NORTH-WESTERN SAHARA AQUIFER SYSTEM

Joint Management of a Transborder Basin

RESULTS OF THE FIRST STAGE OF SASS

JUNE 2003

OSS

SAHARA AND SAHEL OBSERVATORY

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SUMMARY

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The Northern Sahara Aquifer System [SASS], shared by Algeria, Tunisia and Libya, includes considerable water reserves which cannot be exploited in their totality and which are renewed in very small proportions. SASS extends over one Million Km^2 ; it includes the two big water sheets of the Intercalary Continental and the Terminal Complex. For the last thirty years, the exploitation through drilling went from 0.6 up to 2.5 billion m^3 /year. The water resources were used in the agricultural field, for the irrigation of oases, for the supply to cities and industries, notably in the sector of oil and tourism.

The intensive development of the exploitation of the SASS aquifers has to face several risks: **strong interferences between countries, water salinity rates, disappearance of artesianism, drying up of the outlets, excessive pumping depths** … The simulations achieved based on the SASS Model allowed to pinpoint the most vulnerable zones. The most exposed sector is the Chotts basin where the highest densities of the population are found and where the pressure on the water resource is the highest. The made calculations have clearly shown that the simple carrying on of the present intakes would result, towards the year 2050, in some additional reductions which would be unacceptable for the sheet.

The investigations carried out on the model show that the possibilities for further increasing substantially the SASS exploitation level do exist, but they would be possible only at the cost of a breaking off with the traditional exploitation regions : 80 % of the additional intakes would be made in "new" and remote areas : the Big Western Erg, the most remote areas of the Oriental Erg. However, some incertitude subsists over the good knowledge of the system, which would require the conducting of new investigations.

The three concerned parties by the development of the SASS are led to look together for some kind of joint management of the Basin. The starting point is the necessity to keep up and develop the common data base and the model : the setting up of an institutional mechanism of concertation proves to be necessary, and its setting up should be carried out progressively.

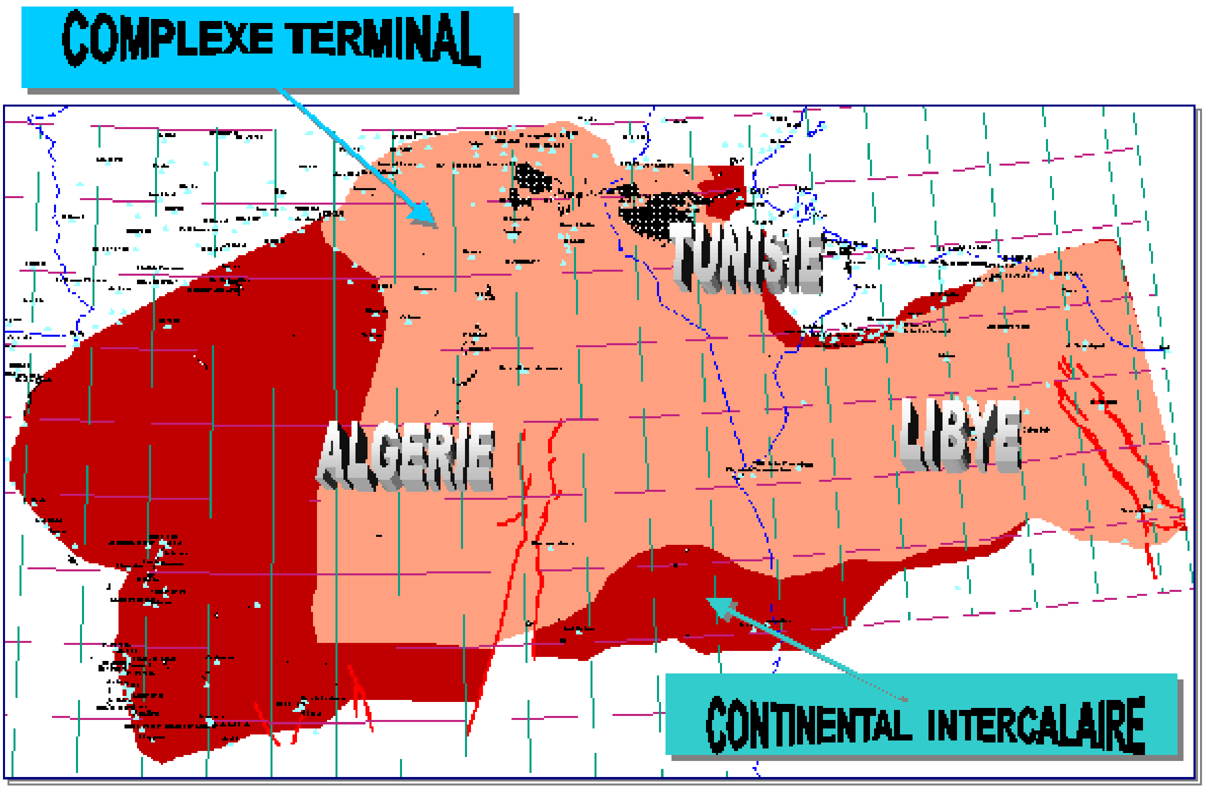
This note has taken into consideration the whole works achieved from July 1999 up to December 2002, for the setting up of the different components of the SASS Project, namely : t**he Acquisition, Analysis and Synthesis of the hydrogeological data ; the Elaboration of the Joint Data Base and of the Information System ; the Development and the Exploitation of the SASS Mathematic Pattern ; the Setting up of a Concertation Mechanism for the joint management of the Basin.**

1- DEFINITION OF THE NORTHERN SAHARA AQUIFER SYSTEM. THE PROBLEMATIC ASPECTS OF "THE SASS PROJECT".

The **Northern Sahara Aquifer System** [SASS] covers a surface of more than one million km2 in the western part of North Africa : approximately 700,000 km² in Algeria, 80,000 km² in Tunisia and 250,000 km² in Libya. They are continental deposits in which two main aquifer formations can be distinguished : that of the " **Intercalary Continental , or IC "** and that of **"the Terminal Complex, or TC".** The geological stratum is composed of layers dating back to the secondary and tertiary eras : Jurassic and Lower Cretaceous for the Intercalary Continental and Upper Cretaceous to the Mio- Pliocene for the Terminal Complex.

The setting up of these water reserves was achieved over several thousands and even dozens of thousands of years. An intricate underground flow emerges on the surface, in the way of springs and foggaras, exploited for some very remote times and which gave birth to well known oases in the three concerned countries. SASS makes up an enormous water reservoir whose water volume is estimated at 30,000 billion m^3 . All these water quantities cannot, alas, be totally used. The reloading of the system corresponds to approximately one billion m^3 per year. It is therefore a very limited renewable natural resource.

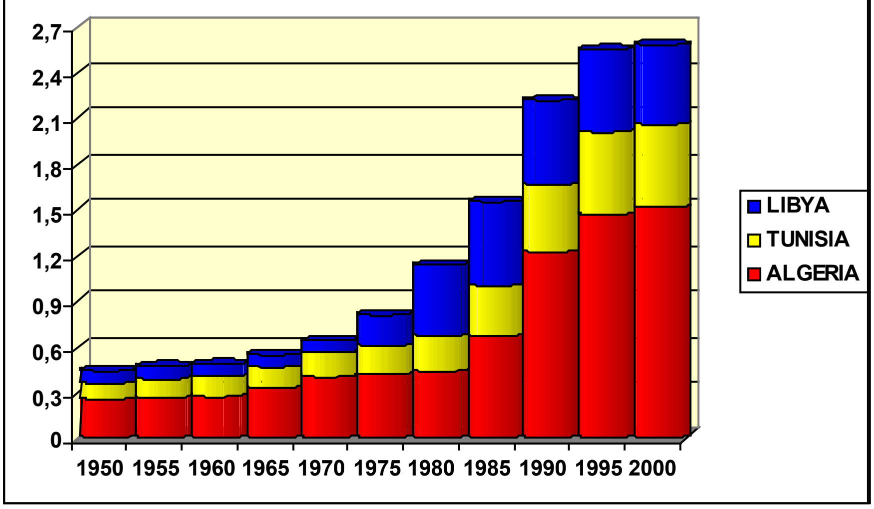
Fig.1 : Extension of the SASS main aquifer formations



We have been exploiting this ressource for more than fifty years : the intakes went from 600 hm3/year in 1970 to approximately 2.5 billion m3/year in 2000 ; these quantities are used in the agricultural sector for irrigation, they are also used as drinking water as well as in the industrial sector (oil exploitation, tourism). The number of listed water points reached 8800, covering boreholes and springs : 3500 in the Intercalary Continental and 5300 in the Terminal Complex. Their distribution per country is as follows : 6500 in Algeria, 1200 in Tunisia and 1100 in Libya.

