Nubian Sandstone Aquifer System (NSAS)
Technical Baseline Meeting

May 8- 12, 2006
Vienna, Austria

IAEA RAF/8/036

in the frame of the

IAEA/UNDP/GEF Nubian Sandstone Aquifer System Medium Sized Project

April 13, 2007

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1. Introduction

At the Second Coordination Meeting, held within the Regional Project RAF/8/036 on *Sustainable Development of the Nubian Aquifer* in December 2005 in Cairo, Egypt, it was emphasized that "*one challenge in developing an adequate management strategy is to gain sufficient knowledge about the aquifer to develop a rational use of the resources that can benefit the four countries*". It was pointed out that there are still critical data and subsequently knowledge gaps of the NSAS. Consequently, it was requested to collect and assess all existing data and information to clarify the "baseline" situation of what is known and what is not known. Thus, a technical meeting was recommended to be organized by the IAEA in Vienna in May 2006, to establish the **"baseline"** technical knowledge and design isotope investigations aimed at filling the data and knowledge gaps. The participating countries were asked to continue with collecting samples to be delivered for isotope and chemical analyses and to provide necessary background information for the database and the assessment of the available data to the Agency as essential input to the technical baseline meeting.

In preparing the meeting, the four participating countries were requested to provide in advance a national report that includes a synthesis of all relevant technical information at the national level and a copy of the national part of the NARIS information system. Furthermore, the participating countries were informed that the technical baseline meeting would pursue the following objectives:

- Review and synthesize currently available technical information, with a focus on isotopic data, as a basis for updating the "baseline" knowledge of NSAS system;
- Determine important information gaps that need to be filled in order to better understand and assess transboundary issues;
- Consider strategies (sampling, monitoring etc.) that could effectively and efficiently lead towards filling these gaps;
- Develop concrete next steps for filling gaps in the frame of the IAEA's co-funded activities for isotope analysis in the IAEA/UNDP/ GEF Nubian Aquifer and in particular to support the development of a "Shared Aquifer Diagnostic Analysis (SADA)"

Finally it was highlighted that the following results/outcomes of the meeting were expected:

- Enhanced technical understanding of the NSAS, increased knowledge on both determined and potential transboundary issues;
- Better understanding of important knowledge gaps as well as needed activities e.g. sampling/ monitoring to fill the gaps;
- Agreement on approach for synthesizing and managing data in the frame of the project;
- Clear approach for isotope studies to support the development of the SADA.
- Sampling strategies for inclusions into 2006/07 work plan(s).

The meeting succeeded in clarifying the current baseline knowledge of the NSAS. The important knowledge gaps were identified and strategies for filling the gaps were discussed. This led to sampling plans for the respective countries for 2006- 2007. Some preliminary discussions were held concerning the approach for data management in the project as well as developing necessary links to past activities and existing databases (NARIS.) Discussions were begun on how future sampling campaigns could be used to support the SADA (Shared Aquifer Diagnostic Analysis) and SAP (Strategic Action Programme) processes. Unfortunately, Egyptian representatives were not able to attend the meeting. However, information was subsequently provided and included in this report.

Discussions related to the Nubian Baseline were subsequently continued during the Nubian Inception Meeting that was held in Tripoli, Libya July 16-20, 2006. The sampling strategies were also presented by each country again, in some cases updated since the Baseline Meeting in May. These updated sampling strategies are attached.

Finally, it is clear that continuous efforts must be made to improve the baseline of information and the participants underlined their commitment to undertake technical investigations necessary to improve the knowledge base needed for effective management of the NSAS. The added information along with renewed analysis efforts (modelling, SADA process etc.) will improve the baseline thereby providing a better basis for sound management.

2. THE MEETING

The meeting was opened by welcoming remarks of Mr. A. Boussaha, Director of Division for Africa, Department of Technical Cooperation, and Mr. P. Aggarwal, Head of the Isotope Hydrology Section, IAEA. They highlighted major objectives and expected outcomes of the meeting and informed that the Egypt counterpart was unable to attend the meeting. After adopting the revised Agenda of the meeting, the participants elected Mr. Mohamed Al Hassan Ibrahim, Sudan, as Chairman, Mr. Yves Travi, IAEA Expert, Co-Chairman, and Mr. K. Froehlich, IAEA Expert, as Rapporteurs for the meeting. The Final Agenda and List of Participants of the meeting are given in the Annexes of this report.

Following detailed background information on the IAEA/ UNDP/GEF Nubian Project Preparation and on the scope and objectives of the meeting given by Mr. A. Garner, Technical Officer and Task Manager for the project, the current technical knowledge of the NSAS was reviewed by presentations and discussions of national reports. These reports were presented by Mr. Lotfi A. Madi, Libya, Mr. Noe Reouebmel, Chad, and Mr. Mohammed El Hassan Abu Buker, Sudan and are highlighted in Section 3 of the report. Following these country presentations, Mr. K.Froehlich presented a “Review of current technical knowledge of the NSAS and identification of knowledge gaps” to which Mr. S. Kebebe, IAEA, contributed GIS figures and data from the ISOHIS. Based on both the national presentations as well as these subsequent technical presentations and the ensuing discussions and additional information provided, the current technical baseline has been summarized in Section 4 of this report.

During the second half of the meeting, special technical aspects were discussed; in particular an overview of NARIS was given by Mr. Lotfi A. Madi, Libya. Gaps in knowledge as well as strategies for addressing gaps were discussed. Mr. Garner presented the approach for developing Nubian Shared Aquifer Diagnostic Analysis (SADA) as well as the Nubian Shared Action Programme (SAP.)The national work plans focusing on transboundary issues and on filling respective data and knowledge gaps were set up in working groups, followed by plenary discussions.

3. Country Reports

The country reports have been given in form of power-point presentations; a copy of these presentations is available from the technical officer of the project. Here aspects relevant for the follow-up activities in the countries are summarized.

3.1. Chad

In the area of north-eastern Chad, there are "several lakes and areas of shallow groundwater with palm tree exploitation and a high biodiversity. A severe water table decline could provoke environmental and agricultural problems as already observed in the Kufra oases. The current project together with the MSP could help to address these issues and provide options for how best to manage these areas in a sustainable way for future generations without further damage.

At the regional level, isotopic investigations could determine the role of the Tibesti Mountains in recharging both the Chad and Libya parts of the Nubian Aquifer. In the same way, the hydrodynamic connection between the two sub-basins could be studied. It was also pointed out that 18 boreholes, drilled by Libya, could be sampled in the first instance. ……. it would be necessary for Chad to start carrying out an accurate inventory of the wells and the boreholes which are available for sampling. Libya will provide some information on boreholes drilled along the transboundary road." (the above three paragraphs have been taken from the report of the Cairo meeting in December 2006, because they give the background for the further activities including the forthcoming missions and sampling campaign to fill gaps.)

Chad only recently joined the IAEA as a member state and cannot refer to previous isotope studies in the area near the Libyan, Egyptian and Sudanese borders. They need substantial support by the IAEA and participating countries, particularly from Libya with regard to delineating and establishing transects along inferred hydraulic gradients from Chad, crossing the border to Libya and further north in Libya.

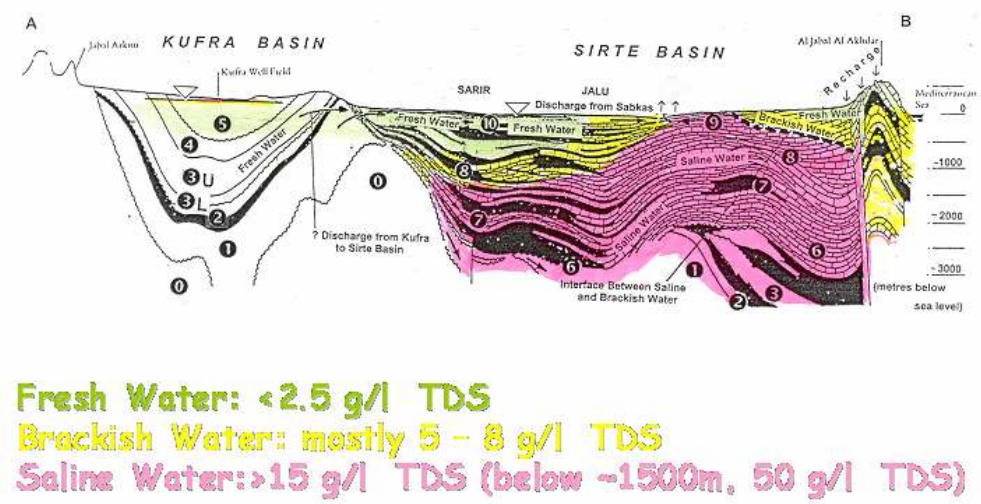
Near the border between the two countries there is supposed to be a watershed. This subject deserves special attention and efforts, in particular a more detailed geological cross section and maps of the piezometric head distribution should be made available.

3.2 Libya

An overview on the activities carried out within the ongoing project has been given and the results of the sample analyses presented. Reference was also made to past German and Libyan isotope studies including ^{14}C and noble gases. From these studies it was concluded that

(1) deep groundwater in Al Kufra and Sirt Basins is mostly older than 15 kyr B.P.;
(2) the ages of shallow groundwater range from a few kyr. To 14 kyr. B.P.;
(3) ^{14}C ages do not show a clear trend of increase in age northwards;
(4) palaeo-temperatures inferred from noble gases appear to be about 1 to 2 °C below the present annual averages.

The figures shown by the presentation included a δ^2H - δ^{18}O plot of the samples taken within the framework of the ongoing project, geological cross sections and logs from boreholes in the Kufra basin. One of these geological cross sections is the following:



Groundwater salinity in the Kufra and Sirt basins

Libya has the logistics available for selecting and sampling wells for transects along hydraulic gradients from the border to Chad towards north, from the border to Egypt in west-east direction, and towards Sudan as well as from Uweinat (recharge area) to north or north-west. Sampling from well defined depths in the NAS and PNAS can be carried out using available wells that tap different parts of the respective aquifers.

Libya is planning to carry out sampling of soil profiles for determining present-day recharge (if any!) in suitable areas (e.g. Uweinat). The assistance requested from the IAEA is particularly related to this soil sampling since so far no experience in this field is available in the country.

3.3 Sudan

There have been several projects in the past on the use of isotope techniques in the water resources of Sudan. The report presented to the meeting focused on the NSAS in the region of North Western Sudan, re-emphasized the objectives and planned activities of the Sudanese part of the ongoing project and addressed briefly some basic technical aspects of the NSAS in Sudan. In this connection, some remarks on the evolution of the Sahara Basins and the Nile River were made, and an overview of the groundwater quality and results of the environmental isotope application in groundwater studies was provided. Generally, the groundwater quality in the Nubian aquifer has been considered to be good. The majority of the analysed groundwater was characterized as Ca + Mg HCO3 and Ca SO4 water; a few samples have found to represent Na (SO4+Cl) water. Since the start of the technical cooperation with the International Atomic Energy Agency, many water samples have been analysed for stable isotopes (2H & 18O) and radioactive isotopes (3H & 14C). An example of these isotope studies has been demonstrated. It was shown that the mixing between Nile water and pluvial groundwater near Dongola could be studied applying the isotopes 3H, 18O and 2H. It was found that the infiltration of Nile water to adjacent groundwater is limited to a distance of about 35 km from the Nile River. Furthermore, diagrams of δ2H versus δ18O for water samples collected during the years 2002, 2003 & 2005 were shown, which demonstrated that there are two end-members of the mixing: the Nile water with highly enriched (upper right) and the old water highly depleted in stable isotopes. Between these two end-members water of various degrees of mixing exist. 14C analysis on some groundwater samples indicated old water with ages of 23 kyr. B.P. (Mehala 2) and 27 kyr. B.P. (Mehala1). Nubian aquifer water of younger ages has also been found.

Apart from the recharge by the Nile River, also recharge at the southern boundary of the NSAS (Umm Kedada Basin) has been addressed in the report. These studies have been carried out within a German-founded project (A. Suckow et al. (1992). The long-term averages of the recharge rate estimated from the measured isotope data were found to be 25mm/yr and 1.5 mm/yr., respectively.

Concerning the ongoing project, there has been sent to the IAEA which is already included in the IAEA 's ISOHIS database. However, like in the other NSAS countries, isotope data is missing so far in the transboundary areas. The working groups have identified necessary sampling sites and sampling activities (see Annex). The geographic coordinates for the sampling sites have been included in an excel file which is available from the IAEA Technical Officer upon request.

3.4 Egypt

Egyptian colleagues were not able to participate directly in the meeting. Their inputs were provided in discussions after the meeting.

