	142	1973	GEFLI (1978)
54	1N15	1174543	-235180	410	1956	UNESCO (1972)	122	K5	1661293	160686	102	1973	GEFLI (1978)
55	2N13	1037731	-247500	378	1959	UNESCO (1972)	123	ZZ2	1686037	154866	91.7	1973	GEFLI (1978)
56	1N13	1060201	-197337	354	1957	UNESCO (1972)	124	WH1	1719515	154866	89	1973	GEFLI (1978)
57	2M13	1032425	-110495	353	1958	UNESCO (1972)	125	ZZ1	1680215	134497	128.9	1973	GEFLI (1978)
58	1N12	928801	-210031	374	1958	UNESCO (1972)	126	WS2	1626361	103942	168	1973	GEFLI (1978)
59	1M12	983556	-188774	358	1958	UNESCO (1972)	127	K7	1702048	102487	137.6	1973	GEFLI (1978)
60	21N11	896736	-257353	369	1958	UNESCO (1972)	128	K8	1687493	76298	161.5	1973	GEFLI (1978)
61	20N11	885496	-207037	342	1958	UNESCO (1972)	129	SR1	1610350	639	270	1973	GEFLI (1978)
62	6M11	885587	-118311	340	1963	UNESCO (1972)	130	FL60	1603072	-11001	281	1973	GEFLI (1978)
63	3M11	856608	-136450	329	1959	UNESCO (1972)	131	WS4	1544851	32648	259	1973	GEFLI (1978)
64	11L11	862618	-8937	350	1969	UNESCO (1972)	132	K9	1710781	-13911	318	1973	GEFLI (1978)

N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference	N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference
65	6N9	711829	-241306	378	1969	UNESCO (1972)	133	CF2	1135263	386872	171.7	1956	UNESCO (1972)
66	R5	244791	-421446	255	1971	UNESCO (1972)	134	109G9	711875	424396	381	1956	UNESCO (1972)
67	11P5	342578	-404795	266	1961	UNESCO (1972)	135	111I8	551578	287760	459	1958	UNESCO (1972)
68	13P6	383800	-408497	277	1959	UNESCO (1972)	136	Hazoua 1	956450	355817	300	reconstitué	BD du SASS

ANNEX : 2

Transmissivities of the Continental Intercalaire (CI)

[cf.SASS/OSS : Vol.2 ;Hydrogeology]

N°	P	Number	Denomination	Tx 10^{-3} m^2/s	Origin	N°	P	Number	Denomination	Tx 10^{-3} m^2/s	Origin	N°	P	Number	Denomination	Tx 10^{-3} m^2/s	Origin
1	A	P00500011	Aoulef 2	5.8	ERESS	47	T	5664005	Ch Fedjej 1	27.7	MAMOU, 1990	93	L	K-9		17.0	GEFLI
2	A	P00600013	Tit 3	8.0	ERESS	48	T	5950005	Ch Fedjej 2	83.0	MAMOU, 1990	94	L	K4		1.3	GEFLI
3	A	L00700003	Hadj Halima	35.0	ERESS	49	T	8429005	Ch Fedjej 3	88.5	MAMOU, 1990	95	L	K-11		0.7	GEFLI
4	A	L00700041	Hassi El Gara	14.1	ERESS	50	T	ZTA 1	Zemlet Taiara	6.0	ERESS	96	L	WH-1		2.6	GEFLI
5	A	K00700030	Foucault	17.0	ERESS	51	T	19394005	Limagues (CI 8)	56.6	MAMOU, 1990	97	L	WS-6		12.0	GEOMATH
6	A	L00700056	Taghit nouveau	9.5	ERESS	52	T	19190005	CF 1 bis	25.4	MAMOU, 1990	98	L	SH-1		1.5	GEFLI
7	A	K00700021	Bel Bechir	10.0	ERESS	53	T	18700005	CF F10	323.0	MAMOU, 1990	99	L	T11-81		25.5	BRL 1997
8	A	M00400284	Timimoun	36.0	ERESS	54	T	19175005	CF 3bis	23.4	MAMOU, 1990	100	L	T96-76		18.0	BRL 1997
9	A	N00400302	Igostene	22.6	ERESS	55	T	18697005	CF F3	88.5	MAMOU, 1990	101	L	T159-89		74.0	BRL 1997
10	A	J00800001	Hassi Fahl	0.5	ERESS	56	T	18698005	CF F8	6.3	MAMOU, 1990	102	L	WG9		17.0	BRL 1997
11	A	J00800020	Hassi Touil	3.5	ERESS	57	T	18699005	CF 9	100.0	MAMOU, 1990	103	L	WG 16		1.7	BRL 1997
12	A	L00700066	Hassi Maroket	0.5	ERESS	58	T	19452005	Steftimi (CI 7)	3.4	MAMOU	104	L	T203-80		75.0	BRL 1997
13	A	K00800016	Dayet Ghanem	5.0	ERESS	59	T	19484005	Behaier (CI 9)	87.0	MAMOU	105	L	T276-77		85.0	BRL 1997
14	A	K00800015	Gouiret Moussa	1.5	ERESS	60	T	19230005	Degache CI2	1.1	MAMOU, 1990	106	L	T277-77		60.0	BRL 1997
15	A	K01200001	Rhourd El Baguel	0.6	ERESS	61	T	19084005	Nefta CI	0.8	MAMOU, 1990	107	L	WG 22		8.3	BRL 1997
16	A	J01100094	Hassi Mesaoud	2.0	ERESS	62	T	BZA 1		2.0	Geomath	108	L	T5-78		2.7	BRL 1997
17	A	L01100011	Gassi Touil	2.0	ERESS	63	T	ZTA 1		6.0	Geomath	109	L	T35-75		7.9	BRL 1997
18	A	In Salah 18	In Salah 18	16.0	ERESS	64	T	ZN A1	Zemlet En Nous	10.0	ERESS	110	L	T110-76		2.7	BRL 1997
19	A	In Salah 19	In Salah 19	16.0	ERESS	65	T	5654005	Bordj Bourguiba	30.0	ERESS	111	L	T125-81		9.2	BRL 1997
20	A	In Salah 20	In Salah 20	27.0	ERESS	66	T	X00700223	El Borma A1	0.4	MAMOU, 1990	112	L	T126-81		28.0	BRL 1997
21	A	In Salah 21	In Salah 21	3.6	ERESS	67	T	X00700217	El Borma A6	43.0	MAMOU, 1990	113	L	T39-78		7.9	BRL 1997
22	A	J01000447	Ouargla 1	3.2	ERESS	68	T	16726005	El-Borma 202(*)	3.1	MAMOU, 1990	114	L	T175-78		11.0	BRL 1997

N°	P	Number	Denomination	Tx 10^{-3} m^2/s	Origin	N°	P	Number	Denomination	Tx 10^{-3} m^2/s	Origin	N°	P	Number	Denomination	Tx 10^{-3} m^2/s	Origin
23	A	J01000480	Ouargla 2	5.1	ERESS	69	T	18684005	El-Borma 203(*)	2.5	MAMOU, 1990	115	L	P20		15.0	GEFLI
24	A	J01000511	Ouargla 3	5.1	ERESS	70	T	18643005	El-Borma 207(*)	1.5	MAMOU, 1990	116	L	P21		0.1	GEFLI
25	A	G00900109	Sidi Khaled	2.3	ERESS	71	T	18644005	El-Borma 208(*)	11.0	MAMOU, 1990	117	L	T-2A		10.0	GEFLI
26	A	H01000042	M'rara	6.0	ERESS	72	T	5717005	Ksar Rhilane	6.0	ERESS	118	L	T313-76		1.6	BRL 1997
27	A	H01100408	Tamerna	6.0	ERESS	73	T	19009005	Ksar Ghilane 3 bis	12.7	MAMOU	119	L	131/77		13.0	BRL 1997
28	A	I01100436	Sidi Mahdi	7.0	ERESS	74	T	19157005	Bou Abdallah (CI 1)	4.5	MAMOU, 1990	120	L	WS 14		6.0	GEOMATH

N°	P	Number	Denomination	Tx 10^{-3} m^2/s	Origin	N°	P	Number	Denomination	Tx 10^{-3} m^2/s	Origin	N°	P	Number	Denomination	Tx 10^{-3} m^2/s	Origin
29	A	I01100437	Sidi Slimane	5.0	ERESS	75	T	19199005	Taourgha (CI 2)	55.1	MAMOU, 1990	121	L	T64-78		24.0	BRL 1997
30	A	X00700035	Guettara	12.0	ERESS	76	T	19140005	Mansoura (CI 3)	2.7	MAMOU, 1990	122	L	T158-89		19.0	BRL 1997
31	A	L00600019	Hassi Inkhal	17.0	ERESS	77	T	19348005	Zaoueïet Anes (CI 5)	13.8	MAMOU, 1990	123	L	Wg-13		4.5	BRL 1997
32	A	M00700020	Oumchen	15.0	ERESS	78	T	19412005	Menchia CI 6	39.7	MAMOU, 1990	124	L	K 12		15.0	Geomath
33	A	6 M 11		0.4	GEOMATH	79	T	19400005	Kébili (CI 10)	9.4	MAMOU, 1990	125	L	B 2		15.0	Geomath
34	A	M01100006	Rhourd Nouss	0.4	ERESS	80	T	19468005	Jemna (CI 11)	3.1	MAMOU	126	L	K5		100.0	GEFLI
35	A	M01200001	Tamendjelt	0.3	ERESS	81	T	20051005	Kébili (CI 16)	2.0	MAMOU	127	L	K6		3.5	GEFLI
36	A	SP 2	SP 2	2.0	ERESS	82	T	19304005	Zaoueiet Chorfa (CI 4)	69.0	MAMOU	128	L	K-10		2.4	GEFLI
37	A	N01100021	Fort Flatters	3.7	ERESS	83	T	20663005	Zouaia CI 22	41.2	MAMOU	129	L	SOF5		1.0	GEFLI
38	A	N01100020	O. Ameskiki	2.2	ERESS	84	T	19916005	DEBEBCHA CI 14	9.9	MAMOU	130	L	NOR1		15.0	GEFLI
39	A	N00700003	Tineldjane	0.8	ERESS	85	T	20109005	S.Lahad (CI 17)	23.0	MAMOU	131	L	J-18		100.0	GEFLI
40	A	N00700004	El Hassene	0.6	ERESS	86	T	20662005	Bou Abdallah CI 21	3.8	MAMOU	132	L	WS-2		8.6	GEOMATH
41	A	O00700055	Fog. Ez Zoug	7.0	ERESS	87	T	20018005	Douz (CI 18)	45.2	MAMOU	133	L	ZZ 1		10.0	GEOMATH
42	A	J00800070	Metlili 5	15.0	ERESS	88	T	19450005	Douz (CI 12)	13.7	MAMOU	134	L	ZZ 2		9.0	GEOMATH
43	A	J00900011	Zelfana 2	23.8	ERESS	89	L	K-1		14.0	GEFLI	135	L	ZZ 3		20.0	GEOMATH
44	A	J00900011	ZELFANA N°3	13.6	ERESS	90	L	K-2		3.5	GEFLI	136	L	ZZ 4		21.0	GEOMATH
45	A	I00800112	Melika 3	12.2	ERESS	91	L	K-7		2.7	GEFLI	137	L	ZZ 5		14.0	GEOMATH
46	A	I00900050	Guerrara 3	10.0	ERESS	92	L	K-8		2.0	GEFLI	138	L	ZZ 6		12.0	GEOMATH
	A	*XXXX*	*MGHAIER AGID*	*14.*	*N-Castoro*		*A*	*YYYY*	*JEMAA AGID*	*9.*	*N-Castoro*	139	L	K3		39.0	GEFLI

ANNEX 3
Reference pieometry – Aquifer of the Complexe Terminal (CT)