In the three concerned countries, the administrations in charge of the water resources are managing this resource : in Algeria the relating administration is the ANRH (the National Agency for Hydraulic Resources), in Tunisia, it is the DGRE (the General Directorate of Water Resources), and in Libya, it is the GWA (General Water Authority). The users are the traditional farmers who are cultivating the oases, those practising the irrigated cereal culture, the stock breeders who profit from the water points or the boreholes, the market gardeners, the city inhabitants, industries such as the oil exploitation industrial sectors. Generally speaking, the administration provides for the necessary investments to make water available. The traditional or modern systems ensure its distribution.

Fig.2 :Total intakes in the saharan aquifers in billions of m3/yearn



The SASS problematic issue, that is to say the essential question which is presently raised, is that how to use to the best possible extent this water reservoir while securing its perenniality, knowing that a certian number of issues is getting more and and more acute :

- By continuously pumping out in the two systems, the water level is regularly decreasing while the pumping cost increases ;
- The natural outlets are drying up (springs, artesian wells) ;
- It was found out that pumping in one particular point had repercussions on the other parts of the sheet. The interferences between the different points of the basin are sometimes very important ;
- The irrigation of cereal cultures in arid areas may have serious effects on the salinisation of the soils and make them non productive,
- Under the effect of pumping out, the risk for the deterioration of the quality of the water and for the increase of its salinity is outstantding ;
- To these risks, the local problems of water draining are to be added.

The three countries' officials became aware of these risks at the end of the sixties and in 1972, a big Tunisian-Algerian programme, the ERESS, allowed to set up a first pattern for the exploitation of this aquifer on the basis of the intakes in the two countries and the utilisation forecasts.

Twenty years later, the Sahara and Sahel Observatory "OSS" organized in Cairo, in 1992, the first workshop on the aquifers of the big basins, followed by a second workshop in 1994, in Cairo also, which was devoted to the economic and environmental impacts of the exploitation of these aquifers. The specific **"SASS"** project was in fact born within the framework of the global OSS programme called **" the big basins aquifers",** after a series of national seminars and workshops held between 1994 and 1997. A draft document was adopted during a seminar organized in Tunis in septembre 1997 at the end of which the OSS was entrusted with the superintendance of the programme and fund raisng.

In 1998 OSS gained the support of the swiss cooperation, that of the FIDA and the FAO for a first three year stage which was officially launched in may 1999 in Rome.

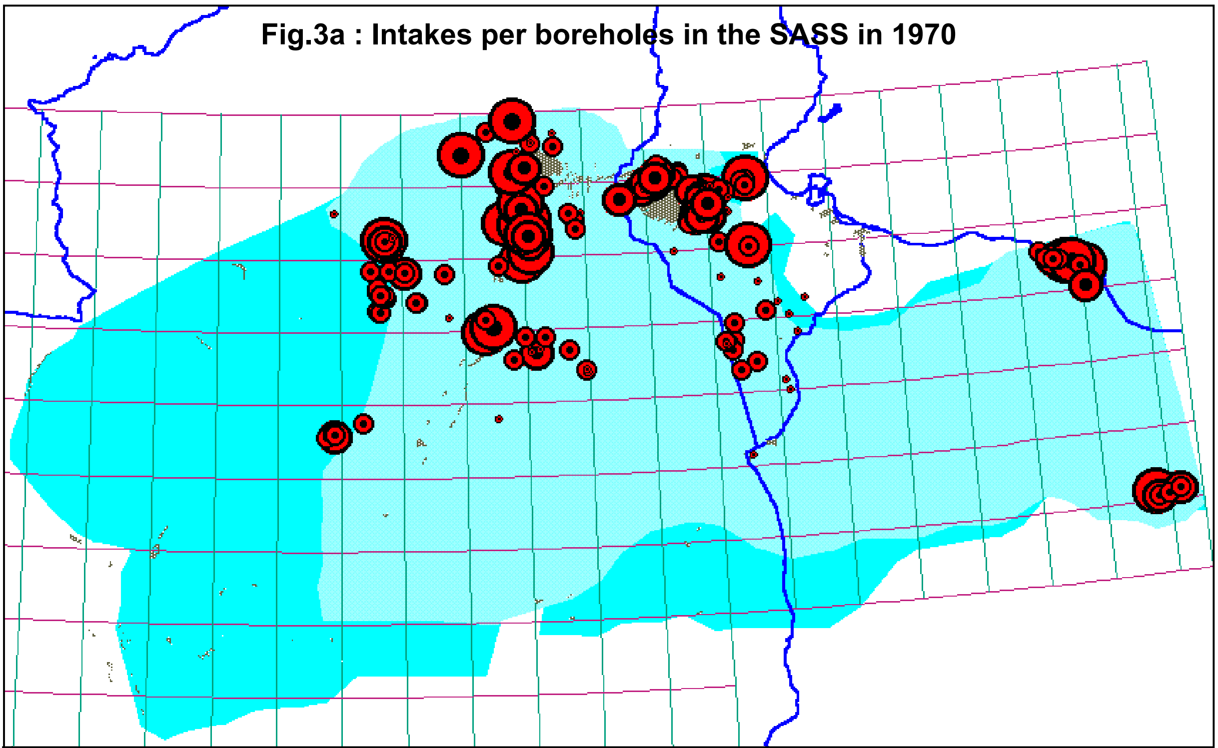


Fig.3a : Intakes per boreholes in the SASS in 1970

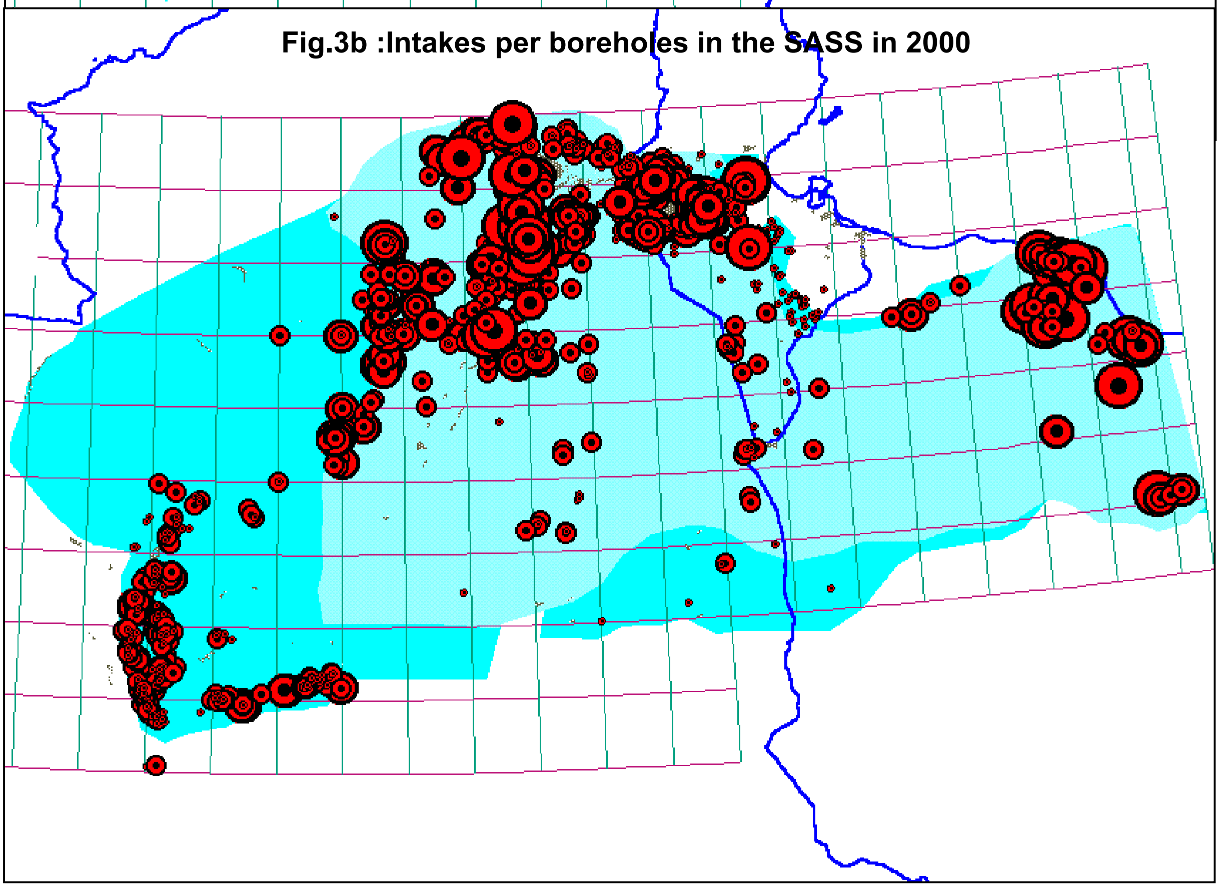


Fig.3b :Intakes per boreholes in the SASS in 2000

2- THE OBJECTIVES OF THE SASS PROJECT

The objectives of the SASS project are defined as follows :

- **Bringing an added value to the preceding models**, notably ERESS, by integrating the Libyan part and through the exploitation of the data and studies which accumulated over thirty years ;
- Making an evaluation of the exploitable water volumes and developing **a mathematical pattern** of management by permanently associating the national competencies of the three countries and while taking into account the national policies ;
- Achieving **a data base common to the three countries** destined to enhance the information and to be a tool of exchanges ; this data base should pave the way to a future **"SASS Observatory"** ;
- organising **thematical and training seminars gathering the technicians from the three countries** working on one single system, for the updating of information and the exchange of experiences ;
- **updating the condition of the intakes** ;
- setting up a **concertation mechanism** in order to institutionalise the cooperation framework created by the programme, to secure perenniality to the information updating, exchange and follow up programmes and to translate in a concrete manner "the basin awareness" which has progressively come into the open, after the holding of workshops by OSS as early as the 90's.
- Inducing reflexions over the **durability of this resource**, the optimisation of its exploitation, the relationship with the struggle against desertification, the improvement of the level of living of the inhabitants and the regional cooperation.

