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Regional Shared Aquifer Diagnostic Analysis For the Nubian Sandstone Aquifer System

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Section 1. Introduction

This Shared Aquifer Diagnostic Analysis (SADA) represents the technical data-gathering element of the GEF Medium Size Project to strengthen cooperative management of the Nubian Sandstone Aquifer System (NSAS) in the Libyan Arab Jamahiriya (Libya), Egypt, Chad, and Sudan. The SADA is process through which transboundary threats are identified and prioritized with the specific purpose of informing the Strategic Action Program (SAP) phase of the project.

1.1 Context

During the past four decades, Egypt, Libya, and Sudan have made separate attempts to develop the shared NSAS. Since the early 1970s, the three countries have expressed their interest in regional cooperation to share their experience and to study and develop this aquifer. They agreed to form a Joint Authority to study and develop the NSAS and to seek international assistance to establish a regional strategy for the utilization of the NSAS water resources. Egypt and Libya initiated the process in the early 1970s and formalized the Joint Authority for the Management of the NSAS in 1992 (Joint Authority). Sudan joined the Joint Authority in 1996 and Chad followed in 1999.

One challenge in developing an adequate management strategy is to gain sufficient knowledge about the aquifer. Accordingly, cooperation was activated from 1997-2002 through important initiatives supported by the International Fund for Agriculture Development (IFAD) under the project management of the inter-regional organization, the Centre for Environment and Development for the Arab Region and Europe (CEDARE). This resulted in a joint survey of the socio-economic development policies and plans in the aquifer areas and the establishment of a Nubian Aquifer Regional Information System (NARIS) database. NARIS was envisioned to facilitate data storage, processing, display and analysis and would provide input files for geographic information systems (GIS) and mathematical models. The groundwater modeling efforts have been well documented (CEDARE 2001) and provide indications of the impacts on water levels and water quality over a period of 60 years of development and abstractions.

The Joint Authority and the CEDARE program made important advances in regional cooperation that resulted in an improved understanding of the aquifer system and established mechanisms for data sharing and groundwater monitoring and modeling. These advances laid the groundwork for a partnership of the Global Environment Facility (GEF), United Nations Development Program (UNDP), and the IAEA to work with member countries to strengthen regional cooperation, address data gaps, improve the technical understanding of the NSAS, and develop policy strategies for managing the aquifer system.

This partnership led to the funding of this project in 2006 by GEF, UNDP, and IAEA as a Medium Sized Project (MSP) titled, The Regional Formulation of an Action Programme for the Integrated Management of the Shared Nubian Aquifer. The overall objective of the project was to develop the framework for the sustainable management and use of the Nubian Aquifer System in the four Nubian countries: Chad, Egypt, Libya, and Sudan. The project expands and consolidates the technical and scientific knowledge base regarding the Aquifer System. This document is being filed as a partial fulfillment of the activities of that MSP. The formulation of a SADA followed by a Strategic Action Programme (SAP) is required for most projects proposed for financing in Operational Programmes 8 and 9 of the GEF International Waters Focal Area.

1.2 The Nubian Basin

The Nubian Sandstone Aquifer System (NSAS) is one of the largest aquifers in the world covering approximately two million square kilometers of Northeast Africa in Chad, Egypt, Libya, and Sudan (Figure 1). It is among the world's largest fossil aquifer systems with reserves estimated at 375,000 cubic kilometers. In the arid desert areas of those countries that share the aquifer, groundwater is a primary source of water for human populations and oasis ecosystems. With growing population pressures and decreasing water available from other sources, there is increasing pressure to enhance the abstraction of this tremendously valuable resource that, under current climatic conditions and based on current knowledge, appears to be only marginally rechargeable. This increased pressure to use these shared groundwater resources, despite unclear knowledge of the transboundary impacts, represents a potential threat to a precious resource that if unchecked, could lead to deterioration of water quality and irrational water use with the potential to harm biodiversity, provoke land degradation processes, or even lead to transboundary conflict.

1.3 Special Characteristics

Groundwater resources are never strictly non-renewable. But in certain cases the period needed for replenishment, on the order of hundreds to thousands of years, is long in relation to the normal time-frame of human activity in general and of water resources planning in particular. In such cases it makes practical good sense to talk in terms of 'non-renewable' groundwater resources. Aquifers have a natural capacity for both water storage and water flow, and thus groundwater simultaneously accumulates and circulates. The volume of groundwater stored in some of the larger aquifer systems is immense and, excluding water presently tied up in polar ice, represents some 97% of our planet's freshwater resources.

Groundwater resource renewal is a concept that derives from a comparison between the natural flow and storage of aquifer systems. In cases where present-day aquifer replenishment is very limited but aquifer storage is very large, the groundwater resource can be termed non-renewable. 'Non-renewability' does not necessarily imply that the aquifer system is completely without replenishment or entirely disconnected from processes at the land surface, since absolutely zero recharge is extremely rare. 'Renewal periods' are necessarily an approximate average for the aquifer under consideration, and may conceal a large range of local variations within the hydrodynamics of the aquifer flow regime. Moreover, both the drainable storage of an aquifer system and its long-term average rate of recharge are difficult to estimate with precision, and thus it may sometimes be difficult in practice to distinguish between essentially non-renewable and weakly replenished groundwater resources.

The development of non-renewable groundwater resources will imply the mining of aquifer storage reserves, such that they will not be available for future strategic use. As such it has special social, economic, and political sensitivity compared to other water resource development. In practice non-renewable groundwater resources become available for exploitation through technical advances and economic improvements which interact to make possible the mining of groundwater from an aquifer. An example is the growth in exploitation of the groundwater storage reserves of the North

Western Sahara Aquifer System (NWSAS) in Algeria, Libya, and Tunisia and that of the NSAS in Libya (The Great Man-made River) as well as in Egypt (western desert & East Oweinat) which has led to the progressive reduction in major spring flows and oases.

The way in which the utilization of non-renewable groundwater arises can be classified:

- ***Planned schemes***, in which mining of aquifer reserves is contemplated from the outset, usually for a specific development project in an arid area with little contemporary groundwater recharge.

- ***Unplanned basis*** with incidental depletion of aquifer reserves, as a result of intensive groundwater abstraction in areas with some contemporary recharge but where this proves small or where there is limited hydraulic continuity between deep aquifers and their recharge area.

Unplanned depletion of non-renewable groundwater reserves can undermine, and potentially erode, the economic and social vitality of the traditional groundwater-dependent community. Hence, there is need to plan the exploitation of non-renewable groundwater resources, and guide their utilization with a view to making communities better prepared socio-economically to cope with increasing water stress as aquifer storage is depleted, that is, to maintain the socio-economic sustainability which refers to the maintenance of well-being of the people most dependent on a resource, through regulating plans and actions that affect the sustainability of the resource while maintaining an equitable inter-generational distribution of benefits.

Socially-sustainable plans for use of a non-renewable resource would thus need to be formulated to meet three main conditions:

- Maintain or improve the well being of communities involved, by meeting as far as possible their social, economic, cultural and environmental needs, now and in the future.

- Manage the actions of concerned individuals or communities that affect resource use, by strengthening their capacity to cooperate in the management of the resource and assuring appropriate financial, legal, technical, institutional and political conditions for them to adhere to the established management plan.

- Address the fundamental concern about human survival by maintaining inter-generational equity in terms of benefits derived from the resource; and ensure economic and social opportunities to all stakeholder groups including future generations.

It is necessary to define an appropriate planning horizon for the exploitation of the non-renewable groundwater resource. A reasonable time frame may be at least 20, and preferably 50 to 100 years. It is additionally prudent to pay full consideration to the questions of external impacts and to anticipate alternatives for the eventual depletion of the resource and climate change implications. Thus time horizons of 100 to 500 years become relevant.

The overall goal should be to use groundwater in a manner that maximizes long-term economic and social development of the community and decreases, over time, the frequency and severity of threats to society, leaving people better prepared to cope with socio-economic stresses associated with increasing water scarcity as aquifer storage is depleted. This will often entail the initiation and expansion of high added-value economic activities that are not water intensive. At the same time an appropriate 'exit strategy' need to be identified, developed and implemented by the time the aquifer is substantially depleted.

A key challenge in the planning process is to determine the quantity of groundwater that can be pumped over the planning period to best serve the communities involved. Such an analysis involves assessment of three key components:

- The economics of groundwater mining and the progressive increase in water production costs under different exploitation options, which will have implications for the feasibility of the proposed uses.
- The long-term effects of the proposed exploitation of aquifer reserves on all traditional groundwater users, so that some form of compensation can be provided for predicted or actual impairment of the resource. Where the protection of indigenous people is an issue, it should be ensured that a sufficient reserve of extractable, adequate quality, groundwater is left in the aquifer system at the end of the proposed period of intensive exploitation to sustain the pre-existing activity, albeit at additional cost. Another way of achieving this end would be to restrict the design average drawdown of intensive exploitation to less than a given average figure over a stated period, for example, 20 m after 20 years or 50 m after 30 years.
- The dependence of any aquatic ecosystems on the groundwater system, and whether these can be sustained, albeit in reduced form, through provision of compensation flow by local irrigation and aquifer recharge of the overdraft and runoff. This consideration will need to be realistically factored into the evaluation of the acceptability of the proposed groundwater development.

In developing the groundwater mining plan, the socio-economic analysis will require planners to look at other sectors besides water. Hence, modeling will be needed to guide the allocation of groundwater abstraction between sectors and over time, so as to determine the optimal abstraction schedule to maximize some economic criteria, often economic efficiency. However, the long-term socio-economic impacts may often be difficult to forecast accurately. But what is known is that the non-renewable groundwater used today will not be available for future use, although it is often the case that the socio-economic benefits to future generations are often greater if some of that resource is used today rather than saved for future use.

In summary the key principles that should adopted for the development of non-renewable groundwater resources are:

- The evaluation phase should result in estimates of the volume of groundwater that can be produced in a fixed time-horizon with reference to an acceptable groundwater level decline

- The development of non-renewable resources must be justified by socio-economic circumstances in the absence of other water resources, and that its implementation is planned and controlled.

In the unplanned situation the socially-sustainable criterion implies that ‘rationalization’ of groundwater extraction and use be imposed with the goal of achieving orderly utilization of aquifer reserves, which will minimize quality deterioration, maximize groundwater productivity and allow time to promote social transition to a less water-dependent economy. In general the groundwater abstraction rate will have to be progressively reduced, and thus the introduction of demand-management measures will be needed. In the longer run potable water supply use will have to be given highest priority and some other lower productivity uses may have to be discouraged.

Resource utilization and aquifer management plans aimed at achieving social sustainability of groundwater use also have to vary considerably according to the stage of development at which the planning intervention is invoked. Management interventions in the case of an aquifer whose non-renewable resources are already being mined at a high rate will entail a different planning approach, and it will often be a more difficult to reconcile and integrate the interests of the various stakeholders into a rational management plan to achieve maximum useful-life of existing water wells and the aquifer system, together with a smooth social transition to other economic activities that are less water-consumptive and/or able to support the much higher cost of alternative water-supply provision. To ease the situation, all available economically-viable opportunities should be taken of enhancing recharge in those aquifer recharge areas that experience intermittent surface water runoff.

The planning process for socially-sustainable mining of groundwater resources or putting the existing mining of groundwater resources on a socially-sustainable basis, must incorporate the following key elements:

- Evaluation of ‘social well-being’ on a periodic basis
- Effectiveness of community participation in groundwater regulation
- Appraisal of the extent to which inter-generational equity is being met.

Specific criteria or parameters for these elements should be incorporated into the management model developed for the aquifer under consideration.

1.4 The Need for a Common Vision

As indicated in the above section, the utilization of non-renewable groundwater resources, whether on a planned or unplanned basis, implies the mining of storage reserves. As such it presents a special challenge due to the social, economic and political concerns that have to be taken into account by policy and decision makers.

In the more arid climates in general and the Middle East and North Africa region in particular, the use of non-renewable groundwater offers an opportunity to alleviate growing water scarcity, improve social welfare and facilitate economic development. Therefore such development should be considered if certain criteria can be met and specific risks can be managed in order to ensure socially sustainable utilization of the resource.

All four NSAS countries plan to place a greater emphasis on groundwater resources to provide for water needs in the future. They all have similar climates, where surface water resources are scarce and groundwater resources need to be explored to meet increasing needs. As a result all countries have attached top priority in their respective national development plans to address water shortages and explore for alternatives. The NSAS provides a unique opportunity, as it is a huge, mostly untapped water basin that lies under all four countries.

Each of the respective aquifer countries is pursuing different development strategies. The NSAS lies in an area of Chad that is not heavily populated. Little is known about the NSAS resources available within Chad and currently small communities and nomadic groups dependent on these resources. The government has developed a national water development strategy that aims to secure the use of more water resources from the NSAS. In Egypt the NSAS is the only source of freshwater in the Western Desert, which covers about 68% of Egypt's area. Egyptian national policy stresses population redistribution over the country's physical area and the Western Desert is one of the target areas. Therefore, the NSAS is seen in Egypt as a strategic resource to support national development policies. In Libya the policy is to increase the transport of water from the NSAS to the coastal and urban areas where a majority of the Libyan population is growing as well as desert reclamation planning. Therefore, the national water development strategy is to continue to develop NSAS resources to match growing populations and water demands. In Sudan, currently a large percentage of water supplied nationally comes from the Nile, an already severely strained asset. Therefore future development plans call, inter alia, for the enhanced use of NSAS water resources.

The interconnectedness of border-crossing groundwater systems inevitably results in the interdependence of all its users and stakeholders who share it not withstanding their potential diversity in many other respects. Water-related activities in one state are likely to impact the water situation in another one and water-related problems such as pollution can often only be solved through transboundary cooperation. Therefore, the need to cooperate on water issues beyond the borders of states has been broadly accepted for many years.

Cooperation can manifest itself in a variety of cooperative institutional arrangements, through which states, formally or informally, agree to a common set of rules that govern their interactions. Awareness of, and cooperation on, water issues has increased tremendously within the last few decades. Yet the challenges keep expanding ever more rapidly due to exponentially growing demand for freshwater resources in all water-using sectors, still further exacerbated by decreasing availability of safe water resources due to pollution and climatic changes which are expected to increase the variability of the hydrological cycle and thus lead to less reliable water supply patterns. Predictions show a strong continuation of all these trends in the future, which has the potential of drastically increasing the severe negative impacts, particularly in developing countries.

Therefore, in order for each of the countries to benefit from the NSAS, they have to manage it cooperatively to ensure that they derive the maximum benefits. In fact, the main original objectives of the Joint Authority are (i) to oversee strategic planning, (ii) to develop a NSAS monitoring programme and (iii) to exchange data and information on the respective water resources and extraction.

1.5 Objectives of the SADA

This Shared Aquifer Diagnostic Analysis (SADA) is functionally similar to Transboundary Diagnostic Analyses (TDA) performed as an element of GEF projects. Like the TDA, the SADA provides the factual basis for the formulation of a Strategic Action Program (SAP) embodying specific actions (policy, legal, institutional reforms or investments) that can be adopted nationally, usually within a harmonized multinational context, to at least address the top priority transboundary concerns and, over the longer term, restore or protect a specific body of water or transboundary ecosystem. A SADA offers advantages in providing greater insight and specificity, thereby providing an improved information base for the formulation of SAP. The SADA permits the logical development of a strategic action program that is based on a reasoned, holistic and multi-sectoral consideration of the problems associated with the state of and threats to transboundary water systems. Furthermore, it is a valuable vehicle for multilateral exchanges of perspectives and stakeholder consultation as a precursor to the eventual formulation of a SAP.