N°	Identification_Reference	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference	N°	Identification_Reference	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference
1	67G11	809997	461774	60	1950	UNESCO (1972)	60	3J14	1058293	184289	104	1966	UNESCO (1972)
2	El Feidh 36	847206	441238	60	1956	UNESCO (1972)	61	1J14	1093492	186509	138	1968	UNESCO (1972)
3	El Hamraia 30	820495	400623	40	1955	UNESCO (1972)	62	6J14	1098209	162948	121	1963	UNESCO (1972)
4	Ourir 29	796811	396272	32.4	1950-70	UNESCO (1972)	63	11J13	993994	145633	111	1970	UNESCO (1972)
5	Oum El Thiour 31	781372	401150	36	1942-70	UNESCO (1972)	64	EAT101	966290	135715	120	1970	UNESCO (1972)
6	Sif El Menadi 28	833531	384480	44	1953	UNESCO (1972)	65	4K13	984480	123899	131.5	1967	UNESCO (1972)
7	Sidi Khelil 26	796187	371274	32	1952	UNESCO (1972)	66	6J12	908591	119417	127	1961	UNESCO (1972)
8	Gouifla 34	1007687	410005	56	1953	UNESCO (1972)	67	Rhourd El Baguel 2	901945	102554	127	1966	UNESCO (1972)
9	Oued Chakmou 33	1009837	401691	54.5	1952	UNESCO (1972)	68	11K11	886803	97262	126	1966	UNESCO (1972)
10	Zaouiel El Arab 31	1012788	397132	49	1932	UNESCO (1972)	69	Fld 1	851271	96333	135	1966	UNESCO (1972)
11	El Louah 25	986212	390258	54	1954	UNESCO (1972)	70	4K11	837419	91374	133.5	1958	UNESCO (1972)
12	El Arfiane 24	800116	349227	42	1948-52	UNESCO (1972)	71	10K12	885027	77529	138	1964	UNESCO (1972)
13	Mazer 22	800606	340483	46.2	1949	UNESCO (1972)	72	3K12	905949	84000	128	1964	UNESCO (1972)
14	41H10	770825	318589	72	1958	UNESCO (1972)	73	Zar1	1023836	131324	127	1964	UNESCO (1972)
15	465HM	870117	338945	70	1962	UNESCO (1972)	74	3K13	1053299	123800	132	1970	UNESCO (1972)
16	413H11	873928	331061	72.4	1957	UNESCO (1972)	75	El Borma 4	1108085	140722	156	1968	UNESCO (1972)
17	35H12	891710	344530	70	1961	UNESCO (1972)	76	RE1	1054192	93745	130		UNESCO (1972)
18	15H12	944863	358276	65.6	1954	UNESCO (1972)	77	Arb1	932013	60770	136	1963	UNESCO (1972)
19	Nefta 20	974273	374752	55.5	1965	UNESCO (1972)	78	6K11	850100	42340	148	1959	UNESCO (1972)
20	Zaafrana 21	985900	377759	63.6	1950	UNESCO (1972)	79	13K11	835247	41252	146.5	1968	UNESCO (1972)
21	Ain Tawergha 22	1054610	372466	37.2	1955	UNESCO (1972)	80	12K11	818770	41121	142	1968	UNESCO (1972)
22	Negga 15	1065065	366300	55.3	1950	UNESCO (1972)	81	El Gassi A2701	768476	28113	155	1960	UNESCO (1972)
23	El Golea 16	1072570	364692	47.5	1950	UNESCO (1972)	82	HII1	733124	5204	161	1960	UNESCO (1972)
24	Bechelli 9	1070968	357182	68	1935	UNESCO (1972)	83	7K11	855728	25898	146.5	1960	UNESCO (1972)
25	16H12	891947	316206	84	1956	UNESCO (1972)	84	5L11	858154	5876	154.5	1959	UNESCO (1972)
26	23H12	887453	306173	82.6	1961	UNESCO (1972)	85	Bir Atch	1098356	66619	150	1963	UNESCO (1972)
27	Moggar 18	812529	308086	60	1954	UNESCO (1972)	86	BRD1	909496	9517	154.5	1963	UNESCO (1972)
28	El Harihira 17	814679	299771	67.9	1953	UNESCO (1972)	87	GTM1	865694	-7318	157.5	1969	UNESCO (1972)
29	8I10	756602	277655	103	1959	UNESCO (1972)	88	Aa N601	824941	-41261	168	1962	UNESCO (1972)

N°	Identification_ Reference	Longitude Lambert (m)	Latitude Lambert (m)	Cote piézométrique (m)	Année de mesure	Reference
31	Methouria 11	1078961	346831	70	1955	UNESCO (1972)
32	Rhelissia 5	1080310	334761	73.5	1952	UNESCO (1972)
33	El Faouar 2	1053734	327888	69	1949	UNESCO (1972)
34	6070B	1107376	332890	75	1953	UNESCO (1972)
35	Chott Tibni 1	1057604	312922	75	1970	UNESCO (1972)
36	9I12	951787	276686	100	1961	UNESCO (1972)
37	Hnb A226H2	890388	253710	113	1960	UNESCO (1972)
38	439I11	864494	264765	105	1959	UNESCO (1972)
39	16J9	669306	182811	151	1957	UNESCO (1972)
40	17J9	683492	186479	145	1966	UNESCO (1972)
41	7I10	789240	213828	112	1957	UNESCO (1972)
42	15J9	699148	168502	145	1958	UNESCO (1972)
43	469J10	807521	191022	112	1961	UNESCO (1972)
44	2I13	1003542	241716	101	1956-1971	UNESCO (1972)
45	Ouargla 6	742842	159152	130.7	1959	UNESCO (1972)
46	475J10	780999	155253	125.3	1969	UNESCO (1972)
47	Bir El Hadjar	690907	109927	151	1957	UNESCO (1972)
48	465J10	795942	145351	125	1961	UNESCO (1972)
49	56J11	847617	149325	127	1959	UNESCO (1972)
50	19J11	869874	152081	121	1960	UNESCO (1972)
51	HB1	932641	180703	109	1970	UNESCO (1972)
52	EHT101	984893	191463	105	1969	UNESCO (1972)
53	8K9	717836	96241	150	1960	UNESCO (1972)
54	SG1	793680	106219	140	1968	UNESCO (1972)
55	BSE101	852334	124141	137	1970	UNESCO (1972)
56	REL101	938784	140992	115	1962	UNESCO (1972)
57	3J12	964729	168352	116	1961	UNESCO (1972)
58	9J13	1002263	161539	105	1960	UNESCO (1972)
59	3J13	1020363	160713	109	1967	UNESCO (1972)

N°	Identification_ Reference	Longitude Lambert (m)	Latitude Lambert (m)	Cote piézométrique (m)	Année de mesure	Reference
90	Tao601	918749	-15624	152	1966	UNESCO (1972)
91	MF101	873505	-53481	165	1963	UNESCO (1972)
92	3L11	860185	-44536	163	1958	UNESCO (1972)
93	4L11	841174	-50829	167	1961	UNESCO (1972)
94	Puits non identifié (P-1)	1665491	260140	12.5	1973	GEFLI (1978)
95	P22	1666872	231182	13.7	1973	GEFLI (1978)
96	P18	1676543	231182	13.8	1973	GEFLI (1978)
97	P21	1619901	235319	13.9	1973	GEFLI (1978)
98	Puits non identifié (P-2)	1593653	228424	30.3	1973	GEFLI (1978)
99	Puits non identifié (P-3)	1595034	218771	38.4	1973	GEFLI (1978)
100	K10	1612994	192571	26	1973	GEFLI (1978)
101	Puits non identifié (P-4)	1632335	181540	18.5	1973	GEFLI (1978)
102	WS9	1601942	163614	28	1973	GEFLI (1978)
103	MG1	1637861	151203	26.8	1973	GEFLI (1978)
104	ZZ2	1688976	156719	33.3	1973	GEFLI (1978)
105	Puits non identifié (P-5)	1654439	204982	14.9	1973	GEFLI (1978)
106	C 66-47	1547715	-69642	490	1970	GEOMATH (1994)
107	C 30-5	1589319	83185	165	1970	GEOMATH (1994)
108	C 40-3	1684170	-29482	280	1970	GEOMATH (1994)
109	C 40-4	1711938	-23924	290	1970	GEOMATH (1994)
110	C 60-14	1518654	58415	222	1970	GEOMATH (1994)
111	PZ3	1757301	-95809	329	1970	GEOMATH (1994)
112	J3	1761184	-104547	325	1970	GEOMATH (1994)
113	C 1-40	1206517	-23933	315	1970	GEOMATH (1994)
114	WG 12	1232808	-47171	369	1970	GEOMATH (1994)
115	F 1-90	1237400	19774	305	1970	GEOMATH (1994)
116	WG 19	1237188	114701	341	1970	GEOMATH (1994)
117	WG 20	1279251	154064	407	1970	GEOMATH (1994)
118	1788/3/4	1393700	171414	501	1970	GEOMATH (1994)

ANNEX 4
Piezometry of the Aquifer of the Turonian

N°	Identification	Lambert longitude (m)	Lambert latitude (m)	Piezometric elevation (m)	Year of measurement	Reference
1	K2	1724895	75119	142.1	1973	GEFLI (1978)
2	P21	1618520	251866	14.5	1973	GEFLI (1978)
3	P15	1647531	249108	14.4	1973	GEFLI (1978)
4	T2A	1648913	253245	15.3	1973	GEFLI (1978)
5	P22	1668254	229803	14.2	1973	GEFLI (1978)
6	MG3	1690358	233940	16.8	1973	GEFLI (1978)
7	P9	1596416	209119	19.7	1973	GEFLI (1978)
8	K10	1612994	195329	19.2	1973	GEFLI (1978)
9	K6	1646150	203603	15.6	1973	GEFLI (1978)
10	WS9	1604705	164992	21	1973	GEFLI (1978)
11	MG2	1571549	142929	30	1973	GEFLI (1978)
12	MG1	1637861	155203	57.5	1973	GEFLI (1978)
13	K5	1661346	160856	64.6	1973	GEFLI (1978)
14	S1	1723514	138793	67.9	1973	GEFLI (1978)
15	K7	1697265	102940	144.9	1973	GEFLI (1978)
16	K8	1683450	76740	136.7	1973	GEFLI (1978)
17	K1	1763577	76700	139.6	1973	GEFLI (1978)
18	déduit de carte piézo (P-6)	1342337	156286	500		PALLAS (1980)
19	déduit de carte piézo(P-7)	1392129	168084	500		PALLAS (1980)
20	déduit de carte piézo(P-8)	1450061	144235	400		PALLAS (1980)
21	déduit de carte piézo(P-9)	1300546	126062	400		PALLAS (1980)
22	déduite de carte piézo(P-10)	1488979	123020	300		PALLAS (1980)
23	Hassi Messaoud	819479	123606	187	corr.densité	FRANLAB (1978)

ANNEX 5
Transmissivities of the Complexe Terminal (CT)

N°	Pays	NCLAS	Denomination	TxE^{-3} m^2/s	Origin	N°	Pays	NCLAS	Denomination	TxE^{-3} m^2/s	Origin
1	A	I01300002	T 01 De La Société Esso	6.00	ERESS	152	T	19113005	Chakmou 4	35.00	SASS
2	A	K01100009	Fes 1-H1	3.00	ERESS	153	T	19121005	El Faouz	24.00	SASS
3	A	K01200002	Loudje 1 Cpa Ld1	15.00	ERESS	154	T	19137005	Ouled Ghrissi	27.00	SASS
4	A	K01200004	Arb 1- El Arbi Du Cp	15.00	ERESS	155	T	19166005	Hazoua 4	20.00	SASS
5	A	K01200006	Rhourde Baguel Rb 10	1.00	ERESS	156	T	19176005	Hazoua BM 2	20.00	SASS
6	A	F01100576	Ain Cheikh D 41 F 69	15.00	ERESS	157	T	19203005	Hazoua BM 1	16.00	SASS
7	A	FR 1	Melah Ben Taïeb	10.00	ERESS	158	T	19250005	Neflaiet 3 bis	6.70	SASS
8	A	I01000007	Square Bresson 2	7.00	ERESS	159	T	19269005	Segdoud Ct1	9.10	SASS
9	A	I01100025	Baba Youcef D1 F111	15.00	ERESS	160	T	19284005	Nefta 5 bis	13.00	SASS
10	A	I01100447	Gueddich Gd1 Pts Eau	5.00	ERESS	161	T	19324005	Mides	0.36	SASS
11	A	J01000469	Carrière P80	20.00	ERESS	162	T	19329005	Manachi 2 bis	24.00	SASS
12	A	J01000475	Ol1	25.00	ERESS	163	T	19335005	Nefta 6 bis	29.00	SASS
13	A	J01000518	F Soviet Bouroubia	6.00	ERESS	164	T	19342005	Oued El Kebir 1 bis	13.00	SASS
14	A	J01000519	F Soviet A.Louise D4	4.00	ERESS	165	T	19357005	Dgoumes 2 bis	5.40	SASS
15	A	J01000522	Bamendil Ii Cofor	12.00	ERESS	166	T	19358005	Hamma 8 bis	8.00	SASS
16	A	J01000533	Garet Chemia D1 F113	4.00	ERESS	167	T	19359005	Hamma 9 bis	22.00	SASS
17	A	J01000625	Ain El Bour Di F 118	9.00	ERESS	168	T	19419005	PK 14 bis	15.00	SASS
18	A	J01000631	Sodexur Bahmid I D1	10.00	ERESS	169	T	19420005	PK 13 bis	30.00	SASS
19	A	J01000792	Outaja D1f116	10.00	ERESS	170	T	19447005	Nefta 8	30.00	SASS
20	A	K01000012	Slassel Yaich Sly1	30.00	ERESS	171	T	19448005	Nefta 9	2.00	SASS
21	A	D11F11	F.Périm. Bendabane Allia D11f11	25.00	ERESS	172	T	19477005	Helba 4bis	21.00	SASS
22	A	G01100036	Ain Naga	0.50	ERESS	173	T	19493005	Helba 1 bis	23.00	SASS
23	A	G01100043	P. Berland Ghegga	3.00	ERESS	174	T	19496005	Kriz 3 ter	9.40	SASS
24	A	G01100067	Ain Naga 4	0.20	ERESS	175	T	19502005	Gardgaya 4 bis	38.00	SASS
25	A	H01000030		20.00	ERESS	176	T	19503005	El Hamma 4 bis	85.50	SASS
26	A	H01000043	Duquenoy N°5 A M'ra	20.00	ERESS	177	T	19525005	Chemsa 1 bis	40.00	SASS
27	A	H01000044	Chaab El Meguedem Sp	1.50	ERESS	178	T	19549005	Cedada 6 bis	4.00	SASS
28	A	H01000047	Hassi Gouira	15.00	ERESS	179	T	19550005	IBN Chabbat 11 bis	30.00	SASS
29	A	H01000077	Ain Draa El Bar F 9	25.00	ERESS	180	T	19575005	Mrah lahouar 1 bis	13.00	SASS
30	A	H01100027	Tarfait Salah Meghai	24.00	ERESS	181	T	19598005	Boulifa 1 (Tozeur 11)	15.00	SASS
31	A	H01100104	Sif El Menadi	4.80	ERESS	182	T	19761005	Oued Naguess	8.50	SASS
32	A	H01100249	Ain Bertin	5.00	ERESS	183	T	19778005	Nefta 11	5.00	SASS
33	A	H01100373	Sebela Metay 1	2.00	ERESS	184	T	19784005	Dghoumes 3 bis	10.00	SASS
34	A	H01100411	Bouhour	1.90	ERESS	185	T	19881005	El Hamma 16	10.00	SASS
35	A	H01100472	Ain Sousou	3.90	ERESS	186	T	19882005	Tozeur 7 ter	22.00	SASS
36	A	X03000007	Tolga N°Demrh 162	1.50	SCET, 1972	187	T	19883005	Tozeur 12	7.00	SASS
37	A	X03000008	Tolga N°Demrh 283	2.00	SCET, 1972	188	T	20026005	Aïn Torba 3 ter	25.00	SASS
38	A	X03000009	Tolga N°Demrh 295	5.60	SCET, 1972	189	T	20040005	El Moncef 4 bis	13.00	SASS
39	A	X03000010	Tolga N°Demrh 334	7.40	SCET, 1972	190	T	20073005	Zaouit El Arab 1 ter	27.00	SASS
40	A	X03000011	Tolga N°Demrh 339	4.80	SCET, 1972	191	T	20281005	Nefta 7 bis	14.00	SASS
41	A	X03000012	Tolga N°Demrh 341	4.00	SCET, 1972	192	T	20282005	Nefta 3Ter	12.00	SASS
42	A	X03000013	Tolga N°Demrh 342	4.30	SCET, 1972	193	T	20290005	Sif Lakhder 1 bis	32.00	SASS
43	A	X03000014	Tolga N°Demrh 344	1.70	SCET, 1972	194	T	20371005	Tozeur Sonede 3	35.00	SASS
44	A	H01100178	Jardin Cmmunal	1.20	ERESS	195	T	20373005	IBN Chabbat 3 ter	10.90	SASS
45	A	H01100340	Ain Debdaba	10.00	ERESS	196	T	20377005	Sedada 3 ter	3.60	SASS
46	A	H01100413	Guemar 1	1.30	ERESS	197	T	20446005	Horchani 2 bis	1.80	SASS
47	A	H01100502	Ain Zaoualia	130.00	ERESS	198	T	20448005	Hamma 17	12.00	SASS
48	A	H01100575	Ain El Khadra D 41 F 68	5.00	ERESS	199	T	20482005	Hezoua 4 bis	20.00	SASS
49	A	H01200015	El Khobna	1.10	ERESS	200	T	20487005	Mrah Lahouar 2 bis	23.00	SASS
50	A	H01200021	Debila N1	1.40	ERESS	201	T	20488005	Tozeur Ras El Aïn	19.00	SASS
51	A	H01200023	Amiche Robah 1	2.00	ERESS	202	T	20489005	Serra Hotel	1.50	SASS