  This project required a permanent cooperation between the three bodies in charge of water resources in the three countries and the setting up of a SASS project team in Tunis, composed of specialists from the three countries.

  The objectives set out herebelow have been exposed in detailed "activities", relating to three components : a first component called **"information System"**, whose main results shall be exposed in paragraph 3-1 called **"Hydrogeology and the SASS Data Base"**, a second component called **"Management Models"** and **"Exploratory simulations"**, whose results are exposed in **paragraph 3-2 "the SASS model",** and a third and final component called **"Concertation Mechanism »**, is exposed in paragraph 3-3.

3- THE REACHEDED RESULTS

3.1- The Hydrogeology and the SASS Data Base

3.1.1 Hydrogeology

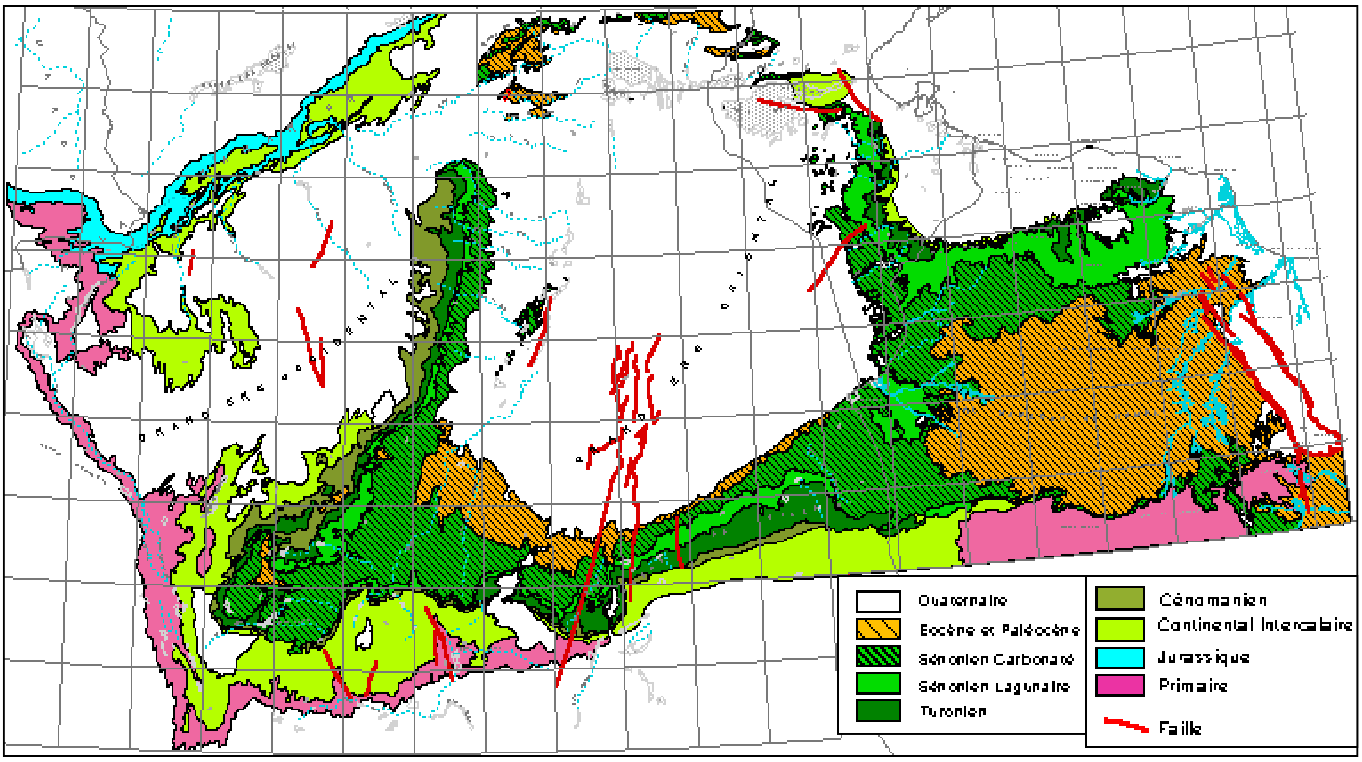
The SASS project allowed the improvement of the geological knowledge of the basin in its totality and that of the sub-basins of the big western Erg, of the Tunisian outlet and of the Hamada El Hamra, thanks to new boreholes and to new hydrogeological studies.

A historical study of the **piezometry** (estimate of the water level measured in springs or boreholes) carried out over 50 years (1950 – 2000), the water **salinity** and its **exploitation**, the chemical and isotopic analyses, and the measurements of **transmissivity** (aptitude of the soil to transmit the water flows) has allowed this synthesis**.**

The SASS aquifer formations have been defined with enough precision through a stratigraphic correlation of the basin layers. The extension of aquifers in these layers has been detailed and the map showing the outcrops of the main aquifer formations has been drawn up. North-South and East-West sections have shown correlations between the different points of the basin.

The **main aquifers geometry** was defined by specifying the **thickness** of the layers saturated with water in the different zones, i.e the difference between the "wall", which means the basis of the aquifer layer and the peizometric surface ; the **storing up coefficients** (capacity of storing-destoring) per layer have also been shown.