This NSAS SADA is a scientific and technical fact-finding analysis used to scale the relative importance of sources, causes and impacts of transboundary waters problems. It is an objective assessment and not a negotiated document. The analysis is cross sectoral, focusing on transboundary problems without ignoring national concerns and priorities. In order to make the analysis more effective and sustainable it included a detailed ‘governance analysis’ which considered the local institutional, legal and policy environment. Further, the SADA preparation was preceded by a full consultation with all stakeholders, and these stakeholders were involved throughout the subsequent process.

The SADA approach is not only a proven way of achieving progress, it also acts as a diagnostic tool for measuring the effectiveness of SAP implementation. The SADA identifies the priority problems, the underlying sectoral causes, and the root causes of the problems. The SAP outlines the actions needed to resolve the priority problems and must be agreed before technical assistance, capacity-building, or investment projects can be developed.

Section 2. Approach to the NSAS SADA

The Shared Aquifer Diagnostic Analysis (SADA) is based on the Global Environment Facility (GEF) Transboundary Diagnostic Analysis (TDA) methodology. A TDA (and this SADA) is an objective, non-negotiated assessment using best available verified scientific information to examine the state of the environment and the root causes for its degradation. The analysis is carried out in a cross-sectoral manner, focusing on transboundary issues without ignoring national concerns and priorities. It provides the factual basis for the formulation of a Strategic Action Programme (SAP). A SAP is negotiated policy document which should establish clear priorities for action to resolve the priority transboundary problems which were identified in the TDA/SADA.

The SADA explores specific actions (policy, legal, institutional reforms or investments) that can be adopted nationally, usually within a harmonized multinational context, to address the major priority transboundary concerns. It is not the intention of the SADA to repeat the valuable studies already conducted on environmental impacts and socio-economic consequences, but to assemble them in a more holistic manner. TDA (and the approach in this SADA) is a cornerstone of the GEF International Waters projects which has, to date, been utilized to better understand surface water bodies such as river basins, lakes and seas. Groundwater, however, is a relatively new field for the GEF diagnostic analysis approach, so the Nubian Aquifer SADA ventures into uncharted territory. In response, an *adaptive* approach has been adopted by the project, using existing lessons learned globally. The SADA essentially involves identification and understanding of priority issues, threats, and root causes of the NSAS. This process helped to identify key gaps in data and capacity, develop sound policies and science based decision making, and set a solid basis for the identification of the appropriate legal and institutional framework.

Diagnostic analysis is a scientific and technical fact-finding analysis used to scale the relative importance of sources, causes and impacts of transboundary waters problems. Stakeholder analysis and stakeholder involvement have been strong features throughout the SADA process and this involvement will continue in the development of the SAP.

Joint fact-finding is the essence of the SADA process. *Joint* implies a coordinated action between key stakeholders to agree on the facts that are relevant to understanding and managing major transboundary problems linked to the shared aquifer system. The first stage in the SADA process was to agree on the transboundary issues. The diagnostic analysis was not undertaken only by experts and oriented towards science, but also included stakeholder involvement. This included, but was not limited to, ministries of water and agriculture, farmers, and local communities and authorities.

2.1 SADA Methodology

This project followed well-defined procedures established by GEF for conducting transboundary diagnostic analyses. The basic elements were training for national counterparts in GEF methods and establishing planning documents for key components of the SADA report (causal chain, governance, and stakeholder analyses). Unique to this project was the collaborative development of a regional groundwater model to provide a technical basis for evaluating transboundary risks. And finally, national SADA meetings were held to discuss issues of national concern in a stakeholder forum.

2.1.1 Training

Several training workshops were conducted during the SADA phase of the project, using the GEF IWLearn TDA/SAP training materials. The initial training workshop was conducted in March 2007 in Khartoum and was attended by representatives of all four Nubian countries. TDA/SAP refresher training was conducted in October 2008 in Cairo and December 2008 in Tripoli. Training workshops were attended by key national staff and were conducted by an international expert on TDA/SAP procedures.

2.1.2 Component Documents

The three main component documents for the SADA were the causal chain analysis, the stakeholder analysis, and the governance analysis. Causal chain analysis provides a systematic approach to recognize and prioritize existing and potential problems. This analysis also enables mapping of the threats in terms of their underlying and root causes. The results of causal chain analysis (Annex 1) provided the basis for Section 5 of this report, Priority Transboundary Risks, Challenges, and Problems. The stakeholder analysis (Section 8 and Annex 2) was conducted to determine the groups and individuals who have an interest in and are affected by the project. Governance analysis (Section 9 and Annex 3) provided an understanding of the political and institutional structures affecting the project.

National coordinators worked with IAEA staff to develop these component documents. The foundation of these documents and an outline of the final SADA report, were developed during the regional meeting in March 2007 (Khartoum). Next, draft planning documents were then prepared by IAEA. National meetings were convened in March through July 2008 for all four countries to review the stakeholder and causal chain analysis documents. These documents were approved and adopted by the national coordinators. The draft governance analysis document was reviewed, approved, and adopted in separate national meetings in July through September 2008. Finally, these three documents were approved by the Project Steering Committee in their second meeting in January 2009 (Vienna).

2.1.3 Modelling

Regional modeling of the NSAS was conducted to provide an objective, technical basis on which to evaluate the priority threats determined through causal chain analysis. The model was developed by an international expert through a series of regional workshops held in Vienna. National program coordinators and national technical experts participated in these workshops. The initial scoping workshop was held in July 2007. The model itself was developed in Vienna by Dr. Clifford Voss and Dr. Safaa Soliman, from March through August 2009 in Vienna. Workshops, again attended by representatives from the four Nubian countries, were held in March, June, and August 2009. Through these workshops, the national program coordinators were able to participate actively in the development of the model.

The final modeling results were presented at the August 2009 meeting. At that meeting, the program coordinators agreed that the modeling approach was valid and the results were reasonable, with final approval and adoption of the model pending review of the final modeling report. The final modeling report was submitted as a draft to the national program coordinators in April 2010. Final discussion of the model took place at the Regional SADA meeting in Khartoum (May 2010) where it was considered for approval and adopted pending a series of minor revisions recommended by the meeting participants. The revised modeling report was submitted to IAEA in September 2010 and is included in Annex 4.

2.1.4 National Meetings and SADA Reports

National meetings provided the opportunity to solicit input from stakeholders and to disseminate project results. Egypt conducted a national stakeholder meeting in October 2008 to assist in the development of their national SADA report. National meetings to disseminate modeling results and solicit further comments from stakeholders were conducted in Sudan (December 2009), Egypt (December 2009), and Libya (February 2010). Chad elected not to conduct formal national meetings, but did solicit comments from stakeholders informally.

National SADA reports were prepared to present baseline data on each country and present their national perspectives on priority transboundary issues. These reports are provided in their complete form in Annexes 5 through 9. The results of the national reports provided the basis for developing regional perspectives presented in this report.

2.2 Coordination and Consultation Process

Current systems of government in the NSAS are highly sectoral in nature. In order to develop a pragmatic programme of action, direct participation of all the key sectors in the problems of the NSAS have been involved. This involvement consisted of national interministerial committees, including appropriate government sectors as well as other relevant stakeholder representatives.

Effective management requires a consensus to be built at every step. By including clear stakeholder representation at all stages of the process, consensus-building, ensuring a greater probability of long-term sustainability of the outcomes. In this respect the project undertook the analysis and identification of key stakeholders and their possible contribution/impact. A series of workshops was conducted for each country for open consultation and participation. A Technical Task Team was also formed for the purpose. Further, consultations with some prominent opinion leaders and experts on the water resources and related issues were undertaken.

2.3 Integration of the Results of Ongoing Activities Undertaken by the Joint Authority and its Partners in the Basin

The formation of the Joint Authority and the CEDARE project represent important successes in cooperative water management in the region. The Joint Authority established mechanisms for cooperation among the Nubian countries to develop regional and national water management policies and to base water management decisions on sound scientific principles[1]. The scope of cooperation was extended and further defined through the CEDARE project, which established data sharing agreements between the Nubian countries, endorsed at the water ministry level in all four countries, and established the first regional database for groundwater information, the Nubian Aquifer Resource Information System (NARIS).

All major components of the current MSP: the SADA, SAP, and Legal and Institutional, build on these frameworks and rely on the Joint Authority for effective implementation at and beyond the SAP phases of the project. For example, regional groundwater modeling undertaken as a key element in the SADA component of this project relied on data compiled from the CEDARE project and on the NARIS database. Policy reforms to support water management strategies developed in the SAP component of this project can be tied directly to articles in the Joint Authority constitution. The legal and institutional component of the project can focus its efforts on enhancing rather than creating legal and institutional mechanisms for cooperation.

[1] Joint Authority Constitution, Articles 3.3 and 3.4.

The MSP benefits from the history of cooperation in the region; however the ultimate success of the project relies on effective integration of the results of the MSP back into the Joint Authority. The degree to which this can be defined in the SAP component of this project will influence the potential for additional funding at the SAP implementation level.

Section 3. The Nubian Sandstone Aquifer System

The Nubian Sandston Aquifer System occupies a region rich in natural and cultural history. Geologic events and climatic patterns created a constantly changing environment in the region which provides, over geologic time, cycles of rainfall and aridity. These cycles, in turn have supported temperate ecosystems filled with lush vegetation, which have yielded to encroaching deserts. In present day, the region is at the point in the climatic cycle of advanced desertification. The enormous resources of the Nubian aquifer offer the potential to hold or reverse the climatic trend in desertification.

This section presents a brief summary of the natural and human resources of the region. It draws on a variety of technical resources which present in greater technical detail information on these topics. This section corresponds to the baseline studies prepared by each of the Nubian countries in Annexes 5 through 9.

3.1 Historical Summary and Perspective

The NSAS occupies about two million square kilometres in the north African countries of Libya, Egypt, Sudan, and Chad. The NSAS is bounded roughly in the east by impervious basement formations of the mountain ranges of the Red Sea. The southern extent is defined in southern Sudan by outcrops of the Kordofan and Darfur blocks of basement rocks. The southern boundary in Chad is a depression defined roughly by the Faya and Archei oases. The western boundary is a groundwater divide extending from the Tibesti mountains in the south and northward along the 19th meridian. The northern boundary corresponds to the Mediterranean coast (Figure 1).

The aquifer is contained in a basin of impermeable Precambrian formation. A complex series of geologic events filled and reshaped the basin over geologic time. Volume II of the CEDARE report (2001) provides a detailed description of the geologic and hydrogeologic history of the aquifer.

The region has a long and interesting history, but the most recent million or so years is of greatest relevance to this project. This was a time of glacial and interglacial periods. In the NSAS region, glacial periods were pluvial periods and interglacial periods were arid. An example chronology based on ice-core atmospheric carbon dioxide is shown below for the past 650ka (Figure 2). There is a periodicity of roughly 100ka for repeated periods, each containing a glacial and an interglacial phase. During pluvial periods, there were likely significant surface water bodies (lakes and rivers) and a shallow groundwater table in NSAS that received recharge from both rain and from surface waters. During arid periods, there was likely little or no groundwater recharge, once the surface waters dissipated. One major paleodrainage channel (the “Kufra River”) of possible Miocene age (>5Ma) has been identified in NSAS by remote sensing, connecting Kufra oasis in Libya to the Mediterranean Sea. The

NSAS has been in an arid-zone state for the past approximately 5ka to 10ka, which is the natural situation during the current Holocene interglacial period.

It is this most recent transition from pluvial to arid which is of greatest interest to archaeologists, ecologists, and water engineers. While the cycles of aridity and humidity have marched on in the sequences shown in Figure 2, was during the most recent humid period that the current ecosystems, or their direct descendents, were established and became a dwelling place for humans.

The human and environmental ecosystems of the NSAS have endured an ongoing transition from humid to arid conditions for thousands of years. Archaeological and paleo-environmental records of the region document the transition of decaying richness in both ecological diversity and human populations during the current arid period. Humans have coped with changes in aridity either by adapting or migrating. Present day conditions are no exception. Progressive desertification has the effect of changing pastures and oases and upsetting the fragile boundaries established in the ranges staked out by competing tribal groups, with resulting conflict.

3.2 Water Resources

The water resources of the aquifer vary significantly across the four Nubian countries. The aquifer is most massive in Libya and parts of Egypt, where it can be up to 5,000 meters thick. In Chad and Sudan the aquifer can be as thin 100 meters or less (Figure 3). The total amount of water stored in the aquifer has been estimated to be about a half million cubic meters. However, only a relatively small amount of this can be recovered for environmental, cultural, technical, and economic reasons. One estimate places the recoverable resource at about 15 thousand cubic meters (Table 1).

The present climatic conditions in the region can be characterized as arid or hyper-arid. Figure 4 shows average annual rainfall in the Nubian countries. While the sparse rainfall in the coastal and southern areas is insufficient for any meaningful recharge to the aquifer, it does manage to support some grasslands toward the south of the region.

The topography of the present-day aquifer, its potentiometric surface, is an artifact of the gradual natural drainage of the aquifer. Pluvial periods, such as the last ice age, are believed to have produced enough rainfall to recharge the aquifer to the land surface. In the five to ten thousand years of arid conditions since the last ice age, the aquifer has gradually drained through natural discharge processes.

Drainage in the aquifer is driven by the hydraulic gradient, which is a quantitative measure of the tendency for water to travel from locations of higher to lower elevation. Outlets for the water include discharge from springs, some rivers, and evaporation and transpiration from oases and riparian channels. Figure 5 illustrates the gradual process of decaying hydraulic gradients through natural drainage. Water moves slowly through the porous sandstone material in the aquifer and as a result, the elevation of the water table may not change perceptibly over periods of years or decades. However, over periods of hundreds or thousands of years this process results in the eventual flattening of the water table. Along the way, higher elevation oases and lakes disappear as the water table vanishes beneath them. There is ample evidence of ancient rivers, lakes, and oases in the Nubian and other regions of the Sahara Desert.

While it is the ultimate fate of many oases to disappear, the natural process may occur on millennial time scales. Abstraction of water from aquifers greatly accelerates this process. Even though the volume of water abstracted for human use may be small in comparison with the total amount of water stored in the aquifer, for the amount of water stored in the aquifer is immense, the real impact of abstraction is in the effect on water table elevation.

Changes in the elevation of the water table, whether by natural changes or human activities, affect the system in two related ways: impacts on oasis ecosystems and indigenous human cultures, and impacts on the accessibility of water. An important difference between changes brought about by natural process, as opposed to human abstraction is the time scale. Natural desertification in the Sahara has occurred over a long enough time frame for human cultures and ecosystems to adapt. Excessive or mismanaged abstraction from the aquifer can result in far more rapid changes to oasis ecosystems and result in ecosystem damage or destruction and the disruption or displacement of indigenous human cultures.

The second way in which changes in water table elevations can affect the system is in accessibility to the water. As was noted earlier, the total storage of water in the aquifer is enormous. However, unlike surface water, such as lakes and rivers, most groundwater resources require investments in well drilling, pumping, and transmission to yield a water supply. As a result, while these groundwater resources are available for the countries to use, it is not free.

3.3 Water Resources Investigations

Much of what is known about the geology and hydrogeology of the NSAS was discovered through petroleum exploration in the region. Key contributors to the knowledge of the hydrogeology of the region have been national institutions; university initiatives, such as the Technical University of Berlin; and commercial studies conducted to support well field development. The CEDARE project provides the definitive collection of knowledge on the hydrogeology of the region.