N°	Pays	NCLAS	Denomination	TxE-3 m^2/s	Origin		N°	Pays	NCLAS	Denomination	TxE-3 m^2/s	Origin
53	A	H01200035	Magrane Souf	10.00	ERESS		204	T	20515005	IBN Chabbat 13 bis	6.50	SASS
54	A	H01200038	Sahane Berry N 1	25.00	ERESS		205	T	20972005	Manachi CRFA	15.00	SASS
55	A	I01100011	Puits Rannou D36f61	40.00	ERESS		206	T	5941005	BAZMA 3	10.00	ERESS
56	A	I01100012	Zaouia Si Labed	7.00	ERESS		207	T	6481005	GUELIADA 1	5.00	ERESS
57	A	I01100014	A.Lamari A Toug D36f	10.00	ERESS		208	T	6690005	Nouaiel 1	20.00	ERESS
58	A	I01100021	Ain Naeglen	17.00	ERESS		209	T	6756005	Ras El Aïn 1	46.00	ERESS
59	A	I01100080	Ain Chotte Touggourt	7.00	ERESS		210	T	9654005	RABTA 2	14.00	ERESS
60	A	I01100206	Puits Devicq 2 D24f2	1.60	ERESS		211	T	5484005	El Faouar 2	5.00	ERESS
61	A	I01100207	Ain Guemmou D33f77	6.00	ERESS		212	T	5571005	El Faouar 1	4.00	ERESS
62	A	I01100223	Gonord Touggourt D36	7.30	ERESS		213	T	11334005	EL FAOUAR 3	4.00	ERESS
63	A	I01100225	Ain Aouf Temacine D3	10.00	ERESS		214	T	6689005	Guidma 1	7.00	ERESS
64	A	I01100226	Ain Midouna D28f10	10.00	ERESS		215	T	5840005	EL HSAY 1	20.00	ERESS
65	A	I01100227	Ain Chaouche 2 D32f1	8.00	ERESS		216	T	6522005	Tarfaïet El Kroub	9.00	ERESS
66	A	I01100448	Taibet	4.50	ERESS		217	T	30025	Douz 2 bis	30.00	ERESS
67	A	X00101188	Ain Madjoudja Ahmed D33 F94	4.00	ERESS		218	T	6906005	Zarcine 2	12.00	ERESS
68	A	D39 F44	Ain Ourirh D39 F44	15.00	ERESS		219	T	5754005	Grad 1	120.00	ERESS
69	A	FR 5	Daoula	3.40	ERESS		220	T	6470005	EL METOURIA 1	8.00	ERESS
70	A	D34 F117	A.Trabelssi El Arbi D34 F117	10.00	ERESS		221	T	12320005	Chott Salhia 1	10.00	ERESS
71	A	D33 F93	Ain Chaouche El Meki D33 F93	7.00	ERESS		222	T	73025	Guettaya 2	6.00	ERESS
72	A	D33 F92	Ain Benhmida Ali D33 F92	7.00	ERESS		223	T	5570005	Negga 3	4.00	ERESS
73	A	D33 F94	Ain Madjoudja Ahmed D33 F94	6.00	ERESS		224	T	16703005	Negga 5	10.00	ERESS
74	A	D33 90	Ain Bourass D33 90	15.00	ERESS		225	T	46035	Toumbar	26.00	ERESS
75	A	D32 F140	Ain Hadri Sayah D32 F140	7.00	ERESS		226	T	5585005	Telmine 2	10.00	ERESS
76	A	H01100484	Tamerna Guedima A. Chemorah	1.30	ERESS		227	T	19246005	MANSOURA 2bis	15.00	ERESS
77	A	H01100166	Reguiba	15.00	ERESS		228	T	5956005	MESSAID 2	8.00	ERESS
78	A	H01100465	Ghamra	10.00	ERESS		229	T	5692005	RAHMAT 2	20.00	ERESS
79	T	6090005	Hezoua 1	6.00	ERESS		230	T	10226005	Rahmat 3	6.00	ERESS
80	T	6922005	El Hamma 4	10.00	ERESS		231	T	5755005	Ksar Tabeul	15.00	ERESS
81	T	8262025	Nefta 2	34.00	ERESS		232	T	2051035	Taourgha 3	8.00	ERESS
82	T	8262035	Nefta 3	10.00	ERESS		233	T	9347005	Om Somâa 1	15.00	ERESS
83	T	8564005	El Hamma 6	50.00	ERESS		234	T	9632005	BOU ABDALLAH 1	20.00	ERESS
84	T	8838005	El Hamma 8	30.00	ERESS		235	T	9653005	Bou Abdallah 2	30.00	ERESS
85	T	12668005	Jhim 1	4.00	ERESS		236	T	16702005	Bazma 5	9.30	MAMOU, 1990
86	T	13351005	Hezoua 2	8.00	ERESS		237	T	17611005	PZ.CHOTT Nefzaoua	2.20	MAMOU, 1990
87	T	13443005	Nefta 4	40.00	ERESS		238	T	18681005	Bechni	59.80	MAMOU, 1990
88	T	5660005	Ghardgaya2	1.00	ERESS		239	T	18746005	Blidette 3	12.90	MAMOU, 1990
89	T	80025	CASTILIA 2	8.00	ERESS		240	T	18755005	Dergine El Ameur	8.50	MAMOU, 1990
90	T	78005	Ouled Majed	6.00	ERESS		241	T	19003005	Ras El Aïn 4	7.10	MAMOU, 1990
91	T	76005	EL HAMMA 2	10.00	ERESS		242	T	19106005	Rabta 2 bis	10.40	MAMOU, 1990
92	T	9455035	ZAOUIT LARAB 3	15.00	ERESS		243	T	19141005	Klebia 2	57.00	MAMOU, 1990
93	T	9456005	Sebaa Biar 1	4.00	ERESS		244	T	19209005	Nefzaoua MILITAIRE	112.00	MAMOU, 1990
94	T	9341005	Kriz 1	50.00	ERESS		245	T	19278005	Zarcine 4	5.40	MAMOU, 1990
95	T	6103005	OUED Shili 1	5.00	ERESS		246	T	19316005	El Golâa 2	47.60	MAMOU, 1990
96	T	800005	Kastilia 2	8.00	SASS		247	T	19317005	Kelwamen	5.50	MAMOU, 1990
97	T	5262005	Helba 2	10.00	SASS		248	T	19340005	Rahmat 5	31.90	MAMOU, 1990
98	T	5436005	Neflayett 1	1.40	SASS		249	T	19345005	Nefzaoua VILLAGE	19.02	MAMOU, 1990
99	T	5487005	Ghardgaya 1	2.10	SASS		250	T	18826005	GUETTAYA 4 bis	6.90	MAMOU, 1990
100	T	5776005	Chakmou	7.00	SASS		251	T	19375005	NEGGA SONEDE 2	3.70	MAMOU, 1990
101	T	5893005	Cedada 1	2.00	SASS		252	T	19375005	NEGGA SONEDE 2	26.10	MAMOU, 1990
102	T	6267005	Chemsa 1	15.00	SASS		253	T	18851005	Guettaya 7 bis	26.10	MAMOU, 1990
103	T	8262005	Nefta	6.00	SASS		254	T	18747005	Guettaya 8	30.30	MAMOU, 1990
104	T	8405005	Tozeur Gare 2	15.00	SASS		255	T	16733005	Guettaya 6	45.80	MAMOU, 1990

N°	Pays	NCLAS	Denomination	TxE-3 m2/s	Origin
106	T	8982005	El Manachi 2	8.00	SASS
107	T	9340005	Kriz 1	50.00	SASS
108	T	9495035	Zaouiet El Arab		SASS
109	T	9627005	Kriz 2	5.00	SASS
110	T	9959005	Zaafrana	10.00	SASS
111	T	10192005	Sedada 3	8.00	SASS
112	T	10193005	El Hamma 9	23.00	SASS
113	T	10452005	Kriz 3	20.00	SASS
114	T	10453005	Degache Nord 1	6.00	SASS
115	T	10453025	Degache Nord 2	12.00	SASS
116	T	12330005	El Hamma 10	30.00	SASS
117	T	13119005	Nefta 5	3.20	SASS
118	T	13346005	herdgaya 4	9.00	SASS
119	T	13991005	Oued Dghouumes 2	7.35	SASS
120	T	13992005	Neflaiet 2	3.00	SASS
121	T	14000005	Degache Sonede	0.90	SASS
122	T	14001005	Tozeur Sonede	4.00	SASS
123	T	14621005	Oued Kebir	2.80	SASS
124	T	14628005	Sif El Akhdar	3.00	SASS
125	T	14630005	Aîn Djedida	1.50	SASS
126	T	16558005	Ben Chaouch	3.00	SASS
127	T	16639005	Nefta 6	28.00	SASS
128	T	16695005	Chouchet Zerga	2.70	SASS
129	T	16732005	El Mekmen	8.00	SASS
130	T	16749005	Hamma12	1.40	SASS
131	T	17656005	Essouni	22.00	SASS
132	T	17679005	Oued Tozeur 8	31.00	SASS
133	T	18650005	Oued Tozeur 5	18.00	SASS
134	T	18651005	Hazoua 1bis	40.00	SASS
135	T	18660005	Oued Shili 2	8.00	SASS
136	T	18728005	Nefta 1bis	0.36	SASS
137	T	18758005	Errached 1	9.00	SASS
138	T	18765005	Nefta 7	10.00	SASS
139	T	18766005	Nefta 2bis	9.00	SASS
140	T	18791005	Oued Touzeur 4	2.10	SASS
141	T	18800005	Hamma 11 bis	7.00	SASS
142	T	18801005	Drâa Nord 2	5.20	SASS
143	T	18802005	El Melah	5.00	SASS
144	T	18844005	Aïn Torba 3	9.00	SASS
145	T	18852005	Oued Kebir 2	18.00	SASS
146	T	18927005	Nefta 3 bis	1.43	SASS
147	T	18928005	Kriz 3 bis	2.00	SASS
148	T	18996005	Zaouiet Larab 1 bis	8.00	SASS
149	T	18999005	Tozeur Gare 2 bis	15.00	SASS
150	T	19029005	IBN Chabbat 13	7.00	SASS
151	T	19031005	IBN Chabbat 10	5.00	SASS

