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MANAGING TRANSBORDER OF GROUNDWATER BASIN IN GREAT MAN MADE RIVER AUTHORITY - LIBYA

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Abstract: *This paper is an attempt to pinpoint the progress in managing trans border groundwater basins in North Africa, namely the Nubian Aquifer System (NAS) that is shared by Egypt, Libya, Sudan and Chad and the North-Western Sahara Aquifer System (NWSAS) which stretches across an area of more than one million square kilometres, is shared by Algeria, Tunisia and Libya. The success in managing these water resources systems hinges on unified corporation of the states sharing these groundwater systems. The framework of this unified corporation is the establishment of a joint authority to study the resources system and monitor their piezometric development. The creation of a unified management strategy can be achieved by the establishment of a unified data base and calibrated hydro-geological model in addition to consultation scheme among the states sharing the groundwater resources. This paper introduces the trans-border cooperation in the framework of the Great Man Made River Project. In this case, the trans-border cooperation is strictly applicable to Jaghbub (in Libya)/ Siwa (in Egypt) region and Ghadames (in Libya)/Algerian development where joint cooperation of the two neighbouring states will result in a sound and sustainable resources development strategy on both sides of the boundaries.*

Keywords: GMRA, GMRP, Groundwater, Hydro-Geological, Modeling.

Introduction

At the beginning of the twenty-first century, the earth, with its diverse and abundant life forms, including over six billion humans, is facing a serious water crisis. All the signs suggest that it is getting worse and will continue to do so, unless corrective action is taken. This crisis is one of water governance, essentially caused by the ways in which we mismanage water. Solving the water crisis in its many aspects is one of the several challenges facing human kind as we confront life in this third millennium and it has to be seen in that context. Currently humans withdraw approximately 600-700 km^3 of groundwater per year (Shiklomanov, 1997). Some of this water is fossil water (ancient water that isn't routinely replenished) that comes from deep sources isolated from the normal runoff cycle. Although over-drafting and contamination of groundwater are known to be widespread and growing problems. Comprehensive data on groundwater resources and pollution trends are not available at the global level. Better management of water resources is the key to mitigating water scarcities in the future and avoiding further damage to aquatic ecosystem. In the short term, more efficient use of water could dramatically expand available resources. The Middle East and North Africa are regions plagued by lack of water. While action and cooperation among the states are necessary in sector other than water and the environment, water stands to become a tool which can enhance peaceful relations between the parties. The hydro-geological and simulation studies of the (NAS) concluded with following results:

- The total volume of freshwater in storage in the (NAS) is about 373 x 1012 m^3 and the corresponding recoverable volumes amounts to 8.9 x 1012 m^3 representing 2.4 percent of the total volume in place. Based on the current abstraction rate of 1380 Mm^3 per year, the recoverable volume for (NAS) would last for a period of 4680 years.
- In Post Nubian Aquifer System (PNAS) the volume of fresh groundwater amounts to 84.60 x 1012 m^3 and the corresponding recoverable freshwater is about 5.57 x 1012 m^3.
- The mathematical simulation model developed by the Centre for Environment and Development for the Arab Region and Europe (CEDARE) indicates regional behaviour of the aquifer systems as the result of the regional influence of future development scenarios. The model indicates limits for the development in the case of Siwa in Egypt and Jaghbub in Libya. The two sites are contiguous to the boundary between the two states where substantial hydraulic interface occurs. Thus, abstractions from Siwa and Jaghbub development have to avoid groundwater deterioration from saline water existing very close to the north of these sites.
- Groundwater flow across the political boundary by CEDARE model indicates a flow in (PNAS) from Libya to Egypt amounting 1.17 m^3/sec during a simulation period of 50 years while no significant variation would occur in the groundwater flow across the Sudan – Egypt border in the case if Egypt implemented East Oweinat project as planned. An increase of groundwater flow from Libya to Egypt is also predicated in correspondence to the piezometric depression created in Egypt by planned additional development of the New Valley and Siwa.

This paper is an attempt to pinpoint the progress in managing trans border groundwater basins in North Africa, namely The Nubian Aquifer System (NAS) that is shared by Egypt, Libya, Sudan and Chad and The North-Western Sahara Aquifer System (NWSAS) which stretches across an area of more than one million square kilometres, is shared by Algeria, Tunisia and Libya.

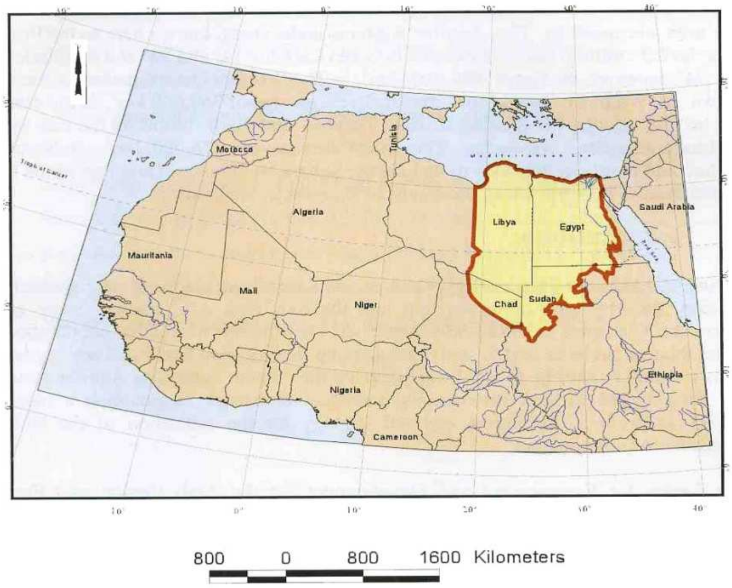
The Nubian Aquifer System (NAS)