Geochemical and isotopic data have been collected in the aquifer since the 1970s, although vast regions of the aquifer have not yet been sampled. The Technical Baseline Meeting Report (IAEA RAF8036, April 2007, Annex 10) provides a thorough overview of isotopic data collected up to 2007 and summarizes previous work and work related directly to this project in RAF8036. No additional monitoring has been conducted as part of RAF8041 (the current MSP). Isotopic data provided the fundamental understanding of how water masses have moved through time and helped shape the current understanding of the aquifer. This provided valuable confirmation and in cases calibration data for the modelling work in this study (Section 4). The long time span for detention time in the aquifer made the use of carbon-14, chlorine-36, and krypton-81 isotopic analyses particularly relevant.

Modelling studies in the aquifer date back to the 1970s to support design of well fields in the Kufra and Sarir sub-basins in Libya and the Western Desert of Egypt. These models were all limited in extent to the immediate area around well fields and did not attempt to model aquifer responses at a regional scale. The first regional model was developed by researchers at the Technical University of Berlin in the 1980s and refined through the 1990s. The second major regional modelling effort was undertaken by CEDARE and built upon their exhaustive compilation of existing geologic and hydrogeologic data (CEDARE Volume III, 2001).

3.4 Groundwater Development

The earliest uses of the aquifer to support human needs were direct extraction from oases and springs, and through the use of hand-dug boreholes. Both of these methods continue to the present and support the range of local water needs: potable use, agricultural irrigation, and for livestock. The next level of intensification in use was the introduction of relatively shallow driven wells which serve the same local needs. These methods are similar in that they create a fairly low-intensity, geographically distributed demand on the aquifer. Because they draw water from only the top meters of the aquifer, these methods are also the most vulnerable to declines in the water table and water quality impairments.

The pattern of groundwater development in the Khartoum-Omdurman urban area for the most part, consists of similarly distributed and low-yield wells. However the density of these wells is much higher than any other place in the region. Additionally, the NSAS is thinner in this area and includes mudstone semi-confining or confining units. As a result this area is particularly vulnerable to drawdown and to contamination from contaminated recharge water.

Starting in the early 1960s, deeper wells were drilled and equipped with high-capacity pumps to support larger scale irrigation projects in Egypt and Libya, as well as for some mining, water supply, and petroleum-related needs. The earliest major development programs were in the Dakhla and Kharga oases in Egypt in 1960. The combined extraction at these two sites from springs, shallow wells, and deep wells was just over 100 million cubic meters per year (mcm/yr). By 1998 nearly two dozen well fields had been developed, mainly in Egypt and Libya, but also in Sudan. The total estimated extraction that year was about 1,300 mcm/yr from the Nubian aquifer and about 900 mcm/yr from the Post Nubian aquifer (CEDARE 2001). Figure 6 shows the locations of major abstraction areas and the history of abstraction in the NSAS is summarized in Table 2.

Until the 1990s all water abstracted from the NSAS was used locally. Starting with the commissioning of the first productions wells in 1993 with the Sarir West Transport Project, Libya’s Great Man Made River Project started transporting Nubian water from the central desert, to population centers on the coast.

Future abstraction from the NSAS depends on factors such as policy decisions regarding national food security, investments in infrastructure, changes in the balance of national water sources, and changes in populations. All of the Nubian countries have national development plans in place.

3.5 Social and Economic Aspects

The demographics of the region reflect the natural resources available. In all Nubian countries oasis areas traditionally have supported a combination of settled agriculturalists and nomadic herders and traders. Toward the south in Chad and Sudan, where conditions are less arid, livestock herders have taken advantage of the sparse grasslands.

Accurate population estimates are difficult to obtain, but Figure 7 and Table 3 provide a summary of the available information. Current population levels are generally proportional to the degree of development of oases. Populations in Chad are lowest in the region, with the highest non-urban populations in Libya and Egypt. The Khartoum-Omdurman area, with a population of about two million is the only urban center in the region and relies on both Nile and Nubian water.

In Sudan, the trade in livestock consisting of sheep and camels takes place year around. The market destination for sheep is Omdurman, for both domestic use and export to Libya. Camels are herded from Dongola to Egypt or through a western route to Libya. In both cases, livestock are herded on journeys of up to 40 days both to Omdurman and Egypt via Wadi el Melik, Ed Debba, and Dongola.

In the Nubian countries agriculture is limited to oasis areas and varies in extent proportional to the degree of groundwater abstraction dedicated to local irrigation. In Chad, agriculture consists of some date palm production, but is limited due to absence of abstraction from drilled wells. In Sudan, agriculture is currently limited to subsistence production of the staple crops of vegetables, melons, cucumber, and citrus. As with Chad there is currently limited use of drilled wells outside of the Nile riparian corridor. Within the Nile corridor several development projects are being planned.

Libya and Egypt have invested in much more development of oases for local agriculture. Additionally Libya has several oasis well fields dedicated to water transport to coastal areas, where water is used for both irrigation and domestic purposes. Both countries have seen success in developing an oasis tourist industry in the oasis areas.

3.6 Summary

In summary, there are some important similarities and differences in how each country interacts with the Nubian aquifer.

- The NSAS is an enormous resource available for all Nubian countries. The magnitude of this resource – the total volume of exploitable water – does vary significantly from country to country. The effects of conducting this abstraction are explored in Section 4.
- For all Nubian countries, oases and the ecosystems and human populations that rely on them is a critical resource. Their vulnerability to changes in the NSAS is examined in Section 5 of this report.
- How the NSAS fits into the water portfolio of each country varies significantly. Egypt and Sudan must balance water available from the NSAS with their management of the Nile River. Libya has made the decision to transform their water portfolio completely through the Great Man Made River. In Chad, the NSAS represents a fragile natural reserve capacity for development and is therefore an important element in their water resource planning.

Section 4. Modelling to Support the SADA

Although it has wide-ranging policy and water management implications, the issue of transboundary impacts of water extraction from aquifers is essentially technical. The causes and effects that define groundwater movement are too complex to be evaluated intuitively and even the location of groundwater in an aquifer is usually invisible and difficult to determine, even under the best circumstances. Policy decisions cannot be made on *a priori* assumptions that transboundary effects either do or do not occur in particular locations. The development of rational water policy and management strategies requires that the response in an aquifer to changes in water management practices can be anticipated. The magnitude or even existence of transboundary effects can only be evaluated using a set of analytical tools agreed upon by member countries and subject to open and transparent analysis.

4.1 Modelling Approach

The modelling process for this project was a collaborative and interactive exercise involving national program coordinators and technical staff from the four countries in the region. An internationally recognized expert in hydrogeological modelling, Dr. Clifford Voss, led the modelling team and was assisted by a hydrogeological modeller from Egypt, Dr. Safaa Soliman. Modelling concepts were introduced at a regional workshop in Vienna in July 2007 attended by participants from all countries. The model itself was developed over a five-month period in Vienna in 2009, which included the participation of all NSAS countries in three regional workshops at various stages in the model development. Modelling activities culminated with a final modelling workshop in August 2009. The final modelling report is provided in Annex 4.

The objective of the modelling effort was to produce a regional model of the aquifer which would have the capability to predict the extent of drawdown, or decrease in aquifer level, due to abstraction. This objective was designed to meet the needs of the SADA component of this project by anticipating the transboundary effects of abstraction under a variety of future development scenarios. An additional criterion was for the model to be useful in the SAP phase of the project and beyond as a tool for member countries to evaluate the effects on the aquifer of alternative development scenarios as they work through the adaptive management of the shared aquifer.

The model itself was developed through a somewhat unique process to overcome challenges presented by the lack of comprehensive geologic and water level data in the region. The aquifer was represented using a highly simplified model structure. The guiding principle was that because information on both the geology and water levels in the aquifer was sparse, to use the simplest model possible that can explain the observed behaviour of the aquifer. Increased complexity requires additional data.

The resulting model structure was a model space with two geologic zones, a southern region and a northern region with the dividing line being the boundary of the Post Nubian aquifer (Figure 1). In each zone the aquifer was assumed to be homogeneous but anistotropic; meaning that within a zone, the aquifer has the same physical properties from the top of the aquifer to the bottom. The aquifer is known to have strata, each having potentially different permeabilities, however the extent of these strata and their hydraulic characteristics is not well understood. Rather than attempting to represent the complex details of stratigraphy by assigning each geologic unit a different set of hydrologic parameter values, the overall effect of the stratification was modelled. This was done by allowing the modelled hydraulic conductivity to be vertically anisotropic, with the vertical value lower than the horizontal value. Vertical anisotropy provides the same regional effect on hydraulic head and groundwater flow as a sequence of high- and low- conductivity units. It is simply more difficult for water to flow vertically than horizontally through such a sequence. Thus, the impact of the complex layering was represented by only one parameter, the vertical anisotropy (ratio of horizontal to vertical hydraulic conductivity). In the final model, the vertical anisotropy was higher for the northern zone of the aquifer, where the aquifer is known to be stratified into the Post Nubian (upper) and Nubian (lower) units, than for the southern zone.

4.2 Calibration

The simplifying assumptions resulted in a model for which four parameters in each of the two zones control how water moves through the aquifer system. Compared with most regional hydrogeologic models, this model is vastly less complex. The result is that the model can be calibrated with less data and with the greatest possible degree of certainty. The calibration process involved adjusting the eight parameters systematically until the model correctly simulated the observed behaviour of the aquifer.

Observations on the behaviour of the aquifer consisted mainly of measurements of the elevation of the aquifer at various locations and times. Observations of the response of the aquifer to pumping in development areas are particularly valuable, but these exist for only a few locations, representing an area of several hundred square meters in an aquifer that has an area of about 200 square kilometers. Measurements of water levels in wells at various locations in the aquifer were available, but there was difficulty using some of the data because many of these locations did not have precise measurements relative to sea level.

The quality of calibration of the model improves with the addition of more data and data from a variety of locations in the aquifer. To overcome the problem of sparse data, the modelling team used a unique approach. As described in Section 3.2, the aquifer has been slowly draining since the end of the last pluvial period about ten thousand years ago. Water elevations in the aquifer today are the artefact of the gradual discharge at topographic low points in the aquifer, primarily oases and sabkhas. These features were used as data points indicating the elevation of the present-day aquifer.

The calibration strategy was to run the model for ten thousand years and adjust the eight modelling parameters until the locations of present-day oases were predicted correctly. Because of the number of controlling parameters, there is not a unique solution to the model. That is, there is not just one combination of the controlling parameters that provides a correct answer. The range in possible solutions was then narrowed considerably by consulting the few field studies that had been conducted in the region. This is shown graphically in Figure 8. Without going into technical detail (which is provided in Annex 4), the area between the upper and lower dashed lines represent combinations of the parameter values that produced reasonably well calibrated models. The points indicate values of the hydraulic parameters available from field tests.

Up to this point in the calibration process, only natural discharge from the aquifer had been considered. Starting in 1960, with the commissioning of the first high-capacity pumping centers, the aquifer started to experience significant withdrawals for human use. These well fields and their records of pumping were then included in the model. Parameter values were refined so that drawdown from the wells predicted by the model matched field measurements as closely as possible.

The model at this stage had been calibrated both to conditions of gradual, regional-scale water level decline due to natural gravity discharge and to localized high-intensity discharge by pumping. This version of the model, the Base Model, was considered to be the best calibration of the model. It is not a final, unique solution, but it is the version that reproduced the behaviour of the aquifer under as many conditions as could be tested, given the data available. This is the final working model for the SADA component of the project.

4.3 Modelling Results

Once calibrated, the Base Model was used to forecast regional drawdown over the one hundred year period from 1960 to 2060. The complete listing of historical and project pumping rates by location is shown in Table 4. A map of predicted drawdowns for the Base Model at Year 2060 is shown in Figure 9.

Results for the Base Model run (Figure 9) indicate that transboundary drawdown is not a significant threat to the region. Jaghboub in Libya and Siwa and East Oweinat in Egypt are the only pumping centers located near national borders. By 2060 each of these produces 1 meter of drawdown near the national border, and slightly across the border in the case of Jaghboub, but does not result in significant transboundary drawdown. The highest-capacity pumping centers of Sarir and Kufra in Libya and Dakhla in Egypt produce significant drawdown, but the lateral extent of drawdown toward national borders is insignificant.

Localized drawdown in pumping locations, however is high. Widespread drawdown is predicted for Sudan. Considering that the aquifer is not as thick in Sudan, abstraction at the projected rates could lead to depletion of the resource in the southeastern lobe of the aquifer. Drawdown in the southeast corner of Egypt and the far southern part of Sudan is not associated with pumping, but is related to natural discharge.

All predictions involve some degree of uncertainty; and sensitivity analyses are typically conducted to determine how errors and natural variability in model parameters affect model predictions. In systems for which modelling parameters are well defined, the range in model predictions may be low. Sensitivity analysis can be a complex process which may involve varying each parameter by a fixed percentage of its base value and observing the percent change in the final prediction. This systematic approach can yield information on which parameters are more prone than others to result in model error. The approach in this modelling study was more fundamental. The objective was to determine the broadest possible range in model predictions, given the simplicity of the model and the scarcity of monitoring data. This range in predictions reflects not only the limitations of the model, but the inherent limitations imposed by a lack of knowledge about the aquifer itself.

The sensitivity analysis is described in detail in Annex 4, and consisted of varying the key modelling parameters by roughly an order of magnitude higher and lower than the calibrated Base Model values. The results of sensitivity analyses are shown in Annex 4 are presented in terms of the variations in model parameters that produced the minimum and maximum drawdown values and the minimum and maximum later extent of drawdown. For the purpose of evaluating the worst case for transboundary drawdown, Figure 10 is relevant. This prediction shows a region of between 1 and 10 meters of drawdown crossing into Sudan from Egypt due to abstraction at East Oweinat. A drawdown of 1 meter, caused by natural discharge, is widespread in all NSAS countries, including Chad.

4.4 Interpretation of Modelling Results

The Base Model was run to estimate aquifer response to one hundred years of abstraction in the NSAS for one set of assumptions for future abstraction. The results of that run are shown in Figure 9. To provide a preliminary assessment of uncertainty, model parameters were varied to extreme values under the assumption that this would provide the maximum possible range in aquifer responses. The worst case for drawdown is shown in Figure 11.

The modelling exercise indicates that there is low likelihood of significant transboundary drawdown in the region. The Base Model prediction shows a maximum of less than 1 meter of drawdown in the pumping areas closest to national borders. The worst case scenario for drawdown does show significant transboundary drawdown at one of the pumping centers, but to create this magnitude of drawdown required manipulating the hydraulic parameters to extreme values. The probability that these values are accurate is extremely low and inconsistent with the aquifer responses indicated by the calibration process.

The extreme responses (Annex 4) are useful, though in bounding the uncertainty in the modelling process and in the state of knowledge about the Nubian aquifer. The model is a reflection of the geologic and hydrological information currently available and these extreme values provide a rough indication of the level of confidence with which predictions can be made. It is most likely that the response of the aquifer to the future pumping scenario will be close to that shown in Figure 9, but it is extremely unlikely that the response can be worse than shown in Figure 10.

From a management standpoint, the modelling results indicate that Nubian countries can develop their water resources without significant concern either that they will affect neighboring countries or that neighboring countries will affect their water resources. Modelling was based on limited data and these data limitations result in sufficient uncertainty in drawdown predictions that continued monitoring is necessary, both to provide additional data to improve modelling efforts and to provide direct evidence that transboundary drawdown does not occur.