N°	Pays	NCLAS	Denomination	TxE-3 m2/s	Origin
257	T	19408005	NOUIEL 2	23.50	MAMOU, 1990
258	T	19102005	Chott yane	6.40	MAMOU, 1990
259	T	19104005	Brika Jemna	6.40	MAMOU, 1990
260	T	19103005	Aïn Salah 1	15.40	MAMOU, 1990
261	T	19343005	El Faouar 4	71.00	MAMOU, 1990
262	T	19351005	Sabria 3	13.70	MAMOU, 1990
263	T	19376005	JEMNA SONEDE	2.60	MAMOU, 1990
264	T	18774005	Negga 6	2.10	MAMOU, 1990
265	T	17608005	Sidi Hamed	186.00	MAMOU, 1990
266	T	19149005	RAHMAT SONEDE	62.70	MAMOU, 1990
267	T	16735005	El Ghoula	11.20	MAMOU, 1990
268	T	18790005	DOUZ 6	15.20	MAMOU, 1990
269	T	19092005	Smida	331.00	MAMOU, 1990
270	L	K1	Nalut	1.00	GEFLI 1978
271	L	K2	Nalut	2.00	GEFLI 1978
272	L	J18	Mizdah-Tigrinna	40.00	GEFLI 1978
273	L	Wg-6		1.76	Srivastava, 1981
274	L	Wg-8		0.19	Srivastava, 1981
275	L	Wg-12		1.97	Srivastava, 1981
276	L	Wg-1		0.26	Srivastava, 1981
277	L	Wg-5		0.00	Srivastava, 1981
278	L	Wg-7		0.03	Srivastava, 1981
279	L	Wg-11		0.02	Srivastava, 1981
280	L	MG1	Nalut	2.00	GEFLI 1978
281	L	K5	Nalut	50.00	GEFLI 1978
282	L	K7	Nalut	0.60	GEFLI 1978
283	L	K9	Mizdah-Tigrinna	0.05	GEFLI 1978
284	L	K3	Mizdah-Tigrinna	0.10	GEFLI 1978
285	L	K4	Mizdah-Tigrinna	0.05	GEFLI 1978
286	L	ZZ1	Mizdah-Tigrinna	0.10	GEFLI 1978
287	L	Wg-14		0.02	Srivastava, 1981
288	L	Wg-15		0.10	Srivastava, 1981
289	L	WG 17		0.01	Srivastava, 1981
290	L	WG 19		0.02	Srivastava, 1981
291	L	MG3	Nalut	40.00	GEFLI 1978
292	L	P22	Mizdah-Tigrinna	10.00	GEFLI 1978
293	L	P22	Mizdah-Tigrinna-Miocène	100.00	GEFLI 1978
294	L	P18	Mizdah-Tigrinna	50.00	GEFLI 1978
295	L	MG2	Nalut	0.20	GEFLI 1978
296	L	K6	Nalut	5.00	GEFLI 1978
297	L	K10	Nalut	1.00	GEFLI 1978
298	L	K12	Nalut	10.00	GEFLI 1978
299	L	SOF2	Nalut	3.00	GEFLI 1978
300	L	SOF5	Nalut		GEFLI 1978
301	L	P9	Nalut	25.00	GEFLI 1978
302	L	P21	Nalut	6.00	GEFLI 1978
303	L	WS9	Nalut	3.00	GEFLI 1978

ANNEX 6
Points whose PM5 identifier is different from the DB

SASS DB Id.	PM5 ID.	Layer	SASS DB Id.	PM5 ID.	Layer	SASS DB Id.	PM5 ID.	Layer
Oued Chakmou	33	1	El Feidh 36	36	1	Rhelissia 5	5	1
Moggar 18	18	1	67G11	38	1	Rhourd El Bag	2	1
Bechelli 9	9	1	El Louah 25	25	1	Valeur d, duit	Pal 10	2
El Golea 16	16	1	Puits non ide	PP14	1	Valeur d, duit	Pal 4	2
Ain Tawergha	22	1	Zaafrana 21	21	1	Valeur d, duit	Pal 12	2
Nefta 20	20	1	Puits non ide	PP17	1	Valeur d, duit	Pal 5	2
Mazer 22	22	1	Methouria 11	11	1	Hassi Messaou	Hassi Me	2
El Arfiane 24	24	1	Puits non ide	PP8	1	Valeur d, duit	Pal 18	2
El Harihira 1	17	1	Puits non ide	PP7	1	Hassi Messaou	Hi Messa	4
Zaouiel El Ar	31	1	Puits non ide	PP15	1	22/87	22-/87	4
Negga 15	15	1	El Gassi A270	1	1	29/83	29-/83	4
Gouifla 34	34	1	El Borma 4	4	1	10/81	10-/81	4
Sidi Khelil 2	26	1	Bir El Hadjar	Bie El H	1	Hassi Inkhal	Hinkhal	4
Sif El Menadi	28	1	Ouargla 6	6	1	Gouret Louazo	Gouret L	4
Oum El Thiour	31	1	Hnb A226H2	HNBH2	1	Hassi Rhaba	Rhaba	4
Ounir 29	29	1	Chott Tibni 1	1	1	Hassi en Nous	Hi Nouss	4
El Hamraia 30	30	1	El Faouar 2	69	1	Hassi Merague	Hi Merag	4
						In Salah 1	In Salah	4

ANNEX 7

Calibration in Steady State

Table 1 : Complexe Terminal (CT) aquifer

	Name	Obs.head	Calc.head	Deviation		Name	Obs.head	Calc.head	Deviation
1	38	60	98.2	38.2	60	3J14	104	115.8	11.8
2	36	60	60.2	0.2	61	1J14	138	127.1	-10.9
3	30	40	37.4	-2.6	62	6J14	121	129.1	8.1
4	29	32.4	27.4	-5	63	11J13	111	113.1	2.1
5	31	36	41.9	5.9	64	EAT101	120	113.8	-6.2
6	28	44	42.5	-1.5	65	4K13	131	116.9	-14.1
7	26	32	31.5	-0.5	66	6J12	127	118.1	-8.9
8	34	56	48.3	-7.7	67	2	127	122.3	-4.7
9	33	54.5	46.6	-7.9	68	11K11	126	124.7	-1.3
10	31	49	45.5	-3.5	69	FL11	135	129.4	-5.6
11	25	54	49	-5	70	4K11	133	132.8	-0.2
12	24	42	49.5	7.5	71	10K12	138	128.8	-9.2
13	22	46.2	54	7.8	72	3K12	128	125.6	-2.4
14	41H10	72	81.9	9.9	73	ZAr1	127	117.9	-9.1
15	40H11	70	72.4	2.4	74	3K13	132	120.2	-11.8
16	413H11	72.4	75.6	3.2	75	4	156	127.2	-28.8
17	35H12	70	73.7	3.7	76	RE1	130	122.5	-7.5
18	15B12	65.6	68.5	2.9	77	Arb1	136	130.2	-5.8
19	20	55.5	55	-0.5	78	16K11	148	143.9	-4.1
20	21	63.6	49.9	-13.7	79	13K11	146	146.1	0.1
21	22	37.2	53.9	16.7	80	12K11	142	149.1	7.1
22	15	55.3	56.1	0.8	81	1	155	163	8
23	16	47.5	57.4	9.9	82	HLL1	161	174.8	13.8
24	9	68	58.3	-9.7	83	7K11	146	148.9	2.9
25	16H12	84	83.2	-0.8	84	5L11	154	155.4	1.4
26	23H12	82.6	86.8	4.2	85	Bir Atch	150	132.9	-17.1
27	18	60	68.6	8.6	86	BRD1	154	151.4	-2.6
28	17	67.9	72	4.1	87	GTM1	157	158.7	1.7
29	8I10	103	101.1	-1.9	88	Aa N601	168	168.8	0.8
30	P3	63	60.5	-2.5	89	Tou1	162	156.8	-5.2
31	11	70	62.3	-7.7	90	TaO601	152	158.7	6.7
32	5	73.5	65.4	-8.1	91	MF101	165	168.5	3.5
33	2	69	63.6	-5.4	92	3L11	163	167.1	4.1
34	6070B	75	72.9	-2.1	93	4L11	167	169.2	2.2
35	1	75	70.3	-4.7	94	PP15	12.5	32.3	19.8
36	9I12	100	91.3	-8.7	95	P22	13.7	36.5	22.8
37	HNBH2	113	97.1	-15.9	96	P18	13.8	28.6	14.8
38	439I11	105	95.3	-9.7	97	PP5	13.9	36	22.1
39	16J9	151	176.9	25.9	98	PP7	30.3	43	12.7
40	17J9	145	165.9	20.9	99	PP8	38.4	45.8	7.4
41	7I10	112	104.6	-7.4	100	K10	26	42.9	16.9
42	15J9	145	157.9	12.9	101	PP14	18.5	43.6	25.1
43	469J10	112	105.7	-6.3	102	WS9	28	49.1	21.1
44	2I13	101	100.1	-0.9	103	MG1	26.8	54.2	27.4
45	6	130.7	132.6	1.9	104	ZZ2	33.3	57	23.7
46	475J10	125.3	124.7	-0.6	105	PP17	14.9	42.2	27.3
47	Bir El H	151	174.6	23.6	106	C 66-17	506	525.9	19.9
48	465J10	125	127.4	2.4	107	C 30-5	165	145.7	-19.3
49	56J11	127	116.1	-10.9	108	C 40-3	280	258.8	-21.2
50	19J11	121	112.7	-8.3	109	C 40-4	290	252.1	-37.9
51	HB1	109	105.1	-3.9	110	C 60-14	222	221.6	-0.4

	Name	Obs.head	Calc.head	Deviation		Name	Obs.head	Calc.head	Deviation
53	8K9	150	163.7	13.7	112	J3	325	253.3	-71.7
54	SG1	140	139.2	-0.8	113	C 1-40	315	337.5	22.5
55	BSE101	137	123	-14	114	WG 12	369	373.1	4.1
56	REL101	115	112.4	-2.6	115	F 1-90	305	350.9	45.9
57	3J12	116	107.4	-8.6	116	WG 19	341	337.9	-3.1
58	9J13	105	110.9	5.9	117	WG 20	407	390	-17
59	3J13	109	112.8	3.8	118	1788/3/4	501	496	-5

Table 2 : Continental Intercalaire (CI) aquifer									
	Name	Obs.head	Calc.head	Deviation		Name	Obs.head	Calc.head	Deviation
1	111I8	459	516.9	57.9	69	SBa	312	317	5
2	109G9	381	429	48	70	TH5B	300	304.7	4.7
3	42H10	362	406.7	44.7	71	66L7	390	394.7	4.7
4	124I8	449	492.4	43.4	72	13P6	277	281.1	4.1
5	T6	280	321.5	41.5	73	6511	317	320.9	3.9
6	WH1	89	120.9	31.9	74	20I7	460	463.5	3.5
7	ZZ2	91.7	121.7	30	75	C1-19	408	410.9	2.9
8	Berriane	445	473.5	28.5	76	Hi Merag	259	261.7	2.7
9	K8	161.5	189.8	28.3	77	CF2	171.7	174.1	2.4
10	228I1	362	390	28	78	4M6	364	366.3	2.3
11	K7	137.6	165.5	27.9	79	MRa	315	317.1	2.1
12	22-juin	269	294.3	25.3	80	1N13	354	355.5	1.5
13	Guerrara	426	450.9	24.9	81	2M14	345	346	1
14	T/41/81	313	337.3	24.3	82	16K8	407	407.8	0.8
15	719	425	449.2	24.2	83	19I7	477	477.7	0.7
16	408H11	362	385.6	23.6	84	EZA1	317	317.6	0.6
17	Zelfana	426	447.3	21.3	85	ZTA1	316	315.8	-0.2
18	K5	102	122.9	20.9	86	5M14	353	352.5	-0.5
19	3M11	329	348.6	19.6	87	M1-Me1	367	365.6	-1.4
20	Hi Messa	375	393.8	18.8	88	PN°8	377	375.1	-1.9
21	511J10	399	417.7	18.7	89	5654	312	309.4	-2.6
22	EG1	242	260.3	18.3	90	1M12	358	355.2	-2.8
23	8-9I7	481	499.3	18.3	91	2M13	353	349.9	-3.1
24	437I11	357	374.9	17.9	92	Gouret L	388	384.9	-3.1
25	10-/81	282	299.9	17.9	93	K10	127.6	124.1	-3.5
26	/11/81	315	332.4	17.4	94	2J14	303	299.3	-3.7
27	1K12	333	350.3	17.3	95	mai-82	190	186.3	-3.7
28	37H12	268	285.2	17.2	96	SP4-1	307	303.2	-3.8
29	In Salah	281	297.9	16.9	97	4K9	425	420	-5
30	158/70	253	269.9	16.9	98	BZA1	307	301.4	-5.6
31	C70-5	304	320.7	16.7	99	21N11	369	363.3	-5.7
32	447J10	405	421.6	16.6	100	Adrar	265	259.3	-5.7
33	SOF5	142	158.3	16.3	101	WS4	259	253.3	-5.7
34	Ghardaia	445	461.2	16.2	102	31K8	435	429	-6
35	-23	314	329.8	15.8	103	Ghadames	349	342.8	-6.2
36	480J10	403	418.7	15.7	104	22/87	208	201.6	-6.4
37	436I11	362	377.5	15.5	105	SNa	315	308.4	-6.6
38	Hi Nouss	257	272.3	15.3	106	EBA7	319	312.2	-6.8
39	20N11	342	356.5	14.5	107	213/76	249	241.2	-7.8
40	T/22/76	312	326.5	14.5	108	OS1	381	372.2	-8.8
41	Rhaba	295	308.9	13.9	109	29/83	254	244.7	-9.3