Review of available isotope data

Isotope techniques and their applications in hydrological studies have been used in Egypt since the early 1960's. During this time many investigations have been carried out covering the different fields of isotope applications (groundwater recharge, evaporative discharge, surface water-groundwater relationships, lakes studies, salinisation and pollution studies). Recently, with IAEA and national authorities assistance, an isotope hydrology laboratory has been established where the different isotopes (O-18, D, T, C-14, C-13, N-15) are measured and analyzed. This is routinely evaluated by IAEA. Most of the investigations carried out using isotopes in Egypt were concentrated around the Nile valley and Delta. However, the NSAS which is the target of this meeting was subject of some studies which are illustrated in the presentation as case studies, Sonntag et al. 1987 and 1983, Aly et al. 1988, Awad et al. 1988, Swailem et al., 1998, Taher et al., 2000, Sadek et al. 2001, Abd El-Samie et al. 2000, Aggour et al. 2001).

The isotope studies on NSAS refer to the main recharge of the NSAS during the late Pleistocene and early Holocene. The radiocarbon ages indicated that the groundwater collected from Kharga, Dakhla, Farafra, Bahariya Oases, as well as Darb El-Arbaen and Toshka area, vary in the range between 20 to 50 kyr. B.P. Groundwater from Uweinat area is of Holocene age. The seepage of surface water from Lake Nasser (High Dam Lake) is indicated in the adjacent area of the Western Desert to a distance of from 10 to 50 km depending on the structural and hydrogeological conditions. Evaporation trends affect this palaeowater where the water table is shallow. There is a possibility of finding deeper zones of recent recharge that mix with the whole volume of the water under pressure.

The groundwater of the NSAS in the Eastern Desert and Sinai is generally more enriched in heavy isotopes than in Western Desert. In the Eastern Desert and Sinai the aquifer system receives current recharge from precipitation on the aquifer outcrop areas and the surrounding hills. In some places of Sinai and the Eastern Desert where structural, geomorphologic, or stratigraphic elements stop recent rain from reaching the aquifer, the isotope values are lower and thus similar to the ones observed in the Western Desert.

Within the program of the project RAF/8/036, two sampling campaigns have been undertaken; the first took place in December 2003 at Toshka where 44 groundwater samples were collected. During the second campaign in December 2004, 26 groundwater samples were collected from Darb El Arbien and East Uwienat. To date, a total of 60 samples have been analysed for chemical elements (major and trace elements) and stable isotopes. (see Annex 5)

Information gaps

- Further investigations are needed using the radioactive isotope (^{14}C). Sometimes there are only a few samples for an area that has been investigated. Future sampling must be co-ordinated at the regional scale to obtain transects along inferred hydraulic gradients. Groundwater stratification has practically not been tackled although new multi-level observation wells (8 in Uweinat, 5 in Darb Elarbien and 25 in Toshka) are available. The 3rd sampling campaign will cover these multilevel wells in Southern Egypt (50 samples for ^{14}C & ^{13}C) in the period from August to September 2006; and the 4th sampling campaign will cover these multilevel wells at the northern Oases Kaharga, Dakhla, Farafra, Baharya and Siwa (50 samples for ^{14}C & ^{13}C).

- Estimation of the evaporation from the NAS especially at natural discharge areas (shallow groundwater level) south Darb El Arbien, Toshka and El Qattara depression at the Northern region of the Western Desert..

4. REVIEW OF CURRENT TECHNICAL KNOWLEDGE OF THE NSAS AND IDENTIFICATION OF KNOWLEDGE GAPS

4.1. Introduction

This review is based on the reports presented at the meeting and considerations in preparation of the meeting.

The present knowledge on the NSAS is to a great extent based on extensive geological, hydrogeological and isotope-geochemical studies carried out in the 1970s and 1980s, including those conducted within the long-term German-funded SFB-project (TU Berlin) in Egypt (Toshka, Dakhla, Bahariya, Farafara) and Sudan (Darfur and East Kordofan) and by the BGS in Libya in the Sarir and Kufra basin in Libya (Brinkmann et al., 1987; Wright and Edmunds, 1971). Also, a more recent compilation of the knowledge on the NSAS by CEDARE (2001a) is based on these studies. The focus of these previous studies was different from the one of the present project, and thus, the knowledge of the geology and hydrogeology of the aquifers crossing the borders between the four countries needs to be improved for a shared use of the groundwater resources of the NSAS. The following brief overview of the geology and hydrogeology of the NSAS is based on these earlier studies summarized in the CEDARE led project (2001a).

4.2 Hydrogeology of the NSAS

The NSAS covers an area of about 2.2 million square kilometres and is shared by the countries Chad, Egypt, Libya and Sudan. Table 1 and Fig.1 summarize and respectively demonstrate recent data and features characterizing the system. A three-dimensional schematic diagram of the Nubian is shown in Fig.2 illustrating the mountainous areas, depressions and the stratification of the system.

Country	Nubian system (Palaeozoic and Mesozoic sandstone aquifers) Area (km^2)	Nubian system Fresh water volume in storage (km^3)	Post Nubian system (Miocene aquifers) Area (km^2)	Post Nubian system Fresh water volume in storage (km^3)	Total volume of fresh water in storage (km^3) 1	Total recoverable groun-dwater volume (km^3) 2	Present extraction from the Post-Nubian system (km^3)	Present extraction from the Nubian system (km^3)	Total present extraction from the NSAS (km^3)
Egypt	815,670	154,720	426,480	97,490	252,210	5,180	0.306	0.200	0.506
Libya	754,088	136,550	494,040	71,730	208,280	5,920	0.264	0.567	0.831
Chad	232,980	47,810	–	–	47,810	1,630	–	0.000	0.000
Sudan	373,100	33,880	–	–	33,880	2,610	–	0.840 3	0.833
Total	2,175,838	372,960	920,520	169,220	542,180	15,340	0.570	1.607	2.170

– Not applicable
1. Assuming a storativity of 10^{-4} for the confined part of the aquifers and 7% effective porosity for the unconfined part.
2. Assuming a maximum allowed water level decline of 100 m in the unconfined aquifer areas and 200 m in the confined aquifer areas.
3. Most of this water is extracted in the Nile Nubian Basin (833 Mm^3/yr) which is not considered to be part of the Nubian Basin.

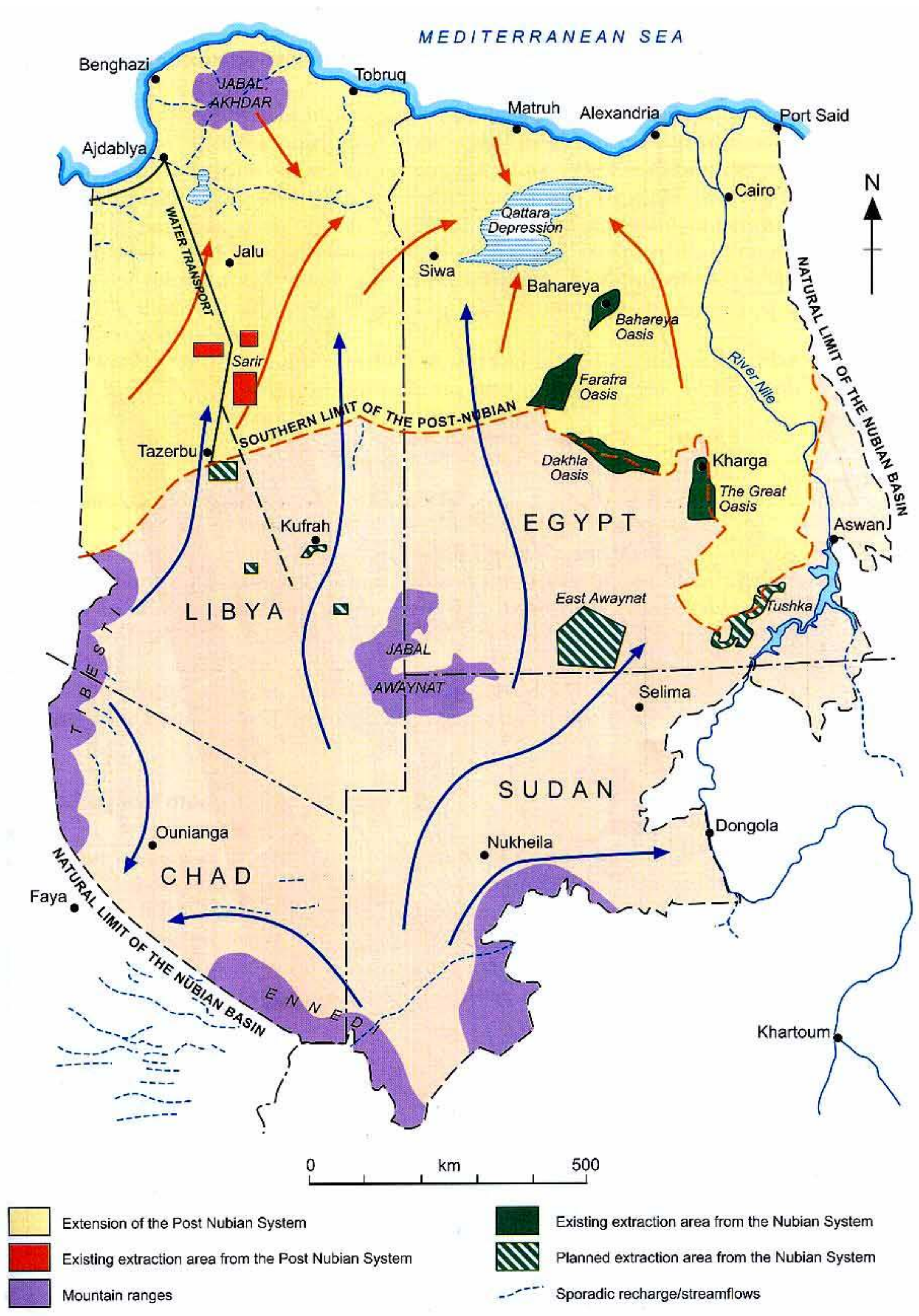
Source: CEDARE/IFAD (Programme for the development of a Regional Strategy for the Utilisation of the Nubian Sandstone Aquifer System).

Table 1: Essential data of the Nubian Sandstone Aquifer System (From Salem and Pallas, 2001)

There are two aquifer systems to be considered under the term NSAS, the Nubian Aquifer System (NAS) and the Post Nubian Aquifer System (PNAS). The NAS (extended over Egypt, Eastern Libya, Northern Sudan and Northern Chad) consists of clastic sediments (mainly sandstone) forming aquifers, confining layers and aquicludes and is of Cambrian to Cenomanian age. It overlies the Pre-Cambrian basement complex. The PNAS extends over North Eastern Libya and the northern region of the Western Desert of Egypt and is represented by marine sediments (mainly clay, marl and limestone) overlain by clastic sediments. The age of the PNAS ranges from Upper Cenomanian to recent.

The two parts (NAS and PNAS) are separated by low permeability layers of Upper Cretaceous to Lower Tertiary. The contact between the two parts is characterized by local discordances with open windows between the sedimentary sequences (either due to non-deposition or Tectonic structures) and reduced thickness of the Upper Cretaceous-Lower Tertiary deposits, which facilitates a direct connection between the two aquifer systems. In the northern part the aquifer system becomes very saline. South of 26°N the aquifer is unconfined.

A typical geological cross section through the Nubian aquifers from the outcrop at the basement of Uweinat through the Kufra to the Sirte basin in Libya is shown in Fig.3, upper part. The lower part of Fig.3 is a cross section through the Post-Nubian in Northern Libya. The main geological formations and the corresponding stratification of the Nubian and Post-Nubian are indicated in this figure.