During the past four decades, Egypt, Libya and Sudan have made separate attempts to develop the NAS. Since early seventies the three countries have expressed their interest in regional cooperation to share their experiences and to develop this regional aquifer system. They agreed to form a joint authority to study the NAS and also agreed to seek international technical assistance to establish a regional strategy for the utilization of the NAS. In March 1999 Chad actually became an active member of the authority. The Centre for Environment and Development for the Arab Region and Europe (CEDARE), The Sahara and Sahel Observatory (SSO) and The International Fund for Agricultural Development (IFAD) among others joined forces to develop a programme for the utilization of the NAS. The formulation of the regional strategy utilization study programme was funded by IFAD and was executed by CEDARE.

1.1 Location

The NAS underlies an area in excess of 2.5 million km^2 within the Eastern Sahara in North-East Africa (figure 1). The area occupied by the aquifer system extends between Latitudes 14° - 33° and Longitudes 19° - 34° to cover in Egypt 828,000 km2, in Libya 760,000 km^2, in Sudan 376,000 km^2 and in Chad 235,000 km^2.

Figure 1: Location Map of the NAS.



1.2 The Geology of the (NAS) and (PNAS)

The regional geological sequence of the NAS was originally established in Late Proterozoic times and continued into Tertiary. The long term geological and geophysical surveys revealed that the basement rocks are dominated by granites and overlain by a very thick sequence of sedimentary deposits. The stratigraphy of the Paleozoic, Mesozoic and Cenozoic sediment (sedimentary section) of the NAS is essentially obtained from the published technical reports and works mainly (Pallas - 1978, El-Ramely – 1983, Klizsch et. al. - 1987, Said – 1990 and Issawi - 1999). Using the geological time scale system in the description of the sedimentary section and avoiding all the local names given in the different countries to the stratigraphic units, the succession is differentiated into:

- The Cenozoic on top, comprising the Tertiary and the Quaternary carbonate sediments.
- The Mesozoic in the middle, comprising the Triassic, the Jurassic and the Cretaceous. This section is dominated by carbonate faces of marine origin intercalated with continental deposits.
- The Paleozoic at the base, dominated by sand faces with minor inter beds of carbonate beds.

1.3 The Hydrogeology of the (NAS) and (PNAS)

The strata of great hydro-geological interest are differentiated into two aquifer systems:

- The Nubian Aquifer System (NAS); underlying almost all the area of Egypt, Eastern Libya, Northern Sudan and Northern Chad. This consists of continental clastic sediments, mainly sandstone. It includes the main aquifers and overlies the Pre-Cambrian basement rocks. The strata forming the NAS range in age from the Cambrian to the Lower Cretaceous.
- The Post Nubian Aquifer System (PNAS); occurring to the north of the 26th parallel in the western desert of Egypt and North Eastern Libya. It is composed of marine sediments generally of clay, marl and limestone overlain by continental clastic sediments which exhibit faces variation in the Northern parts of Egypt and Libya to pass laterally into carbonate faces. This succession ranges in age from the Upper Cretaceous to Recent.
- The two systems are separated by low permeability layers (aquitard or confining beds).

1.3.1 Groundwater Extraction from the (NAS)

Groundwater from the NAS has been utilized since centuries in the Oases all over the area through springs and shallow wells. In 1960 the groundwater was extracted mainly from naturally flowing shallow wells and springs while now 97 percent of the extracted water is pumped from deep wells. The total extraction water from the NAS in 1998 is approximately 1376 Mm^3, of which 683 Mm^3 in Egypt, 286 Mm^3 in Libya and 407 Mm^3 in Sudan (CEDARE – 2001). The total groundwater extracted from the PNAS in 1998 is approximately 911 Mm^3, of which 346 Mm^3 in Egypt and 565 Mm^3 in Libya.

1.3.2 Groundwater Quality of the (NAS) and (PNAS)

Water quality in the unconfined part of the NAS is good (TDS less than 1000 ppm) to excellent (TDS less than 500 ppm) all over the area. For the confined part of this system particularly in the area up to Latitude 30° in Egypt and Latitude 26° in Libya, the water quality changes laterally and vertically where the upper part of the confined aquifer system (Mesozoic) contains fresh water (TDS less than 2000 ppm) while the lower part of the confined aquifer system (Paleozoic) becomes saline very rapidly north of the Latitude 26° and west of Longitude 27° till it reaches the freshwater / saline-water interface where the whole aquifer become saturated with hyper-saline water. On qualitative basis, the groundwater of the PNAS shows a wide variation in chemical quality. In areas of intensive development as Sarir, Jalo, Siwa and Wadi El-Fareigh the good quality of water is endangered by up-coning and/or the lateral flow of saline water.