	Name	Obs.head	Calc.head	Deviation		Name	Obs.head	Calc.head	Deviation
43	WG-13	319	331.8	12.8	111	B2	177	167.2	-9.8
44	WS2	168	180.7	12.7	112	1N5	410	399.3	-10.7
45	1J8	422	434	12	113	Hinkhal	385	374.3	-10.7
46	WG-9	323	334.9	11.9	114	EBA4	318	306.8	-11.2
47	20J8	432	443.4	11.4	115	11L11	350	337.4	-12.6
48	ZZ1	128.9	140	11.1	116	Oum Chei	373	360.3	-12.7
49	T/96/76	331	341.1	10.1	117	SR1	270	257.2	-12.8
50	P21	65.5	75.6	10.1	118	2N13	378	365	-13
51	C70-8	308	317.8	9.8	119	K12	175	161.8	-13.2
52	Metlili	443	452.7	9.7	120	OKA1	301	287.2	-13.8
53	6368	306	315.3	9.3	121	4N7	346	330.2	-15.8
54	131/77	291	300.3	9.3	122	FL60	281	264.9	-16.1
55	67J8	441	450.1	9.1	123	1N12	374	357.7	-16.3
56	OF101	279	288	9	124	Hazoua 1	300	282.3	-17.7
57	3N14	383	391.7	8.7	125	5717	310	292.2	-17.8
58	PN°2	327	335.4	8.4	126	WS6	281	262.3	-18.7
59	WG-16	321	329.3	8.3	127	46/77	320	300	-20
60	K6	87.8	95.4	7.6	128	208/76	279	258.5	-20.5
61	130/77	297	304.2	7.2	129	K9	318	297.2	-20.8
62	1I14	335	341.6	6.6	130	6N9	378	356.9	-21.1
63	PN°4	343	349.6	6.6	131	ECHA1	342	320.7	-21.3
64	15K8	414	420.5	6.5	132	B3	174.5	153.1	-21.4
65	6M11	340	346.3	6.3	133	R5	255	232.9	-22.1
66	El Golea	401	406.9	5.9	134	TK105	266	243.2	-22.8
67	7000	322	327.8	5.8	135	SK4	495	458.5	-36.5
68	11P5	266	271.6	5.6	136	17J6	490	450	-40

Table 3 : Turonian aquifer							
Name	Obs.head	Calc.head	Deviation	Name	Obs.head	Calc.head	Deviation
MG2	30	74.4	44.4	S1	67.9	77.4	9.5
WS9	21	65	44	MG1	57.5	64.6	7.1
K10	19.2	56.2	37	Hassi Me	187	189.8	2.8
P9	19.7	54.5	34.8	K8	136.7	136.9	0.2
K6	15.6	49.4	33.8	Pal18	300	299.5	-0.5
K1	139.6	162.4	22.8	K5	64.6	61.1	-3.5
P15	14.4	36.6	22.2	Pal12	400	395.8	-4.2
P22	14.2	35.6	21.4	Pal5	500	490.8	-9.2
P21	14.5	35.7	21.2	K7	144.9	114.2	-30.7
MG3	16.8	33.1	16.3	Pal4	500	463	-37
T2AV	17.9	33.8	15.9	Pal10	400	356.3	-43.7
K2	142.1	156.3	14.2				

ANNEX 8
Wedging in Transitiry State

		CT-Libya								CI-Libya											Grès Supérieurs (« Upper Sandstone »)										
	NOCLAS	PZ4	PZ5	2135 (P5)	2128 (P6)	MW-1287	J3	PZ3	NOCLAS	ZZ 2	Mar 01	3.83	MW-1219	WG 16	BAK-4	WH 1	B-5(1/81)	SIQ1	T/2D/005/0/83	**NOCLAS**	19260005		19233005		19084005	19227005		19162005		19224005	19231005
	denomination	PZ 4	PZ 5	P5 2135	P6 2128	Pz 1287	Hun J 3	Hun Pz 3	denomination	Zemz ZZ2	Mardum 1	Taw 3.83	MW-1219	WG 16	Bay BAK4	Wash WH1	Boun B-5	Saf S1Q1	Nina N2	denomination	EL HAMMA C.I.1bis		EL HAMMA CI 2		Nefta CI	NEFTA CI2		Tozeur CI 1		Tozeur CI 2	DEGACHE CI 3
	altitude			30.88	73.77															Altitude	87.3		102.4		104	105.3		95.51		105	138
	1970	329	328				325	329	1970					320.6						1970											
	1971								1971											1971											
	1972								1972											1972											
	1973								1973	67.1										1973											
	1974			2.18	-2.774				1974	50										1974											
	1975	327.6	328.3	1.28	-3.004			328.6	1975	44			321.5							1975											
	1976	325.3	326.9	0.28	-4.434			327	1976	41			321.2		157	98.23				1976											
	1977	323	324.7	-0.37	-4.964		325.5	324.1	1977	38			320.9							1977											
	1978	317.8	319.5	-0.89	-5.734	3.65	320	318.6	1978	37	185.7	140.5	320.7					199.7		1978											
	1979	314.6	313.5	-1.22	-4.904	4	318.1	314.1	1979				320.7							1979											
	1980			-2.8	-6.044	3.25			1980				320.4							1980											
	1981			-3.99	-7.354				1981				320.1	320.6						1981											
	1982			-4.02	-10.13				1982								238.2			1982											
	1983			-5.64	-11.25				1983											1983					241.5	242.8					
	1984			-5.93	-11.76				1984										366.5	1984								193.0			
	1985			-6.12	-12.28	3.15			1985											1985	162.8		178.9		177.2	191.3				147.5	176.0
	1986			-6.27	-12.83	3.2			1986											1986	141.8		157.1		143.0			120.5		123.4	174.5
	1987			-6.69	-13.28				1987											1987	117.3				137.0			110.5		121.1	171.0
	1988				-13.2	3.17			1988											1988			147.9								
	1989								1989				316.6	316.9						1989			150.4								
	1990								1990											1990			135.4								
	1991					3.4			1991											1991	120.3		136.4							112.6	
	1992			-7.68	-14.87	3.24			1992											1992	114.3		131.7							109.1	
	1993			-7.79	-14.97				1993											1993						140.5		108.7			
	1994			-8.5	-16.38	3.12			1994				315.4	315.4						1994			137.8			140.5				117.1	
	1995					3			1995				315.9							1995	117.8		133.4					102.4		97.0	168.5
	1996								1996											1996	117.3		133.0					102.4		97.0	171.2
	1997					3.1			1997											1997			132.4			110.3		106.0		90.1	171.0
	1998					3.1			1998											1998	117.3		133.0					102.4		93.1	168.6
	1999			-8.75	-17.86	3.1			1999				315.5							1999											
	2000			-9.02	-18.4	3.08			2000											2000											

CI - Algeria

NOCLAS	H01200037	L01100011	J01100094	L00700068	K01100024	I00700008	K00400005	G01000463	G00900109	I01100437	K01200001	H01100408	P00500030	M00400296
denomination	BOU AROUA BAR 1	GT 101 GASSI TOUIL	HASSI MESSAOUD	KEF N 27	NEZLA F16	OUED MEHAIGUENE	Oued Namous	OULED DJELLAL	SIDI KHALED	SIDI SLIMANE	SINCLAIR MPC RB2	TAMERNA	AOULEF 17	TIMIMOUN 2
1956	267.9		375.0			481.0	495.0		381.0			348.8		
1957														
1958														
1959														
1960														
1961														
1962		350.0		403.3						394.1				
1963														
1964														
1965														
1966														
1967														
1968														
1969		349.0					487.4				333.0			
1970	267.9		357.0						351.0	339.7		333.3		279.5
1971														
1972														
1973														
1974								353.0						
1975										333.6				
1976														
1977														
1978														
1979														
1980														
1981												293.6		
1982								360.0	335.0	251.2		233.6		
1983								330.0						
1984														
1985														
1986														
1987														
1988					342.0									
1989					341.2									
1990						477.7					263.0		250	277
1991														
1992														
1993														
1994														
1995														
1996													247	277
1997					336.2									
1998	247.8			394.1	336.2					259.5	312.6	256.6		
1999														
2000														

CI - Tunisia

NOCLAS	19190005	18696005	18697005	05664005	05950005	05717005	19009005	19432005	19484005	X00700216	X00700217	20019005	19400005	19412005	19893005
denomination	CF 1 bis	CF F2	CF F3	CF1	CF2	KSAR GHILANE 1	Ksar Ghilane 3 bis	MAHBES 1	Behaier (CI 9)	El Borma A4	El BORMA 6	El Faouar (CI 19)	Kébili (CI 10)	Menchia CI 6	Mansoura (CI 13)
Altitude	33.55	30	27	33.55	30.95	220	199.6	236.2	53.31	257.3	242	58	55.57	40	37
1956				157.4	171.8	317.8									
1957															
1958															
1959															
1960	154.8			154.8	163.1										
1961															
1962															
1963															
1964										318.2					
1965					161.1										
1966															
1967															
1968															
1969															
1970	146.6			146.6		309.1									
1971											324.2				
1972															
1973															
1974															
1975															
1976															
1977															
1978															
1979															
1980															
1981															
1982							270.4								
1983	133.7						267.6								
1984	126.4	134.9	117.8	128.0			267.5								
1985							266.1	293.7							
1986					125.4			293.7	190.6				231.6		
1987	119.2							291.2	190.3	289.2			223.1	242	
1988									190.3				222.6	250	
1989	112.4							292.4							
1990							266.8	293.2					222.6	235	
1991							265.1	293.2							
1992	105.9							291.2						235	234.3
1993	104.9	113.5	100.7									269.7			234.3
1994	98.9		99.6									269.7			
1995															
1996													220.6		
1997												250			
1998												269.7			
1999								284.2	158.3			238			212
2000							260.9	287.2	158.3	272.8	249				

CT - TUNISIE 1

GROUPE	Rejim Maatoug				Tozeur				Metlaoui		El Faouar Sabria				Douz El Hsay					NOUIL				Douz Tarfaiet				Kebili Sud			
NOM	REJIM MAATOU	REJIM MAATOU	ENNASAR C3 N	**RejimMatoug_Synthèse**	DJEDIDA	Neflayett 1	Menachi 3	**Tozeur _ Synthèse**	Metlaoui 2	**Metlaoui _ Synthèse**	EL FAOUAR 3	EL FAOUAR OUE	SABRIA	**FaouarSabria_Synthès**	EL HSAY 1	EL HSAY 2	EL HSAY 3	SMIDA	**Douz El Hsay_Synthèse**	NOUIL	GHIDMA	DARJINE EL AN	**NOUIL _ Synthèse**	TARFAIET ELKR	DOUZ 2	BECHNI	**DouzTarfaiet_Synth**	GUELIADA 2	RAHMAT 2	RAHMAT 4	**Kebili Sud _ Synthèse**
NOCLAS	18678005	18745005	19877005		12667005	05436005	14388005		19053005		11334005	17675005	17609005		05840005	06800005	06801005	19092005		06690005	06689005	18755005		06522005	05263005	18681005		13531005	05692005	16700005	
Altitu	42.5	42.5	47.2		27.2		50		31.4		48.6	46.2	50.3		62.9	63.8	63.3	38.8		43.4	42.1	28.5		55	68.1	36.7		29	46.7	36.9	
1950						51.9		51.9																	80.6						
1951								51.8																					62.4		62.3
1952								51.8							73.2				73.2												62.3
1953								51.7											73.1												62.2
1954								51.7											73												62.2
1955								51.7											72.9					76.8			76.8				62.1
1956								51.6											72.8					76.5			76.5				62
1957								51.6											72.6	72.6	70.7		72.6	76.2			76.2				62
1958								51.6											72.5				72	75.9			75.9				61.9
1959								51.5											72.4				71.4	75.7			75.7				61.8
1960								51.5											72.3				70.8	75.4			75.4				61.8
1961								51.4											72.2				70.7	75.1			75.1				61.7
1962								51.4											72.1				70.7	74.8			74.8				61.6
1963								51.4											72				70.7	74.5			74.5				61.6
1964								51.3											71.9				70.7	74.2			74.2				61.5
1965						51.3		51.3											71.8				70.7	74			74				61.4
1966																			71.6				70.7	73.7			73.7				61.4
1967																			71.5				70.7	73.4			73.4				61.3
1968																			71.4				70.5	73.1			73.1				61.2
1969											70.5			70.5					71.3				70.2	72.8			72.8				61.2
1970					46.2			46.2							71.1	71.2			71.1		70			72.5			72.5		61.1		61.1
1971					45.4			45.4						69.5									69.6	72.3			72.3	65.4			60.2
1972								44.5						69.6					71.2				69.2	72			72				59.3
1973								43.7						69.6					70.7				68.9	71.7			71.7				58.4
1974					42.8		44.6	44.6						69.7					70.3				68.5	75.5			71.5	60.3	57.5		57.5
1975							44.1	44.1						69.7		69.1	69.4		69.1	62.1	68.1			74.2			70.1	59.1	57.2	53.8	57.2
1976							43.5	43.5					69.8	69.8		69.6	68.4		68.4	67.3	68.8		68.8	69.8			69.8	59.4	56.2	52.1	56.2
1977	80	80		80	44		42.1	42.1				71.1	68.8	69.8		68.8			68.3		67.6		67.6	69.9			69.9	58.6	54.7	53.2	54.7
1978	79.7	79.7		79.7	40.3		41.1	41.1				69.7	68.7	69.7		69.2			68.1	67.3	65.2	68.5	65.2	68.3	70.6	69.7	68.3	58.7	53.2	51.4	53.2
1979	79.4	79.4		79.4			41.5	41.5				69	68	69		68.6	68		68	66.6	65.6	68.7	65.6	67.2	70.7	67.4	67.2	59	52.5	51.4	51.4
1980		79		79	39.8		41.1	41.1				69.2	67.8	69.2		68.1	67.1		67.1	66.6	64.4	67.7	64.4	67.7	69.3	66.7	67.7	56.8		48.6	51.4