MEDITERRANEAN SEA
Benghazi
JABAL AKHDAR
Tobruq
Matruh
Alexandria
Port Said
Ajdablya
Cairo
N
Qattara Depression
WATER TRANSPORT
Jalu
Siwa
Bahareya
Bahareya Oasis
Sarir
Farafra Oasis
River Nile
SOUTHERN LIMIT OF THE POST-NUBIAN
Tazerbu
Dakhla Oasis
Kharga
The Great Oasis
NATURAL LIMIT OF THE NUBIAN BASIN
Kufrah
EGYPT
Aswan
LIBYA
East Awaynat
Tushka
JABAL AWAYNAT
TIBESTI
Selima
SUDAN
Ounianga
Dongola
Nukheila
CHAD
Faya
NATURAL LIMIT OF THE NUBIAN BASIN
ENNEDI
Khartoum
0
km
500
Extension of the Post Nubian System
Existing extraction area from the Post Nubian System
Mountain ranges
Existing extraction area from the Nubian System
Planned extraction area from the Nubian System
Sporadic recharge/streamflows

Fig.1: The Nubian Sandstone Aquifer System (From Salem and Pallas, 2001)

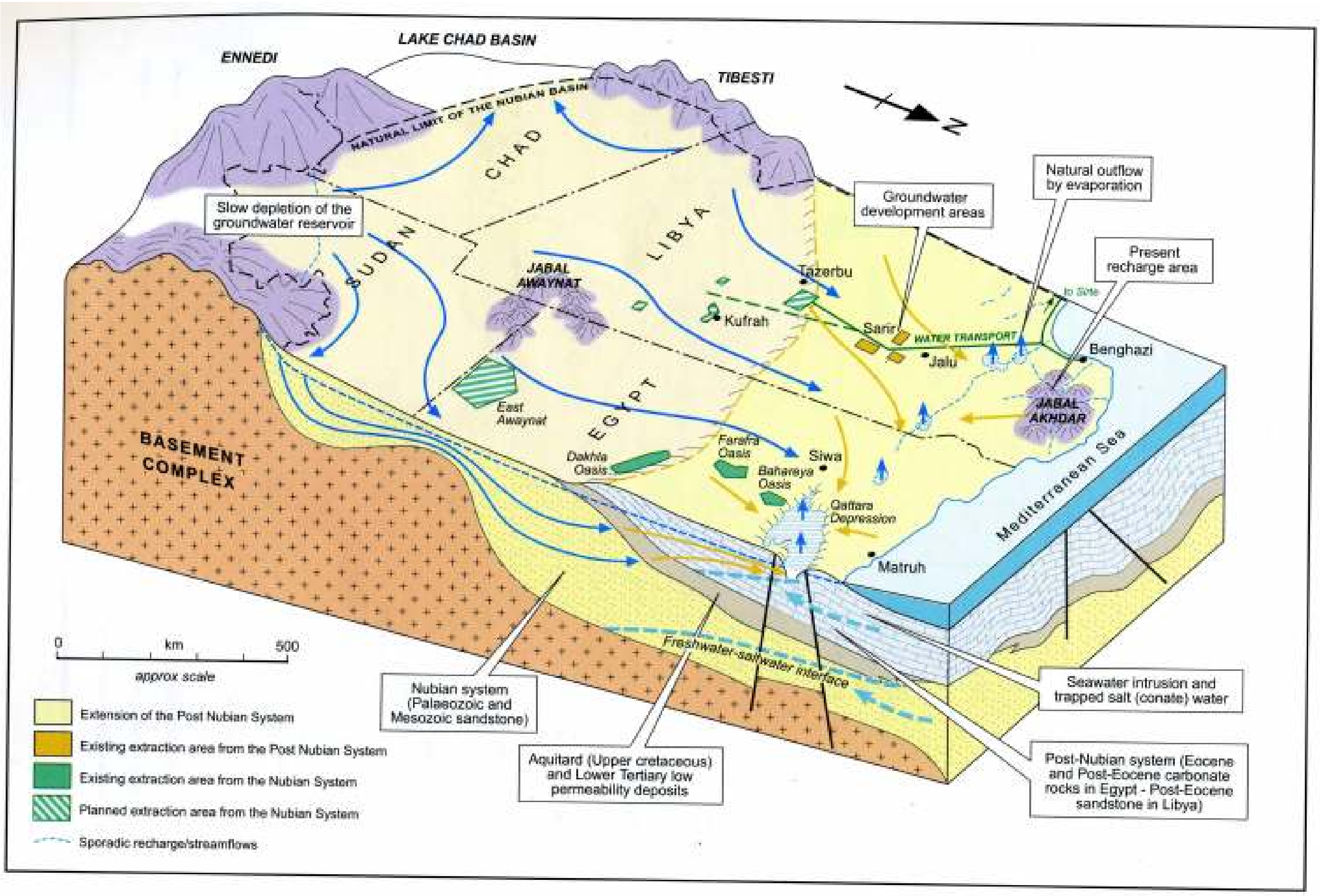


Fig.2: 3D-Diagram of the Nubian (From Salem and Pallas, 2001)

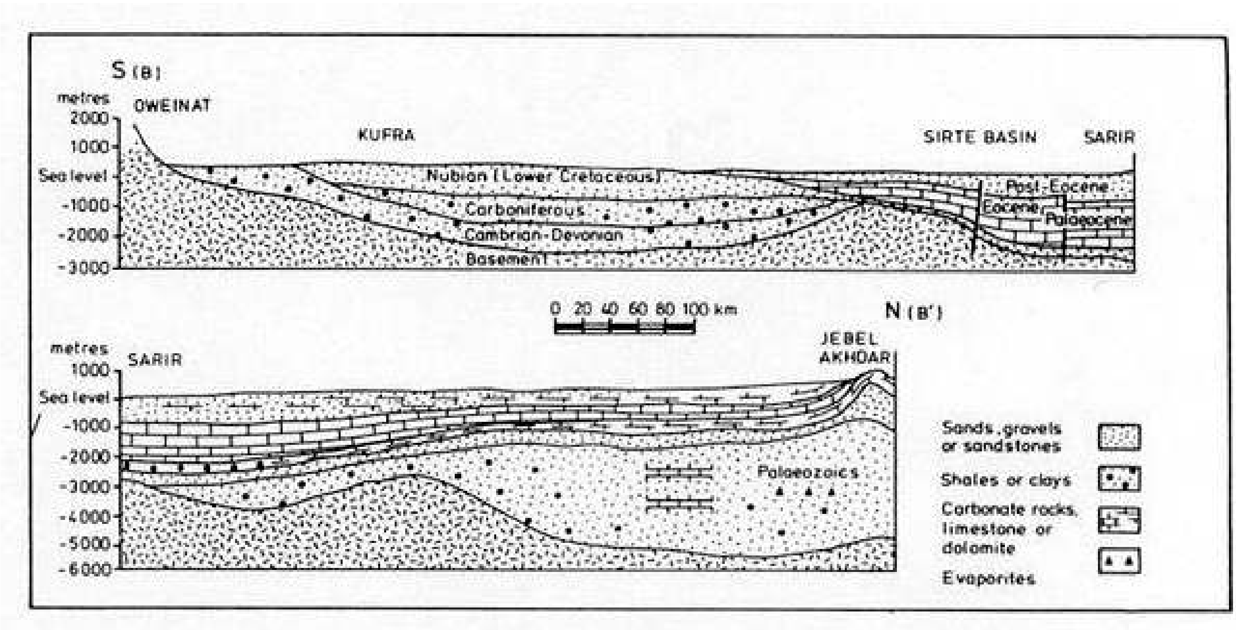


Fig.3: Simplified geological cross section through Kufra and Sirte basin in Libya (From Wright et al., 1982)

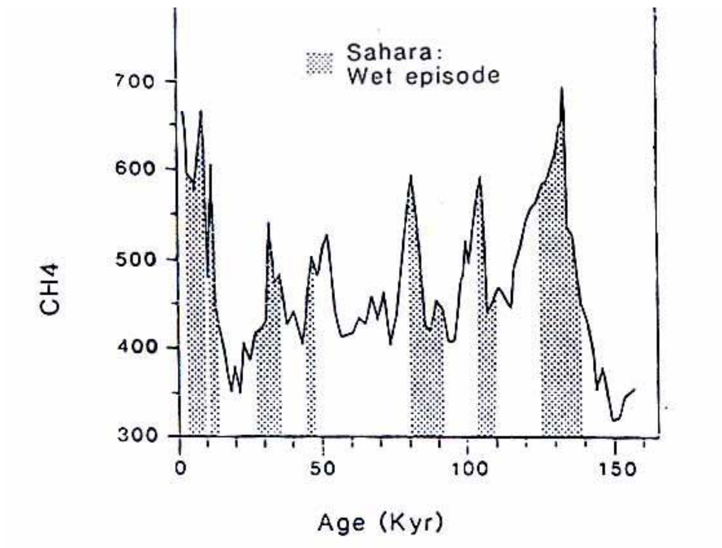


Fig.4: Global climate changes (indicated by the atmospheric concentration of the greenhouse gas methane) over the last 150 kyr, and the pluvial phases in the Sahara. (After Petit-Maire, 1993)

The NSAS has been recharged by local rainfall during the past pluvial phases, which are well-known from palaeo-climatic studies. The rainfall originated from air moisture transported by west-wind drift from the Atlantic source regions to the eastern Sahara. The wet episodes in the Sahara during the last 150 000 years are indicated in (Fig.4). The major pluvial phase ended about 8000 years before present (B.P.) and was followed by an about 4000 years semi-arid phase. Since about 3500 years B.P. a hyper-arid phase has been prevailing. Recent recharge by rain is virtually absent, although it is speculated that there is some present-day recharge by rain in the mountain regions of Tibesti and Uweinat. This question of present-day recharge by rainfall in these areas (including southern area of Sudan) constitutes one of the knowledge gaps and thus is subject to detailed isotope studies to be carried out within the ongoing project.

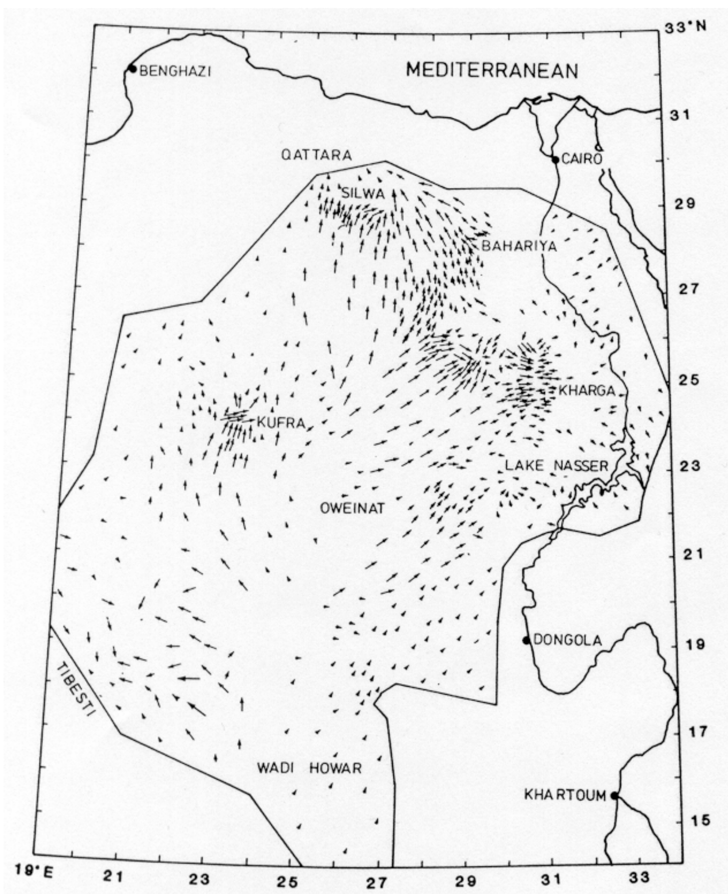


Fig.5: Modelled groundwater flow directions (after Brinkmann et al., 1987)

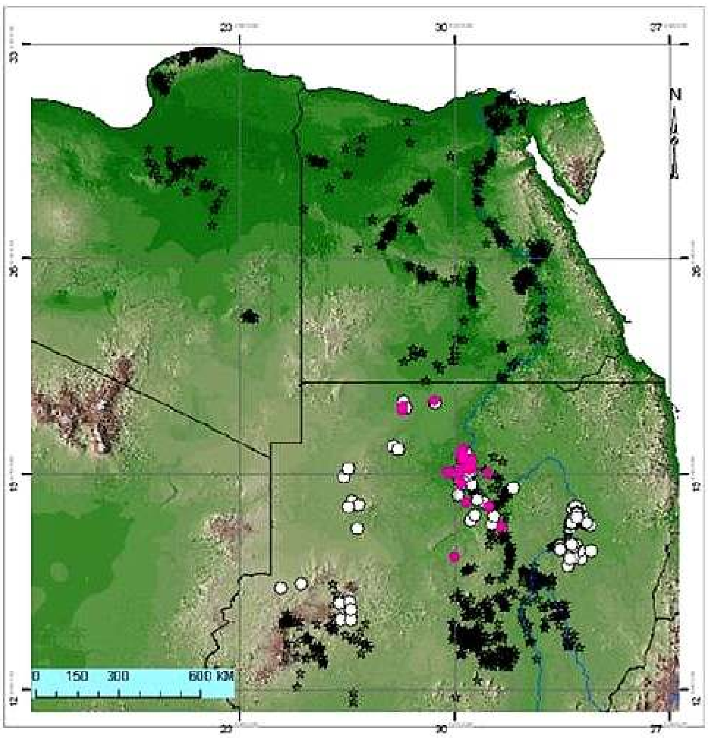
On the basis of this climate scenario, the groundwater balance of the NSAS and its groundwater flow regime have been simulated for the first time by a numerical model developed at the end of the 1970s at the TU Berlin, Germany (Brinkmann et al., 1987). Fig.5 shows the calculated regional pattern of the groundwater flow regime before intensive groundwater development took place (about 1960.) There is a general trend in the flow direction from southern Sudan to the north of the region with areas of convergence (discharge) at depressions (oases) in Egypt and Libya and of divergence (recharge) in mountain regions (Uweinat and Tibesti).