Fig. 4 : Geological map of the SASS basin

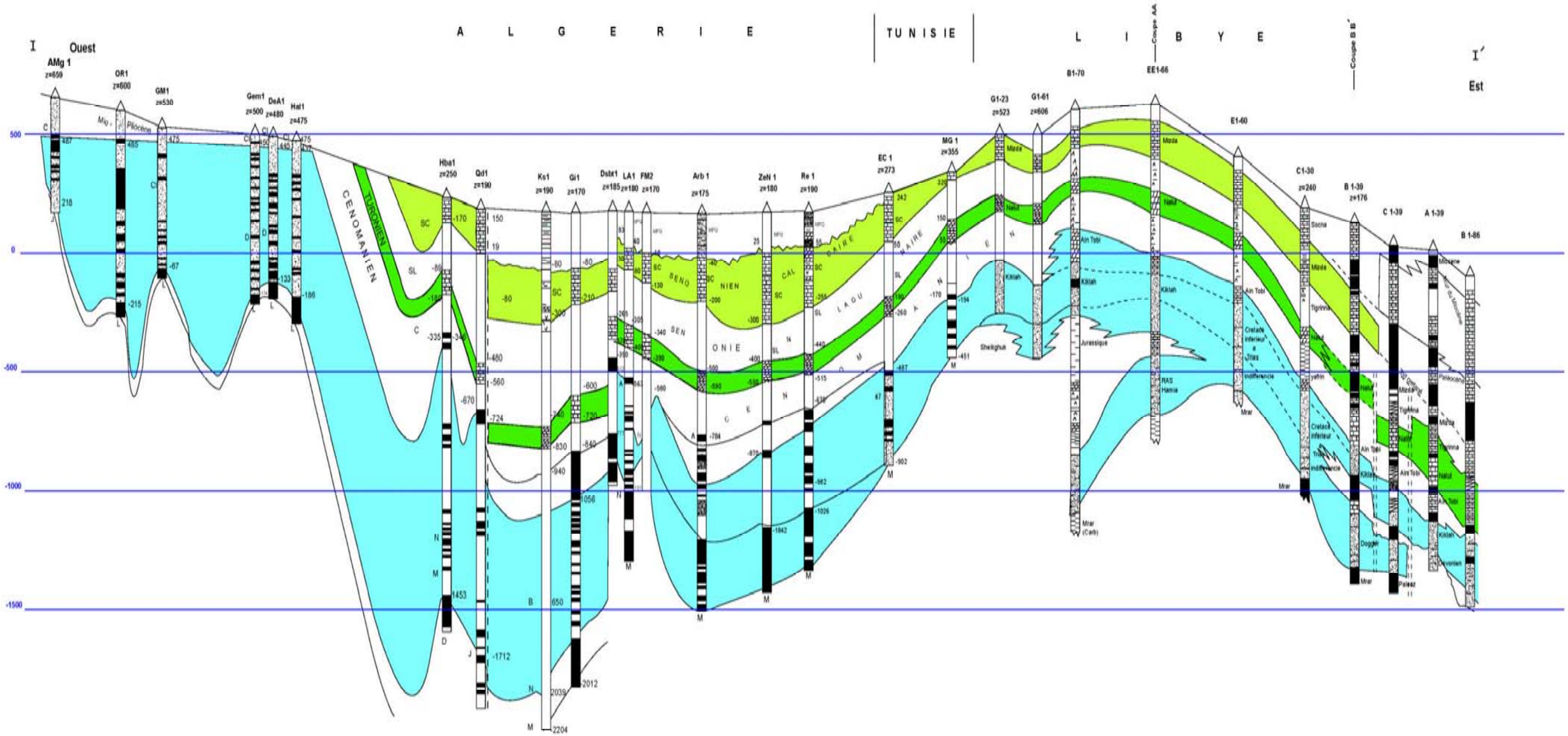


Another result is a better knowledge of the outlets and the zones which contribute to the reloading of the sheets such as the Sahara Atlas, the Dahar, the Djebel Nefussa.

The result of this thorough knowledge of the basin hydrogeology is a laying out of the aquifer schemes for the achievement of the mathematical pattern. An alternance of the permeable layers having hydraulic links with one another, makes up "aquifers" of various thicknesses, with less permeable layers called "aquitards"

The sahara basin is a big multi-layer sedimentary entity. The adoption of a representation of all the "aquifer – aquitard" layers into a multi-layer system allowed to account for the lateral and vertical links which condition the hydraulic and chemical exchanges and thus to account for the behaviour of the system in the mid and long term. The sequence of the SASS layers is taken up in the drawing of fig. 6 .

Fig. 5 : West-east correlation of the wester Basin in Tawargha
[sources : UNESCO 1972, and SASS data base]



Another problem consisted in defining the northern, southern, eastern and western limits of the different aquifer layers in order to well delimit the field of application of the model. **The SASS hydrodynamics has been precised thanks to the piezometric surveys of the controlled points and a piezometric reference map has been plotted.** The supply sectors were precised. The natural outlets were studied in a forecast perspective, considering the recorded decrease in the flow of the springs. The map of the transmissivities of the whole basin was established.

Fig.6 : Diagram of the Sahara multi layers

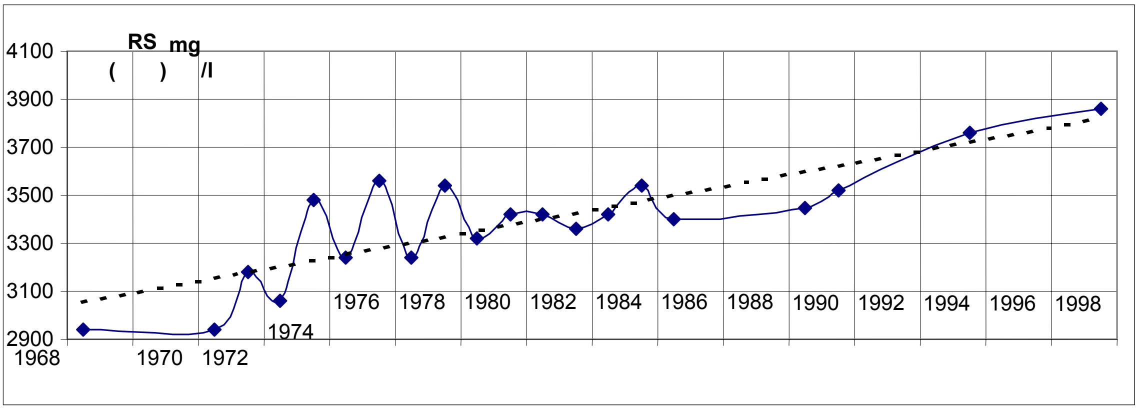
HYDROLOGICAL SCHEME OF THE NORTHERN SAHARA		
ALGERIA	**TUNISIA**	**LIBYA**
WATERPFOOF TOP		
SAND SHEET	DJERID SAND SHEET	SAND AND LIMESTONE LOWER MIOCENE
TERMINAL COMPLEX SHEET - UPPER CRETACEOUS		
LIMESTONE SHEET	NEFZAOU LIMESTONE SHEET	MIZDAH UPPER CRETACEOUS
SEMI PERMEABLE		
TURONIAN SHEET- NALUT SHEET		
SEMI PERMEABLE		
INTERCALARY CONTINENTAL SHEET - KIKLAH AQUIFER		
LOWER CRETACEOUS JURASSIC TRIASSIC	LOWER CRETACEOUS UPPER JURASSIC	**LOWER CRETACEOUS UPPER JURASSIC**
WATERPROOF OR SEMI PERMEABLE SUBSTRATUM		CARBONIFEROUS
PALAEOZOIC	**LOWER JURASSIC TRIASSIC**	**CAMBRO-ORDOVICIAN**

The project then dealt with the analysis of the intakes**, per aquifer and per country**, by setting up the history of the flows. It was found out that the multiplication of drillings had adverse effects on the artesian flows and on the spurting of springs. A piezometric history of each sheet was achieved in the three countries. The reached conclusion was a general piezometric decrease over the whole of the TC and the IC, a decrease linked to the multiplication of drillings : it is of about 25 to 50 metres in average.

The project has carried on, in each country, studies on the water chemical quality and more particularly on the water salinity. A differentiated increase of such a salinity was recorded, which might be due to the chotts and to the return of the drainage waters to the zones where the sheet covering is not thick enough.

The chemical composition in Ca, Mg, Na, K, SO4, Cl and HCO3 ions was enhanced as well as its development. The underground circulation speeds and the transit times were studied using isotopic analysis (O18, deuterium). It shall be noted that the SASS waters have been set up over dozens of thousands of years, during the rainy episodes of the quaternary. The algerian- tunisian chotts zone was then composed of big lagoons, two to three times bigger than the surface of the present chotts. The climate became more arid and a slow draining of these lagoons and of the aquifer system was witnessed. The aquifer system has been recording a more and more important decompression since the beginning of the XXth Century .

Fig.7 Evolution of the DR of the waters of Bou Abdellah 1 borehole



3.1.2 The SASS Data Base

The objectives of the SASS project need the implementation of a specific data base which would be capable, on one hand, of re-entering and reformating the data of the three countries, in a homogeneous way, and to absorb a very big quantity of new data, on the other.

It shall be recalled that a data base, which makes up a constitutive element of an information system, is a structured collection of data relating to one particular sector, managed by one or several specific softwares allowing the management of the base.

The installed Data Base Management Sysytem "SGBD" is the tool which will be handled by the user in order to establish relations between the information he chooses. In the case of SASS, the most important base entity shall be the **"water point"**, which is in general a drill bore defined by parameters, measuring units : their origin, their date of aquisition, their location, etc…

The SASS project team has thus successively achieved the following stages :

- The stage of **diagnosing the existing data** in the three countries and the development guide lines of the base ;
- The stage of designing **a data pattern** (MCD, data design pattern) for the base ;
- the stage of achieving the data base, after choosing the SGBD and its components (material, software, periphericals,…) ;
- the stage of the **implementation of the base**, with the objective of ensuring its installation simultaneously at the head office of the project and in each administration in charge of the water resources in each of the three countries.

We can measure up the difficulty of this task when we appreciate the problems of data heterogeneity, both in time and in space, of the handling habits of such or such a pre-existing system in each of the three countries, and of the difficulty of getting accustomed to a new system.

Some technical choices have been made, while taking into account the format and the entry of data in the digital pattern, the technological tendencies of the time, the already existing data in the three countries and the simplicity of their implementation and their mastery by the national teams. Taking into account the increasing power of the SGBD, it has been decided to choose **ACCESS** version 2000 which allows the handling of up to 2 Go, in a network and in intranet, it also allows a good protection, a multi-user access and the possibility of migrating to heavier systems such as SQL/SERVER, forecast by the DGRE and the ANRH.