4.5 Adoption and Application of the Model

The modelling efforts undertaken by the Nubian countries and led by an internationally recognized team of modelling experts made several important contributions to this project. The model created a platform agreed upon by all countries through which data can be shared and interpreted in an open, transparent manner. This constitutes a logical extension and strengthening of the successes of the Joint Authority in shaping cooperative agreements for data sharing and formation of a shared aquifer database.

The model in its current state has been calibrated to the best knowledge available in the region and is the final work product of the collaborative modelling effort. As such, the Nubian countries have accepted the model as a joint planning tool and have adopted the model for future activities related to the SAP phase of the project.

The model is ready for use in the SAP implementation phase of the project as a technical tool for evaluating the impacts of alternative development scenarios. The model is currently configured to examine regional-scale processes, but can be modified for more detailed analysis of local areas. The model platform was designed to be used directly by the member countries. Additional training for this purpose is anticipated as a component of SAP activities.

Section 5. Priority Transboundary Risks, Challenges, and Problems

Understanding priority threats and their root causes is the initial step in defining both the technical challenges in managing the NSAS as well as identifying the policy and institutional reforms necessary to manage the resource in the most rational and effective way possible.

5.1 Introduction

The process of identifying priority transboundary concerns was initiated with diagnostic analysis training (Khartoum, March 2007) and evolved through national workshops in the late-summer and autumn of 2007. In these workshops priority problems and their root causes were assessed through the formal process of causal chain analysis. The analysis itself was conducted by each country separately through national workshops. The results were presented in a summary document (Annex 1) in late 2008 and approved by the Project Steering Committee at their January 2009 meeting. The analysis revealed several dozen areas of concern in the NSAS. The process of evaluating interrelationships between immediate problems and assessing their underlying and root causes led to the selection of five as high priority problems of transboundary dimensions which merit project intervention:

- Declining water levels
- Water quality deterioration
- Changes in groundwater regime
- Damage or loss to ecosystems and biodiversity
- Climate change

These are analyzed in Sections 5.2 through 5.5 below using the following format:

- Risks and transboundary importance
- Risk in relation to time scale
- Major environmental impacts and social-economic consequences
- Linkages with other transboundary problems
- Immediate, underlying, and root causes
- Knowledge gaps (See also Section 6)

- Conclusions and recommendations

Additionally, the potential for climate change to affect the system is considered in Section 5.6.

5.2 Declining Water Levels

The relationship between abstraction and decreases in aquifer water levels is intuitive. More difficult, however, is to understand the relative impact of near versus distant demands on the aquifer and to predict future declines in water level accurately. The modelling work described in the previous section provides insights into likely aquifer responses and can be used as a tool in the ongoing, adaptive management of the system, thereby mitigating, or at least minimizing, the threat of transboundary impacts.

5.2.1 Risks and Transboundary Importance

The importance of understanding the precise cause and effect relationship between abstraction and water level declines in the region cannot be overstated. Several production areas, such as Siwa, Jaghboub, and Oweinat (Figure 9) are located near national borders and are of great interest in the region for their potential impacts on neighboring countries. Drawdown due to pumping has been observed in all production areas of Libya and Egypt and has occurred in magnitudes consistent with previous modelling predictions, such as the engineering studies for the design of the Great Man Made River. However to date, pumping has not occurred long enough or close enough to national borders for any transboundary effect to be observed. This is a critically important observation, because it establishes that no transboundary impairment has been observed, although it should be noted that monitoring data are sparse, and that regional management activities can be focused on prevention rather than mitigation of transboundary declines in water level.

Although no transboundary declines in water level have been observed, the risk is clearly that anticipated rates of extraction will lead to transboundary declines. The current modelling efforts indicate that under expected scenarios of development, transboundary drawdown will not occur (Figure 9). As discussed in the previous section, this conclusion was based on a model developed through rigorous calibration, however the data used to calibrate the model were sparse. Sensitivity analyses indicated that it is possible to re-calibrate the model to show that transboundary drawdown could occur due to abstraction at the East Oweinat area, however it was necessary to use extreme values of the key hydraulic parameters controlling the model to produce this result.

In relation to transboundary risk, the modelling results should inspire both reassurance and caution. The rigorously calibrated model indicates low risk of transboundary drawdown. However enough uncertainty exists in the model to prompt vigilance in the region to maintain a shared and transparent monitoring network. Shared monitoring data and collaborative interpretation of the data through additional modelling efforts can both improve the quality of the model and provide ongoing assurance that transboundary declines in water level do not occur.

While the risk of transboundary drawdown remains low under nearly all modelling scenarios, the risk shared by all countries in the region is that localized effects of abstraction on aquifer levels is high. All models of the aquifer predict high drawdown in the immediate vicinity of pumping areas. In Libya and much of Egypt, where the aquifer is thicker, this can result in high drawdown, but insignificant depletion of the resource. The aquifer is sufficiently thin in Sudan (Figure 3), however, that both high drawdown and resource depletion is a significant risk.

The situation in Sudan with regard to drawdown may be unique. The current model indicates widespread drawdown with the threat of resource depletion in the southeastern lobe of the aquifer in Sudan (Figure 9). This area is intersected by the Nile River. The current version of the model assumes no sources of recharge. Rainfall is low enough in the NSAS region that zero recharge is a valid assumption for all areas with the possible exception of the Nile corridor.

Groundwater interactions between the Nile River and Nubian aquifer are not well characterized, but it is believed that the river channel itself is sealed by fine particulates and direct exchange is low. However annual overbank flooding may provide periodic recharge to the Nubian aquifer. Assuming the potentiometric surface of the adjacent Nubian aquifer is low enough that there is not loss of Nubian water to the river under low flow conditions, exchange between the Nile and Nubian always recharges the Nubian aquifer. If this is the case, prolonged abstraction in the Nile area of Sudan would not change basic flow patterns, although it may change hydraulic gradients associated with recharge. Further investigation of Nile groundwater interactions is underway by IAEA in a separate GEF/UNDP project (RAF8042) and the results should provide insights to these interactions.

5.2.2 Risk in Relation to Time Scale

Natural drainage in the aquifer has occurred over the past ten thousand years or so and has resulted in the disappearance of oases and rivers and the associated displacement of human cultures. The effect of human activities in most ecosystems is to accelerate their decline and the NSAS is no exception. The time scale for the onset of environmental, economic, or social impacts depends on the management strategies employed. The current modelling efforts indicate that under the projected extraction regime, minimal transboundary decline will occur in the 100-year timeframe. Within that same timeframe however, the model predicts very high localized declines and in water level, particularly in Sudan (Figure 9).

5.2.3 Major Environmental Impacts and Social-economic Consequences

Declines in water level in most cases constitute an insignificant change in the total volume of water stored in the aquifer, yet can have broad and significant impacts in the region due to dependence of human and ecosystem on near-surface waters. With regard to environmental impacts, shallow oases are the most vulnerable to water level declines. Deeper surface water features, such as the Ounianga Lakes in Chad may be better suited to surviving declines in water level, as shoreline ecosystems can migrate downward as water levels decline. Shallow oases, however are likely to either disappear or make a transition to saline sabkha-like features as less and less vegetation can be supported. The decrease in vegetation abundance can be expected to be accompanied with losses in biodiversity.

As oasis ecosystems are degraded, the conditions for human subsistence decline as well. Indigenous human populations will have reduced access to both the surface water in the oases as well as near-surface groundwater traditionally extracted from hand-dug wells. Loss of vegetation dependent on near-surface water will impair grazing potential, further stressing human subsistence. Disruptions in patterns of human subsistence can result in a loss in the cultural heritage and identity of the region, but can also force a shift in seasonal migration routes, with the potential of provoking competition and confrontations.

Declines in water levels also create engineering and economic challenges. Water production schemes require large investments in drilling and maintaining wells, and, in pumping and transporting water. Optimizing the return of water for the capital investment in infrastructure, operation, and maintenance is a well-recognized engineering problem in the region. For example, the service life of the Great Manmade River was determined based on how long it would take to achieve a certain design drawdown.

An aspect of managed drawdown that may not be so fully recognized in the region is that of mitigating environmental impacts in production areas. All production areas in the region are located in oasis communities. While the service lives of the production wells themselves may be optimized for the best ratio of benefit to cost, the resulting decline in the water table may result in damage to ecosystems and drying out of shallow wells.

5.2.4 Linkages with Other Transboundary Problems

Declining water levels are highly linked with other priority issues. The most tightly linked priority issue is damage to ecosystems and loss of biodiversity, which follows directly from water level decline in oasis areas. Changes in groundwater regime are a logical consequence of the decline in water levels, since abstraction can result in reversed hydraulic gradients, but are unlikely based on our present knowledge of the aquifer. Water quality deterioration is linked to declining water levels to the extent that excessive extraction may promote intrusion of saline water from certain regions of the aquifer (Section 5.4.1).

5.2.5 Immediate, Underlying, and Root Causes

Water level decline is directly related to abstraction, so the immediate cause of any associated problems would be excessive abstraction from the aquifer. Since the primary use for abstracted water is agricultural irrigation, the underlying causes would be related to demands related to the expansion of agriculture, and intensified by issues of efficiency and conservation. Examples of inefficiency are technical and managerial shortcomings and pumping water in excess of demand for various reasons. The root cause is population growth, which implies increasing water demand for all purposes, and may affect institutional decisions regarding food security, and consequently agricultural water demand.

5.2.6 Knowledge Gaps

Knowledge gaps at the national level vary with overall capacity in groundwater monitoring. Libya and Egypt have made investments in groundwater monitoring both to support technical understanding of production capabilities, but also in the general area of groundwater science. These countries have also been able to take advantage of petroleum prospecting data which has provided important basic information on the characteristics of the aquifer.

Sudan has coped with limitations in infrastructure and economic support through highly resourceful efforts in the Groundwater and Wadis Directorate, of the Ministry of Irrigation and Water Resources. Sudan is in an excellent position to develop the modelling capabilities necessary for managing the high drawdowns expected from future groundwater development in the Khartoum region of the aquifer.

In Chad, the hydrogeology of the region is not well understood and there are few observations of groundwater levels. Groundwater extraction in Chad is also the most limited of the Nubian countries. However, it is in the interest of the country to monitor its resources, particularly in terms of understanding the availability for future development and assurance that transboundary exchanges do not occur.

At the regional scale, data on groundwater levels lack systematic monitoring programs except in economically important development areas. Monitoring wells near border areas are necessary, but are difficult to establish due to the remoteness of the areas for both installation and monitoring. Investments in automated datalogging and data transmission are necessary in addition to the capital investment in the wells themselves.

The effectiveness of a monitoring program can only be realized with a framework for data sharing and interpretation. This has already been proposed and initiated by the Joint Authority under their NARIS database.

5.2.7 Conclusions and Recommendations

The region has cause for both reassurance and caution. To date no transboundary declines in aquifer levels have been observed and the risk of transboundary decreases in water level are low under practically all modelling scenarios. This provides a promising starting point for cooperative management of the aquifer from at least two standpoints: (1) Nubian countries can make national decisions regarding groundwater abstraction without the immediate threat of transboundary impairments and (2) member countries can work collaboratively to focus on prevention of both transboundary and national impairments to the aquifer system.

The modelling results provide assurance that the risk of transboundary water level declines is low, but not zero. Sufficient uncertainty exists that member countries should be vigilant in strengthening cooperative monitoring, data sharing, and modelling activities for continuous improvement of the understanding of aquifer responses to water management decisions. That there is no current transboundary impairment is the ideal starting point for a cooperative program to prevent direct transboundary declines in water level.

While the transboundary risk of water level declines is low, it is certain that localized drawdown will be high in magnitude in production areas. The southeastern lobe of the aquifer in the Nile area of Sudan is particularly vulnerable. The region must take advantage of the opportunities created by this project, and previously by the formation of the Joint Authority, for the sharing of data and expertise to minimize the shared regional risk of high localized declines in water level.

5.3 Water Quality Deterioration

Two basic mechanisms of water quality impairment can be anticipated with continued abstraction from the NSAS: degradation of surface and near-surface waters related to the uses of extracted Nubian water and saline intrusion from coastal or other high-salinity zones caused by displacement of the fresh water abstracted from the aquifer.

5.3.1 Risks and Transboundary Importance

Water extracted from the aquifer is used primarily for agricultural purposes, either near the locations of the wells, or in the cases of the Great Man Made River projects in Libya, transported to the Mediterranean coastal area. Water used locally is essentially recycled. All water that is not evaporated or transpired is returned to the surficial aquifer or surface pools in oases. Water quality impairment can occur as the excess water accumulates solutes, such as salts, nutrients, agricultural chemicals, and human waste. The risk of this problem is directly proportional to the magnitude of development and inversely proportional to the implementation of measures for conservation and pollution prevention. Water transported outside the NSAS creates the same potential for water quality impairments in coastal areas.

The risks of groundwater pollution vary with regional characteristics. The highest risks of water quality impairment from agricultural development occurs in the oasis production areas of Libya and Egypt. The same is expected in the proposed agricultural developments in Sudan, such as the Seleim and Khowi Basin agricultural development project in the Dongola basin (Annex 8). Water use in Chad is at the subsistence level of pastoral development and limited date palm farming. It is assumed that minimal chemical additives are used and limited irrigation occurs, which likely results in minimal risk of impairment. Should Chad initiate programs of aquifer exploitation, the same risks would apply.

Risks associated with urban development exist, but are limited at present to the Khartoum – Omdurman urban area. The cities currently lack storm and sanitary sewerage, so high levels of nutrient, chemical, and biological waste may be expected to contaminate the surficial aquifer system. The risk is compounded by the presence of mudstone formations which create a perched aquifer system underlying much of the city. Sewerage infrastructure is being installed in the city, but this will not be done quickly and the history of groundwater pollution will result in lasting contamination of the aquifer.

Some of the aquifer water is used as drinking water. Water from the Great Man Made River is used for a variety of purposes, including potable. Water extracted in agricultural areas may also have potable uses. A very limited use has been bottled water for export. All of these potable uses have a risk of contamination. This risk is likely low except for shallow source wells. Water quality monitoring data are needed to assess the magnitude of this risk.

Saline intrusion is the other basic mechanism for water quality impairment. This may occur in production areas located near saline coastal aquifers or in the vicinity of higher-salinity zones within the continental Nubian aquifer. The risk of saline intrusion is related to the magnitude of movement of water due to abstraction. Modelling indicates that the low transmissivity and massive size of the aquifer result in limited capture zones. As a result, physical displacement of water is low and the risk of saline intrusion is low as well.

The low transmissivity of the aquifer and the distance of water discharge locations from national borders make the risk of direct transboundary water quality impairments very low. Mobilization of pollutants great distances requires high advective water velocity, which does not exist in this aquifer. As with the issue of water level declines, water quality impairments are at risk to be localized problems shared in the region.

5.3.2 Risks in Relation to Time Scale

The time scale necessary to observe water quality impairment depends on a variety of factors. Higher levels of water extraction and local use increase the availability of water release to the surficial aquifer. Impairment is also accelerated by poor conservation or agricultural practices. Water quality impairments may occur most quickly in situations where excess water laden with nutrients and chemicals is transported to surface water features or is extracted from hand dug wells or boreholes. For these rapid conduits the time scale is practically immediate. If contamination of groundwater occurs in locations remote from exploitation of the surficial aquifer, the time scale may be beyond any of human concern.