On the basis of this mode,l a new model was developed in the frame of the CEDARE led project, which is presently used to predict future changes in the water balance and water quality of the NSAS on both the regional and the local scale (CEDARE, 2001b). To further improve the performance of the model, environmental isotope and geochemical data have shown specific potential in constraining boundary conditions of the model and verifying model results in terms of recharge and flow regime, mixing between aquifers and changes in groundwater quality.

4.3 Review of past isotope hydrological studies on the NSAS

Isotope and geochemical studies have been an integral part of earlier studies of the NSAS such as the German SFB-Project (see e.g. Thorweihe and Schandelmeier, 1993) and work carried out by the BGS (Edmunds and Wright, 1978). The IAEA conducted the following projects related to the NSAS:

Project	Date	Project Title	Project site
SUD/8/002	Early 1970s	Radioisotopes in Hydrology	East Kordofan; Darfur; El Geizira
SUD/8/004	Early 1980 and 1990s	Isotopes in Hydrology	Kordofan; El Geizira, Nile valley between Khartoum and Dongola
SUD/8/005	Early 1990s	Use of isotopes in groundwater assessment	Nile River and El Geizira
EGY/8/016	1999 - 2003	Using isotope techniques to study water resources	Farafra and Bahariya Oases
RAF8/010	1990s	Water resources in the Nile Valley	The Nile Valley in Sudan and Egypt
RAF8/022	Late 1990s	Isotopes in groundwater resources development	The Nile valley in Sudan and Egypt
RAF8/037	Ongoing since 2003	Sustainable Development and Equitable Utilization of the common Nile Basin Water Resources	The Nile Valley in Sudan and Egypt and up stream countries



The isotope and geochemical data as well as the related/relevant hydrogeological information are being collected and included in the IAEA's ISOHIS database. This database presently comprises data from more than 1000 samples from various sampling sites. The distribution of all sampling sites selected by the various projects for isotope and chemical analyses (Fig.6) clearly shows that a considerable part of these sites are

Fig.6: Sites selected by previous IAEA and non-IAEA projects, for which isotope and geochemical data are available and which are included in the IAEA-ISOHIS database (black stars). Sites included in the NARIS data base of CEDARE are marked by white points; sampling sites of RAF/8/036 are represented by points in pink.

located near the river Nile. The isotope and geochemical data of these sites have been useful for studying Nile – adjacent groundwater interaction, such as the possibility of river water infiltration to the Nubian (with the risk of groundwater contamination) and, vice versa, discharge of Nubian to the Nile. Although these investigations are important for understanding the flow-discharge-recharge regime at the eastern boundary region of the Nubian, their relevance for specific transboundary issues is comparatively limited. Some of the previously sampled sites/wells are sufficiently close to the border between Egypt - Sudan and Egypt – Libya, especially the ones at the southern rim of the Dakhla basin. But in general there appears to be a gap in sampling sites (production and/or observation wells) to address transboundary issues.

The following figures have been drawn to indicate gaps in this data to be filled by further sampling and isotope and geochemical analyses within the ongoing project.

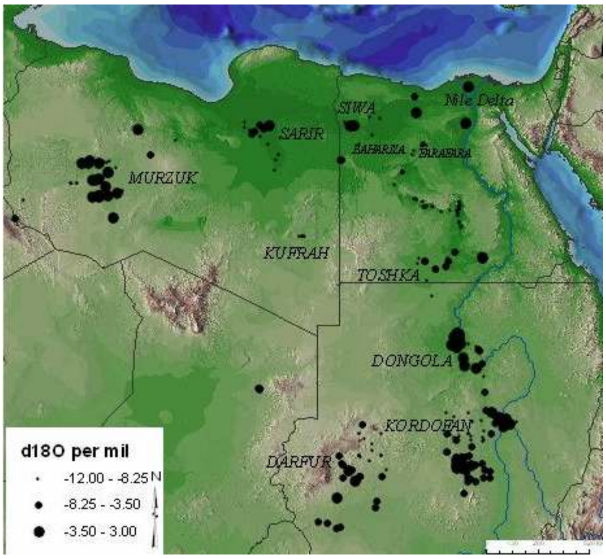


Fig.7: Distribution of $\delta^{18}O$ values (the size of the black circles indicates the range of the $\delta^{18}O$ values).

Fig.7 points to the specific potential of $\delta^{18}O$ (and $\delta^{2}H$) to address origin and mixing of groundwater. The higher $\delta^{18}O$ values (larger black circles) indicate surface water (e.g. Nile) or mixing between surface and old groundwater. In the northern part of Libya and Egypt, higher $\delta^{18}O$ values can also be due to mixing between groundwater and saline water (including water from the Mediterranean Sea). Low $\delta^{18}O$ values indicate palaeowater, i.e. groundwater recharged during last pluvial phases.

Chloride and $\delta^{18}O$ values of groundwater from various sites in Egypt are compiled in Fig.8. The chloride concentration of the groundwater ranges over three orders of magnitude. The low values below a few tens mg/l appear to characterize recharge water; higher values are due to leaching of salt deposits since most of them are associated with about the same $\delta^{18}O$ content of the water. However, there are also higher salinity values accompanied by higher $\delta^{18}O$ values, indicating mixing with saline water including Mediterranean Sea water.

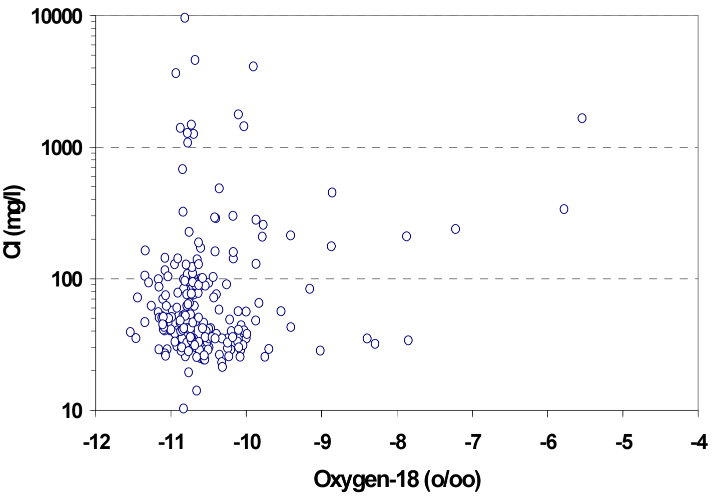


Fig.8: Chloride concentration versus $\delta^{18}O$ of groundwater in Egypt.

Among the various environmental isotopes, radiocarbon (^{14}C) is the most powerful in studying recharge and flow of groundwater within a time scale up to about 40 kyr. A vertical gradient of ^{14}C can be interpreted in terms of present and past recharge, and a ^{14}C gradient in groundwater flow direction can be used to estimate the groundwater flow rate. The knowledge of both recharge and flow rate is indispensable for a rational management of the groundwater resource. Given the past and present climatic conditions in the study area, the average recharge and flow rates are assumed to be rather low and, consequently, the use of ^{14}C requires a proper selection of the sampling sites, i.e. vertical profiles and transects close to regions of major (past) recharge (e.g. Uweinat, Tibesti, Enneni …).

The spatial distribution of all ^{14}C data presently included in the ISOHIS database (Fig.9) reveals some regions with younger groundwater (higher ^{14}C values), especially in the southern part of Sudan (Darfur, Kordofan) and Egypt (Toshka) and near the Nile. Whether this is an indication of some present-day recharge remains to be assessed by further sampling and analysis of ^{14}C.

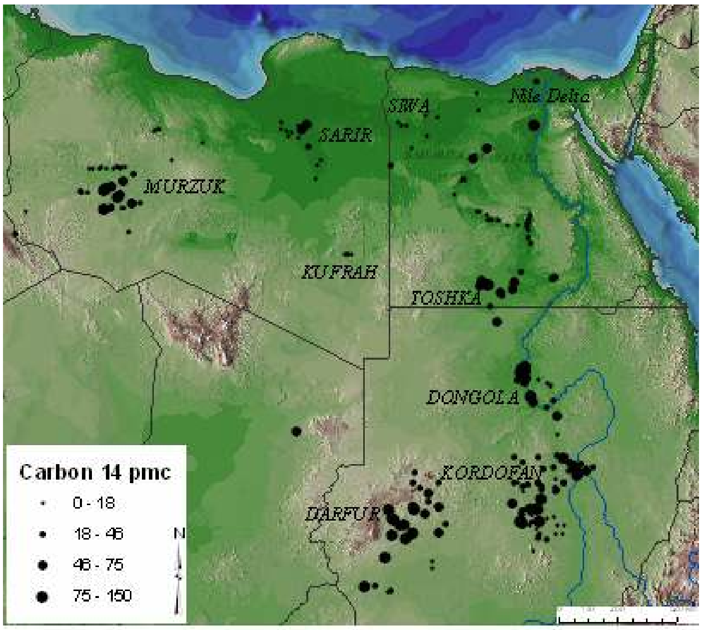


Fig.9: Spatial distribution of ^{14}C in groundwater of the NSAS (data included in ISOHIS).

Fig.10 is a plot of all ^{14}C values (included in ISOHIS) of the NSAS in Egypt versus depth. In many cases "depth" is the maximum depth of the borehole and the groundwater sample can assumed to be a mixture of portions from various (unknown) depth intervals. Notwithstanding this deficiency in knowledge of the depth interval from which the sample has been taken, Fig. 10 allows some useful conclusions.

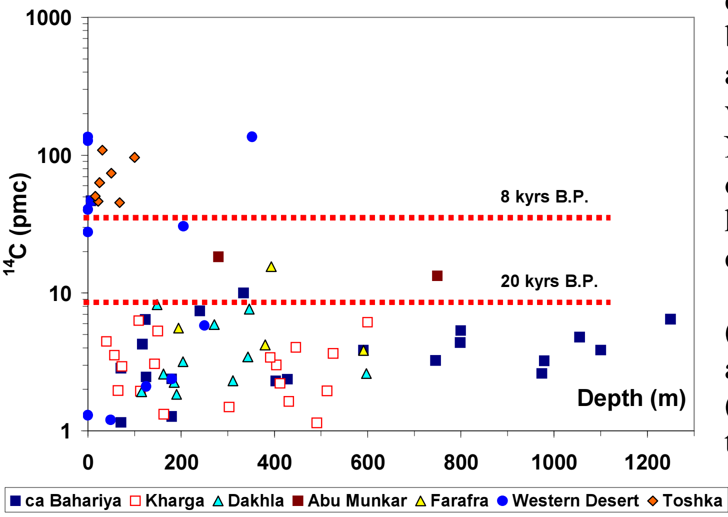


Fig. 10: Radiocarbon versus depth in groundwater of the NSAS in Egypt (data included in ISOHIS)

(1) The ^{14}C concentration is in many wells above the detection limit of about 1 pmC (percent modern Carbon), even wells more than 1000 m deep. Thus, if sampling sites and depths are appropriately selected, ^{14}C data can provide unique information related

to the recharge and flow regime in the NSAS.

(2) There is no systematic trend between ^{14}C and depth, which suggests that the samples represent mixtures between portions from different depths. Assuming unconfined conditions with local recharge during pluvial phases, the average (long-term) recharge rate (R) can be estimated by the relationship: R = pH/T, where p = porosity, T = ^{14}C age, H = thickness of the aquifer (depth of the well). Assuming a depths between 500 and 1000 m and a porosity of 10%, a ^{14}C age of >20 kyr. (see dotted line in Fig.10) would correspond with an recharge rate of < 2.5mm/a (H = 500 m) or twice this value if H = 1000 m is assumed. This simple estimation demonstrates the potential of ^{14}C in studying groundwater recharge (and flow) in the NSAS. To make full use of this potential, efforts must be taken to select appropriate sampling sites and wells, from which groundwater samples from well defined depths (regions) can be collected.

(3) The assumption of distributed recharge over the region from Kharga to Bahariya is supported by the fact, that in all these areas ^{14}C above the detection limit has been found. Also this aspect would be highly relevant for improving the knowledge about the NSAS and its rational management.

(4) In some areas, especially in Toshka, ^{14}C has been found indicating late Holocene or even recent recharge. This finding is relevant for the objectives of this project and deserves follow-up activities.

The few selected examples based on data included in the ISOHIS have shown that this database is of invaluable significance for this project, in particular in connection with follow-up sampling and analysis the to fill the gaps in data and information indicated above. In this context it should also be noted that the NSAS, one of the world's largest aquifer systems, has been used to demonstrate the application of a mix of isotope and chemical tracers to provide historical records of hydrological and climate change before, during and after the LGM. In combination with stable isotopes (^{2}H, ^{18}O, ^{13}C) and cosmogenic radionuclides (especially ^{14}C), noble gases and their isotopes (e.g. ^{3}He, ^{4}He) have been measured in groundwater of this system to derive information an past climate changes and its implications for the groundwater formation in the NSAS (e.g. Sonntag et al.). Therefore, it is suggested to consider integrating noble gases as a palaeowater indicator, if questions related to such aspects may arise. Since the sampling of noble gases requires special techniques and experience, such activities could be planned for a later stage in the project implementation.