1.3.3 The (NAS) and (PNAS) Potential Groundwater Resources

The CEDARE study concluded that the total volume of fresh groundwater stored in the NAS is about 373 x 1012 m^3. The total recovered groundwater from the NAS is about 8.9 x 1012 m3 representing approximately 2.4 percent of the volume in the aquifer storage. Therefore, if the annual groundwater extraction of 1380 Mm^3/year presently extracted in the aquifer four sharing countries would be kept constant, the recoverable reserves would last for a period of about 4860 years. The study also indicated that the total volume of fresh groundwater in PNAS storage is about 84.60 x 1012 m^3. If we limit the freshwater occurrence to the North by the depression marked by several Sabkhas along the parallel 30° north the recoverable volume of freshwater is about 5.57 x 1012 m^3.

1.3.4 Mathematical Model of the (NAS) and (PNAS)

The model developed by the CEDARE for the NAS and PNAS is not supposed to provide a detailed prediction of the aquifer response to various water development scenarios, but it has been designed to predict the regional behavior of the aquifer and the regional influence of water development scenarios in existing and future well fields. As anticipated, the unconfined part of the NAS includes the most important groundwater potential of the whole basins; therefore, the extension of the cones of depression resulting from the water abstraction in existing and future planned well fields in that part of the Nubian domain is always limited. North of the 26th parallel, on the contrary, where the Nubian is under confined condition, the aquifer response to water abstraction makes up a unique large cone of depression, though deeper in correspondence to the abstraction zones. This behavior of the Nubian aquifers, north of 26th parallel made it necessary to limit the future groundwater abstraction much lower than proposed. In the case of Siwa in Egypt and Jaghbub in Libya (at the political border) the interference between the two development areas is so strong, hence, the planned abstraction have to be limited to 68 Mm3/year from both areas to avoid the deterioration of the groundwater with the saline water that exists very close at the north.

The flow across the political boundaries was calculated by the CEDARE model at various periods of the simulations as follow:

- For the PNAS, the flow from Libya to Egypt would be approximately 1.17 m^3/sec. all over the simulated period (1960-2060).
- For the NAS, no significant variation would occur in the flow across the Sudan – Egypt border if Egypt implements East Oweinat project as planned. An increase of the flow from Libya to Egypt would also be observed in relation to the piezometric depression created in Egypt by additional development of the New Valley and Siwa.

2. The North – Western Sahara Aquifer System (NWSAS)

The Saharan Aquifer Systems is the name given to two main bearing layers, the Intercalary Continental (IC) the deeper of the two and the Terminal Complex (TC) an aquifer strongly exploited. The aquifers stretch across an area, in North Africa, of more than one million square kilometers of which 60 percent in Algeria, a little less than 10 percent in Tunisia and 30 percent in Libya. Because of the Sahara climate, the two aquifers system receives little recharge, i.e. a total of about one million m^3/yr, which mainly infiltrates the piedmont of the Sahara Atlas mountains in Algeria, and Jabal Nefusa and Dahar in Libya and Tunisia respectively. Considerable reserves have been accumulated in the two aquifers from pervious Pleistocene pluvial periods (fossil water). A conclusion can be drawn from previous recharge studies that the two aquifer systems receive, at the present, very little meteoric recharge and the management of these aquifers should take into account the impending ultimate depletion of their reserves. Thus, the problem encountered by the three sharing states is how far can the Sahara aquifers be exploited above their recharge rates (defining the safe yield of the two aquifers) and maintain sustainable development and avoid risking irremediable harm to the resource level. During the last three decades, abstractions from wells have seriously punctured these groundwater reserves. Between 1970 – 2000 the amount of water that was drawn for agricultural, industrial and domestic use rose from 0.6 to 2.5 billion m3/yr, and as the wells dried up, they were replaced by deeper wells.