5.3.3 Major Environmental Impacts and Social-economic Consequences

The ecosystems and human inhabitants of the oases have developed a reliance on aquifer water of relatively high quality. Impairment through addition of nutrients can cause problems of eutrophication in oasis ecosystems and ultimately may make water quality unsuitable for sustaining their aquatic communities. Impairment through higher salinity can cause removal of salt intolerant plants and gradually diminish the diversity of the ecosystem. Sufficiently high salinity can make the surface waters of the aquifer and oases non-potable.

Water quality impairment creates a variety of burdens. Indigenous human communities likely do not have the resources to treat water from oases or hand-dug wells and would need either to relocate or to rely on allocation of water produced from the deeper aquifer production wells. The ecosystems impaired by poor water quality would either perish or have to be remediated either through water quality restoration programmes or have water quality improved by dilution from water diverted from production wells. Any type of water quality restoration will be far more costly than implementation of pollution prevention strategies.

5.3.4 Linkage With Other Transboundary Problems

Water quality deterioration is closely linked to water level decline, as well as ecosystem damage and loss of biodiversity. Changes in groundwater regime are also linked, to the extent that sufficiently large displacements of water can result in transport of higher-salinity water toward extraction areas.

5.3.5 Immediate, Underlying, and Root Causes

The immediate causes of water quality deterioration are pollution, salinization, and disturbed water balance. These causes are of a technical nature. The underlying causes are agricultural and industrial growth and improper waste disposal leading to aquifer contamination. The root causes of water quality deterioration are the increase in agricultural and industrial development, related to the combination of increased population and national decisions related to food security priorities.

5.3.6 Knowledge Gaps

Knowledge gaps fall into the two broad categories of monitoring and best practices. Water quality monitoring programs are already in place in the region (CEDARE 2001), but are limited in extent and in the degree to which data are assembled and shared. A coherent, coordinated programme of data collection, sharing, and interpretation is necessary to maintain a high level of awareness of water quality in the region.

The other side of the water quality problem is prevention. Knowledge and application of best practices for conserving water, limiting use of agricultural chemicals, and other strategies for preventing the release of contaminants are necessary to prevent water quality problems in the region.

5.3.7 Conclusions and Recommendations

Water quality impairments are not currently recognized as a widespread problem in the region, although the cumulative effects of agricultural development in oases place these ecosystems at risk. Urban water quality impairment has been observed in Khartoum related to human waste. Sources are expected to diminish over time with the installation of sewerage infrastructure, but the legacy of decades of waste discharge into the aquifer will remain in place for the foreseeable future.

The risk of water quality impairment is compounded because pollutants are long lived and the threat exists for cumulative impacts as time goes on. Adverse effects can be mitigated by conservation strategies. These strategies have the added benefits of providing more water per unit energy consumed, reducing costs of chemical applications, and preventing deterioration of oasis ecosystems due to eutrophication or related impairments. The harm caused by water quality impairment is likely to be realized in locations dependent on surficial aquifer water, such as hand-dug wells and oases. As a result, water quality protection strategies should be directed toward areas where surficial aquifer is used.

As with the issue of water level declines, the risk of direct transboundary impacts is low, but the risk of localized national problems is high. Because the water quality impairments are not currently a problem, the opportunity exists for implementing management strategies to prevent or delay impairments.

5.4 Changes in the Groundwater Regime

Groundwater abstraction can create steep hydraulic gradients toward production wells. Over time, these develop into widespread cones of depression which are superimposed on regional hydraulic gradients. Water flows in the direction of these gradients, so sufficiently large-scale abstraction has the potential to reverse the flow of groundwater in some locations.

5.4.1 Risks and Transboundary Importance

Depending on aquifer properties, cones of depression due to pumping can be large in area and influence flow regimes in groundwater systems. Modelling studies, supported by observations of drawdown caused by pumping in Egypt and Libya, indicate that transmissivity in the aquifer is low, resulting in steep, but areally small cones of depression. As a result the risk of regional changes in flow patterns is very low. The current model was used to perform an analysis of water movement in two of the extraction areas, Kufra and East Oweinat (Figure 11). The results indicate that after two hundred years of pumping, the translation in position of water parcels was on the order of tens of meters. It is reasonable to expect that the transboundary importance, and even the local importance, of changes in flow regime are insignificant.

As indicated in Section 5.2.1, Sudan faces the unique risk of widespread drawdown in the southeastern lobe of the aquifer. More refined modelling of that area is necessary to determine the impacts of development on flow regimes. If any changes in flow regime occur in the NSAS, it will be in this region.

5.4.2 Risks in Relation to Time Scale

Cones of depression and their resulting impact on flow regimes increase over time. However abstraction for hundreds of years would be necessary to result in any meaningful effect to be realized in most of the region. The flow regime in Sudan however, has the potential to be severely altered on a time scale of decades. More detailed monitoring and modelling are necessary to better characterize the risks involved.

5.4.3 Major Environmental Impacts and Social-economic Consequences

The effects of changes in flow regime are expected to be subtle or undetectable. The magnitude of change in most locations will be insignificant. It is possible that abstraction effects in Sudan will be severe enough that environmental impacts could occur. These would be consistent with those described previously in Section 5.2.3 and could include saline water intrusion and magnified effects of waste water returning to the aquifer after use.

5.4.4 Linkages With Other Transboundary Problems

Changes in flow regime are directly related to changes in water levels. Water quality deterioration is also related, but only if the flow regime is sufficiently changed to cause salt water intrusion or if resource depletion results in magnified effects of contaminated water infiltrating back to the aquifer. Similarly, linkages with ecosystem and biodiversity issues are only expected in extreme cases of change in flow regime.

5.4.5 Immediate, Underlying, and Root Causes

The immediate cause of change in groundwater regime is a drop in water levels. The underlying cause is over-abstraction which is aggravated by unmanaged water use and exploitation. The root causes are again the growth in agricultural and industrial sectors due to population growth and related to decisions on food security.

5.4.6 Knowledge Gaps

Groundwater flow cannot be measured directly. Understanding groundwater flow regimes requires data-intensive modelling efforts. The current model is adequate to describe regional patterns of groundwater flow, including quantification of flow regimes. However, with the exception of the southeastern lobe of the study area in Sudan, flow regime itself is not an issue of critical concern in the region. Addressing knowledge gaps in water level decline (Section 5.2.6) will directly contribute to a better understanding of flow regimes.

5.4.7 Conclusions and Recommendations

Changes in flow regime were proposed as an issue of primary concern in the formative stages of this project. This issue has been analyzed through the development of causal chains and the application of the current three-dimensional groundwater model, which is particularly well suited for analyzing flow patterns. Except perhaps in part of Sudan, changes in flow regime are not a critical issue and the recommendation is that this issue be excluded as an area of priority transboundary concern.

5.5 Damage or Loss of Ecosystem and Biodiversity

Declining water levels in the Nubian aquifer and impairment in water quality can logically lead to damage or loss of ecosystem function and biodiversity. Because of the low amounts of annual rainfall (Figure 4), nearly every ecosystem overlying the Nubian aquifer, and the biodiversity that each supports, relies exclusively on water supplied by the Nubian aquifer (Section 3). Furthermore, these ecosystems rely on the surficial waters that are the most vulnerable to environmental change, either natural or human-caused. The very existence of these ecosystems depends on the supply of Nubian water and the integrity of these ecosystems depends on the quality of available water. Protecting these ecosystems and preserving as much of the remaining biodiversity as possible will be a significant challenge in the management of the aquifer system.

5.5.1 Risks and Transboundary Importance

The key risks associated with the integrity of most ecosystems and the biodiversity they support are degradation or loss due to changes in water levels and impairment due to poor water quality. Because there is not significant recharge of the aquifer system from rainfall, natural hydraulic gradients toward discharge locations at the topographic low areas that form oases, marshes, and sabkhas form the only source of water supporting Nubian ecosystems distant from the Nile River.

The transboundary importance is closely related to the issues discussed in Section 5.2.1 regarding changes in water levels. The threat of a direct transboundary effect exists in ecosystems located across national borders from major abstraction areas, but only if abstraction results in sufficiently large declines in water level to deprive the ecosystem of surficial aquifer water. As previously discussed, this risk is low, but bears careful attention. The greater risk to ecosystems and biodiversity is the effect of local abstraction. This is a very high level risk that is shared by every country in the region.

Terrestrial ecosystems do not typically rely as much on the Nubian aquifer. These are the sparse grasslands of northern Chad and Sudan. These fragile and vanishing ecosystems rely primarily on rainfall and in limited regions on the Nubian aquifer. These ecosystems are more vulnerable to climate change than human-caused abstraction, and are important to biodiversity of the region.

5.5.2 Risks in Relation to Time Scale

The time scale for ecosystem impairment and loss of biodiversity for Nubian-dependent ecosystems corresponds closely with that of water level decline and water quality. As with decreases in water level, the direct transboundary effects may not be observed after tens or hundreds of years of abstraction. The localized national effects however, may be far more immediate depending on extraction and management strategies employed.

Progressive loss of rainfall-reliant ecosystems has been observed and continues in response to prolonged aridity. The time scale for further change in terrestrial ecosystems depends on forecasts for climate change in the region and is largely unrelated to abstraction activities.

5.5.3 Major Environmental Impacts and Social-economic Consequences

Oasis communities are completely reliant on stable water levels and are sensitive to water quality. Most of the oasis ecosystems are not particularly deep and as a result can perish in response to relatively small decreases in water levels. Deeper desert aquatic systems, such as the Ounianga Kebir and Ounianaga Sekher in Chad would have more resilience to decreases in water levels.

Deterioration in water quality will affect ecosystem health and subsequently biodiversity. Increased nutrient loads associated with agricultural runoff or seepage may initially stimulate more intense growth of aquatic plants, but ultimately will probably lead to eutrophication, or nutrient over-enrichment. In this case, aquatic vegetation grows at a sufficiently fast rate that biological decay of dead plant matter results in de-oxygenation of the water. High nutrient concentrations also favour growth of certain algae forms toxic to both aquatic and terrestrial animals. Eutrophication typically leads to a loss in biodiversity and is extremely difficult to reverse.

In the NSAS areas of Sudan and Chad, terrestrial vegetation consisting mainly of annual perennial grasses and herbs form what is known as the Gizzu and provide forage for herds of camels, sheep, and goats. In the span of human memory herders have been forced to move farther south. This natural succession has limited the areas in which pastoral farming can be practiced.

An important aspect to consider in evaluating the risks associated with degradation of ecosystems and biodiversity is that once damage occurs, regardless of cause, the ecosystem may never return to its earlier state. Ecosystem restoration under the most favourable conditions is typically expensive and difficult to achieve. From a purely economic standpoint, costs associated with ecosystem restoration, or even treating polluted water for potable use, far exceed costs associated with the deliberate management strategies necessary for prevention of ecosystem impairments. In terms of biodiversity, it is generally acknowledged that diminished biodiversity is difficult to restore, and of course extinctions cannot be reversed.

Social and economic consequences of ecosystem degradation are similar to those for water level decline (Section 5.2.3) and water quality impairment (Section 5.3.3). At a minimum, the human communities relying on surface water or shallow wells may no longer be able to use these resources. As the level of impairment increases, the ecosystems may become uninhabitable or may not support economic activities, such as herding, that constitute a means of existence for indigenous human cultures.

5.5.4 Linkages With Other Transboundary Problems

Impairments to ecosystems and biodiversity are tightly linked to changes in water levels and water quality deterioration. It is possible that changes in flow regime could result in ecosystem changes, but conditions in the Nubian aquifer do not appear to support this linkage.

5.5.5 Immediate, Underlying, and Root Causes

The immediate causes of impairment to ecosystem health and losses in biodiversity are different for aquatic and terrestrial ecosystems. For the oasis ecosystems, the immediate causes are water level decline and water quality deterioration, which can occur either separately or in concert. The underlying causes are similar to previously described impairments: over-abstraction resulting in declining water levels and inadequate pollution prevention practices resulting in water quality deterioration. The root causes are expansion in agricultural and industrial sectors due to population growth and related to decisions on food security. For terrestrial ecosystems, the immediate cause is decline in rainfall, and the root cause is climate change.

5.5.6 Knowledge Gaps

Systematic monitoring of ecosystem characteristics and health and of biodiversity has not been a high priority in the region. While the general responses of ecosystems to impairment can be anticipated, a program of monitoring is necessary to document actual changes in ecosystem health and biodiversity. These data are particularly important to separate the relative effects of direct human activities and the more indirect effects of climate change.

5.5.7 Conclusions and Recommendations

Healthy freshwater oasis ecosystems not only support biological diversity, but also support indigenous human communities. Impairments can cause irreversible damage and irreplaceable loss of ecosystem function. The threat of direct transboundary effects is low, but the risk of localized effects shared among countries in the region is high. Fortunately only low levels of impairment to oasis communities have been observed. The opportunity exists for improved monitoring and cooperative development of strategies to preserve these ecosystems.

Terrestrial ecosystems in Chad and Sudan are highly vulnerable to continued desertification and changes in these ecosystems are largely independent of extraction patterns in the Nubian aquifer. Monitoring of these ecosystems is necessary to anticipate changes in biological diversity and the ability of these ecosystems to support pastoral activities.

5.6 Climate Change: What Does It Mean for the Region's Water Resources?

Climate change in the form of higher temperatures and more arid conditions can affect water resources in the region in several ways. The aquifer itself will be almost unaffected, since there is practically zero recharge as it is. Higher evaporation and transpiration in oasis and sabkhah areas will increase, but will not affect the water budget in any significant way.

The changes that can occur vary in the region. For example, if Mediterranean coastal rainfall decreases, Libya may rely more on the Great Man Made River as a freshwater source, resulting in increased demand on the aquifer there. The situation in Egypt is similar, but somewhat more complex. The Intergovernmental Panel on Climate Change predicted that flow in the Nile will remain steady or increase slightly over the next hundred years or so. However other factors, such as increased evaporation in Lake Nasser, reallocation of Nile resources among the riparian countries, and population increases all have the potential for increasing Egypt's reliance on the Nubian aquifer. Sudan is in the same situation as Egypt, except that their Nubian resources are more limited due to lower aquifer thickness in the southeast region of the aquifer.

Increased aridity in Chad and parts of Sudan should not affect the aquifer resources themselves, but can significantly affect the grassland ecosystems that support pastoral practices. Reductions in the extent of grasslands have already resulted in regional instability because nomadic herders were obliged to modify their trekking routes. This brought them into direct conflicts with the settled communities. In fact, conflicts in Darfur are partially attributed to this problem.

5.7 Summary: Critical Issues of Transboundary Concern

This project started with the recognition among member countries that they share a natural resource which is vast, yet vulnerable to certain impairments unless development proceeds in a deliberate, rational manner. The five areas of concern recognized at the onset of the project were: declining water levels, water quality deterioration, changes in groundwater regime, damage or loss of ecosystems and biological diversity, and climate change. Of these, the primary concern in the region is the threat of transboundary decreases in water level. The results of the collaborative modelling effort indicate that decreases in water level due to abstraction are indeed the critical issue shared by all countries in the region. However this concern is mitigated by two important factors: (1) the modelling results indicate that there is likely to be little transboundary effect to abstraction in the next hundred years and (2) there is no current impairment to the system.