Considering a groundwater velocity in the order of magnitude of 1 m/a, a groundwater parcel would need 100 kyr. for a flow path length of 100km. Thus, the age of a major part of the groundwater within the NSAS can assumed to be far beyond the upper limit of the ^{14}C dating range (about 40 to 50 kyr.). Therefore, more recently some attempts have been made to use radio isotopes with half lives in the order of more than 100 kyr., in particular $^{234}U/^{238}U$ (half life of ^{234}U = 245 kyr.), ^{36}Cl (half life = 301 kyr.) and ^{81}Kr (half life = 100 kyr.). In the following section, the results of these studies are briefly discussed.

4.4 Recent studies of the Nubian Aquifer (Western Desert, Egypt)

Dabous and Osmond (2001) found distinctive uranium isotopic signatures among the water masses of the NSAS in the Western Desert of Egypt. They conclude that at Bahariya and Farafra Oases, the Nubian artesian water that is migrating from the south has been augmented by local recharge during pluvial times. At Dakhla, Kharga and Baris Oases, the main source is suggested to be water moving from southeast Uweinat Upland and Sudan. From uranium isotopic mixing diagrams it is concluded that "deep aquifer sources predominate; however, the pluvial contributions are significant, ranging from about 5% at south-eastern Baris Oasis to about 26% at the more northerly Farafra Oasis."

Sturchio et al. (2004) measured $^{81}Kr/Kr$ ratios in deep groundwater from NSAS in Egypt by extracting Kr gas from about 2-ton groundwater samples and applying a new laser-based atom-counting method. The determined ^{81}Kr groundwater ages range from about 200 kyr. to 1000 kyr. (Fig.11) and correlate with ages derived from $^{36}Cl/Cl$ ratios of the same wells. The authors conclude that the determined ages are consistent with a lateral groundwater flow from a recharge area near the Uweinat Uplift in SW Egypt.

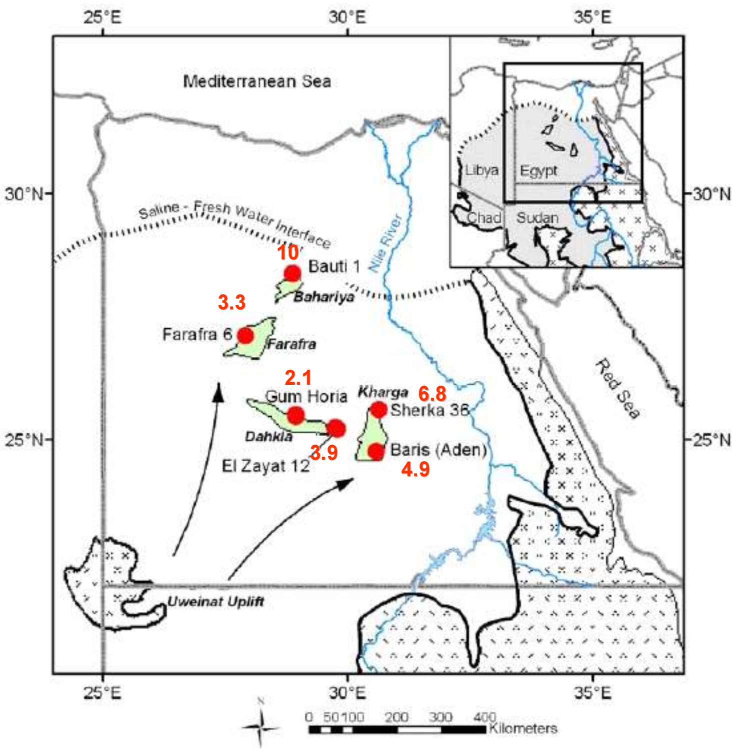


Fig. 11: Sample locations (red circles) in relation to oasis areas (shaded green), Precambrian basement outcrops (patterned), and other regional feature. Groundwater flow in Nubian Aquifer is toward northeast. Red numbers = ^{81}Kr age in 10^5 years. (After Sturchio et al., 2004)

In the same study area, the radioactive chlorine isotope ^{36}Cl, the stable chlorine isotopes and radiogenic noble gases (^{4}He and ^{40}Ar) were measured (Patterson et al., 2005) to determine the residence time (age) of groundwater in the Nubian Aquifer of the Western Desert in Egypt and to complement the $^{81}Kr/Kr$ application (Sturchio et al., 2004). From the $^{36}Cl/Cl$ ratios apparent residence times were derived for deep groundwater (600 to 1200 m) assuming constant chloride concentration. The obtained values range from about 200 to 1200 kyr. For shallow groundwater (<600 m) with higher chloride values the estimated groundwater age has been found to be about 160 kyr. The various unknowns in calculating ^{36}Cl groundwater ages in the Nubian Aquifer (initial $^{36}Cl/Cl$ ratio, Cl^- content of recharging waters, extent of the recharge area, and subsurface ^{36}Cl production) have been estimated making "informed assumptions". For the subsurface and initial $^{36}Cl/Cl$ ratios reasonable estimates have been used. The unknowns with respect to the Cl^- concentration of the groundwater could, to a large extent, be addressed evaluating the measured distribution of the Br/Cl ratio, the stable chlorine isotopes ($\delta^{17}Cl$) and the Cl^- concentration.

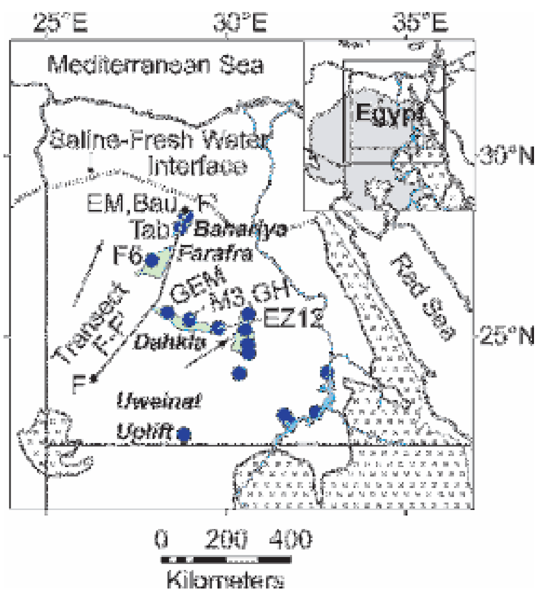


Fig.12: Modelled transect F-F' and groundwater flow directions (arrows) in the Nubian Aquifer. (From Patterson et al., 2005)

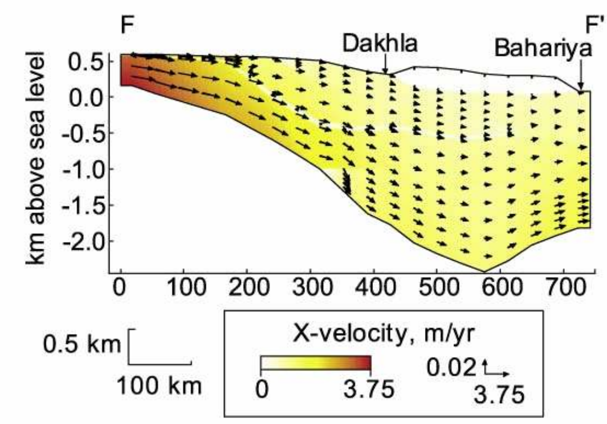


Fig.13: The modelled groundwater flow velocities
(From Patterson et al., 2005)

The distribution of these parameters suggest that "deep, dilute and up-gradient (Dakhla, Farafra, Baris) samples demonstrate the predominance of well-flushed Cl^-; shallow samples show the effects of evaporative concentration and possible diffusion of Cl^-; and where subsurface addition of Cl^- occurs, it is localized in areas with thick shale beds or increased clay percentage in the aquifer matrix.", respectively. Radiogenic ^{4}He accumulation was found to be qualitatively consistent with the age progression indicated by the $^{36}Cl/Cl$ ratio. The production and accumulation of ^{40}Ar within the aquifer was found to be minimal; the $^{40}Ar/^{36}Ar$ values do not exceed the atmospheric ratio.

A two-dimensional numerical hydrodynamic model of the aquifer was constructed for a transect from the area of the Uweinat Uplift to the northern Bahariya Oasis (Fig.12). The model assumes that the flow regime is under a steady state condition, recharge enters the transect as base flow through the left boundary and discharge occurs through the right boundary (Fig.13). Possible recharge distributed over the (unconfined part) of the aquifer has been disregarded. Therefore, the simulated groundwater ages are mainly a function of the distance along the flow, and vertical age stratification is negligible (Fig. 14). Model parameters (aquifer properties) have been estimated by fitting the measured $^{36}Cl/Cl$ ratios to the modelled ratios. In this way a reasonably good agreement

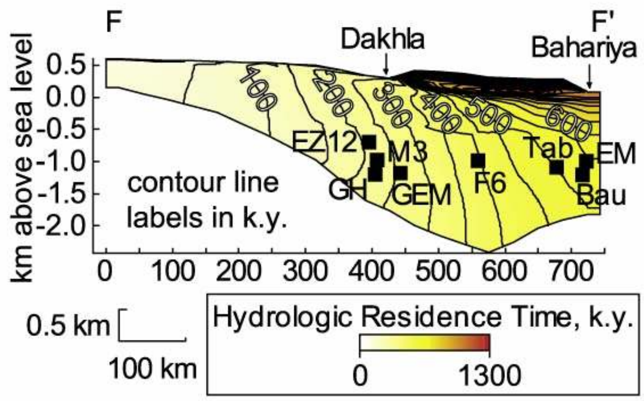


Fig.14: Groundwater ages (residence times) predicted by the model. Black squares indicate locations of wells proximal to the modelled transect. (From Patterson et al., 2005)

between the ages calculated by the model and the ones derived from the measured $^{36}Cl/Cl$ ratios was reached (Fig.15). The authors conclude that "by mutually calibrating multiple methods (hydrodynamic, ^{36}Cl, and ^{4}He), a consistent picture of the Nubian Aquifer has emerged in which lateral flow from a southern recharge area dominates the deep horizons, while shallow horizons contain younger, autochthonous recharge."

In summary, the recent attempts in dating groundwater in the Nubian Aquifer of the Western Desert in Egypt, appear to have confirmed that groundwater in the NSAS reaches ages of hundreds of thousand years covering several glacial and interglacial periods and respective pluvial and arid periods. Nevertheless, these studies also leave gaps in understanding the flow and recharge regime of the NSAS, especially in the studied area in Egypt. In particular, Patterson et al. (2005) assume, in their (conceptual) model, a rather localized recharge area (Uweinat) in the south and disregard distributed recharge along the transect. This is in disagreement with the model developed by the TU Berlin (Brinkmann et al. 1987) and the upgraded version used by CEDARE. It is thus suggested to consider an alternative approach in addressing the NSAS' recharge and flow regime, especially in the Western desert of Egypt. The following simplified conceptual model may be taken as an illustration of such an approach.

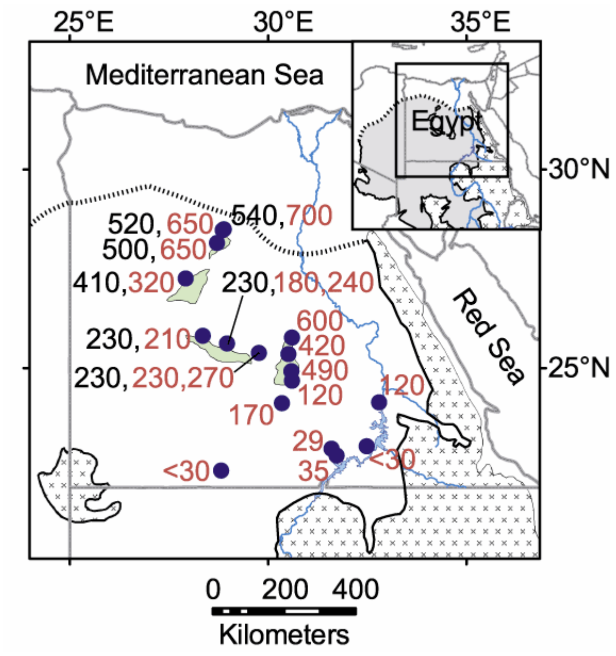


Fig.15: Map of the Western Desert showing hydrodynamic ages (black numbers) and ^{36}Cl ages (red numbers). (From Patterson et al., 2005)

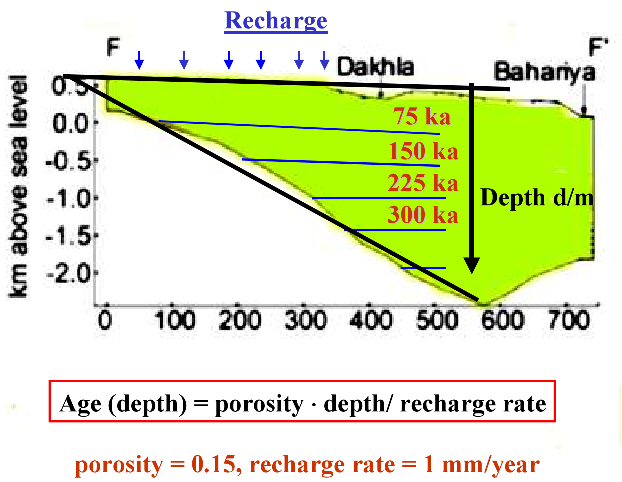


Fig.16: Simplified conceptual model with distributed recharge along the transect selected by Patterson et al. (2005)

Assuming that the geometry of the aquifer is approximated by a triangle (Fig.16) and that porosity and permeability of the aquifer are constant within the aquifer, it can be shown by simple hydraulic considerations that the age of the groundwater is a function of depth (Fig. 16), which appears to be in contrast to the model used by Patterson et al., (2005).