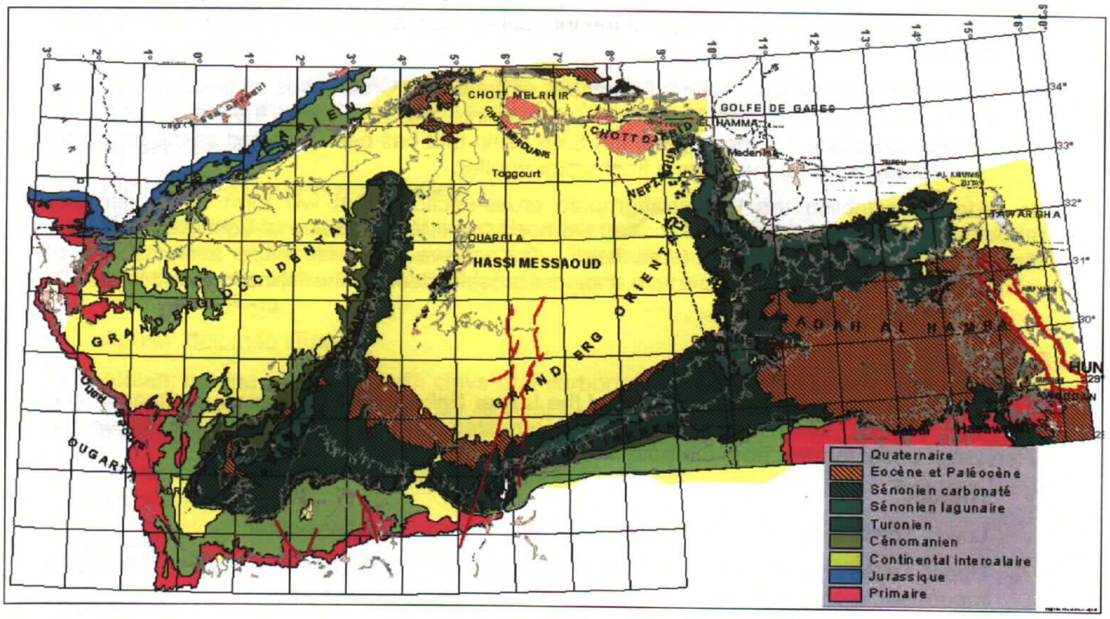
The Saharan system has been identified and exploited through 8800 water points, wells and sources of which, 3500 in (IC) and 5300 in (TC). The breakdown per country is; 6500 in Algeria, 1200 in Tunisia and 1100 in Libya. Continuing the abstraction trend in the three countries could jeopardize the future of the Sahara regions, where the first signs of deterioration in the state of the water resources are already beginning to appear. This is the main problem facing the development of (NWSAS). The increased development of (NWSAS) is creating sizable risk such as strong inter-country hydraulic interference effects, deterioration of water quality, elimination of artesian, excessive pumping depths, etc. Thus, the three countries sharing the resource system realized the impending problems of sustainable use of these reserves and strove to improve the existing state of knowledge and the natural management of these reserves. Therefore, a joint comprehensive programme was launched by the three countries under the administration of the Sahara and Sahel Observatory (SSO) to model and evaluate the usable resources and predict their future use.

3.1 The Geology of the (NWSAS)

The term Intercalary Continental (IC) refers to a continental sequence between two marine sedimentary cycles: the Palaeozoic cycle, the final phase of the Hercynian Orogeny below, and the Upper Cretaceous cycle above, The Terminal Complex (TC) is a very mixed group that includes Upper Cretaceous carbonate formations and clastic deposits from the Tertiary, particularly the Miocene. Figure (2) is a geological map of the North Western Sahara platform which shows extensive outcrops of the Upper Cretaceous that starts with the Cenomanian transgression. A geological database from 175 oil wells and deep water boreholes, were used in a lithostratigraphic correlation of the regional geological succession of aquifer formations identified in Algeria, Tunisia and Libya respectively. The final step of a simplification produced a conceptual model of the (NWSAS) exhibiting three aquifer layer separated by semi-permeable layers (aquitard). If we exclude the salt water aquifer layers of the Triassic and Jurassic in Algeria and fresh water aquifer of the Triassic sandstone aquifer in Libya and assuming purely lithostratigraphic criteria what we get three superimposed water bearing formation levels of unequal size, their vertical organization and regional connections clearly become apparent. From bottom up the three superimposed layers are as follows:

- The Intercalary Continental (IC) in Algeria and Tunisia extends in Libya as the Kiklah aquifer.
- The Turonian Aquifer in Algeria and Tunisia extends in Libya as the Nalut aquifer.
- The Limestone Aquifer in Algeria and Tunisia (Senonian and Eocene carbonates) in Algeria extends as the Nefzaoua limestone aquifer in Tunisia and its equivalent is the Mizdah aquifer in Libya. The Mio – Pliocene aquifer is also included in this group to form the Terminal Complex (TC).

Figure 2: The Geology of North – Western Sahara Platform.



3.2 The Hydro-geological Simulation Model

One of the main objectives of the study on the North – Western Saharan Aquifer System was to construct a multi – layered digital simulation model. The model was programmed to make a coherent synthesis of data and hydro-geological knowledge acquired on aquifers and water resources assessment projects contributed by the sharing states, as well as to determine the exploitable resources and draw up the terms and conditions for managing these resources on the basis of development scenarios. The model consists of 16,523 elements and covers an area of nearly 2,580,000 km^2.

3.2.1 The Exploratory Simulation

Initially, the exploratory simulation were adopted to assess the ability of the (NWSAS) to achieve the three countries objectives for water resources and give indication of what is required and how far we can go exploiting these water resources given the uncertainties regarding hydro-geological, economic and social parameters. The exploratory simulations are run for 50 years and the initial references state being the year 2000 as reproduced by the model. This scenario consists of keeping the year 2000 abstraction rates as shown in table (1) below and computing water level changes in the system over the next 50 years. This unlikely scenario is necessary in order to assess and compare the effects of the various other scenarios in an informed manner.

Table 1: The year 2000 abstraction rates for the exploratory simulation – zero (m^3/sec)

Country	(IC)	(TC)	Total
Algeria	21.2	20.9	42.1
Libya	3.4	7.4	11.8
Tunisia	2.7	14.5	17.2
Total	**30.2**	**42.8**	**70.1**

Source: The Centre for Environment and Development for the Arab Region and Europe (CEDARE) 2001, Regional Strategy for the Utilization of the Nubian Aquifer System, Vol. I, II & III.