5.7.1 Direct Versus Shared Transboundary Risks

All of the risks described in this section have the potential for transboundary effects, however at present and under forecast conditions, risks of *direct* transboundary impacts for all areas of concern (Sections 5.2 through 5.6) are low. Take for example abstraction in the East Oweinat production area in Egypt and its potential effects on Sudan. The risk of water level decline is low or non-existent, depending on the accuracy of recent modelling. There is no transboundary risk of water quality deterioration on the Sudan side of the border near East Oweinat, because of the low mobility of contaminants that could enter the aquifer at the Oweinat agricultural areas. The risk of change in groundwater regime is lower than the risk of water decline, which itself is at or near zero. The risk of loss of ecosystems or biological diversity is linked to changes in water level decline, but there would have to be an oasis ecosystem present in Sudan near enough to the East Oweinat production area to be affected.

The example of East Oweinat can be repeated for the other two existing production areas near borders, Siwa in Egypt and Jaghboub in Libya. The current modelling results indicate that there is little risk of cross-border effects. This example can be extended to unforeseen near-border developments as well, for example along the camel route between Sudan and Egypt to the east of the East Oweinat production area. These are areas worthy of more focused attention in the region for direct transboundary impacts. The current modelling effort and all previous modelling studies agree that there is no risk of direct transboundary effects due to production areas distant from borders. Even abstraction projects as large as the Great Man Made River result, by all accounts, in only localized direct transboundary effects.

At a regional level, the existing and prospective near-border development projects constitute the only direct transboundary risk and these risks are low. Of far greater importance are the *shared* transboundary risks. These are the adverse impacts of water extraction that have only national effects, but are common to the region. Viewed from this perspective, all of risks evaluated in Sections 5.2 through 5.6 have a shared regional relevance.

5.7.2 Management of the Aquifer for Prevention of Impairments

One aspect of risks due to abstraction in the region, whether they are considered direct or shared, is that no significant adverse effects have yet been observed. This presents a unique opportunity to create shared management strategies oriented around prevention. The risk of direct transboundary effects is low, but sufficiently large to merit vigilance in monitoring. This risk is also low enough that each country can exercise their sovereign right to use their resources as they see appropriate. The region is also in a position to take advantage of the existing framework of the Joint Authority to cooperate in shared management of the aquifer to minimize the risk of adverse impacts of national origin.

As previously discussed, these risks appear to be primarily of national rather than transboundary concern, however they are all of great importance as risks shared by all countries in the region. These will be the four priority issues carried forward to the SAP. Management plans will be developed to fully address these at the transboundary level with links to national action plans.

Section 6. Gaps

Although the Nubian countries have made great advances in understanding the condition of the aquifer and the linkages between potential changes in the aquifer and responses of environmental and human systems, much work remains.

- ***Geology and Water Levels:*** The single greatest limitation in analyzing data for this project was the uncertainty introduced by the lack of geologic and hydrologic data. Vast expanses of the aquifer are essentially unknown. Modelling activities described in Section 4 were able to provide forecasts of future effects of abstraction, however, improved knowledge is necessary to confirm these findings and improve statistical confidence in the predictions.

- ***Isotopic Age Dating:*** A promising technique employed in this project has been the analysis of groundwater in Egypt for krypton isotope ratios. These data revealed ages of groundwater on the order of hundreds of thousands of years and were important in confirming theories regarding water movement in the aquifer. These theories supported statistical confidence in the current modeling efforts. Existing wells in Libya and Egypt can be sampled for this analysis and as a result important information can be provided at a relatively low cost.

- ***Ecosystem Vulnerability:*** The calibrated regional groundwater model has not yet been applied extensively. An important early application of the model is to refine the grid in the region of pumping and oasis areas and determine the vulnerability or oasis ecosystems to abstraction.

- ***Ecosystem Assessment:*** Only limited data appear to be available on the condition of terrestrial and oasis ecosystems. As indicated in Sudan's Baseline Report (Annex 8), additional monitoring is necessary to understand the current extent and conditions of ecosystems.

- ***Climate Change Threat:*** Adverse environmental change can occur in both terrestrial grassland, as well as aquatic oasis ecosystems, in response to some combination of abstraction, climate change, and even a continuation of the current climatic conditions. A better understanding of the impacts of climate change is necessary in order to separate the effects of the natural trajectory of the desert ecosystems from the human-related impacts.

- ***Capacity Equalization:*** The Nubian countries vary considerably in their capacities for field, laboratory monitoring, and groundwater modeling activities. The cooperative mechanisms developed through the Joint Authority need to be exploited to equalize capacity among the countries.

Section 7. Benefits

Benefits related to this MSP have already been realized and additional benefits can be anticipated with the completion of the SADA, SAP, and legal components of the project. The SADA component of this MSP has resulted in several benefits and opportunities for Nubian countries.

- ***Improved Data Sharing:*** For reasons related primarily to limitations in capacity, the NARIS database has not been updated since 1998. This project has resulted in data sharing that enabled updating of hydrogeologic databases for modeling purposes.

- ***A Shared Regional Groundwater Model:*** As a result of SADA activities, the member countries now have a common basis for sharing and interpreting hydrogeologic data. This model has already produced results that have reshaped how member countries view their national and transboundary aquifer resources (e.g., Section 5.2).

- ***Improved Understanding of Transboundary Threats:*** Perhaps the single greatest benefit realized by the project so far has been the recognition that the immediate, direct transboundary threat of water-level declines due to cross-border abstraction are far lower than originally thought. This awareness does not relieve the member countries from maintaining and enhancing their shared monitoring programs, but does inspire a variety of related benefits, including the recognition that water management strategies can be directed toward *preventing* rather than *mitigating* both transboundary and national and water management problems.

Section 8. Stakeholder Analysis

A detailed stakeholder analysis, the interests of the stakeholders and the relative power or importance of the stakeholders was undertaken and reported in 2008 (Annex 2). This work was undertaken by a working group that defined a list of stakeholders and interests and reviewed both the primary stakeholders (those who are ultimately impacted by the activities of the project, e.g. farmers, local tribes, etc.) and secondary stakeholders (e.g. government departments, NGOs, private sector organisations).

In addition to the national stakeholders, international and regional stakeholders (e.g. international organisations, the Joint Authority for the Study and Development of the Nubian Sandstone Aquifer Waters, etc.) are described. The detailed stakeholder report (Annex 2) also provided a breakdown of the involvement of different stakeholder groups at the varying stages of the plan development and implementation.

8.1 Introduction

Stakeholder analysis is a process of systematically gathering and analyzing qualitative information to determine whose interests should be taken into account when developing and implementing the MSP. Stakeholder analysis might be also defined as it is technique that can help project team members understand the variety of stakeholders that have an interest in the project, and the individual nuances that can affect project risk. In an environment where organizational or office politics often appear to cloud a project's progression, stakeholder analysis provides the team with views and some basic measures that can help uncover and remove barriers. Consequences of completing such an analysis include information for additional tools that could prove valuable for the project team: a communication management plan, a risk management plan, and possibly a set of previously unspoken project requirements.

The technique compels project leaders to identify and support the interests of the key stakeholders either they are individuals or groups. When interests that cannot be supported arise, the knowledge that they exist and what level of influence the stakeholder may impose can be a great asset to the project team. The difference between success and failure can simply know project advocates and opponents, understanding their respective needs and levels of influence, and aligning the project accordingly.

It is important to identify who is vested interest in stakeholder in the region. Based on the resources available, each national project coordinator and SADA group in consultation with the project manager and the consultant decided on the stakeholders to be interviewed. The working group defined the list of stakeholders (beginning flexible and open) based on the following key questions:

- Who is paying for this project? What do they expect? What conditions will they impose on the project?
- Who benefits from this project? What requirements do they have? How will it help and can the benefit be described in tangible and intangible terms?
- What is the size and scope of the current problem or situation the project will attempt to solve? Does not solving the problem expose any of the society groups to risk? Is the level of risk acceptable?
- What other groups or individuals are required to implement the project? What conditions and constraints will they impose on the project?
- What groups will be key influencers in the project outcomes and success? What is the risk if the influencers do not support the project? What is required to get the influencers to support the project?
- Are there other individuals, groups or departments that will have an interest or a stake in the project or the process. What is their interest likely to be and how will it affect the project.

The stakeholder analysis includes such stakeholder characteristics as knowledge of the project policy, interests related to the project, position for or against, potential alliances with other stakeholders, and ability to affect the project implementation process.

Stakeholder analysis allows the counterpart countries to interact more effectively with key stakeholders and to increase support for the long term project objective "equitable and sustainable management of the Nubian Aquifer". Stakeholder analysis was (should be) conducted before the implementation of the Strategic Action Plan is implemented; counterpart countries can detect and act to prevent potential misunderstandings about and/or opposition to the plan to grantee more chance for the success of the plan implementation.

Stakeholder analysis yields useful and accurate information about those organizations that have an interest in NSAS development and management. This information can be used to provide input for other analyses; to develop action plans to increase support for guiding the participatory, consensus-building process.

There are various approaches and ways to conduct the stakeholder analysis. The following main steps were considered to accomplish the stakeholder analysis which based on the guidance note on How to do stakeholder analysis, developed by Overseas Development Administration (1995):

1. A list of all possible stakeholders and their interests;'
2. An assessment of stakeholders' relative power and influence, importance to the project, their possible contributions to the success of its activities, and
3. Possible risks that might affect the project's successful implementation: positive relations between stakeholders can be used as an entry point for project activities, conflicts of interests between stakeholders might hinder progress if they are ignored.

8.2 Stakeholder Identification

8.2.1 Identifying Stakeholders and Their Interests

As starting point to identify the stakeholders and their interests, the stakeholders were divided into primary and secondary stakeholders. Table 5 provides the list of the primary and secondary stockholders in each country.

Primary stakeholders are those people and groups ultimately affected by the project. This includes intended users of the commonage or those negatively affected (for example, farm workers involuntarily resettled or removed). In most projects primary stakeholders will be categorized according to socio-economic assessment. Thus, primary stakeholders should often be divided by gender, social or income classes, occupational or service user groups. In many projects, categories of primary stakeholders may overlap (e.g., women and non-income groups; or minor commonage users and ethnic minorities).

Secondary stakeholders are intermediaries in the process of delivering aid to primary stakeholders. They can be divided into funding, implementing, monitoring and advocacy organizations, or simply governmental, NGO and private sector organizations. In commonage projects it will also be necessary to consider key individuals as specific stakeholders (e.g., extension officer) other agencies, which have personal interests at stake as well as formal institutional objectives. Also note that there may be some informal groups of people who will act as intermediaries. For example, politicians, local leaders, respected persons with social or religious influence.

Beside what is presented in Table 5 there highly interested secondary stakeholders in the project like IAEA, GEF and UNDP.

8.2.2 Stakeholder Interests in Relation to the Project

The resulting list of stakeholders forms the basis of a tabulation of each stockholder's interests in the project (Tables 6 and 7), and the project's likely impact on them. Interests of all types of stakeholders may be difficult to define, especially if they are "hidden", or in contradiction with the openly stated aims of the organisations or groups involved. A rule of thumb is to relate each stakeholder to either the problems which the project is seeking to address (if at an early stage of the project), or the established objectives of the project (if the project is already under way). Interests may be drawn out by asking:

- What are the stakeholders' expectations of the project?
- What benefits are there likely to be for the stakeholders?
- What resources will the stakeholder wish to commit (or avoid committing) to the project?
- What other interests does the stakeholder have which may conflict with the project?
- How does the stakeholder regard others in the list?

Information on secondary stakeholders should be available from institutional appraisals; information on primary stakeholders should be available from social analyses. Especially in the case of primary stakeholders, many of the interests will have to be defined by the persons with the best "on-the-ground" experience. Double-check the interests being ascribed to primary groups, to confirm that they are plausible.

8.3 Assessing the Influence and "Importance" of Stakeholders

Key stakeholders are those which can significantly influence, or are important to the success of the project. Influence refers to how powerful a stakeholder is; "importance" refers to those stakeholders whose problems, needs and interests are the priority for the success of the project - if these "important" stakeholders are not assisted effectively then the project cannot be deemed a "success".

By combining influence and importance using a matrix diagram, stakeholders can be classified into different groups, which will help identify assumptions and the risks which need to be managed through project design. Before outlining this matrix, ways of assessing influence and importance are suggested.

Influence is the power, which stakeholders have over a project - to control what decisions are made, facilitate its implementation, or exert influence, which affects the project negatively. Influence is perhaps best understood as the extent to which people, groups or organizations (i.e. stakeholders) are able to persuade or coerce others into making decisions, and following certain courses of action.

Power may derive from the nature of a stockholder's organization, or their position in relation to other stakeholders (for example, GEF that controls the budget). Other forms of influence may be more informal (for example, Local/National Parliament Members). It may also be necessary to consider stakeholders whose power, and therefore influence, will increase because of resources introduced by the project.

Assessing influence is often difficult and involves interpretation of a range of factors. Factors that may be involved might be considered during the balancing and evaluating the influence/power for the secondary and primary stakeholders are summered as follow:

Within and between formal organisations for Secondary Stakeholders

- Legal hierarchy (command and control, budget holders)
- Authority of leadership (formal and informal, charisma, political)
- Possession of specialist knowledge (e.g. Agricultural staff)
- Negotiating position (strength in relation to other stakeholders in the project
- Control of strategic resources (supplying subsidized power , aids and water)

For informal interest groups and primary stakeholders

- Social, economic and political status
- Degree of control of strategic resources significant for the project
- Informal influence through links with other stakeholders
- Degree of dependence on other stakeholders

Importance indicates the priority given to satisfying stakeholders' needs and interests through the project. Importance is likely to be most obvious when stakeholder interests in a project converge closely with the common objectives.

Importance is distinct from influence. There will often be stakeholders, especially unorganized primary stakeholders, upon which the project places great priority (e.g. women, resource poor users etc). These stakeholders may have weak capacity to participate in the project, and limited power to influence key decisions. A checklist for assessing "importance" to the project is provided as follow:

- Which problems, affecting which stakeholders, does the project seek to address or alleviate?
- For which stakeholders does the project place a priority on meeting their needs, interests and expectations?
- Which stakeholder interests converge most closely with policy and project objectives?

Tables 8, 9, 10, 11 represent the importance and influence matrixes for Egypt, Libya, Sudan and Chad.

8.4 Assumptions and Risks Affecting Project Design and Participation

8.4.1 Identifying Assumptions and Risks About Stakeholders

The success of a project depends partly on the validity of the assumptions made about its various stakeholders, and the risks facing the project. Some of these risks will derive from conflicting interests. Risks may be driven from conflict between the ministry of water that manage the water resources and some of other users ministers like Agriculture, Industry, livestock, local government and planning and development with regard to the allocated water shares for various development activities. Risks might come from the conflict between the ministry of environment and those ministries that responsible for development with regard to the adverse impact of the development expansions on the environment. Risks may drive from another conflict between the ministry of agriculture or local government and the agriculture investors with regard to the ownerships of the land.

8.4.2 Identifying Appropriate Stakeholder Participation

Defining who should participate, in what ways, at what stage of the project cycle, contributes to a well-designed project. Although the project cycle defines the responsibilities of the project team, the use of a matrix to clarify the roles to be played to inform, consult, partnership and control is still necessary for each project, because of the difference in dynamics and human aspects of each project. Stakeholder participation recommends the use of a matrix to clarify the roles to be played, at each stage of the project cycle, by all key stakeholders.

8.5 Using the Findings of a Stakeholder Analysis

Findings from a stakeholder analysis are already recorded in the tables and matrix diagrams, and the risks and assumptions arising from the analysis should be included in the log frame. In addition, the analysis should have contributed to a participation matrix that is used to explain project design. These records of the analysis are the basis for revision later on in the life of the project.