The age values given in Fig.16 have been calculated assuming a porosity of 15%, which is typical for the NSAS, and a recharge rate of 1 mm/yr. The order of magnitude of these ages correspond with the one of the values calculated with the measured $^{81}Kr/Kr$ and $^{36}Cl/Cl$ ratios by Sturchio et al. (2004) and Patterson et al. (2005), respectively. This shows that the assumed average recharge rate represents a realistic figure, and the assumption of distributed recharge appears to be justified. Recognizing that pluvial phases covered about 30% of the last 150 kyr. (Fig.4), the average recharge rate during pluvial periods appears to be about 3 mm/yr., a value sufficient to top up an aquifer in the order of 1000 years.

The model represented by Fig.16 has also important implications for the applicability of ^{14}C to determine groundwater recharge (and flow) rates. For an upper limit of the ^{14}C dating range of 40 kyr., the above relationship yields a depth of about 300 m corresponding with the detection limit of ^{14}C.

- Therefore, samples for ^{14}C determination (together with ^{13}C and other relevant chemical parameters) should be taken at various depths between 0 and a few hundred metres.

- In addition to depth specific sampling, also samples should be taken along transects established on the basis of conceptual models.

4.5 Recent ^{14}C results on the NSAS in Libya and in Egypt

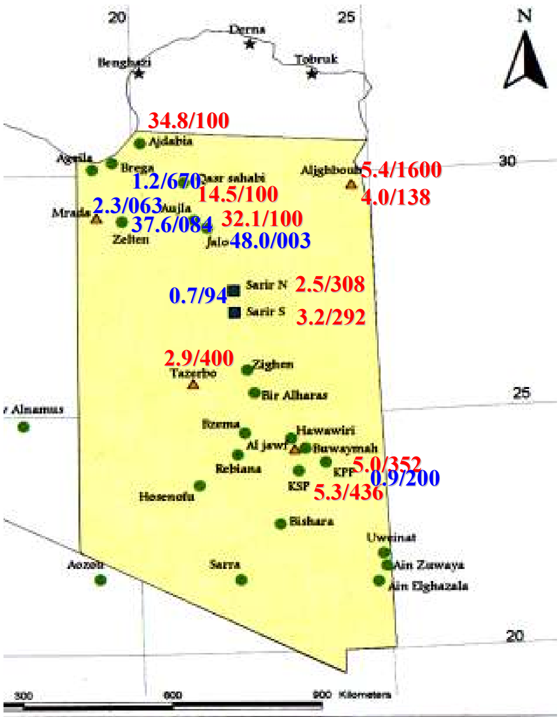


Fig.17: Distribution of ^{14}C in the NAS and PNAS in Libya. First number – ^{14}C (pmC), second number – depth of sampling. Red colour – recent data from RAF/8/036, blue colour – data by Edmunds and Wright, 1978.

The data obtained so far within the ongoing project RAF/08/036 for the study area in Libya give further evidence for the conclusions presented in section 3.4. Furthermore, the data facilitate a comparison with earlier ^{14}C data published by Edmunds and Wright (1978).

- Between Kufra in the NAS and Sarir in the PNAS only a slight change has been found in the ^{14}C concentration of groundwater at comparable depths. This result encourages further ^{14}C studies in (and between) these areas to consolidate conceptual models about the recharge regime in this area and hydraulic interconnections between the NAS and the PNAS.
- Further north in the PNAS (Jalo, Aujla, Ajdabia) the groundwater is of more recent age (Holocene) indicated by the higher ^{14}C values. etc.).

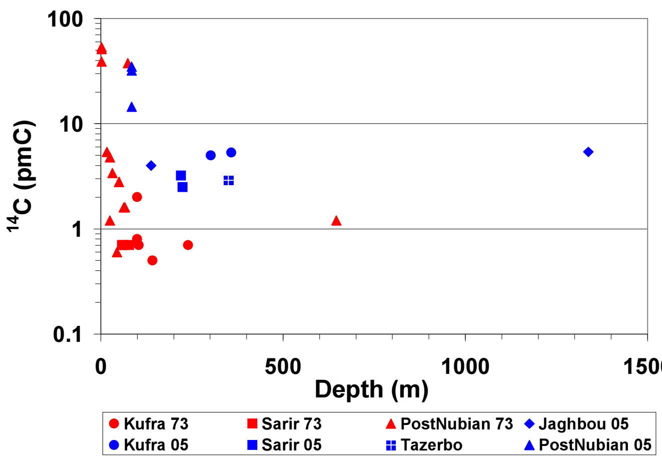


Fig.18: Plot of ^{14}C versus depth of sampling in the NAS and PNAS in Libya. Comparison between the values published by Edmunds and Wright (1978) and values obtained recently within RAF/8/036.

- At Aljghbough a rather negligible change of ^{14}C with depth was found, similar to findings in Egypt (Fig.10).
- Figs. 17 and 18 reveal a remarkable change in the ^{14}C values of the groundwater in these areas of Libya since the 1970s. Also this result indicates the potential of ^{14}C (in combination with ^{13}C and other environmental isotopes and geochemistry) to study the long-term response of the aquifer system to groundwater abstraction. Therefore, the network of sampling sites should be extended, especially towards the boundaries.

Egypt carried out extensive sampling campaigns between 2001 and 2003 at sites at East Uweinat, Darb Elarbien, Toshka, Farafra and Bahariya. The numbers of collected and analysed samples are as follows: stable isotopes = 301, tritium = 14, ^{14}C = 31, ^{13}C = 8. Like in other countries, there is a considerable deficit on ^{14}C and accompanying ^{13}C determinations. None of the tritium values was found to be above detection level. Therefore, either the detection level for tritium should be further improved or the tritium level in groundwater can be considered too low for any meaningful evaluation and hydrogeological interpretation. In the latter case, tritium sampling and analysis can be left out. (For surface water studies tritium appears to still be a useful environmental tracer.) The ^{14}C values of Bahariya samples taken in 2003 show a similar pattern (Fig.19) to the ones found in earlier studies in Egypt as well in Libya (see Figs.10, 17 and 18), namely ^{14}C values well above the ^{14}C detection limit (< 1 pmC) in very deep groundwater, and only slight (irregular) changes over the vertical depth profile. For Bahariya deep groundwater, however, Patterson et al. (2005) determined a ^{36}Cl age of more than 500000 years which is ten times higher than the ^{14}C dating limit. In fact, in some of the samples taken in Farafra and Bahariya area ^{14}C was found to be below the detection limit.

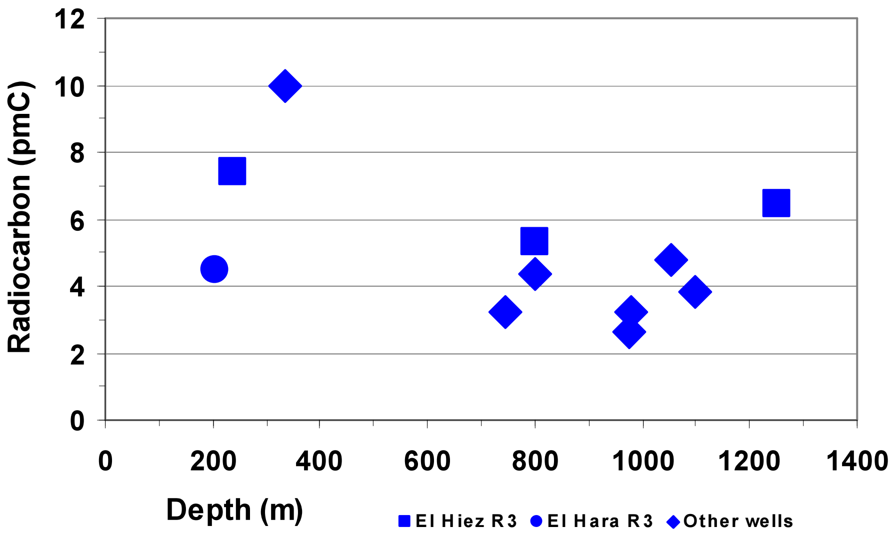


Fig.19: Plot of ^{14}C versus depth of sampling in the NAS and PNAS in Libya.

This finding and the discrepancy between the ^{14}C results on the one hand and the ^{36}Cl and ^{81}Kr results (Sturchio et al., 2004) on the other hand appear to be one of the major challenges for the forthcoming sampling and analysis campaign in Egypt and the other countries. The forthcoming work should include some methodological studies with regard to the potential contamination by ^{14}C from atmospheric CO_2 during sampling or other sources, as well as a reconsideration of the conceptual hydrogeological model(s) for the evaluation of the ^{36}Cl and ^{81}Kr as well as the ^{14}C measuring values. A suitable ^{36}Cl depth profile and transect should be considered in this regard. Given the recent ^{36}Cl and ^{81}Kr studies, the region from Uweinat towards Bahariya in Egypt could be most suitable for this study.

A review of the chemical data of the study regions in Egypt shows that there are some inconsistencies demonstrated by unacceptably high differences between the sum of anions and the sum of cations, between repeated δ^{18}O and pH measurements. This issue of precision and reliability of chemical and other data applies also to the other countries, thus effort has to be taken towards analytical quality control. Otherwise the subtle questions related to recharge and flow in such a complicated system as the NSAS can hardly be answered.

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5. Overview of Data Gaps and Strategy for Filling Them

After reviewing the baseline of information, key data gaps became apparent. An attempt was made to document the data gaps and then to determine the appropriate strategy for filling them. The following list of issues related to the strategy for filling the data and knowledge gaps has been developed during plenary discussions of the workshop (Tab.2).

Table 2: Review of Data Gaps, Relation to Transboundary Aspects and Potential Strategy

"Shared" Management Issues	Gaps in Knowledge	What will we learn?	Strategy	Sampling points
	Definition of hydrological boundaries	Defined areas of interest in the project;	Literature review	
Potential changes in conditions	Natural transboundary flow conditions	Potential changes in conditions Depth to water and spatial extent of change	Sampling of isotopes, chemistry and trace elements along selected transects; Re-sample where samples exist from the past	Chad and Libya Sudan and Libya
Pollution and water quality changes	Recharge (localized or widespread)		Soil Profiles, sampling along short transects (stable isotopes, C14, tritium) (Sample potential recharge areas	Tibesti, Uweinat, Darfur and Kordofan, Nile(?)
Land degradation and ecosystem services	Discharge	Source of the water is coming from and rate of discharge	Sampling in springs, lakes oases, and sabkhas (or wells to get samples before evaporation), Literature review including Eastern Deserts Project	Bezima lake (L), Ounianga (C), Oases (S)
Constraints to development	Flow and stratification (yes or no)	To understand age distribution to depth and better understanding of recharge and flow conditions	Depth-oriented samples at the same location at appropriate bore holes	Border areas depending on availability of wells
		Storage volume?	Literature review, thickness and porosity	
	Constraining	By calculating	Using the isotope	

	the hydrogeological parameters	flow velocity you can also estimate hydraulic conductivity using the radiometric data	data obtained in the other sampling	
	Cross-formational flow	Understanding upward and downward leakage	See above for stratification, core sampling, related to new drilling	Border areas depending on availability of wells
	Flow through palaeo-channels (related to issue of dual porosity)	Direction and connection between recharge and discharge	Parallel transects in the channel and outside (chemistry, stable isotopes and radiocarbon)	Tibesti
	Identify Risk Indicators and places to monitor			

6. COMPILATION OF THE NATIONAL WORK PLANS SET UP DURING THE MEETING

Based on the previous sections, workplans were developed to respond to gaps in line with the suggested strategy for filling gaps. These plans were later discussed again and slightly revised in the frame of the Nubian Inception Meeting held in Tripoli, Libya from July 16-20, 2006.