Drawdowns are calculated and figure (3) and figure (4) show in turn the map of drawdowns in the (IC) and (TC) respectively in year 2050. The effects of maintain the year 2000 abstraction rates would result in a considerable drawdowns by year 2050 throughout the Algerian Lower Sahara in the (IC) and in Tunisia the drawdown is about 20 m everywhere. In Libya the drawdowns are about 25 m in a 100 km X 300 km strip around the main exploitation at Bani-Walid, Wadi Zamzam, Wadi Ninah and Sufaljin. Elsewhere, drawdowns are calculated at 10 m throughout Al-Hamada Al-Hamra. Artesianism is lost in El-Borma and Ghadames sectors.

In the case of the Terminal Complex (TC) drawdowns in Algeria are more than 30 m throughout the Oued Rhir Valley and reach 60 m north of the Chotts. In Tunisia drawdowns are between 20 m and 30 m throughout Djerid and Nefzaoua. In Libya the maximum drawdown (about 60 m) is in the south – east, around Soknoh, Hammam and Ferjan. The next two exploratory simulations are related to Libya:

Figure 3: The Drawdown in the Intercalary Continental (IC) Aquifer (2000 – 2050)

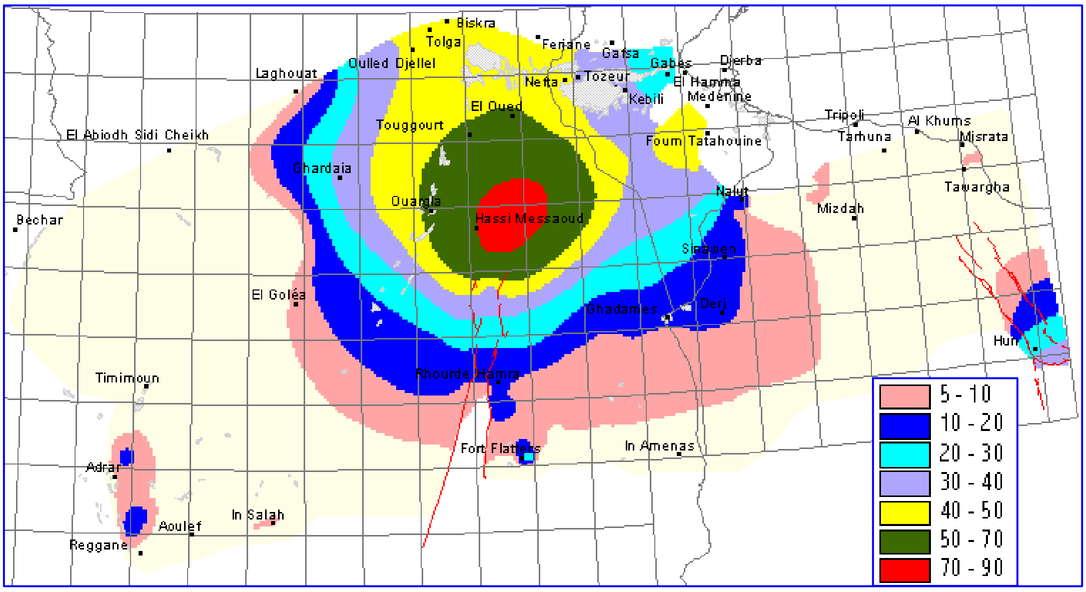
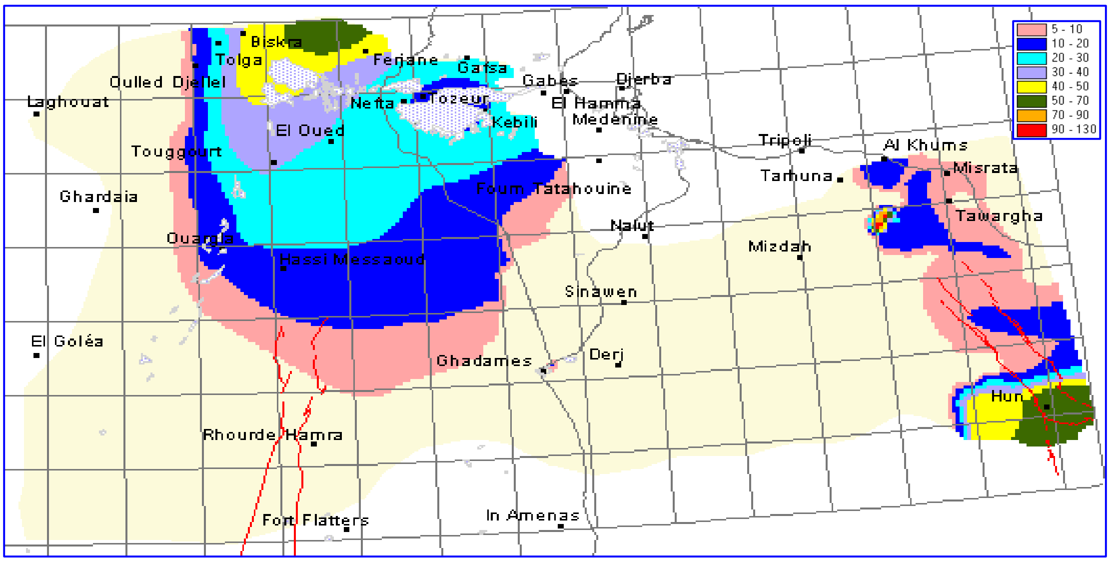