Table 1 : Implementation Stages of the Informatic Sstem in the short and mid term

Stage	Regional Level	National Level	SASS Level
For the needs of the pattern		- Improvement of the DB structure - Harmonization of the codifications -Recuperation of heterogeneous data	- Designing of a common data base and a SIG (General Information System) on the SASS Zone - Collection of all the available data up to this day - development of tools allowing to interface with the digital pattern
For the concertation Mechanism	Constitution of regional compatible bases with a possibility to update the central DB	-development of updating mechanisms of the common base -Integration of social-economic data -more detailed SIG	- Development of concerted management tools at the level of the basin

Considering the importance of the localisation of the 9 000 base entities (the water points) and of the geographical processings to be executed as well as the necessary cartographical deliveries, the SI is completed by a **SIG** (Geographic information system). It has been decided to choose **ARCVIEW** for its simplicity, its power, its compatibility with ACCESS and its already current use in the water management. Moreover, it allows to write some specific utilitary entries on the pattern. The SPATIAL ANALYST and IMAGE ANALYST extensions have also been acquired to make interpolations between the points, iso-value cards, the scanned cards digitalisation and processing. **The chart herebelow** lists up the entities making up the SI, with first of all, the water point.

Table 2 : list of entities making up the SI

Entity	Description
Water point or work	Underground water work which can be a drill bore, a well, a spring, a piezometer…
Hydrogeol. unit or aquifer unit	A natural entity limited in space according to hydrogeological criteria. It is a unit for the evaluation and mananagement of ressources.
Topo Map	Reference of the sheet on which the water point was listed. The identifying factor of this entity includes the scale + the map n°
Administrative Area	A first level Administrative Unit (Governorate, wilaya, province)
Geophysical Zone	A Limited surface object of a geophysical study. The access key being the reference of the study.
User	Denomination of the user of the waters of the work : Name of an agglomeration, water supply company, irrigated perimeter, industrial or touristic unit …
Destination	Code and denomination of the entity for which the work is destined, once it enters into exploitation.
Type	Type of work (drilling, well, spring, …)
Condition	Present condition of the water point.
Object	Object of the water point at the time of its achievement (survey, exploitation, …)
Usage	Usage of the water point : domestic, irrigation, tourism, …
Level	Geological level of the layers crossed by the water point (the international codification is adopted, followed by the local name, if it exists)
Lithological Layer	Characteristics of the met formations , whether they are aquifers or not.
Stratigraphy	Relation describing the stratigraphy of the layers crossed by the water point.
Tubing	Relation desccribing the water point equipment
Basin slope	Natural surface entity
Weather station	Station to observe the weather parameters
Weather History	Relation containing the history of the weather observations values

Pollution Source	Identified Point liable to cause pollution : urban refuse , industrial unit, agricultural field …
Entity	**Description**
Date	Entity created in order to allow the setting up of relations with the water point. These relations consist in observations and chronological measurements (piezometry, intakes, …).
Piezometry	Piezometric levels report . The access key is composed of the identifying code of the water point followed by the measurement date.
Intakes	Intake report .The access key is composed of the identifying code of the water point followed by the measurement date.
Chemistry	History of the results of chemical analyses. The access key is composed of the identifying code of the water point followed by the measurement date.

The data design pattern has been elaborated while respecting the principle of the separation between the data structure and the processings it undergoes. we have considered that :

- a water point can catch one or several aquifers,
- on a given date, a water point has a fixed outflow ;
- a water point may serve several users ;
- a user may be supplied by several water points ;
- a water point has a mesh number in a given mesh net.

One can see that several parameters can be entered with respect to one single water point, such as climatology, its belonging to a basin slope, its topography, geology (lithological layers, stratigraphy, level etc…) piezometry, intakes, the users, its chemistry, to which are of course added the date of entry of the data and the precise location of the water point (coordinates, administrative entity), the exploitation history.

Once the SI is set up as per the above, a certain number of operations becomes hence possible : **statistic enquiries** (such as the number of water points per wilaya and per aquifer, year by year, intakes, variation of the piezometry,…), **drawings** (such as the evolution of intakes per aquifer and per year), **data transfers**, the **entry of new data,** some checkings, coherence tests, **DB-GIS connections and maps delivery**.

All these tools were gathered under the name **"SAGESSE" , (Assistance System for the management of the Northern Sahara Waters).** SAGESSE includes all the basic elements for the creation of an instrument panel for the follow up and the exploitation of the basin waters. We shall see, further down, that the link between SAGESSE and the SASS pattern shall allow, through appropriate simulations, some forecasts and prospectives for a durable management of the waters, which is the ultimate target of the SASS programme.

As a conclusion, we can say that we are now in possession of a very good quality management tool for each of the three countries and which is functional in each administration. The necessary materials and software for its use have already been acquired and installed in each country, and the concerned staff members are already trained. It should however be improved further. As a matter of fact, many boreholes are still deprived from any identifying code and do not have any coordinates, the spatial and time distribution is not homogeneous and the intakes are not well controlled. Moreover, a big number of boreholes are not yet indexed and entered in the base. A list of tasks specific to each country has been set up, and it is up to each administration to fullfil them.

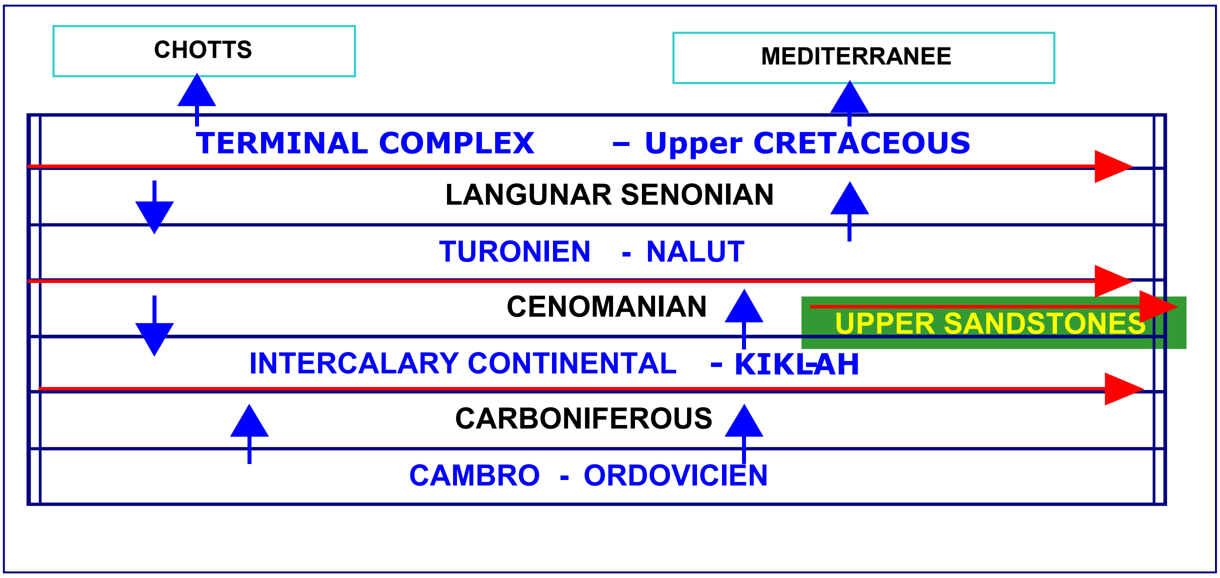
3.2- The SASS Model

The SASS model was elaborated in three stages : a first stage allowed to mark out the aquifer system, taking advantage of the hydrogeological studies described in paragraph 3-1, the second stage consisted in elaborating the mathematical pattern including the steps of its construction and its fixing ; the third stage was reserved to the achievement of provisional simulations according to different hypotheses.

The SASS model shall start from the multi-layer system described in 3-1, then it shall establish a spatial distribution of the piezometric levels on a given date, the transmissivities, the estimates of the top and the substratum, the intakes and drainging zones with a preliminary estimate of the flow exchanges and the potential flow exchanges between adjacent layers. Then, for each permeable layer, the historical series of intakes, of levels, of salinity, are identified, analysed and put into a format ; the spatial distribution of the storing coefficientrs is also set up.

All the parameters described in the preceding paragraphs are then taken into account for the hydrological and hydrodynamic characterizations. After a first adjustment stage, the model structure in the tunisian south was reviewed and a new structural plan for the model described in the following plan, was elaborated :

Fig.8 : Structure of the SASS Model



The grid of the model consists of **12.5 km x 12.5 km square meshes**, making a total of 16,523 meshes, covering a developed area of about **2.6 million km²**. The SASS model is a quasi three-dimensional model based on the hypothesis of a multi-layer system : **with a flow running parrallel to the layers in the acquifers and perpendicular to the layers in the aquitards**.

The selected software, to be installed on PC in the three countries, **is PMWIN – Version PM5**. An interfacing programme between the data base and PM5 has been developped.