6.1. NATIONAL ACTION PLAN CHAD

Advantages:

Selecting of water points from:
- Data base of Direction of Hydraulics;
- Reports of hydraulic projects in the area from 1992 – 2000;
- Libyan boreholes.

Actions to be carried out:
- Inventory of all water points in the area;
- Select by giving priority to water points with technical and lithological characteristics available ;
- Sampling planning.

Characterization of aquifer:

Sampling maximum water points for chemistry and isotope analysis;

Delimitation of recharge zone and possible stratification of aquifer (*)

- Following up of minimum one transect by ^{14}C and probably ^{36}Cl analysis with selecting few boreholes for its technique equipment and depth.

Determination of Nubian Sandstone aquifer discharge zone

- Sampling spring water feeding lakes and lakes for isotope analysis and attempting isotope balance (input = spring water, output = evaporation) → quantification of aquifer discharge;
- Measurements of lakes water level.

(*) Working with Libyan part (transect) for determining divided water flow.

Preliminary conditions:

1) Logistics

- Car :must be negotiated
  - Cars PNUD projects;
  - Location ;
  - Cars of French Development Agency projects;
  - Cars of European Union projects,
  - Petrol and maintenance budget.
- Materials for sampling and in situ analysis ;

2) Training on sampling (chemistry and isotope) and on basic isotope hydrology concepts.

NATIONAL WORK PLAN (Chad)

Issue to be investigated	Activity	Inputs	Where	When
Availability of water points for sampling	Selecting of water points from Data base of Direction of Hydraulics; Reports of hydraulic projects in the area implemented (1992 – *2000*) and Libyan boreholes.	Project staff	Chad	From Jun to July 2006
Capacity building	Training on sampling (chemistry and isotope) and on basic isotope hydrology concepts	Project staff, IAEA	?	October/November 2006
	Expert mission for helping project staff on preparing field operations	Project staff, IAEA	Chad	November/December 2006
Characterization of aquifer	Sampling operations in maximum water points and chemistry and isotope analysis. Sampling through one transect for ^{14}C and probably ^{36}Cl analysis in few boreholes selected for its technique equipment and depth	Project staff, IAEA	Chad Vienna	During 2007
Determination of Nubian Sandstone aquifer discharge zone	Sampling operations and isotope analysis and attempting isotope balance of springs and water feeding lakes and lakes.	Project staff, IAEA	Chad Vienna	During 2007
	Measurements campaign of lakes water level	Project staff	Chad	During 2007

6.2. NATIONAL ACTION PLAN LIBYA

1. General aspects

What is available?

1. Pre-project data, reports, papers and open files available for Kufra and Sasrir basins. The work was carried out since the 1970s up today, specifically drilling activities, water sampling for chemical and isotope analyses and monitoring for changes in water level and water quality.
2. Ongoing activities on the use of isotopes are related to Garyounis University that is located in Beghazi, jointly with German expertise/experts (academic activity). Results obtained by this group are being made available.
3. Relevant information (cross section, lithology, aquifer parameter, water quality of the aquifer, hydraulic parameters) is available for the drillings/wells from which samples are (will be) taken.

Gaps identified?

In addition to the results already obtained under the ongoing IAEA project for selected locations, more sampling should be carried out at different depths and locations for determining stratification and establishing transects.

- SR-3 (on the Libyan-Chad border) at 450 m depth in Nubian) – near borderS12-D (deep aquifer 1200m)
- S4-S (shallow ca. 150m)
- S4-M (GMMR already results available, medium depth ca 415m)
- SR2 (SW-2) shallow well already taken, 70m), ^{18}O,^{2}H available, ^{14}C not yet
- SR2-M (depth about 400m)
- 2 Springs in Aouinet region: Ain Zuwaya, Ain Elghazal

The remaining sampling locations as listed in the table below should be continued.

Soil sampling for recharge investigation:

- for NAS in Oweinat region (wadi area near the two springs, identified) and in Kufra area;
- for the PNAS in two other sites in Tazerbo and Mrada area.

Planning for sampling campaigns

The sampling fof the wells/sites is scheduled for the period June to October. The sampling will be carried by GWA, the field measurements during sampling and the chemistry will be done by GWA staff and laboratory. The samples for isotopes will be sent to IAEA (or any recommended laboratory within the region). Experience and logistics requested from the IAEA include

- Hand auger and related equipment for soil sampling;
- expert service for this kind of sampling.
- Expert service requested for water retention also needed.

These expert services should be scheduled for July/August 2006. Further details are given in the table below.

Issue To be investigated	Activity	Inputs	Where	When
Completion of programmed sampling course for the purpose of the NSAS study	Collecting the remaining samples (14 locations as in attached table)	General water authority (GWA)	GWA Zone Five (Kufra Sarir Branch)	From June. To Aug 2006
Estimating the impact of irrigation return	Collection of water & Soil samples (about 5)	GWA IAEA	GWA Zone Five (Kufra Sarir Branch)	From June. To Aug 2006
Issues related to MSP (estimation of Evaporation rates)	Collection data from natural lakes	GWA	GWA Zone Five (Kufra Sarir Branch)	From June. To Aug 2006
Re-updating the data base of NSAS	collecting of the PZ wells data , Chemistry and the hydrogeological data	General water authority (GWA	GWA Zone Five (Kufra Sarir Branch)	From June. To Aug 2006
Water samples analyses	-Chemistry - Trace Elements -Radio active isotope	-GWA - IAEA -IAEA	-GWA - IAEA -IAEA	From June. To Oct 2006
Procurements	- Rain gauges (4) - Books and Software - Field computer (1)	IAEA	IAEA	From June to Dec. 2006
Training for 3-6 months for isotope hydrology	2-3 personnel	IAEA	IAEA	During 2006
Missions: 1- Expert Mission (1) 2- Scientific Mission (1)	To assist in data evaluation & Interpretations	IAEA	GWA	July, 2006 Nov., 2006
Regional Workshop	evaluation & Interpretations and discuss the preliminary results	IAEA	?????	During 2006

Table 2: List of remaining sample locations

S. No.	Site Name	X Longitude E	Y Latitude N	Remarks
1	Brega	19 34 50.4	30 15 46.8	
2	Aqeila	19 09 40.8	30 07 52.8	
3	Qasr Sahabi	21 05 48.0	29 50 31.2	
4	Marada	19 13 33.0	29 07 54.0	
5	Zighen	22 17 25.2	25 55 15.6	
6	Bir Al Harash	22 25 09.6	25 26 50.4	
7	Buwaymah	23 25 09.6	24 15 47.4	Kufra
8	Bzema	22 11 36.6	24 36 18.6	
9	Rebiana	22 01 55.8	24 09 28.2	
10	Waw Alnamus	17 38 42.0	24 48 57.0	
11	Zelten	19 46 27.0	29 03 09.6	
12	Hosenofu	21 13 33.0	23 31 43.8	
13	Bishara	22 50 19.8	22 41 03.0	
14	Ain Zuwaya	24 54 11.4	22 00 00.0	Uwienat
15	Ain Elghazal	24 46 27.0	21 25 15.6	Uwienat
16	Uwienat	24 58 03.0	21 44 12.6	
17	Assara	21 50 39.7	21 39 56.6	Site 2
18	GMRA Well field	22 28 02.91	23 33 01.71	Kufra

6.3. NATIONAL ACTION PLAN SUDAN

National Work-Plan 2006 - 2007 (Sudan)

No	***Issues to be investigated***	***Activity***	***Inputs***	***Target area/staff***	***Where***	***when***
1	Age & origin of groundwater	Third sampling campaign	Field trip / National	Oases + Oweinat wells	Near boarders	Sept. 2006
2	Aage & origin of groundwater	Fourth sampling campaign	Field trip / National	Wadi Muggadam * El Milk + Merawi project observ. wells	Centre & east of project area	Dec. 2006
3	Aage & origin of groundwater	Fifth sampling campaign	Field trip / National	Nukheila and Atron Oases + Wadi Hawor wells	Dar Fur Region	March 2007
4	Analysis of samples for isotopes	Shipment of w samples	National / IAEA		Khartoum / Vienna	Jan 2007
5	Analysis of water samples	Chemical analysis	National / IAEA	Lab.staff	Khartoum	Oct.2006 7 Jan. 2007
6	Training (on the job)	Install TRI-CARB scintillation apparatus	Expert mission IAEA	Chemists of isotope lab.	Isotope lab.	???
7	Training	Isotope hydrology	IAEA	Hydrologists / geologists	Abroad	
8	Capacity building	Procurement of TRI-CARB scintillation apparatus	IAEA	Isotope lab. Staff	Isotope lab. (Khartoum)	
9	Capacity building	Fellowships (isotope hydrology)	IAEA	Trained hydrogeologists	Abroad	
10	Capacity building	Scientific visits	IAEA	Project staff	Abroad	
12	Determine groundwater flow	Monitoring G W level + quality	Field trip /National	Dongola Area + Qaab Depression + Merawi Observation Wells	Dongola Area + Qaab Depression +	

6.4. NATIONAL WORK PLAN EGYPT

The National Work Plan is compiled in the table below. It is based on the work plan originally drafted at the 2nd Coordination Meeting in Dec. 2005 held in Cairo, Egypt, and then revised based on discussions with Dr. Taher Hassan in the frame of his Scientific visit to Vienna, Austria, IAEA Headquarters, June 2006. Egyptian representatives presented a revised version at the Nubian Inception Meeting in July 2006.

Procurements

The following items are requested for procurement, in accordance with the priority needs for the project implementation:

- For the already delivered compressor the accessories are needed: flexible 1" hoses and 4 to 8 inches adaptors, Qt. 120 m.
- Two inches submersible pump yield $3m^3/h$ from head 100m, with the accessories, generator and flexible hoses Qt. 2.
- Multi parameters meter for measuring water level, temperature, EC, pH and dissolved oxygen; length of the cable 100 m – Qt. 2
- Complete Set for CFC sampling
- Modelling Software (GMS Ver 9, WMS and GIS Imagine other for Geochemical and Isotope interpretations (Chem5, Solmineq).
- Bottles and chemicals for sampling

Analytical services

Analytical service for isotope analyses will be provided by the EAEA laboratory in Cairo, Egypt, except for 14C AMS and for CFCs.

Objective 1: Compilation of historical data about the aquifer system				
Issue to be investigated	Activity	Inputs	Where	When
• Transboundary Issues	3rd Sampling Campaign Collecting 100 samples for O18 & H2, 50 samples for C13&C14, 10 samples for H3	•Int. Expert Mission. •Delivery of air Compressor accessories.	RIGW EAEA	Nov. 2006
• Discharge/ Extraction Zones	4th Sampling Campaign Collecting 50 samples for Cl profiles, H3, CFC and Nobel Gasses from south Egypt, Kharga, Dakhla, Farafra, Bahariya, Siwa and N Western Desert.	•Analytical Services, IAEA Labs	RIGW EAEA IAEA	Feb. 2007
• NSAS Boundary Conditions	5th Sampling Campaign Selective sampling from new observation wells (50 samples for O18 & H2 and 20 samples for H3 and C13 & C14).	•Analytical Services •IAEA Labs	RIGW EAEA IAEA	May 2007
• Fresh / Saline Boundary Area	6th Sampling Campaign Selective sampling from relevant observation wells (Cl, H3, CFC and C13).	•Analytical Services •IAEA Labs	RIGW EAEA IAEA	Sept. 2007

7 Nubian Shared Aquifer Diagnostice Analysis

Based on the presentation made by Mr. Andy Garner, Technical Officer for the Nubian project, discussions were held on the approach for carrying out the Nubian SADA. The SADA process will work to identify all transboundary issues, threats, risks etc. that are shared by the respective NSAS countries. Therefore future sampling efforts should be geared towards improving the status of knowledge of the transboundary aspects of the Nubian as well as cause and effect relationships to Nubian activities. The Nubian SADA will form the basis for developing the a joint management programme for the Nubian (Nubian Strategic Action Programme- SAP.)

8 CONCLUSIONS AND RECOMMENDATIONS

8.1. Conclusions

The objective of the meeting was to gather and enhance baseline knowledge on the NSAS in terms of hydrology and dynamics (recharge and flow regime) of the system, with special emphasis on the transboundary regions. The presentations and discussions focused on the use of isotopes in past and present studies of the NSAS, on the identification of gaps in the databases and on setting up a work plan to fill these gaps through sampling campaigns, sample analyses and joint evaluation of the data as soon as feasible.

1. The meeting succeeded in updating the baseline knowledge, in identifying gaps as well as in defining measures/strategies to fill the gaps.