The findings of a stakeholder analysis need to be included (with different amounts of detail) into the project plan. Such a summary can be brief, depending on the nature of the plan, and the analysis will probably be revised as the project plan develops, interests change, and more information becomes available.

Section 9. Governance Analysis

The analysis of governance presented here was developed as part of the SADA process in 2008 and appears in full as Annex 3. Additional material on governance can be found in the baseline and national SADA reports prepared by the individual countries (Annexes 5 through 9). Additional information on governance from the perspective of the legal and institutional frameworks that authorize ministry missions and establish regulatory structures can be found in the national and regional reports associated with the Legal and Institutional Framework component of this project. At present these documents are in preparation.

9.1 Chad

9.1.1 Context

The “Direction de l’Hydraulique” (Direction of Hydraulics) which is under the “Ministère de l’Environment et de l’Eau” (Ministry of the Environment and Water) is responsible for the supply of drinking water to most urban and semi-urban centres. The Chad Water and Electricity Company supplies water to 11 cities in Chad, including the capital, N’Djamena. According to UNDP’s Human Development Indicators, in 2004 the population in Chad using improved sanitation was 9 percent. However, the same report states that the share of the population not using an improved water source for the same year was 58 per cent. This reflects the difference between the access to water for drinking and the access to appropriate sanitation. The low level in sanitation can pose threats and problems to the quality of the water coming from surface and groundwater sources. Many towns and villages are already affected by water quality issues due to pollution.

There is no functional sewage system or a proper waste management system in place. There are few drainage systems and the country lacks the necessary technical and financial resources. All of this has negative effects on the quality of water especially on surface waters. Hence, groundwater is increasingly important as a source of drinking water throughout the country. However, sanitation problems ought to be addressed as well, in order to avoid further pollution going into the groundwater.

9.1.2 Socioeconomic Situation

In Chad, the proportion of the population with permanent access to safe water in rural areas was 17% in 2000; the proportion implementing environmental health measures was 7%. In towns equipped with a drinking water supply (DWS), only 9.7% of the population have a connection, while 27.5% obtain water from a public stand-pipe and 63% have to draw water from (often traditional) wells. On the whole, permanent access to drinking water is limited to 23% of the Chadian population. None of the towns has a functioning wastewater sewerage system and the collection networks are dilapidated. Less than 2% of city-dwellers have sanitary facilities with running water, while latrines are almost non-existent in rural areas.

The poor are vulnerable to chronic diseases related to poor living conditions and lack of access to water and sanitation. Women and girls from villages without access to a drinking water point devote a great deal of time to fetching water (up to several hours each day in some bedrock areas) which, along with other chores, is often one of the factors depriving them of their right to education (the basic education-level school-attendance rate among girls in Chad was 35.6% in 1999) and preventing them from acquiring skills that would enable them to become involved in more productive and rewarding activities.

Food production: at present, according to the national poverty reduction strategy, the level of food poverty, i.e., the proportion of households that cannot meet all their food requirements6, is about 54% in Chad. This should be reduced to 27% in 2015. Efficient use of water resources and land over an additional 100 000 ha, the improvement of productivity and yields brought about by training farmers and through income-generating activities should make a large contribution to reaching the goal of reducing hunger.

From the economic point of view, the agriculture, stock-rearing and fishery sectors, which currently represent 40% of Chad's GDP, fundamentally depend on decisions made regarding water access levels (quantity and quality), spatial distribution of hydraulic networks within a homogeneous area or basin, national, regional and local water management methods, provision of management training and conservation of healthy basin aquatic ecosystems. This severe lack of basic infrastructure and the multiple water-related issues prompted the Government to draw up a national water policy and integrated management strategies, defined in a plan setting out guidelines and planning investments and the rational use of national water resources in order to meet the population's basic needs more effectively. At the Government's request, the first Integrated Plan for Chad's Water Development and Management was drawn up entirely in Chad, under UNDP2 funding and with methodological and technical support from UNDESA3. This reference document should contribute to making food crops less vulnerable to climatic variations, while reducing sources of conflict. It will also contribute to protecting the aquatic and basin ecosystems upon which the country's main economic sectors and rich biodiversity depend. In light of these needs the SDEA covers sanitation, a natural extension of any water supply system, as a specific important subsector.

Since Chad is entering the crude oil era and 72% of its oil revenues will be allocated to expenditure in declared priority sectors in Chad, i.e., education, healthcare and water, by virtue of Law 001/PR/99 of 11 January 1999. A great deal of work has been carried out over three years to draw up an inventory and assessment of the existing situation and predict future needs for infrastructure and local capacity-building in order to meet the goals that have been set. These efforts have resulted in a water policy, strategies for mobilising financial, institutional and human resources and an action plan, covering a ten- and twenty year period. This participatory approach to planning has also enabled the administrations of various sectors to reach a consensus on specific strategies for monitoring water resources (both surface and groundwater) and aquatic ecosystem resources, notably how they are protected and used by five subsectors: village water supply, urban and semi-urban water supply, sanitation, pastoral water supply and agricultural water supply (not forgetting fisheries, hydropower, tourism and natural or anthropogenic risk management).

In Chad the state of the economy has been inferior to that of the other countries participating in the Nubian Aquifer Project. GDP is low compared to the other countries, official development assistance is low and agriculture still accounts for a large share of GDP. Farming and stock farming is still a form of livelihood for many families. A large percentage of the population lives in the rural areas of the country and there is still a large nomad population. Although industry (and its share in GDP) has grown, it is not enough to ensure a faster GDP growth. Much of the industry is in oil, which has generated migration towards the oil producing areas. Nowadays, much of the infrastructure in these areas is inadequate to handle the population numbers.

Water collection is a task mainly done by women and children. According to one report[i], rural women in Chad spend 6 to 8 hours on domestic chores, mostly fetching water and wood; they are therefore the most concerned by the supply of drinking water to households and have no time for other income-generating and leisure activities.

9.1.3 Governance Structures

The institutional framework for drawing up the Integrated Plan for Water Development and Management is provided by the ministry responsible for water: the Ministry of the Environment and

Water (MEE), through the Directorate of Hydraulic Affairs. The institutional framework of the inter-sector consultation process has been set up on three levels under the Prime Minister's supervision:

- The intersectoral technical level (Intersectoral Technical Committee for Water - CTIE), which rules on the technical aspects of each subsector document;
- The administrative and strategic level (National Water Management Committee - CNGE - including several elected representatives of civil society), which gives opinions to the HCNE (High National Council for the Environment) on the Integrated Plan for Water Development and Management;
- The political level (HCNE), which is placed under the authority and arbitration of the Prime Minister, and whose secretariat is provided by the MEE. Finally, the decision-making level, which refers to the Council of Ministers at the HCNE's request.

The Ministry of the Environment and Water acts as both the permanent secretary of the HCNE and the president of the CNGE and the CTIE. The Ministry of Economic Promotion and Development (MPAT) acts as vice-president of the HCNE and the CNGE and thus guarantees that the process is integrated and that the Integrated Plan for Water Development and Management is drawn up in a manner which is consistent at all levels with sectoral policies, the objectives of the national economy and with regional development and the environment.

Regarding the governance in water resources, there are limits on the government's side to provide the Ministry of Environment and Water with the necessary resources to improve the water governance. The Official Development Assistance that the country has received is significantly less than that received by the other countries participating in the Nubian Aquifer Project. GDP is also inferior to that of the other countries.

9.2 Egypt

9.2.1 Context

Throughout history, most of the attention regarding water resources in Egypt was given to the Nile. However, in recent decades growing water demand driven mainly by population growth has lead to the adoption of water policies taking into account alternative water resources. Outside the reach of the Nile River and oases around the country, groundwater is the only alternative source of potable water in Egypt. In Egypt, the Ministry of Water Resources and Irrigation is responsible for the development and management of water system.

Development policies are based on studies of the actual socio-economic and cultural conditions in the local areas and on integrated water resources management required to secure sustainable development. Current research activities in order to enhance available water resources under the established Groundwater Sector include methodology development for desalination of brackish groundwater, artificial recharge and storage for drinking, industrial, and agricultural uses.

The main issues facing Egypt's development include, among others: (a) partial utilization of its land area territories (less than 10%); (b) unbalanced population distribution and continuous immigration from rural to urban areas; (c) a decreasing per capita share in water and agricultural land; and (d) lack of proper water supply and sanitation in the rural and desert areas.

9.2.2 Socioeconomic Situation

Demographic aspects such as population rate of growth, natural increase, population distribution by sex and by location, as well as population density are all factors that may explain some differences in the health and nutrition status of the participants in any society. Total population in Egypt reached 76 million inhabitants (2007) and were estimated by 57 million inhabitants in 1991. With the annual rate of increase of 2.8% population are projected to reach 125 million by the year 2025. The population rate of growth for 1960 to reach 1.9% on average over the period 1966-76. However, since 1976 an upward trend in it is remarkable to reach 2.8% in 1986. This indicates the importance of health services and food intake for the growing size of population in the last two decades. The geographical distribution of Egyptian population clearly shows considerable distortions population is concentrated along with the river Nile (95% of the Egyptian occupied 4% of the country area).

The surface area of around one million square kilometres, Egypt has a thriving economy. With an annual GDP of over 100 billion US dollars and with GDP growth of 6.8 percent in 2006, the Egyptian economy is succeeding on many grounds. Egypt shifted in its development efforts from adopting an independent model in the central planned era to a dependent strategy in the open-door era. Meanwhile the role of the state as the main provider of social services has been significantly affected by changing from socialism to liberalization. Land reform, rent control legislation and taxation measures would help to prevent the exploitation aspects of private ownership.

9.2.3 Governance Structure

The Ministry of Water Resources and Irrigation (MWRI) is in charge of water resources research, development and distribution, and undertakes the construction, operation and maintenance of the irrigation and drainage networks. Specifications and permits for groundwater well drilling are also the responsibility of MWRI. Within MWRI, the following sectors and departments are of importance:

- The Planning Sector is responsible at central level for data collection, processing and analysis for planning and monitoring investment projects.
- The Sector of Public Works and Water Resources coordinates water resources development works.
- The Nile Water Sector is in charge of cooperation with Sudan and other nilotic countries.
- The Irrigation Department provides technical guidance and monitoring of irrigation development, including dams.
- The Mechanical and Electrical Department is in charge of the construction and maintenance of pumping stations for irrigation and drainage.

Further to the above institutions, other public authorities are directly related to MWRI:

- The High Dam Authority is responsible for dam operation.

- The Drainage Authority is responsible for the construction and maintenance of tile and open drains.
- The National Water Research Center comprises 12 institutes and is the scientific body of MWRI for all aspects related to water resources management.

MWRI also represents Egypt in the meetings of the Nile basin countries on Nile water issues. There are several joint projects between those countries for the development of Nile water. These projects, if completed, would increase the water shares of member countries significantly. Egypt would gain an additional 9 km^3 of Nile water.

The Ministry of Agriculture and Land Reclamation (MALR) is in charge of agricultural research and extension, land reclamation and agricultural, fisheries and animal wealth development. The Agricultural Research Center comprises 16 institutes and 11 central laboratories and is the scientific body of MALR for all aspects related to agricultural development. The Land Development Authority is in charge of contracting and monitoring land development projects and manages land allocation to investors and individuals. The Agricultural Development and Credit Bank provides credit to farmers to finance various production requirements.

Water management

The Government has indicated its intent to shift emphasis from its role as the central (or sole) actor in developing and managing water supply systems, towards promoting participatory approaches in which water users will play an active role in the management of irrigation systems and cost sharing. Important institutional and legislative measures have been taken recently to promote the establishment of sustainable participatory irrigation management (PIM) associations. However, despite these measures, the development of water users' associations (WUAs) as effective partners in irrigation management remains at an early stage. In the new lands, the concept of PIM is not yet effectively operational for a variety of economic, financial and institutional reasons.

While most settlers recognize the importance of WUAs in the equitable distribution of available water, uneven water availability, either due to design shortcomings or to lax enforcement of rules against excess abstraction by front-end water users, has acted as a disincentive to the successful operation of WUAs in many instances.

Finances

The government invests considerable resources in the land-reclamation programme. Investment is primarily in irrigation and drainage infrastructure, settlement construction, and provision of potable water, electricity and roads. Very little is invested in social services (education and health), and no investment is made in the provision of agricultural services (technology, water management and rural finance). Consequently, poor settlers face difficulties in settling and farming, and a considerable percentage move back to the old lands and abandon their new land farms.

Both MWRI and MALR activities are considered public services and their water and land development projects are budgeted in the national economic and social development plan.

Policies and legislation

The main water and irrigation strategy is concerned with the development and conservation of water resources. This is done through adopting water rotation for irrigation canals, limiting the rice growing area, lining irrigation canals in sandy areas and prohibiting surface irrigation in the new developed areas outside the Nile basin.

Recent water resources policies include different structural and several non-structural measures. Structural measures include: irrigation structures rehabilitation; improvement of the irrigation system; installation of water level monitoring devices linked to the telemetry system; and expansion of the tile drainage system. Non-structural measures include: expansion of water user associations (WUAs) for irrigation ditches; establishment of water boards on branch canals; promotion of public awareness programmes; and involvement of stakeholders.

The legal basis for irrigation and drainage is set in Law No. 12/1984 and its supplementary Law No. 213/1994 which define the use and management of public and private sector irrigation and drainage systems including main canals, feeders and drains. The laws also provide legal directions for the operation and maintenance of public and private waterways and specify arrangements for cost recovery in irrigation and drainage networks.

The most recent water policy was drafted in 1993. It included several strategies to ensure satisfying the demands of all water users and expanding the existing agricultural area at that time of 7.8 million feddan (about 3.12 million ha) by an additional 1.4 million feddan (about 560,000 ha).

The Government of Egypt is working in a significant and important way to improve the water sector governance and financial sustainability through partnerships between the public and the private sector. The sectors are working together to design, build and operate irrigation infrastructure to the benefit of populations across the country. There are programmes and projects in the country to mitigate environmental degradation caused by excessive drawdown of groundwater and to support sustainability in irrigation and its infrastructure. The country has also benefited in term of its water resources governance from contributions and technical cooperation projects with various donors and international organizations.

9.3 Libya

9.3.1 Context

Studies of various basins led to the implementation of several agricultural projects in remote areas in the desert. Fertile lands are, however, found along the coastal area together with the main population distribution. This has led to the establishment and implementation of the world's largest groundwater conveyance scheme (The Great Man-made River) which will transport about 6.5 million cubic meter of water per day from the desert to the coastal areas. All of these developments encouraged the Libyan authorities to continue studying the water resources in the basins in detail and to seek more information from other neighbouring countries sharing the basins.

Responsibility for all water resources assessment and monitoring rests with the General Water Authority, while the Secretariat of Agriculture and Animal Wealth is responsible for the development of irrigated agriculture and the implementation of major projects. A special Authority – The Great Manmade River Water Utilization Authority – is responsible for the use for agricultural purposes of the water transported from the desert to the coast. The Secretariat of Municipalities takes care of water supply to urban settlements.

9.3.2 Socioeconomic Situation

Libya has a total area of about 1.76 million km^2. About 95 percent of the country is desert. The cultivable area is estimated at about 2.2 million ha which is 1.2 percent of the total area of the country. Permanent pastures account for 13.3 million ha, annual crops for 1.8 million ha and permanent crops for only 0.3 million ha.