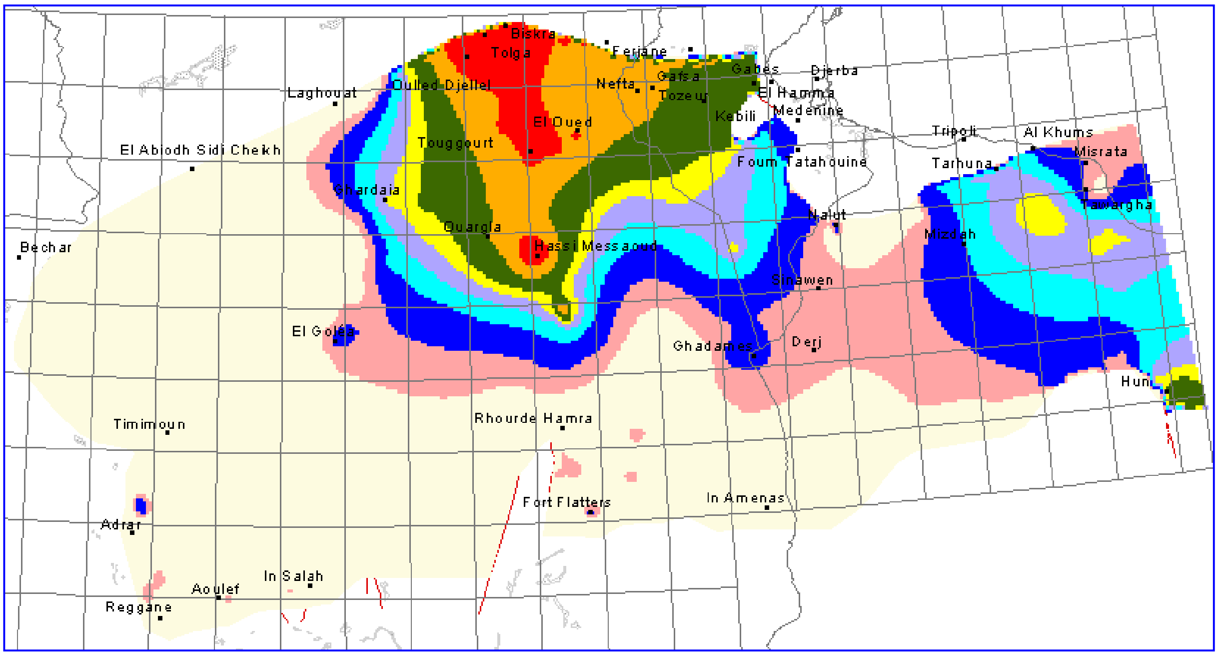
The model fixing was achieved afterwards, defining a state of reference. The state of reference for the fixing of a model has to reflect a **permanent regime of the system.** 1950 served as reference for the fixing under permanent regime. The system status variables (piezometric cards, observed punctual values, outflows) were reconstituted ; some modifications in the parameters were introduced and a SASS water balance was drawn out, for 1950. The distribution of the piezometric level differences [calculated – observed] makes up a good indicator for the "*regionalized fidelity*" of the model with respect to the reality on the field : 70% of the aquifer surface, both at the IC and the TC show gaps, inferior to 25 m. The superposition of the isopiezometric curves, calculated and observed, gives an idea about the capacity of the model to match up the shapes of the curves and thus to have the same point of view as that of the hydrogeologist.

After that stage, the **fixing of the model under a transient regime** was carried out, while making sure that the spatial distribution of the storing coefficients effectively took place. The model managed to deliver **1950 – 2000 drawdown maps** for the IC and the TC, that is to say **maps showing the decrease of the level of these two aquifers**. It also drew out the SASS balance in 1950 and in 2000.

The 2000 balance shows that the sum of inputs of the system corresponds to only 43% of the drill bore drawdowns, while the intakes from the reserves correspond already to 66 % of the drill bore intakes. The flow of the tunisian outlet has decreased by approximately 50% ; TC outlets to the chotts and sebkhas also show a sharp reduction : 2m^3/sec in 2000 against 8m^3/s en 1950 ; this evolution is presumed to be very dangerous for the chotts area.

The next stage was that of the provisional simulations :

Fig. 9 : 1950-2000 drawdowns as reproduced by the Model



Exploratory simulations have first of all been defined in order to evalute the SASS capacity to meet the expected requests. In order to do so, scenarii or development plans with respect to the year 2000, in terms of spatially distributed additional drawdowns have been specified. The conditions for the calculation, the inital status, the entry parameters, the conditions to the limits have been defined.

The adopted simulation period extends over **fifty years,** the reference initial status being that of the year 2000, is reproduced by the model. The simulated flow rate is constant throughout the calculation period, this flow corresponding to the maximum contemplated flow. Every scénario is defined by a maximum flow. The following results are produced for each scenario :

- 2000 – 2050' drawdowns map ;
- drawdowns curves for this period ;
- 2050' balance main terms ;
- evaluation of the scenario impact on each of the neighbouring countries ;
- map showing the depth of the piezometric level in 2050 with respect to the ground level ;
- map of the depth of this level under the algerian-tunisian chotts, definition of the intensity of the salinisation risk.

A **reference scenario**, consisting in maintaining the current situation, or **"zero simulation"**, sometimes called "business as usual " was defined. It consists in keeping the intake rates calculated in 2000, constant, and in calculating the corresponding evolution fifty years later.

Several other scenarii were then implemented :

- **For Algeria**, two scenarii :
  - An hypothesis called **high, corresponding to an additional intake of 101 m^3/s**, which would bring the algerian intakes from 42 to 143 m^3/s from 2000 to 2030 , and
  - An hypothesis called **low, for an additional intake of 62 m^3/s,** which would bring the intakes from 42 to 104 m^3/s .
- **In Tunisia** the contemplated scenario foresees that the savings made by improving irrigation efficiency will compensate the additional demand of the new irrigated perimeters ; it corresponds to the scenario called "business as usual".
- **In Libya** the exploratory simulations concern two programmes : the Ghadames-Derj pumping field, with an additional flow of 90 Mm^3/year, and the Djebel Hassaounah catching field.

The results of these scenarii are as follows :

- **Scenario zero :**
  - **for the IC :** scenario zero shall entail important drawdowns, superior to **40 metres** in the lower algerian Sahara ; in Tunisia, they shall be of about 20 m, sometimes 25 and 40 around Chott Fedjej ; in Libya, the drawdowns shall be of about 25m.
  - **for the TC :** this scenario gives the following results : in Algeria, drawdowns exceeding 30m and 60m around the chotts ; in Tunisia 20 to 30m, in Libya, 60m as a maximum.
  - One shall also record a total disappearance of all kinds of artesianism in the region of the algerian-tunisian chotts. we finally demonstrated that there is a risk for a refeeding of the TC sheet by the waters from the chotts, with a high probability for a contamination by salts. **From this point of view, carrying on the same pace constitutes a major potential danger.**
- **"High Hypothesis" Scenario :**

  At the IC, the drawdowns shall be of **300 to 400m** in the lower algerian Sahara, with a total disappearance of artesianism ; Libya is not concerned by this scenario, as for Tunisia, drawdowns of **200 to 300m** as well as the disappearance of arterianism and the tunisian outlets shall be recorded.

  At the TC, there is no impact in Libya, there are important drawdowns in Algeria, the chotts shall be in a position to be refed with water .
- **"Low hypothesis" Scenario :**

  At the IC the drawdowns are also important (250 m), artesianism disappears from all the southern part of the Sahara, the pumping depths are of 100 m, the tunisian outlet has dried up.

  At the TC the drawdowns are high and the chotts are in a position of potential refeeding. In Libya, no effects are recorded.

  These exploratory simulations show the risks to which the water resources are exposed. In order to keep on exploiting the IC and TC water sheets, such risks have to be minimized and managed, as follows :

  - Disappearance of artesianism
  - excessive and costy pumping depths
  - drying up of the tunisian outlet
  - exaggerated interference of the drawdowns between the countries
  - potential refeeding by the Chotts.

These simulations have shown the limits of the pure simulation approach in the perspective of the research of durable managament plans for the SASS. Another way to define some acceptable solutions was looked for, through the elaboration of a **miniature model, or micro model.**

Its principle is as follows : in a mesh **"i"** , an intake equal to the flow unit is applied and maintained constant during the whole simulation period, and then the drawdown in each of the meshess of the model is calculated ; the calculation is then carried out again with respect to all the meshes in order to reach a matrix of influence at $\mathbf{n^2}$ where n corresponds to the total number of the model meshes. A formula is then obtained, which defines the drawdown provoked in **j** through a pumping in **i.** In fact, the calculation shall be limited to the meshes which shall be called to serve, at one particular time, for pumpings. By doing so, one make do without development scenarii which seem to be, at first sight, without any direct relations with the characteristics of the aquifer, based exclusively on the forecasts of water needs, in order to built up scenarii on a **"hydraulic" only on the forecasts of the water needs, in order to build up scenariis on** basis, basis, that is to say based on the SASS production capacities while minimising the detrimental factors.