2. Filling the gaps will facilitate a more comprehensive evaluation of the isotope data in combination with data from other hydrogeological studies for a better understanding of the dynamics of the system.

3. In particular, the data are expected to help better validate and constrain the models used for managing the shared groundwater resources of the NSAS.

4. There are two databases on the NSAS, the NARIS (major emphasis on hydrogeological parameters, well data, piezometric levels etc.) that is operated by CEDARE, and the ISOHIS (focusing on isotope and related data) operated by the IAEA. Both databases appear to have significant gaps. The meeting worked to identify gaps in the ISOHIS.

   - First of all, there is an imbalance between stable isotopes, ^{3}H (for earlier studies) and chemistry on the one hand, and ^{14}C and ^{13}C on the other hand. The latter isotopes are indispensable to study past recharge regime and flow regime in the upper part of the aquifers.
   - There are many gaps in parameters indispensable for the hydrogeological evaluation of the isotope data. These parameters include depth (depth range) from which the samples have been taken, characteristics of the wells/boreholes used for sampling, geographic coordinates of the wells etc.
   - The meeting highlighted that the sampling sites covered by previous studies are unequally distributed over the NSAS, and in particular there are only a few sites (in South Egypt, North Sudan, South Libya) that can be used for addressing transboundary issues.
   - So far, there are only three studies, carried out under purely scientific goals that use long-lived radioisotopes to specifically address the very old groundwater within the NSAS. Two studies (in the Dakhla basin in Egypt) are on the potential of ^{36}Cl and ^{81}Kr in

characterizing the age and dynamics of groundwater in the system, and another one is on the use of uranium isotope disequilibrium for characterizing mixing of the very old part/component with the component infiltrated more recently, especially during pluvial phases of the Holocene.

5. A discrepancy appears to exist between the apparent (model) ages of the deep groundwater indicated by recent ^{36}Cl and ^{81}Kr determinations and the ^{14}C data obtained by recent and past isotope studies in the Bahariya region (and elsewhere). To resolve this discrepancy is one of the major challenges for the forthcoming work within the project.

8.2. Recommendations

1. Concerning the databases the meeting strongly recommended to establish close links between the two databases NARIS and ISOHIS, to make them compatible and accessible by the concerned countries and organizations.

2. A number of measures have been agreed upon to fill the gaps through Shared Aquifer Diagnostic Analyses (SADA). These are the following:

    - Implementation of sampling campaigns in cooperation between the countries and by support of the IAEA
    - Major aspects to be taken into account in selecting sampling sites for the forthcoming sampling campaigns: (1) sampling must be co-ordinated at the regional scale to obtain transects along inferred hydraulic gradients and crossing the borders of the neighbouring countries; (2) this approach requires concerted actions in sampling between the concerned countries; (3) groundwater stratification has practically not been tackled so far; therefore wells/boreholes have to be selected that enable depth-oriented sampling.
    - Major aspects in selecting the isotopes and other parameters to be measured in the groundwater of the NSAS: (1) place special emphasis on ^{14}C (plus ^{13}C) to resolve the imbalance between the various isotopic tools (note that ^{14}C will be below the detection limit in very deep groundwater, i.e. the best way would be to sample at various depths from about 0 meter down to a few hundred meter at given sites; (2) in selected regions sample for ^{36}Cl and/or uranium isotopes to address the mixing/flow of very old groundwater; (3) consider that isolated/single measurements of these isotopes hardly can provide conclusive results; they need establishing evolutionary trends along transects and depth profiles and data from complementary isotopes and chemistry.
    - The analytical quality control should be strengthened to avoid inconsistencies in the data (including chemical data) and improve the precision of the measurements..

3. Important questions to be answered in case of Libya are (1) whether there is an interrelationship between the Kufra and Sirte basin; (2) possible exchange between PNAS and NAS.

4. One question for Chad and Libya to be addressed by the forthcoming activities: Is there a water divide near the Chad border to Libya.

5. The deficit of wells in the Tibesti area as a potential present-day recharge zone should be overcome by establishing wells and sampling available springs.

6. The question of present-day recharge by rainfall in Southern Sudan deserves also special attention. In this context, all available data (with preliminary interpretations included in reports) must be plotted on the same graph. This includes the data of groundwater close to the Nile, on the one hand, and the data of the Darfur and Kordofan areas on the other hand. This evaluation/interpretation requires a better knowledge of the input signal of the Nile water and its variation in time, especially due to flooding. The mixing of Blue and White Nile downstream of their confluence has also to be taken into account.

7. Recent modelling of the groundwater dynamics in the Western Desert of Egypt (Patterson et al., 2005) assumes a localized recharge area (Uweinat) disregarding distributed recharge

along the transect. This is in disagreement with the model developed at TU Berlin (Brinkmann et al. 1987) and the upgraded version used by CEDARE. It is thus suggested to set up appropriate sampling networks for ^{14}C and ^{36}Cl sampling (transects, depth profiles) from Uweinat region towards north-east in Egypt and north-west in Libya, if feasible also towards neighbouring Chad and Sudan regions.

8. The question of potential ^{14}C contamination by ^{14}C from atmospheric CO_2 during sampling or other sources should be addressed by, among other things, applying alternative sampling techniques and comparing ^{14}C values of a given sites (and depths) measured by AMS with those measured by conventional decay counting technique.

9. For a closer comparison of the various dating techniques a suitable ^{36}Cl (and ^{14}C) depth profile and transect should be considered in this regard. Given the recent ^{36}Cl and ^{81}Kr studies, the region from Uweinat towards Bahariya in Egypt could be most suitable for this study.

Annex 1

Agenda of the meeting

Nubian Sandstone Aquifer System (NSAS) Technical Baseline Meeting

IAEA/UNDP/GEF Nubian Aquifer Project (RAF8/036)
May 8- 12, 2006

IAEA Headquarters, Vienna, Austria

Room (F0579)

Day 1: Monday, 8 May 2006

Opening Session

10:00 – 10:30 Opening of the Meeting and Welcome Remarks– A. Boussaha & P. Aggarwal

Introduction of Participants L. Abdul-Malik

- Selection of the Chairperson and Rapporteur
- Adoption of the Agenda
- Objectives of Meeting

Session 1: ***Review of Technical Component of the IAEA/UNDP/GEF Nubian Project***

10:30- 11:00 Overview of the IAEA/ UNDP/GEF Nubian Project Components and Improving the Technical Understanding Of the NSAS A. Garner, IAEA

11:00 -11:15 **Coffee Break**

Session 2: Review of Current Technical Knowledge of the NSAS

11:15- 12:00 National Reports: Presentation of National Baseline- Sudan

12:00- 12:45 National Reports: Presentation of National Baseline- Libya

12:45 - 14:00 Lunch

14:00- 14:45 National Reports: Presentation of National Baseline- Chad

14:45:15:30 Discussion

15:30-16:00 **Coffee Break**

16:00- 16:45 Discussion of what is known

16:45- 17:15 Review of Results/ information from Day 1and Plan for Day 2

Close for the day

Day 2: Tuesday, 9 May 2006

Session 3: Review of Gaps in the Technical Knowledge of the Aquifer

9:00- 10:30 Summary of Information Available in order to identify gaps K. Froehlich

10:30- 11:00 Coffee Break

11:00- 12:30 Discussion about identification of gaps

12:30 - 14:00 Lunch

14:00- 15:00 Discussion of transboundary aspects in relation to filling in gaps of technical knowledge of the aquifer

15:00-15:45 Developing a Strategy for Filling in the Gaps, P. Aggarwal

15:45-16:15 **Coffee Break**

Session 4: Isotopic Investigations to Build a Better Technical Understanding of the NSAS

16:15- 17:00 Discussion on Strategy for Isotopic Investigations to Fill Information Gaps

17:00- 17:30 Review of Results/ information from Day 2 and Plan for Day 3

Social Event

Day 3: Wednesday, 10 May 2006

Session 5: Data/ Information Management for the NSAS

9:00- 9:30 *Introduction of* ISOHIS

09:30-10:15 *NARIS Information System, .* L. Madi, Libya

10:15- 10: 45 *Discussion on Information Management for NSAS Cooperation*

10:45-11:00 ***Coffee Break***

11:00- 12:30 Integrating Data to Complete National Data Sets- Working Groups (led by P. Aggarwal)
- Chad (facilitated by Yves Travi)
- Sudan (facilitated by A. Herczeg)
- Libya (facilitated by K. Froehlich)

12:30- 14:00 ***Lunch***

Session 6: Work planning to Fill in Data Gaps

14:00- 14:30 Administrative aspects of IAEA Nubian Activities, Lameen Abdul- Malik,

14:30- 15:00 Review of current work plans and new sampling at the national level, Andy Garner

15:00- 17:00 Working Groups (led by P. Aggarwal)
- Chad (facilitated by Yves Travi)

	- Sudan (facilitated by A. Herczeg) - Libya (facilitated by K. Froehlich)
16:30 – 17:00	Review of Results/ information from Day 3 and Plan for Day 4

Close for the day

Day 4: Thursday, 11 May 2006

9:00- 9:30	National Workplans and Review of Relevance and Feasibility, Time frame etc. P. Aggarwal and K. Froehlich
9:30- 12:00	Working Groups on National Workplans
12:00- 13:30	***Lunch***
13:30 15:30	National Presentation of Sampling Plans
15:30-16:00	**Coffee Break**
16:00-17:00	National Presentation of Sampling Plans- continued
17:00- 17:30	National Inputs into Regional Work Plan – What will SADA Look Like ? A. Garner
17:30- 17:45	Review of Results/ information from Day 4and Plan for Day 5

Close for the day

Day 5: Friday , 12 May 2006

Session 7:	***Nubian Technical Baseline Report and Workplan***
9:00- 10:45	Final review and adoption of the Technical Baseline Report and new Workplan and consideration of how it will contribute to the overall IAEA/UNDP/GEF Nubian Aquifer Programme
10:45- 11:15	**Coffee Break**
11:15- 12:00	Review of Meeting report, Technical Baseline report including Workplans/ Sampling Plans
12:00- 14:00	Review of Next Steps and National Commitments, Time lines etc.

Closing of the Meeting, Ali Boussaha, Pradeep Aggarwal IAEA

Nubian Sandstone Aquifer System (NSAS) Technical Baseline Meeting

May 8- 12, 2006

IAEA Headquarters, Vienna, Austria

Objectives of the Meeting

- Review and synthesize currently available technical information, with a focus on isotopic data, as a basis for updating the "baseline" knowledge of NSAS system;
- Determine important information gaps that need to be filled in order to better understand and assess transboundary issues;
- Consider strategies (sampling, monitoring etc.) that could effectively and efficiently lead towards filling these gaps;
- Develop concrete next steps for filling gaps in the frame of the IAEA's co-funded activities for isotopic analysis in the IAEA/UNDP/ GEF Nubian Aquifer and in particular to support the development of a "Shared Aquifer Analysis (SADA)"

Desired Results/ Outcomes

- Enhanced technical understanding of the NSAS, increased knowledge on both determined and potential transboundary issues;
- Better understanding of important knowledge gaps as well as needed activities e.g. sampling/ monitoring to fill the gaps;
- Agreement on approach for synthesizing and managing data in the frame of the project.
- Clear approach for isotopic studies to support the development of the SADA.

Expected Outputs

- Nubian Baseline Technical Report
- Sampling strategies for inclusions into 2006/07 workplan (s)
- Approach for information management

Necessary Inputs- Background Information Needed Before the Meeting

- 4 National Reports that provide a synthesis of all relevant technical information at the National level. (see separate guidelines for the reports
- Copy of the NARIS information system (its contents)

Annex 2

List of participants of the meeting

RAF8036/9003/01
Technical Baseline Meeting
Austria, Wien
2006-05-08 - 2006-05-12

List of Participants
(as of 2006-05-11)

1	**IAEA**	Mr Muhammed Lameen Abdul-Malik- IAEA, TCAF
2	**IAEA**	Mr Pradeep Kumar Aggarwal- IAEA, NAPC
3	**IAEA**	Mr William Andrew Garner- IAEA, NAPC
4	**IAEA**	Mr Seifu Kebede Gurmessa- IAEA, NAPC
5	**IAEA**	Mr Andrew Leslie Herczeg- IAEA, NAPC
6	**IAEA**	Mr. Ali Boussaha
7	**IAEA**	Mr. Mokdad Maksoudi
8	**France**	M. Yves Marie Travi
9	**Tunisia**	M. Kamel Zouari
10	**Chad**	Mr Djirab Alifei Mbodou
11	**Chad**	Mr Noe Reouebmel
12	**Libyan Arab Jamahiriya**	Mr Hamza Hamza
13	**Libyan Arab Jamahiriya**	Mr Lotfi A. Madi Farag
14	**Sudan**	Mr Mohammed El Hassan Abu Buker
15	**Sudan**	Mr Abd Alla Mohamed Kheir Fadl El Moula