CT - TUNISIA 2

NOCLAS	18678005	18745005	19877005		12667005	05436005	14388005		19053005		11334005	17675005	17609005		05840005	06800005	06801005	19092005		06690005	06689005	18755005		06522005	05263005	18681005		13531005	05692005	16700005	
1981	78.62	78.6		78.62	41.1		40.6	40.6				67.7		67.7		67.9	67.6		67.6		65.2	66.9	65.2	67.8	69.3	66.7	67.3	54.3		48.5	48.6
1982		78.5		79.52			40.7	40.7	58.1		66.07	67.73		67.43		66.43	64.98		64.98			66.31	64.38	66		65.98	67			46.23	48.5
1983		77.49		78.02					57.1		63.77	66.13		66.43		66.37	63.98	62.88	63.98		63.38	63.91	63.38	63.5		63.98	66	55.6		44.23	46.23
1984		77.39		77.7			39.2	39.2	55.25		64.57	66.13	64.46	66.43				62.38	63.38		63.28	63.51	63.28	63.9		63.18	62.65	53.3		43.93	44.23
1985		76.39		77.42					53.4		63.68	65.03		65.23		63.55	62.4	61.68	62.4		63.78	63.71		63		63.28	63	51.7			43.93
1986		75.19		75.52							62.57	65.23		65.23		63.17	62.13	61.63	62.13		63.08	61.71		62.45		63.38	62.45				
1987		75.14		76.17					53.9			63.43		64.5				59.88	59.88		60.58	61.01	60.58	61.5		61.18	61.5	52.7		42.93	42.93
1988							34.5	34.5	52.1		62.07	62.73		63.43				60.48	59.48		60.58	61.01		59		61.18	59	51			
1989							34	34	51.4		62.07	62.53		62.93				58.28	57.98		60.08	60.51	60.08			59.98		50.05			
1990							33.4	33.4	42.9		52.87	60.23		60.73				56.18	55.48		57.58	58.91	57.58			58.18	58.18				
1991												60.33		60.33				55.28	55.28		57.48	60.01	57.48		57.69	57.98	57.98				
1992							30	30				59.33		59.33				50.78	51.28		54.48	56.71	54.48		56.09	56.18	56.18	43.5	33.65		36.09
1993			70.72	70.72			29.6	29.6	40.4			58.73		58.73				50.78	50.78		52.98	53.51	52.98		54.71	52.68	52.68	41.5			33.65
1994			68.52	68.52					39.8			57.28		57.28				50.28	49.58		52.98	53.81	52.98			53.18	52.18	40.9	32.05		33.65
1995				69.42										56.43				49.28	48.18		53.08	55.91	51.98			54.68	51.78		33.8		33.8
1996			74.22	67.92			27	27						55.13				50.18	46.98		51.48	52.81	50.48			52.98	54.88	36.5			
1997			67.92	67.92			27	27	39.4			53.53		55.13					46.98		50.28		50.48			50.18	52.26	38.7	31.35		31.35
1998							27	27																				37.8	31.85		31.85
1999							25	25																					26.9		26.9
2000			64.42																			48.51				48.68		32.5	25.33		

CT - ALGERIE

GROUPE	MGHAIER		Hassi Khalifa		EL OUED			Djamaa Nord			Toggourt		OUARGLA		Ouargla Est		Gassi Touil	
nom	AIN DEGUEL (D1 F7	SIDI AHMED TIDJAN	MAGRANE SOUF	SAHANE BERRY N 1	GUEMAR 1	KOUININE	KHOBNA	AIN TOUMI TIGGED	AIN CHERAGA	TAKHFOUNT MABR	MERDJAJA D36F64	BERRAHMOUNE NE	F SOVIET BOUROU	AIN BEN SACI D4F8	HASSI RHENANI N°2	NOUVELLE WILAYA	ERG EL AGREB AR	AZEL NORD ALN 1
NOCLA	H01000051	H01100356	H01200035	H01200038	H01100413	H01100530	H01200015	H01100363	H01100479	H01100482	J01100432	J01100512	J01000518	J01000761	J01000465	J01000531	L01100006	L01100008
1950			69.32				65.63											
1951																		
1952		31.94																
1953	40.03							53.63										
1954							65.63											
1955											70.7							
1956																		
1957					72.38										124.9	133		
1958																		
1959																		
1960																		
1961			68.32							53.4								167.6
1962	28.79																	
1963									45.2								148	
1964																		
1965																		
1966													129.3	130				
1967																		
1968																		
1969																		
1970		19.14	67.3	66.75	68.02		60.03								124.5	132.5		
1971		15.74											128.3	129				
1972																		
1973																		
1974																		
1975																		
1976																		
1977				61.7	63													
1978					59.3													
1979																		
1980																		
1981						69.8												
1982					59.3							64.67						
1983																		
1984																		
1985																		
1986																		
1987																		
1988																		
1989																		
1990																	147	166.6
1991	22.84				56			44.83	35.56	44.9								
1992																		
1993																		
1994																		
1995		-0.2				51.95												
1996																		
1997											50.13	56.2	123.4	121.2		128.7		
1998	-11	-8	41.12	33.43		49.55	30.9											
1999																		

ANNEX 9 : Reference piezometry for Transitiry Wedging

Table 1 : CT aquifer

N° PM5	Identification_PM5	Denomination_BD_SASS	NOCLAS_BD_SASS	Lambert longitude (m)	Lambert latitude (m)	Reference
1	M'Ghaier			811215	382101	
		AIN DEGUEL (D1 F7) OUM THIOUR	H01000051	789533	397578	BD_SASS
		EL HAMRIA	H01100104	822964	394204	BD_SASS
		SIF EL MENADI	H01100104	838915	378110	BD_SASS
		RECON S.E.S FR 13	H01100522	813937	363489	BD_SASS
		SIDI AHMED TIDJANI	H01100356	802598	367503	BD_SASS
2	H.Khlifa			902472	335485	
		MAGRANE SOUF	H01200035	891925	338537	BD_SASS
		SAHANE BERRY N 1	H01200038	905412	336288	BD_SASS
3	Djamaa-N			807227	331301	
		AIN TOUMI TIGGEDDINE	H01100363	807271	332030	BD_SASS
		AIN DJENANE	H01100364	806156	331378	BD_SASS
		AIN CHERAGA	H01100479	805827	336082	BD_SASS
		TAKHFOUNT MABROUKA	H01100482	807535	329388	BD_SASS
4	Toggourt			809595	279299	
		MERDJAJA D36F64	I01100432	813645	278314	BD_SASS
		BERRAHMOUNE NEZLA	I01100512	815430	281668	BD_SASS
		DAIRA DE TOUGGOURT F	I01100549	813537	280867	BD_SASS
		AIN NAGA	I01100540	805131	263501	BD_SASS
5	Ouargla-			748455	150789	
		GARET CHEMIA D1 F113	J01000533	744457	151697	BD_SASS
		F SOVIET BOUROUBIA	J01000518	749287	156007	BD_SASS
		BANOUNOU D2 F54	J01000521	748714	156855	BD_SASS
		A CHERIF D4 F80	J01000536	752147	143788	BD_SASS
		AIN BEN SACI D4F86	J01000761	750643	153300	BD_SASS
6	Ouargl-E			799971	147875	
		DAIA RHEMTA	J00900015	797501	160702	BD_SASS
		HASSI RHENANI N°2	J01000465	801703	141788	BD_SASS
		A.EL CADI DJEDIDA D4	J01000526	762467	154192	BD_SASS
		NOUVELLE WILAYA D1 F	J01000531	780561	154413	BD_SASS
7	G. Touil			838262	4982	
		FORT LALLEMAND	K01100004	846285	62808	BD_SASS
		HASSI LAROQUE P-C	K01100006	860488	36799	BD_SASS
		ERG EL AGREB AR 101	L01100006	824777	-1115	BD_SASS
		AZEL NORD ALN 1	L01100008	850083	-55654	BD_SASS
		EL HASSANI HSN 101	L01100019	825785	-39660	BD_SASS
8	Regim M.			1006562	315216	
		REJIM MAATOUG 1	18678005	995295	314515	BD_SASS
		REJIM MAATOUG 2	18745005	995378	314519	BD_SASS
		Rejim Maatoug 7	19777005	993109	314604	BD_SASS
		ENNASAR C3 N1	19877005	989762	314434	BD_SASS
		GUETIRA 1	19383005	980317	315461	BD_SASS
9	Tozeurct			1002954	384057	
		DJEDIDA	12667005	1077850	364063	BD_SASS
		HELBA 3	05262025	1003599	383538	BD_SASS
		Neflayett 1	05436005	1000262	387811	BD_SASS
		Ouled Majed	14387005	1011705	390910	BD_SASS
		Menachi 3	14388005	1008600	387748	BD_SASS
10	Metlaoui	Metlaoui 2	19053005	1051353	430050	BD_SASS
11	ElFaouar			1059773	323934	
		EL FAOUAR 3	11334005	1054677	323825	BD_SASS
		EL FAOUAR 4	19343005	1054706	323327	BD_SASS
		EL FAOUAR OUEST	17675005	1052656	316614	BD_SASS
		DRAA SAKKOUM	16730005	1085372	319733	BD_SASS
		SABRIA	17609005	1062716	322589	BD_SASS
12	Douz -			1088629	328143	
		EL HSAY 1	05840005	1086194	329728	BD_SASS
		EL HSAY 2	06800005	1086193	329748	BD_SASS
		EL HSAY 3	06801005	108615	329746	BD_SASS
		EL HSAY 4	06815005	108636	329738	BD_SASS
		EL HSAY 5	06821005	1086360	329758	BD_SASS
		DOUZE SONEDE	06999005	1088239	335400	BD_SASS
		SMIDA	19092005	1082316	337041	BD_SASS
13	Nouil -			1076003	340167	
		ZAAFRANE 2	10199005	1078390	333958	BD_SASS
		ZAAFRANE 3	13996005	1077933	333840	BD_SASS
		ZARCINE 3	13999005	1067810	343420	BD_SASS
		ZARCINE 4	19278005	1069479	343075	BD_SASS
		NOUIL	06690005	1077272	338730	BD_SASS
		GHIDMA	06689005	1068949	332140	BD_SASS
		DARJINE EL AMEUR	18755005	1051443	336433	BD_SASS
		BLIDETTE 3	18746005	1071250	337182	BD_SASS
14	Douz Nor			1085322	348886	
		TARFAIET ELKROUB S	13551005	1082955	334091	BD_SASS
		TARFAIET ELKROUB1	06522005	1080942	334810	BD_SASS
		DOUZ 2	05263005	1088362	334058	BD_SASS
		DOUZ OUEST	17615005	1085908	335559	BD_SASS
		BOUHAMZA	14622005	1086605	332622	BD_SASS
	Nclas a changé	EL GHOULA	16735005	1082369	340343	BD_SASS
		GRAAD	05754005	1084657	341281	BD_SASS
		BECHNI	18681005			
				1065617	337551	BD_SASS
15	Kebili-S			1083719	358504	
		BAZMA 3	05941005	1085112	357553	BD_SASS
		BAZMA 4	13446005	1085660	357886	BD_SASS
		BCHELLI 2	13994005	1076273	351574	BD_SASS
		BOURZINE 1	14623005	1083398	348003	BD_SASS
		BEN ZITOUN 2	18641005	1072360	348143	BD_SASS
		EL METOURIA 2	16701005	1086102	346467	BD_SASS
		GUELIADA 2	13531005	1072756	347816	BD_SASS
		JEMNA 2	14022005	1085647	348438	BD_SASS
		RAHMAT 2	05692005	1083276	355842	BD_SASS
		RAHMAT 4	16700005	1082909	356370	BD_SASS
		SCAST 4	05713005	1085680	352039	BD_SASS
		SCAST 6	14380005	1086335	352279	BD_SASS
		SIDI HAMED	17608005	1081919	347813	BD_SASS
		MESSAID 2	05956005	1080996	352736	BD_SASS