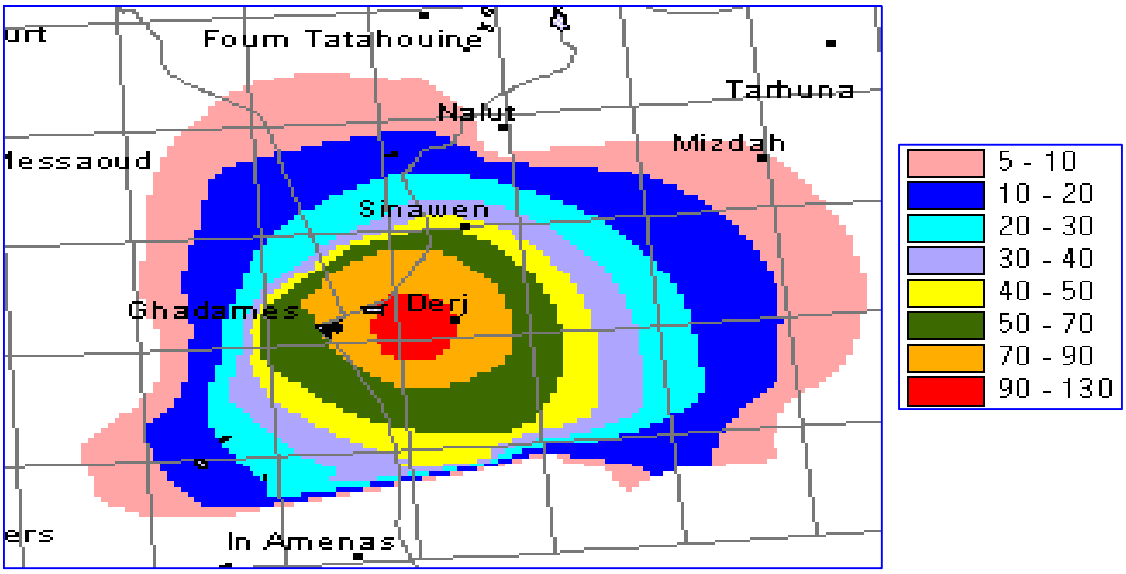
Figure 4: The Drawdown in the Terminal Complex (TC) Aquifer (2000 – 2050)



3.2.1.1 The Ghadames Field (Phase 4 of the GMRP)

This simulation represents constant abstraction at a rate of 2.85 m^3/sec in the Ghadames – Derj wellfield presently under construction. Abstractions are from the (IC) aquifer from 2001 to 2050. The net drawdown equals the drawdown calculated from this simulation minus the corresponding drawdown calculated in the zero simulation. This represents the specific impact of the Ghadames abstractions as shown in the drawdown map of figure (5). The effects of this scenario are negligible in the case of the (TC) aquifer. However, in the Intercalary Continental calculated net drawdown are around 100 m in the Ghadames – Derj wellfield and these effects become negligible in a distance of 200 to 300 km away from the field. The Tunisian far south is affected throughout by the withdrawals from Ghadames wellfield where induced drawdowns vary between 10 m (200 km from the wellfield to 80 m at Borj El-Khadra). In Algeria induced drawdowns are around 60 m in the Debdeb region.

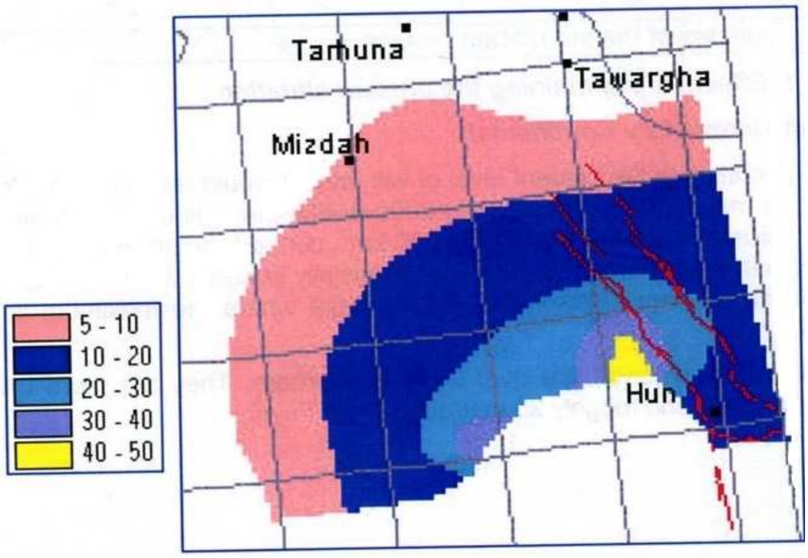
Figure 5: The Net Drawdowns in the Intercalary Continental (IC) Aquifer in year 2050, Ghadames Wellfield.



3.2.1.2 The GMRP Abstraction at Jabal AL-Hassauna Wellfield (Phase II)

These abstractions are effected by two wellfields, the North – East and East wellfields at Jabal Al-Hassauna, amount to 23 m^3/sec by pumping from Cambro – Ordovician sandstone aquifer. The numerical values for the drawdowns from the Cambro – Ordovician were obtained from Geomath's simulation (6) are imposed on the corresponding NWSAS model from year 2001 to 2050. The specific impact in Jabal Hassauna wellfields after deducting the effects of maintaining the 2000 abstractions rates on the (IC) are shown in figure (6).