We were led to define all the potential pumping sites, namely **89 sites** (55 at the IC and 34 at the TC). Each site made the subject matter of a unitary simulation calculating, over 50 years, the drawdown function. We had to construct a flow-drawdown converter allowing the user to have, on the same screen, both the data and the results; this was furthermore made easier by the decomposition of the study space into micro-models per country and per sheet, with transborder pilot wells.

Fig.10 : Flows – Drawdowns Converter

Zone	A	B	C	D	E	F	G	H	I	J	K	L	M	DRAWDOWNS
Flows	0	5	0	0	0	3	0	2	0	3	5	0	0	18
A	0	8	0	0	0	0	0	0	0	0	0	0	0	8
B	0	250	0	0	0	0	0	1	0	2	4	0	0	258
C	0	68	0	0	0	0	0	0	0	1	2	0	0	72
D	0	4	0	0	0	0	0	0	0	1	2	0	0	9
E	0	8	0	0	0	2	0	9	0	35	79	0	0	134
F	0	1	0	0	0	43	0	4	0	4	5	0	0	57
G	0	5	0	0	0	15	0	16	0	23	30	0	0	90
H	0	2	0	0	0	6	0	54	0	43	42	0	0	147
I	0	1	0	0	0	6	0	41	0	23	23	0	0	95
J	0	4	0	0	0	4	0	29	0	98	125	0	0	259
K	0	4	0	0	0	3	0	17	0	75	118	0	0	216
L	0	2	0	0	0	1	0	7	0	28	75	0	0	113
M	0	1	0	0	0	2	0	14	0	39	74	0	0	130

The result of the simulations realised on the micro- model allowed to foresee a certain number of scenarii which meet the development objectives while minimising the degradation risks. These scenarii were afterwards simulated on the digital model and gave more complete results, allowing to specify the constraints.

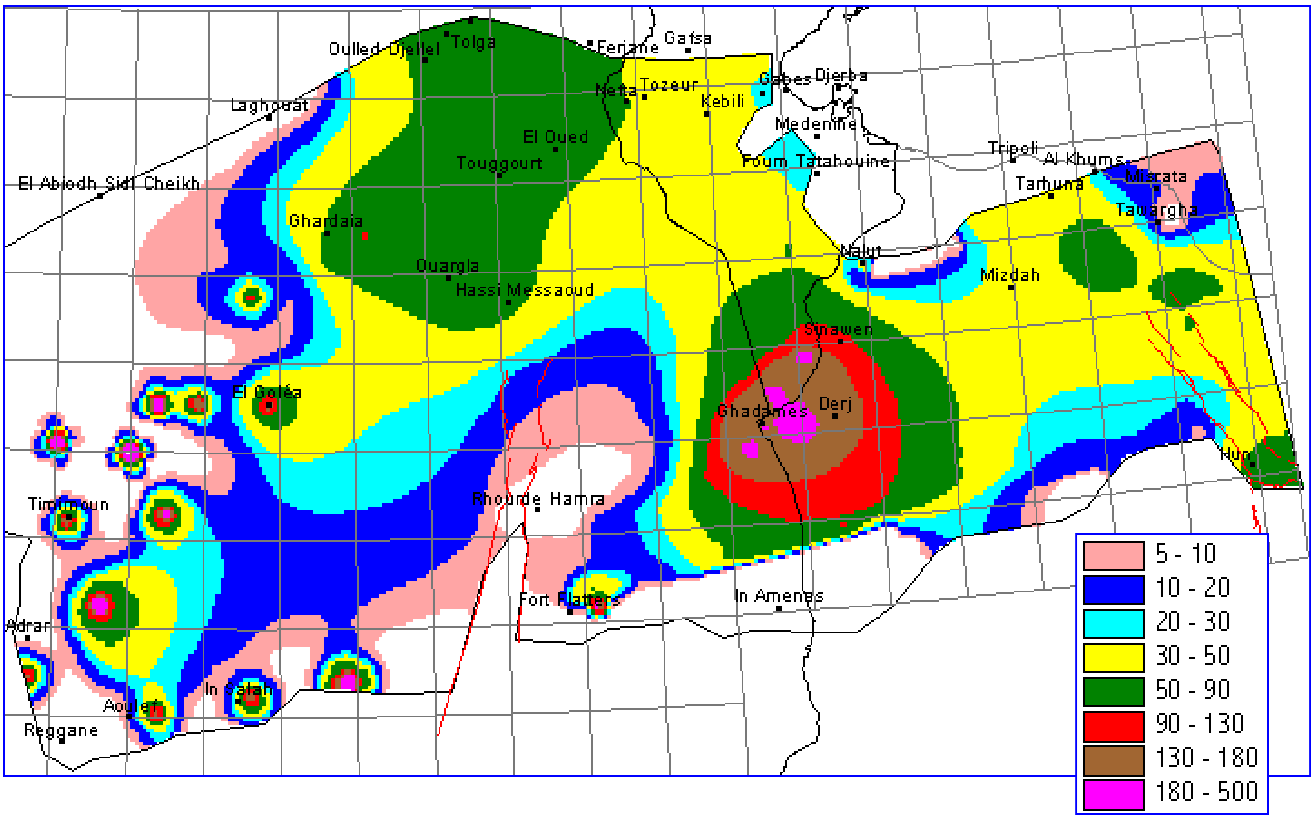
The exit indicators are : the net drawdowns, the drawdowns interfeence, the outlet flow, artesianism for the IC and the position of the levels with respect to the chotts for the TC ; the water balance in 2050. Eight simulations were achieved on the IC and five on the TC, the number and nature of the simulations being fixed by the hydrogeological province : lower algerian Sahara, Tunisia, Ghadames basin, the whole of the IC on the central basin, the big western erg, the whole of the IC, Libya ; Oued Mya.

One of the results of the carried out investigations allowed to confirm that there was a possibility to bring the SASS exploitation per boreholes up to the level of **7.8 Billion m3/year by 2050**.

Reaching such a development level could be achieved only at the cost of a breaking off with the traditional exploitation regions : **80% of the additional drawdowns have to be made in "new" and remote areas :** the IC Western Basin, the far southern parts of the TC…

Per country, this corresponds to **6.1 Billion m3/year in Algeria, 0.72 Billion m3/year in Tunisia, 0.95 Billion m3/year in Libya**. Such a possibility would bring the SASS exploitation to a level exceeding by eight (8) times its renewable resources. Such an operation is possible only by means of an important pumping out of the reserves of the system.

Fig. 11 : Final Simulation at the IC (CI8) ; drawdowns induced in 2050



As it could be noticed, the combined exploitation of hydrogeological knowledge and the use of a model allow to reach some realistic conclusions on the SASS capacities to supply noteworthy water quantities while minimising the risks caused to the environment. The obtained results show that it is more judicial to **jointly** manage this resource. It is in the perspective of preparing such a joint utilisation that a **"concertation mechanism"** has been developed, as described in the following paragraph.

3.3- The Concertation Mechanism

The simulations realised on the Model have shown the zones where the shared resources seem to be most vulnerable. Between Algeria, Tunisia and Libya, the present Terminal Complex, and the Intercalary Continental, in the future, are in such a state of exploitation that it is mandatory, sooner or later, to adopt a joint control policy if not a reduction in the pumping flows. How could such flows be controlled within the framework of the States' will to mutually work for the region better future, notably through a concerted policy targetting the protection of the water resources ?

Among the reasons which urge to act in a concerted manner, we quote the management of crises and more particularly the risk for the degradation of the resource ,as a result of an over-exploitation, which makes up a major reason.

Besides, the recourse to partnership in the course of the SASS project has progressively instaured a mutual trust climate between the technical teams, it has enhanced the conviction that joint action improves the efficiency of the solutions and strenghthen the certainty that the exchange of information, which makes up the basis of any kind of solidarity, has become, at the end of the SASS programme not only a possible but also a necessary activity.

As a matter of fact, the process which guarantees the control while showing the minimum of constraints is actually the information exchange.

in this respect, the OSS, has already allowed, through the SASS programme, the achievement of considerable steps forward: the elaborated Data Base including all the present and past information on all the water points, their levels, their flows, is operational and accessible to the three countries. The good will of the three water authorities for the information exchange proved to be, in this sense, exemplary.

Besides, the SASS Model is already available and operational in each of the three countries. An efficient concertation may first of all consists in securing the maintenance, the development and the permanent updating of the two following tools : the Data Base and the Simulation Model. This mission should be bestowed to a permanent body endowed with the indispensable qualities to secure perenniality to the operation.

From the SASS study to the Mechanism Project

The present SASS situation requires a tight concertation between the three countries, through the bias of a permanent three-party-mechanism in charge of the SASS. For this purpose, a certain number of proposals under the form of a concertation mechanism inspired from the existing institutional procedures, have been submitted within the framework of the FAO-*TCP/RAB/0065* project*,* carried out in close coordination between the OSS and the concerned countries.