CT AQUIFER

N° PM5	Identification_PM5	Denomination_BD	NOCLAS_BD_SASS	Lambert longitude (m	Lambert latitude (m)	Reference
16	PZ 4		PZ4	1769336	-85687	BD_SASS
18	PZ 5		PZ5	1766166	-90688	BD_SASS
20	P5 2135	2135 (P5)		1657215	251114	
21	P6 2128	2128 (P6)		1652276	258344	
22	Pz 1287		MW-1287	1248277	72296	BD_SASS
23	El Oued			884138	316956	
		DEBILA N1	H01200021	882726	326488	BD_SASS
		GUEMAR 1	H01100413	879418	327837	BD_SASS
		KOUININE	H01100530	882127	322674	BD_SASS
		KHOBNA	H01200015	894168	308084	BD_SASS
		EL OUED	H01200016	886195	313311	BD_SASS
63	Hun J 3		J3	1766790	-100251	BD_SASS
64	Hun Pz 3		PZ3	1763135	-96385	BD_SASS

Table 2 : CI AQUIFER

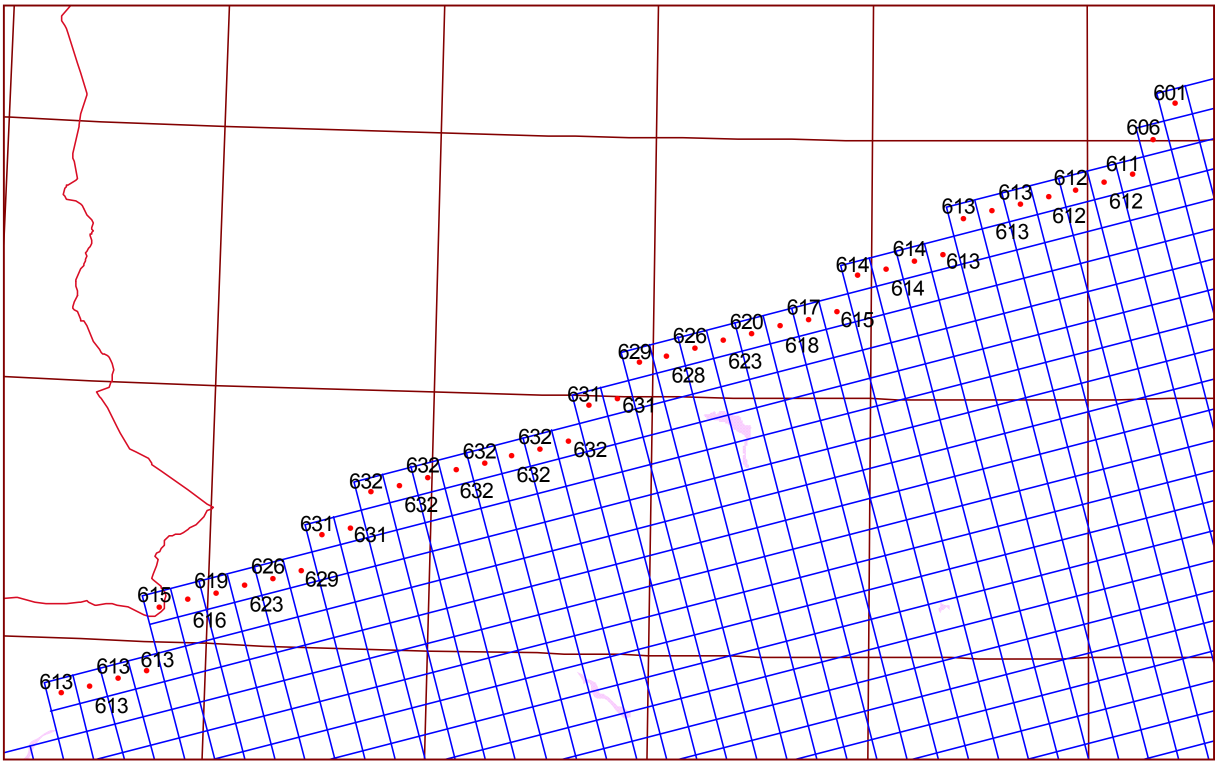
N° PM5	Identification_PM5	Denomination_B	NOCLAS_BD_SASS	Lambert longitude (m	Lambert latitude (m)	Reference
17	Zemz ZZ2	Fawar el	ZZ 2	1692306	157823	BD_SASS
19	Mardum 1		Mar 01	1595444	197632	BD_SASS
24	Kef N 27	KEF N 27	L00700068	517598	-134	BD_SASS
25	Sinclair	SINCLAIR MPC RB2	K01200001	906281	93747	BD_SASS
26	HM-GToui			864400	-8633	
		GT 101 GASSI TOUIL	L01100011	864400	-8634	BD_SASS
		NEZLA F16	K01100024	858863	40563	BD_SASS
27	Tamerna-	TAMERNA	H01100408	804195	318190	BD_SASS
28	S.Khaled			681062	423518	BD_SASS
		OULED DJELLAL	G01000463	716090	427818	BD_SASS
		SIDI KHALED	G00900109	715192	424396	BD_SASS
29	Bar 1 -	BOU AROUA BAR 1	H01200037	941498	360063	BD_SASS
30	O.Nam-OM			500135	250202	
		OUED MEHAIGUENE	I00700008	500135	250203	BD_SASS
		Oued Namous	K00400005	292671	78671	BD_SASS
31	Aoulef22		O00500063	357078	-396608	BD_SASS
32	Taw 3.83		3.83	1632487	183978	BD_SASS
33	WG 16		MW-1219	1241116	-22521	BD_SASS
34	WG(1219)			1310762	6807	
35	Bay BAK4		BAK-4	1739393		BD_SASS
36	K.Rhilan			1148527	288002	
		KSAR GHILANE 1	05717005	1148527	288002	BD_SASS
		Ksar Ghilane 3	19009005	1148489	287949	BD_SASS
39	CF 1 bis	CF 1 bis	19190005	1143060	388790	BD_SASS
45	Kebili10	Kébili (CI 10)	19400005	1082481	362092	BD_SASS
46	Wash WH1		WH 1	1722771	154851	BD_SASS
47	Mahbes 1	MAHBES 1	19432005	1148898	269778	BD_SASS
48	Boun B-5		B-5(1/81)	1570887	187271	BD_SASS
50	Bahaier9	Behaier (CI 9)	19484005	1107030	373053	BD_SASS
51	Mansoura	Mansoura (CI	19893005	1055721	363964	BD_SASS
54	Faouar 9	El Faouar (CI 19)	20019005	1053892	322881	BD_SASS
55	Menchia6	Menchia CI 6	19412005	1070449	370571	BD_SASS
56	Borma205			1118796	135850.6	M. CHAIEB (ENIT,1986)
58	Borma A4			1125071	128977	BD_SASS
		El Borma A4	X00700216	1125071	128977	BD_SASS
		El BORMA 6	X00700217	1125072	128977	BD_SASS
59	Saf S1Q1		SIQ1	1595763	159054	BD_SASS
60	Borma204			1118745	136647	M. CHAIEB (ENIT,1986)
61	Nina N2		T/2D/005/0/83	1707690	-32299	BD_SASS
62	CF-Synth			1142625	388790	BD_SASS
		CF 1 bis	19190005	1143060	388790	BD_SASS
		CF F2	18696005	1140968	390151	BD_SASS
		CF F3	18697005	1140652	387380	BD_SASS
		CF1	05664005	1142625	389061	BD_SASS
		CF2	05950005	1135264	386873	BD_SASS

Table 3 : GRES SUPERIEURS (« Upper Sandstone ») AQUIFER

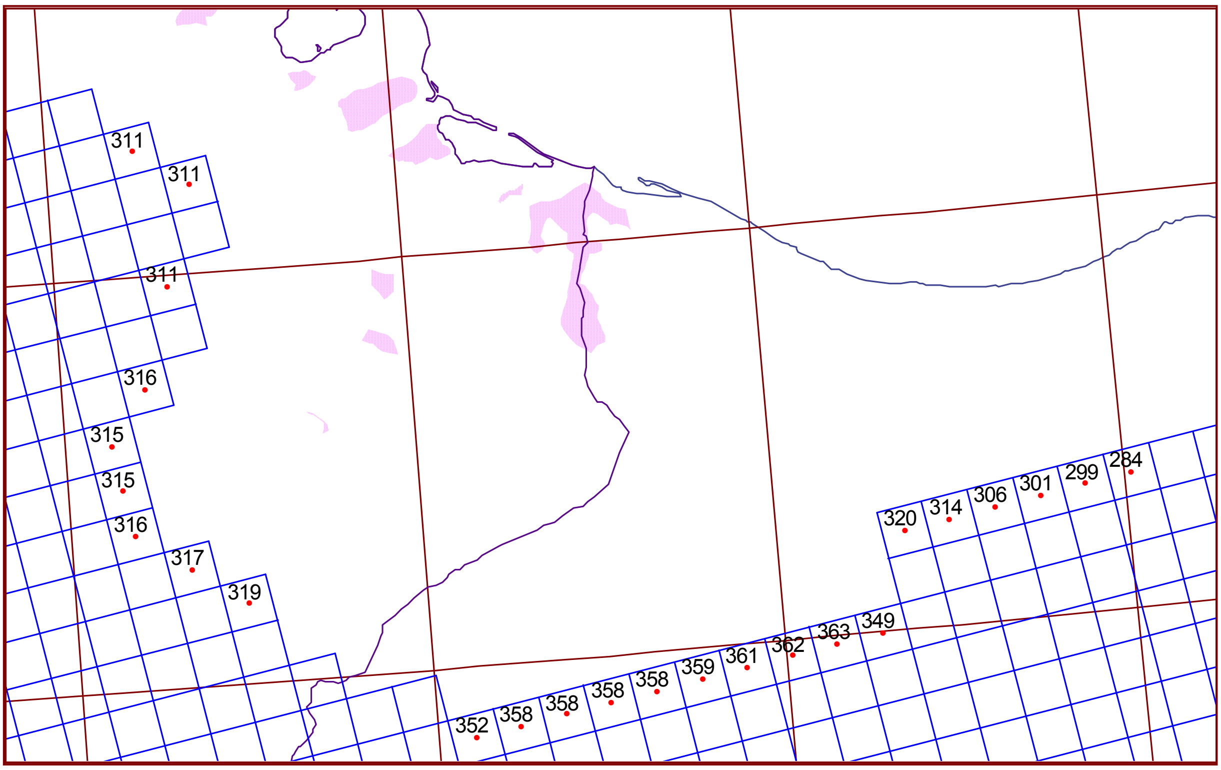
N° PM5	Identification_PM5	Denomination_B	NOCLAS_BD_SASS	Lambert longitude (m	Lambert latitude (m)	Reference
37	NeftaCI1	Nefta CI	19084005	978561	377016	BD_SASS
38	Tozeur 1	Tozeur CI 1	19162005	1000832	382294	BD_SASS
40	Tozeur 2	Tozeur CI 2	19224005	999183	381160	BD_SASS
41	NeftaCI2	NEFTA CI2	19227005	978689	376972	BD_SASS
42	Degache3	DEGACHE CI 3	19231005	1012962	393876	BD_SASS
43	HammaCI2	EL HAMMA CI 2	19233005	1006262	389923	BD_SASS
44	HammaC1b	EL HAMMA C.I.1bis	19260005	1006283	389854	BD_SASS