Figure 6: The Net Drawdowns in the Intercalary Continental (IC) Aquifer in year 2050, Hasouna Wellfield



In the (TC) aquifer, the net drawdowns induced by Jabal Al-Hassauna withdrawals are slight with a maximum of 10 to 20 m in the centre of Hun Graben. On the other hand, in the (IC), the influence of Jabal AL-Hassauna withdrawals is limited to the Hamada – El-Hamra basin and does not reach as far as the Algerian and Tunisian borders. In Libya, calculated drawdowns for a ring centered on the wellfields with maximum of 50 m in south.

3.3 The Consultation Mechanism

Exploratory simulations and analyses of their results have pinpointed the risks of certain harmful consequences attached to continual development of the water resources at its actual pace. On the other hand, the predicative simulations is to check the raising of the (NWSAS) abstractions from 2.2 billion cubic meters per year, the year 2000 estimate to 7.8 billion cubic meters per year with undue disregard for restrictions imposed to parry the risk of resource degradation. In the case of (NWSAS) optimal solutions are possible only if the region traditionally subjected to intense exploitation is abandoned in favor of unconfined (high specific yield) and distant regions. These optimistic results of predictive simulations need to be strongly tempered. Emphasis must be placed on the need to confirm certain of these results and require further investigation. Increased exploitation of the (NWSAS) is only possible if sufficient hydro-geological information is available so that the impending risks inherent in the water resources system can be minimized and managed. This can be achieved by the three states sharing the water resources system to work together on some form of concerted basin management scheme in order to minimize impending risks inherent in the water resources system and thus maintain a sustainable resource management. After lengthy debate during three national workshops held in Tripoli, Tunisia and Algeria in November 2002 the following points of convergence and consensus were achieved:

- Continuation of work on improving the state of knowledge of the system and how it is utilized.
- Establishment of a consultation mechanism and anchor it in an institution (during the first phase, at the Sahara and Sahel Observatory (SSO), an international organization).
- Establishment Gradual implementation, of a simple, effectively structured mechanism that can become more elaborate and autonomous, and in time will be assigned more important attributions.

Another regional workshop was held at the Food and Agricultural Organization (FAO) headquarters in Rome during Dec. 2002, in which the creation of the consultation mechanism and the three countries recommendations were validated.

3. The Libyan Example of Trans border Cooperation: The Great Man Made River Project

The renewable water resource in North Africa represents only 2.5 percent from the total water resources of Africa while groundwater abstraction rates in North Africa amount to 46 percent of the total abstractions in African Continent. In Algeria, more than 60 percent of its water requirement is derived from groundwater resources while in Libya this percentage amounts up to 96 percent. However, it is obvious that North Africa consumes more water than is locally available of the renewable water resources. This has lead the countries of the region, especially Libya, to exploit the non-renewable water resources (fossil water) accumulated in the basins of southern desert region. Although, there are several projects operating actually and exploiting groundwater from sharing basins in the region but this paper would present the Great Man Made River Project, especially The Kufra - Tazerbo Water Supply System and Ghadames – Zuwarah - Az–Zawiyah System (Phase 4) that are exploiting the ancient groundwater from the NAS and the North Western Sahara System respectively, as an ideal example of the cooperative interactions that occurred in managing transborder basins.

The Great Man Made River Project scheme was devised to convey high quality ground water from deep aquifers in the Sahara Desert to the coast were over 90 percent of the population live. These vast water basins were discovered during the exploration for oil. Water is extracted in well fields and conveyed to the coast through four-meter diameter pre-stressed concrete cylinder pipes. Because of the size of the pipes and the amount of water they convey over thousands of kilometers, the scheme became known as The Great Man Made River Project (Figure 7). Phase I or the Sarir-Sirt/Tazerbo-Benghazi (SS/TB) conveyance of the project consists of two lines and involves conveying two million cubic meters of water per day, from well fields in Sarir and Tazerbo to end reservoirs at Sirt and Benghazi. The total length of PCC pipes used is 1900 kilometers, the majority being four meters in diameter. The system is designed to ultimately carry a flow of 3.68 million cubic meters per day in the future, with the additional water being drawn from a wellfield at Kufra. This phase is complete and under operation. Phase II of the Great Man Made River Project involves conveying two million cubic meters of water from well fields at East Jabal Hasouna and North East Jabal Hasouna to Tarhouna and Tripoli. Two hundred eighty-seven production wells at the East Jabal Hasouna well field will produce 1.4 million cubic meters of water per day and 153 production wells at North East Jabal Hasouna will produce a total of 0.6 million cubic meters per day. This phase is complete and under operation. The Gardabiya-Sedada system will link Phases I and II, enabling bi-directional flow. This phase is currently under construction and progress is 27 percent complete. Future phases include:

The Kufra-Tazerbo System, which will add 1.68 million cubic meters per day to the Phase I conveyance from about 285 wells in Kufra. At present, this phase is under construction.