In the light of these proposals, we can consider that the three countries are favourable to the creation of a permanent three-party mechanism of concertation at the level of the SASS.
The starting point shall be the necessity to maintain and develop the SASS common data base, as well as any other system for a regular exchange of data and information. The exchange of data should afterwards serve as a basis for the definition of water strategies and policies. Hence, the setting up of an elaborated and durable institutional mechanism proves to be necessary, its implementation should be made progressively.

National Worshops and Regional Workshop

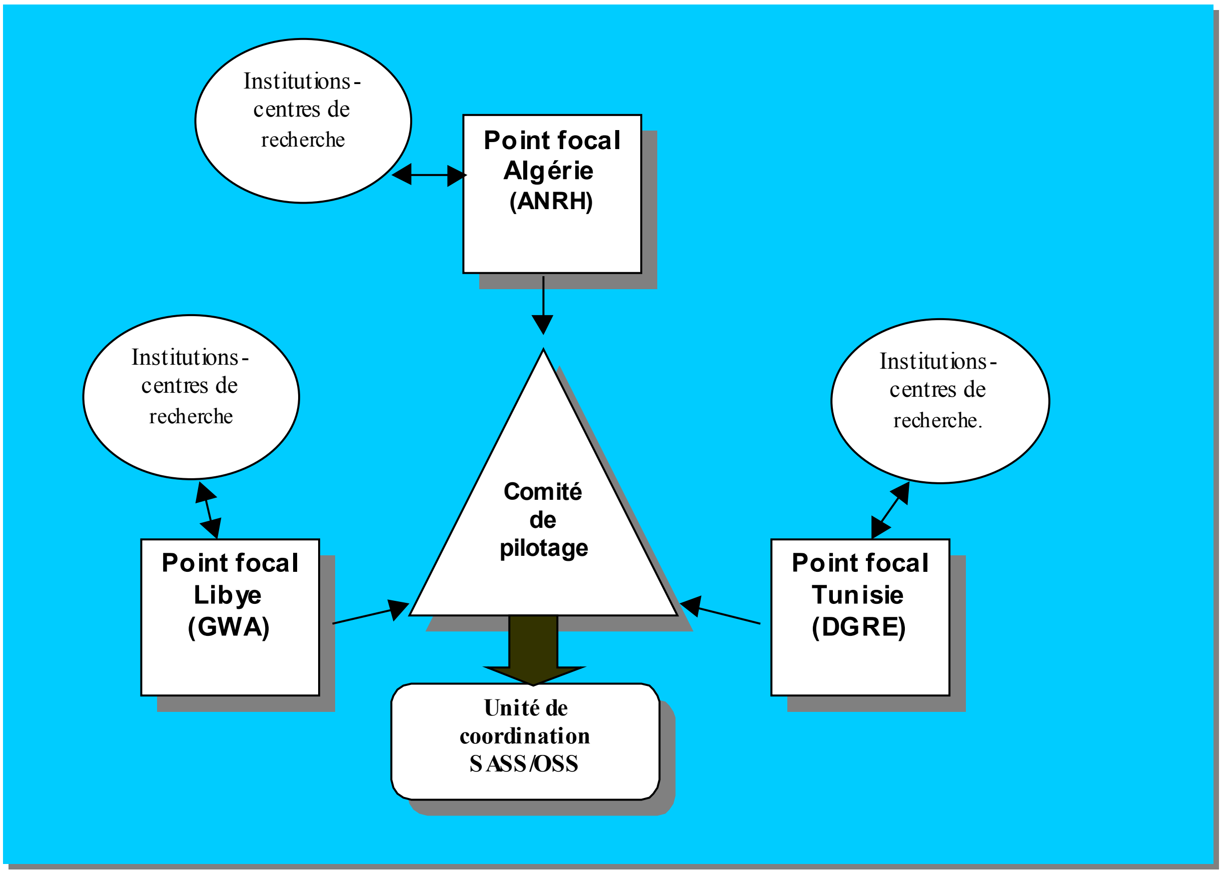
The selected working method for preparing the mechanism consisted in elaborating all the reflection, the ideas and the proposals, following evaluations made by national consultants in each of the three countries. All these proposals are then discussed in the course of three national workshops held in Tripoli, Tunis and Algiers, respectively, in november 2002. Out of these three workshops, a number of converging points as well as a consensus emerged, they related to :

- the necessity to secure a continuity to the works concerning the improvement of the knowledge and exploitation of the system (evaluation of the risks, management of the common Data Base, updating of the Model, setting up of a common observation network, training, understanding of the social-economic problems, development of research, etc…)
- the necessity to set up a concertation mechanism and its institutional rooting as a first stage, within an international body, namely the OSS.

- the necessity to strengthen the technical tools, the definition of a working programme, more particularly the common observation network, and a protocol for the exchange of information
- the progressive implementation of this mechanism, starting from an efficient and light structure towards a more autonomous and more elaborated mechanism enjoying, in due course, more important prerogatives.

The synthesis Regional Workshop was held in Rome on December 19-20, 2002. At the end of the discussions and the debates, which lasted two days, the participants aproved the following form concerning the implementation of the SASS Concertation Mechanism.

Fig.12 : organization chart of the concertation mechanism during its first stage



Research institutions-centres
Focal point Algeria ((ANRH)
Research institutions-centres
Steering committee
Focal point Libya (GWA)
Research institutions-centres
Focal point Tunisia (DGRE)
Coordination Unit Sass/OSS

Characteristics of the Concertation Mechanism

The main characteristics, agreed upon in Rome Workshop, are the following :
The Objective *is to* Coordinate, promote and favour the rational and concerted management of the SASS water resources.

The structure is composed of :

- *a steering commitee* composed by the national structures in charge of the water resources, acting as national focal points ;
- *a coordination unit* managed and hosted by the OSS ;
- *an ad hoc scientific committee* for the evaluation and the scientific orientation.

Its main prerogatives are :

- the management of the tools developed by the SASS project (data base and management model) ;
- the implementation and follow up of a reference observation network ;
- the processing, analysis and validation of data on the knowledge of the resource ;
- the development of data bases on the social-economic activities in the region, with respect to the usage of water ;
- the production and publication of indicators on the resource and the usages in the three countries ;
- the promotion and realisation of studies and reseach works conducted within the framework of a partnership by competencies from the three countries ;
- the elaboration and implementation of training and enhancing programmes ;
- updating of the SASS model, on a regular basis ;
- reflecting over and formulation of, proposals on the evolution and functioning of the concertation mechanism, and on its implementation during the second stage.

4- CONCLUSION : SASS DURABLE MANAGEMENT

The SASS project has reached the set out objectives : it delivered to its partners, in full cooperation with them, an operational data base and a mathematical patern, as durable management tools of the water resources. Thanks to the SASS thorough knowledge of hydrogeology, the setting up of a data base, the creation of the mathematical pattern and the achievement of simulations, according to very different hypotheses, the palpable reached results , as far as the fundamentals are concerned, prove :

- **that the simple carrying on of the present intakes at the same pace may constitue a danger for the Terminal Complex sheet in the chotts region ;**
- **that the simulations based on high hypotheses lead to an unacceptable situation ;**
- **that there is a possibility to increase three times the present intakes, but the cost shall be a breaking off with the traditional exploitation regions : 80% of the additional intakes would be made out of "new" and remote regions : the Western Big Erg, the remote areas of the Eastern Erg ;**
- **that despite the efforts made by the project, some uncertainties subsist with respect to the knowledge of the system, which shall require the conducting of new investigations .**

The first stage of the OSS SASS programme was completed at the end of 2002, exactly within the set period and the budget allocated to the programme.*We can say, as a conclusion, that this first stage brought along some objective and rather optimistic prospects for the water exploitation, on the condition that the results and remarks entailed by the model, be taken into account in some concerted manner, and that, from now on, all the factors of risks as well as the socio-economic factors, pointed out by the SASS study, be considered.*

NORTH WESTERN SAHARA AQUIFER SYSTEM

JOINT MANAGEMENT OF A TRANSBORDER BASIN

RESULTS OF THE FIRST STAGE OF SASS

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 note has taken into consideration the whole works achieved from July 1999 up to December 2002, for the setting up of the different components of the SASS Project, namely : the Acquisition, Analysis and Synthesis of the hydrogeological data ; the Elaboration of the Joint Data Base and of the Information System ; the Development and the Exploitation of the SASS Mathematic Pattern ; the Setting up of a Concertation Mechanism for the joint management of the Basin.

PARTNERES

Agence Nationalledes Ressources Hydrauliques (ANRH, Algérie)

Direction Générale des Ressources en Eau (DGRE, Tunisie)

General Water Authority (GWA, Libye)

Fonds Internationanal de Développement Agricole

Département du Développement et de la Coopération Suisse

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Allemagne (GTZ)

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