ANNEX 10

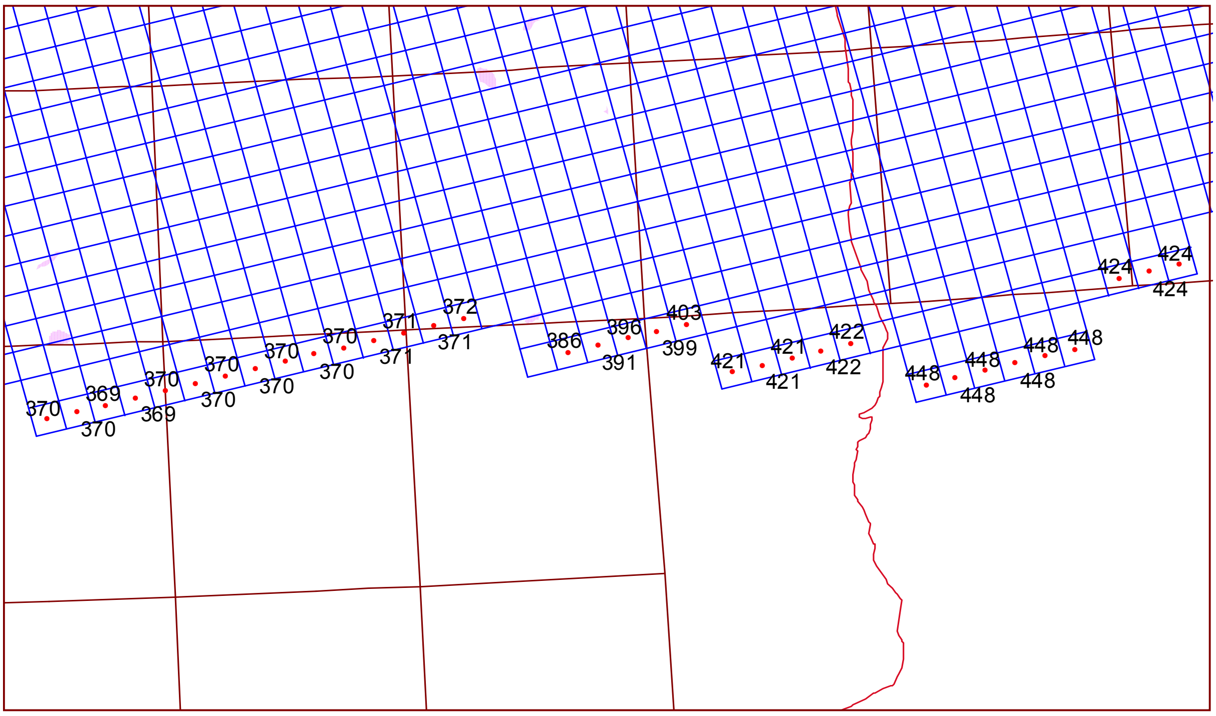
Annex 10.1 : CI : Potential Imposed on the North-Western Boundary : Saharan Atlas



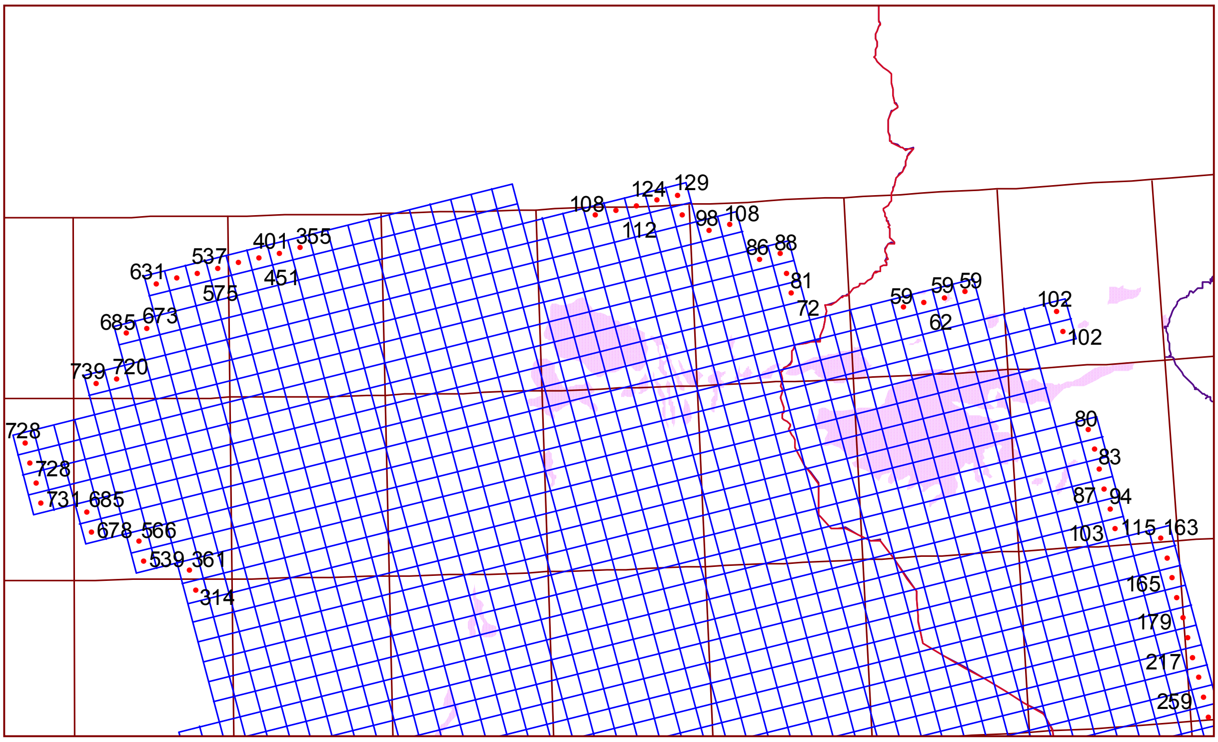
Annex 10.2 : CI : Potential Imposed on the Dahar – Dj. Nefusa boundary



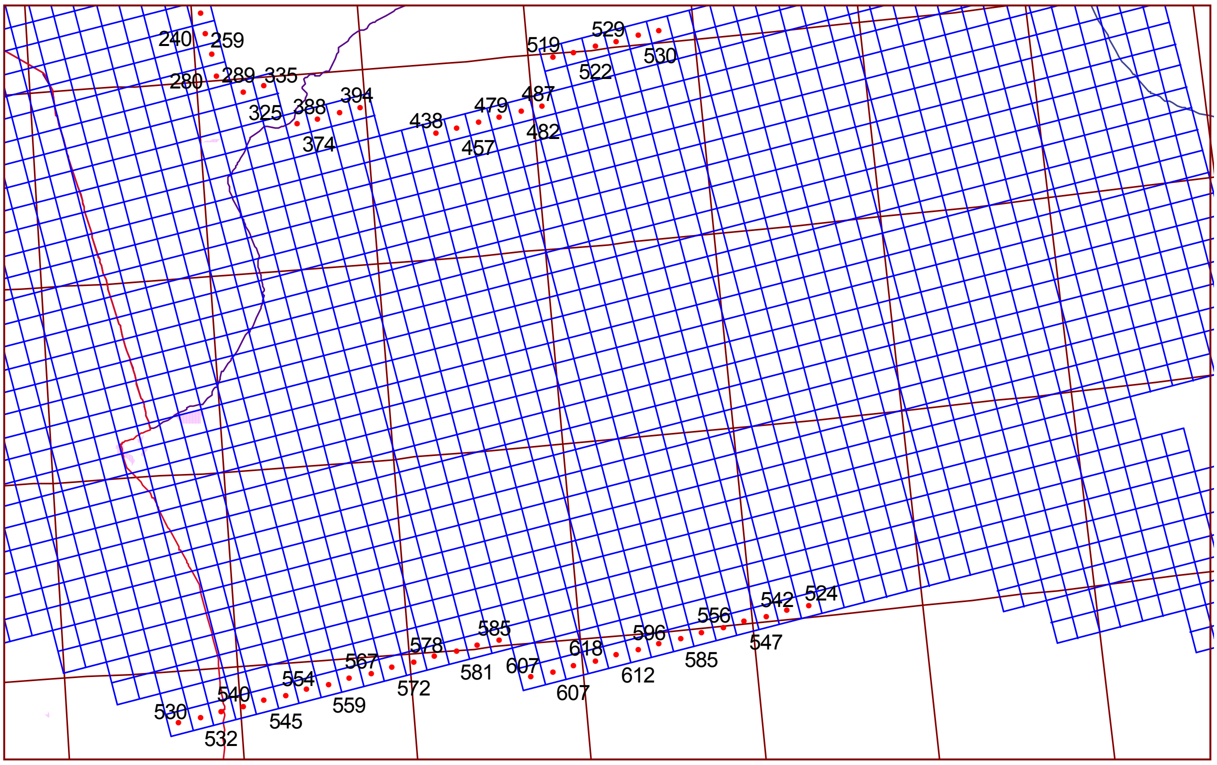
Annex 10.3 : CI : Potential Imposed on the Southern Algeria – Libya boundary : Plateau of Tinhert



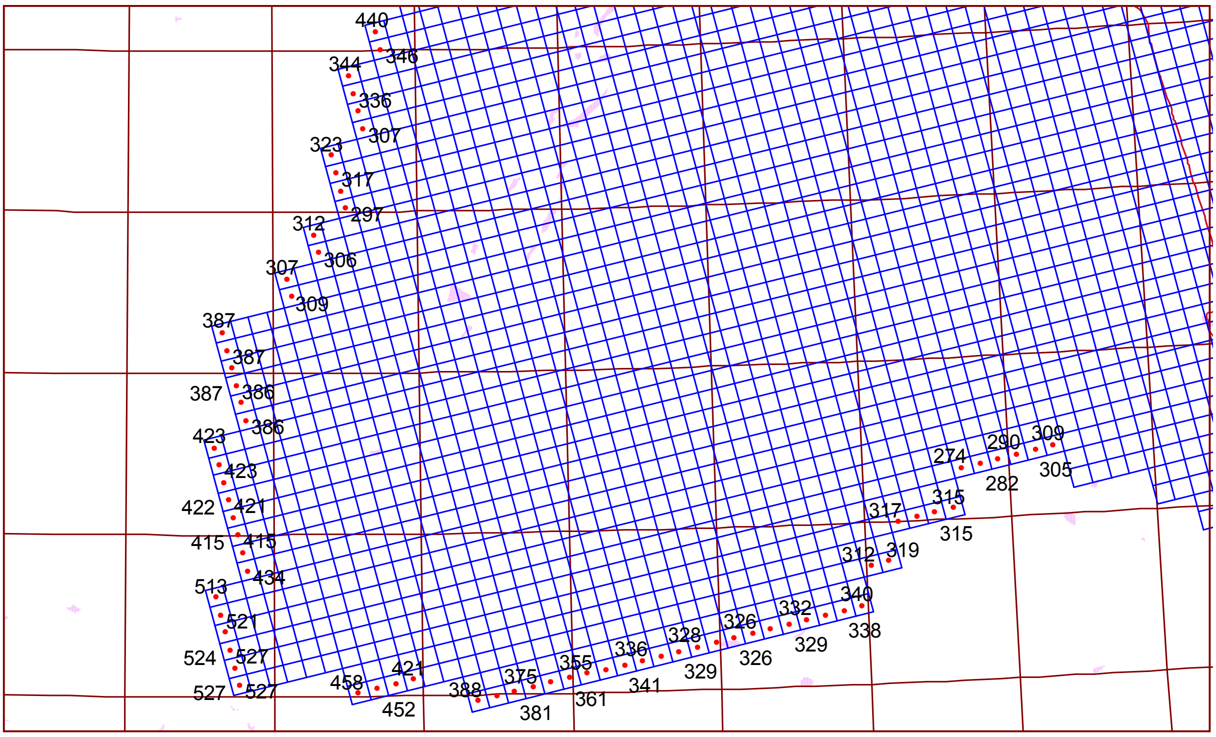
Annex 10.4 : CT : Potentiel Imposed on the northern boundaries of the model, Dahar and Saharan Atlas



Annex 10.5 : CT : Potentiel Imposed on the Southern-Libya and Dj. Nefousa boundaries



Annex 10.6 : CT : Potentiel Imposed on the South-West Algeria boundaries



Design and realization of the cover: Faiez Taarit

THE NORTH-WESTERN SAHARA AQUIFER SYSTEM

BASIN AWARENESS

MATHEMATICAL MODEL, VOLUME IV - FEBRUARY 2004

Serving as a driving and facilitating force, OSS, in carrying out the SASS Programme, relies first and foremost on the expertise available in specialised, well experienced institutions of the three countries as well as on broad international partnership.

The North-Western Sahara Aquifer System, (NWSAS), shared by Algeria, Tunisia and Libya, has considerable water reserves that cannot be totally exploited and are only very partially renewed. The NWSAS stretches over a million km2 and is composed of two major water-bearing layers, the Continental Intercalary and the Terminal Complex. Over the last thirty years, abstraction by drilling has risen from 0.6 to 2.5 billion m3/yr. This rate of abstraction involves many risks: strong impact on neighbouring countries, salinisation, elimination of artesianism, drying up of outlets, etc. Simulations on the NWSAS Model have enabled OSS to pinpoint the location of the most vulnerable areas and map the risks facing the aquifer system. The three countries concerned by the future of the NWSAS will need to work together to develop a joint management system for the basin. A consultation mechanism needs to be instituted and gradually put into operation.

This final report gives an account of all the works conducted in the framework of NWSAS project, between January 2000 and June 2002, for the design of a mathematical model of the North-Western Sahara Aquifer System.

This document is organized in three parts:
- One first part called: Characterization of the Aquifer System and Conceptual Model, namely including the geological, hydrological and hydro-dynamic characterization of the basin,

- The second part is called: Design of the Mathematical Model, describing the construction and calibration phases of the model in steady and transient states,

- The third part is devoted to the Execution of Predictive Simulations. This part successively develop: the definition and execution of exploratory simulations, the construction of a NWSAS miniature model to investigate the reservoir, the definition and performing of predictive simulations.

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