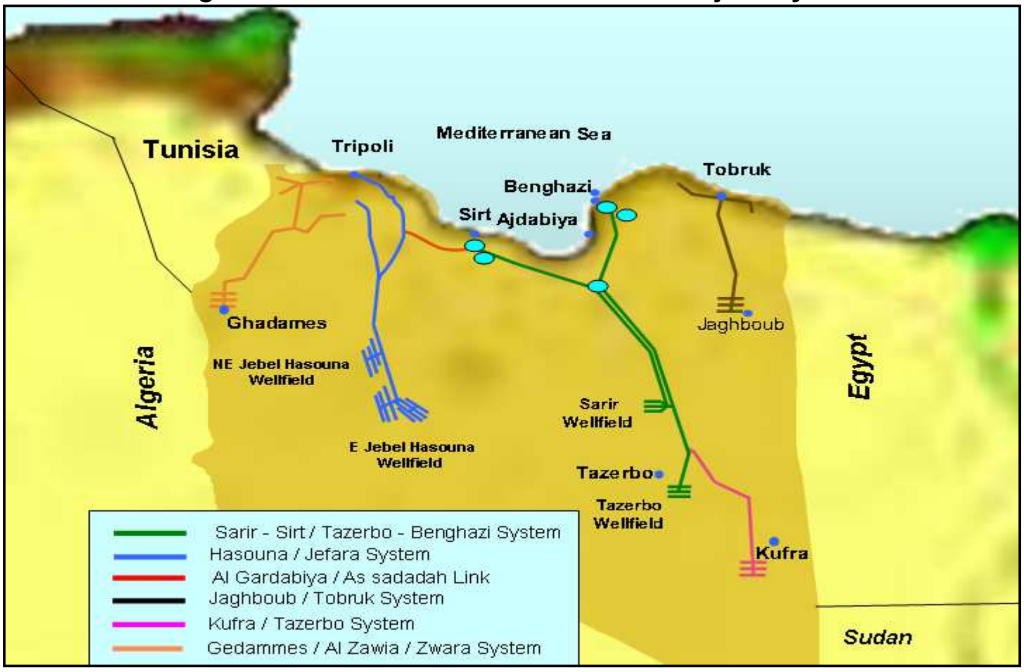
Jaghboub – Tobruk System, which will supply Tobruk and the eastern coast of Libya with 50 million cubic meters per year of water for domestic use from about 47 wells in Jaghbub.

Exploratory wells are currently being drilled in Jaghbub in order to determine the optimum location of the well-field.

Ghadames – Zuwarah, Al-Zawiyah System, which will have a total production of 90 million cubic meters per year from 106 wells in Ghadames. This phase is currently being under construction.

The Great Man Made River Project will ultimately convey over 6 million cubic meters of water per day through mainly 4-meter diameter pipes.

Figure 7: The Great Man Made River Project Systems



4. Conclusion

1. The Kufra - Tazerbo Water Supply System is based on the development of a new major wellfield at Kufra (in the Nubian Aquifer System), with a planned yield of 1.68 Mm^3/day. The Kufra wellfield supply will be connected through a conveyance pipeline directly to the Sarir – Sirt / Tazerbo -Benghazi System at a point approximately 100 km south of Sarir.

   The Kufra – Tazerbo Water Supply Project consists of:

   - 285 wells in the wellfield area.
   - 4 meter diameter of Prestressed Concrete Cylinder Pipe (PCCP) for the main conveyance pipeline. (Contract of pipe manufacturing has been awarded approximately $1000 million).
   - 383 km is the total length of the main conveyance pipeline. (Contract of pipe laying has been awarded approximately $600 million).
   - 10 conveying pumps at the Pump Station.
   - 2 Regulating Stations, 2 Flow Control Stations, and Break Pressure Station.

2. Ghadames – Zuwarah, Az– Zawiyah System (Phase 4) will be a water supply system from wellfield near Ghadames (The North – Western Sahara Aquifer System), located about 600 km south-west of Tripoli (about 400 km south of Zuwarah) , convey the water through pipeline and distribute to various settlements and existing agricultural projects on route and to coastal towns to Az- Zawiyah and Abu-Kammash.
   The Ghadames Water Supply Project consists of several components:

   - The well field, comprising 106 wells and the pipes used to convey water to the tank of the main wellfield pumping station (PS-1).
   - The subsystem between the pumping station of the wellfield and the tank of the second pumping station (PS-2). The total length of the section of pipe is about 62 km.
   - The subsystem between the second pumping station and the tank of the third pumping station (PS-3). The total length of the section of pipe is about 80 km.
   - The subsystem between the third pumping station and the Jawabiyah reservoir located at the highest point of the pipeline. The total length of the section of pipe is about 80 km.
   - The El Haraba branch, which serves different villages of the mountain area. This consists of a pumping station (PS-4) located on the site of the Jawabiyah reservoir and of a 61 km-long transmission main.
   - The downstream gravity subsystem, which serves all downstream towns and villages either directly from the pipeline itself or via the Al-Jawsh, Abu-Kammash and Az-Zawiyah branches. The Az-Zawiyah branch, which at first delivers water to Az-Zawiyah, is designed to convey water to Az-Zawiyah via PI-51 (control valve station) Az-Zawiyah branch in the other direction from Az-Zawiyah to Abu-Kammash, when Az-Zawiyah will be supplied from Tripoli. In addition, note that the huge difference in altitude between Jawabiyah and the coastal zone, solutions were taken to limit the pressures to admissible maximum values. The total length of the section of pipe is about 305 km.

5. References

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