The total population was about 5.7 million in 2004, and 6 million in 2006 including some 0.8 million non-Libyans. Of the total population only 13 percent is rural. The annual population growth rate for the period 1995-2000 was estimated at 2.2 percent. However, growth appears only in the urban areas, with the rural population showing a negative growth of 1.3 percent. The average population density of about 3 inhabitants/km^2 varies between 150 inhabitants/km^2 in the northern regions to less than 1 inhabitant/km^2 elsewhere. In 1995, 54 percent of the Libyan population lived in the western coastal area (Jifarah plain and Misratha area). The eastern coastal area (Al Jabalal Akhbar) is the second area of population concentration with 21 percent. This means that 75 percent of the population is concentrated over 1.5 percent of the total area of the country. In 2002, 72 percent of the population had access to improved drinking water sources (72 percent of the urban population and 68 percent of the rural population). About 97 percent of the urban population and 96 percent of the rural population had access to improved sanitation services.

The total GDP was US$19,100 million (current US$) in 2002, with an estimated growth rate of 3.2 percent per year while the .GDP of 50 million US dollars, with annual growth of 5.6 percent in 2006. The Libyan economy depends primarily upon revenues from the oil sector, which contributes practically all export earnings and about 25 percent of GDP. The non-oil manufacturing and construction sectors, which account for about 20 percent of GDP, have expanded from processing mostly agricultural products to include the production of petrochemicals, iron, steel, and aluminium. Agriculture contributes to about 9 percent of GDP and provides employment for about 5 percent of the total economically active population. While 25 percent of the total economically active population are women, in the agricultural sector they account for 67 percent of the labour force. The unemployment rate is about 30 percent.

Given the arid nature of much of the Libyan Arab Jamahiriya, irrigated farming systems have always been of crucial importance in generating much of the country's agricultural output. About 50 percent of the cereal production and about 90 percent of the fruit and vegetable production originates from irrigated agriculture. With very limited renewable water resources, the Libyan Arab Jamahiriya relies heavily on imports to satisfy food requirements. In 2000 the import of cereals, sugar and oil represented a contribution of 68 percent to the national calorie budget. The degree of need satisfaction and quality of diet at household or individual level varies. In the current situation, food security at national level has been achieved, but at the same time food self-sufficiency is not feasible.

9.3.3 Governance Structure

The responsibility for all water resources assessment and monitoring rests with the General Water Authority (GWA) which was established in 1972. The GWA is composed of six General Directorates: Planning, Follow-up and Statistics, Water Resources, Dams, Irrigation and Drainage, Soils, and Finance and Administration. It is concerned with the supervision of irrigation and drainage projects. Furthermore, it performs research and studies aimed at improving the irrigation network and it organizes on-the-job training programmes for its staff. It has a documentation centre and has recently established a system for data storage and retrieval linked to GIS. It also has a central laboratory equipped for various analyses related to water and soils.

The Secretariat of Agriculture and Animal Wealth is responsible for the development of irrigated agriculture and the implementation of major projects. A special Authority, called "The Great Manmade River Water Utilization Authority", is responsible for the use for agricultural purposes of the water transported from the desert to the coast. The Secretariat of Municipalities takes care of the water supply to urban settlements. At present, no water fees are imposed on users of water for irrigation purposes.

Libya faces many challenges when it comes to water resources. Water demand is much higher than the supply, which results in the exploitation of its groundwater resources. This has brought consequences to the quantity and quality of water coming from these sources. The public water sector in Libya is fragmented; it is in a decentralized system that has resulted in split responsibility among various agencies and with not sufficient coordination. However, this has allowed for better control on water management issues.

On another note, Libya has identified priority areas to work towards improving the water resource management. First among them is the governance and institutional development through establishing a water coordinating body and by working on capacity building for the various agencies involved in the water sector. The other key, priority areas identified by Libya include the improvement of information systems, monitoring and assessment, planning and water efficiency (through reviews of policies and strategies in the water sector) and stakeholder involvement.

9.4 Sudan

9.4.1 Context

Sudan’s total natural renewable water resources are estimated to be 149 km^3/yr, of which 30 km^3/yr are internally produced. In a 10^{th} frequency dry year, the internal water resources are reduced to about 22.3 $km/^3yr$. Of the internal water resources, 28 km^3/yr are surface water and 7 km^3/yr are groundwater, while the overlap between surface water and groundwater is estimated at 5 km^3/yr. As a result of the Nile Waters Agreement with Egypt, total actual renewable water resources of the country amount to 64.5 km^3/yr.

Total water withdrawal in the Sudan was estimated at 37 km^3 for the year 2000. The largest water user by far was agriculture with 36 km^3. The domestic sector and industry accounted for withdrawals of 0.99 km^3 and 0.26 km^3 respectively. Water used in Sudan derives almost exclusively from surface water resources. Groundwater is used only in very limited areas, and mainly for domestic water supply.

Groundwater is used for both domestic and agriculture. 79% of the water used for domestic in the rural area is groundwater and that ratio became 53% in the urban areas. The groundwater used for irrigation was estimated by 870 million cubic meters which cultivate 118000 acre. That cultivated areas were concentrated in El Shamalia, Kasala, Khartoum and south Kordfan.

9.4.2 Socioeconomic Situation

Sudan's population is 34.3 million (2004) and 37 million, (2007) with annual growth of approx. 2 .2%. Population density is 14 inhabitants/km^2 and 60 percent of the total population is rural. Most of the population lives along the Nile and its tributaries, and some live around water points scattered around the country. At the national level, 69 percent of the population had access to improved drinking water sources in the year 2002. In urban areas this coverage was 78 percent, while in rural regions it was 64 percent. In some areas, displaced families have increased the total population of villages, which has placed pressure on potable water resources.

The Human Development Index ranks Sudan in 139th place among 177 countries. Poverty in the Sudan is massive, deeply entrenched and predominantly a rural phenomenon. Over two-thirds of the population, and under the most favourable assumptions still around 50-70 percent, are estimated to live on less than US$1/day. In recognition of the severity of poverty in general, and of rural poverty in particular, the Government started to prepare a draft Poverty Reduction Strategy Paper (PRSP) and launched a pilot poverty-reduction programme in 2001 to improve long-neglected rural social services. The programme is financing basic education, primary health care, malaria prevention and drinking-water supply.

According to the World Development Indicators database (2007), the GDP of the Sudan was US$17.8 billion (current US$) in 2003 and it grow up to 37.6 million US dollars, with annual growth of 13 percent in 2006. The agricultural sector is the most dominant in the country's economy, even though its share has declined recently because of decreased agricultural production and the increased exploitation and export of mineral oil. In 2002, the sector contributed over 39 percent to the GDP and employed 57 percent of the total economically active population in 2004. It contributed about 90 percent of the Sudan's non-oil export earnings.

Sudan's agro-ecological zones support a variety of food, cash and industrial crops. Vast natural pastures and forests support large herds of livestock including cattle, sheep and goats. The main exported crops are cotton, Arabic gum, sesame, groundnuts, fruits and vegetables; livestock is also important for exports. Within the agricultural sector, crop production accounts for 53 percent of agricultural output, livestock for 38 percent and forestry and fisheries for 9 percent (IFAD, 2002).

Rain-fed agriculture covers by far the largest area in Sudan. The area actually cultivated and total yield may, however, vary considerably from year to year depending on variability of rainfall. The rain-fed farming system is characterized by a small farm size, labour-intensive cultivation techniques employing hand tools, low input level and poor yields. Crops grown in the rain-fed sector include sorghum, millet, sesame, sunflower and groundnuts. According to the latest estimates, the traditional rain-fed farming sector contributes all the production of millet, 11 percent of sorghum, 48 percent of groundnuts and 28 percent of sesame production of the country. Mechanized rain-fed agriculture comprises about 10 000 large farmers with farm sizes of 400-850 ha and a few large companies with holdings of 8 400-84 000 hectares (Dafalla, Y. M. 1996 & El-Farouk, A. E. 1994).

Sudan has the largest irrigated area in sub-Saharan Africa and the second largest in the whole of Africa, after Egypt. The irrigated sub-sector plays a very important role in the country's agricultural production. Although the irrigated area constitutes only about 11 percent of the total cultivated land in Sudan, it contributes more than half of the total volume of the agricultural production. Irrigated agriculture has become more and more important over the past few decades as a result of drought and rainfall variability and uncertainty. It remains a central option to boost the economy in general and increase the living standard of the majority of the population (FAO 1997).

Sudan is generally self-sufficient in basic foods, albeit with important inter-annual and geographical variations, and with wide regional and household disparities in food security prevailing across the country. The high-risk areas are North Kordofan, North Darfur, the Red Sea, Butana and the fringes of the major irrigation schemes in addition to the Southern States. Major constraints to higher farm productivity and incomes are high marketing margins on agricultural produce and an inadequate allocation of budgetary resources and of the scarce foreign exchange earnings. As a result, the low input/low-productivity model of production continues to prevail, and small farmers' incomes remain depressed. In the wake of the food shortages experienced in the 1980s, a high priority has been given by the Government to producing food crops. This has resulted in large expansions in sorghum and wheat areas and output. Much of this has been at the expense of the main cash crop, cotton, with production declining by more than 40 percent since the mid-1980s (FAO 2000).

9.4.3 Governance Structure

In Sudan, there is a federal type of government composed of central government and 26 states (16 states in the north & 10 states in the south). There is a Water Resources Act which distinguishes two types of water bodies: 1) transient waters (those which cross the boundaries of two states or international boundary) and 2) non-transient water (water within one state). Thus, the situation in Sudan is unique to other NSAS countries. Sudan and Egypt have an agreement that defines the share of each country for the River Nile. As for Groundwater, the only cooperation is through the Joint Authority for the Study and Development of the NSAS.

The Ministry of Agriculture and Natural Resources (MANR) supervises the Agricultural Corporations that manage the large irrigation schemes, while the Ministry of Irrigation and Water Resources (MIWR) is responsible for managing the water resources and delivering irrigation water. The Ministry of Irrigation and Water Resources (MIWR) is the federal body in Sudan legally responsible for all water affairs (policies, strategies, management, planning and programming (surface and groundwater)). It offers technical advice and assistance to water projects within the states and the private sector. It is in charge of the groundwater, the non-nilotic streams and valleys under the Groundwater and Wadis Directorate. The directorate of Groundwater, the general department of Water Resources within the MIWR, is responsible for the management of groundwater, studies, investigation, and exploration and monitoring. Under the MIWR there is the National Water Corporation which looks after the drinking water (Programming, planning, specification …etc). MIWR has the following responsibilities:

- Satisfaction of the water requirements of the various users through the country;
- Water resources planning, management and development;
- International and regional cooperation concerning the shared water sources;
- Planning, design, execution, operation and maintenance of the different irrigation schemes;
- Control of water abstraction;
- Construction of new irrigation works;
- Operation and maintenance of all large-scale irrigation structures and drinking water facilities;
- Provision of the means for hydropower generation and protection of the water-related environment.

***Water Management and Legislation*s**

Generally the water resources managed in Sudan within the national legal framework that determined by the following Acts, laws and legislations:

- Environment and natural resources law
- Water resources law
- Groundwater regulations
- Wadi Nyala Basin water act
- Wadi El Gash basin water act

Historically, the groundwater resources were managed by the Sudan's National Authority for Rural Water up to year 1994 when that authority was resolved into three companies and the groundwater research directorate. Since that time the three companies were privatized and responsibility of groundwater management was transferred to MIWR through the General Groundwater & Wadis Directorate. According to the political conditions, the Groundwater Directorate concentrate its activities in North Sudan and it has no activities in the southern part. The northern part was managed geographically and divided into 5 sectors (Eastern, Darfour, Meddle, Kordefan, and Northern) plus separate directorate for Khartoum state. The head quarter of the General Groundwater & Wadis Directorate located at Khartoum and consists of five divisions (Groundwater research, Groundwater Basins & water legislations, Laboratories, Information centre and operation and maintenance). The groundwater division divided into three unites (Geo-Physics, Hydrogeology and Geology) while the Groundwater Basins & water legislations division is responsible for monitoring, information analysis, groundwater modelling, legislations and national projects.

In each State of Sudan (16 in the North and 10 in the South of Sudan) there is a ministry of Agriculture, Irrigation and water Supply. Within each of these ministries there is a Regional (local) Water corporation composed of Urban Water Supply and Rural water Supply. These local bodies look after provision of water for domestic, livestock and drinking water supply.

As everywhere in Sudan, the Gezira Scheme is a good example reflecting the situation of the water management in the whole country. Gezira is managed on a vertically integrated basis by the semi-autonomous Sudan Gezira Board (SGB). The MIWR is responsible for managing the Sennar Dam on the Blue Nile and the upper reaches of the irrigation system, responding to requests for water delivery from SGB's field staff. Within the scheme, the SGB serves as landlord, operates and maintains the lower reaches of the irrigation system and provides most of the inputs and services required by farmers to produce cotton, which is transported by the Board to its ginneries and sold on behalf of growers by the Sudan Cotton Company Limited. The SGB recovers the cost of advances made for inputs and services from the cotton sales before payment is made to the farmer. Tenants are wholly responsible for growing other crops in prescribed rotations with cotton (sorghum, groundnuts, forage, wheat, vegetables), making their own arrangements for input supplies and marketing.

By 2001 in the Gezira Scheme, Minor Canal Committees had been formed along the minor irrigation canals and representatives of each of these committees constitute the Irrigation Committee at the block level. In addition to the Irrigation Committee, a Financial Committee has been established that is coordinating the reimbursement of the seasonal credits and arrangements for procurement of new inputs. The Irrigation Committee with representatives of each of the minor canal committees will be responsible for the operation and maintenance of the minor irrigation system, a task presently entrusted to the SGB, with the Ministry of Irrigation responsible of supplying the main system.

In Sudan as well as every where in the world, to be able to manage the groundwater system in a sound manner, various elements within the groundwater system should be evaluated, starting from the individual well to the groundwater basin. Sustainable groundwater management should base on logical information. The information needed can best be indicated by the following questions:

- What are the long-term yield capabilities of the aquifer?
- Will the proposed development have any detrimental influence on other components of the hydrologic cycle?
- What will be the effect of the proposed scheme(s) on regional and local groundwater levels?
- Are there likely to be any undesirable side effects, such as land subsidence, change in quality, or sea water intrusion, that could limit the development?
- Where should the water wells be located? How many wells are needed?
- What pumping rate can be sustained?

These issues cannot be addressed through the present fragmented approach to water resources management as it would lead to inappropriate investments in the different water supply sub sectors and prevents adequate considerations of alternatives uses, water conservation and environmental effects. Integrated water management is thus strongly recommended.

The emerging challenge to Sudan groundwater management is thus how to achieve sustainable development in the face of continued expansion to population and economic activities and the perceive of problems of poverty and environmental degradation. This calls for a different approach to groundwater management to satisfy sustainable development. Sustainable development is generally a function of the availability of the natural resource base over time to attain such a development, management and conservation of natural resources and orientation of technological and institutional change should be planned in such a manner as to ensure the attainment of continued satisfaction of human needs for present and future generations.

It could be concluded that, the major issues threaten the groundwater management, among others: (I) miss-allocation of water (low-value uses consume a significant share of the resource while high-value uses suffer shortages); (ii) water quality is rarely monitored leading to inappropriate use of low quality water and to long-term adverse effects on land and groundwater; (iii) water and sewerage services, especially for the poor communities, are inadequate, and (iv) development and remediation of groundwater resources is difficult being also associated with high costs.

To address some of the problems facing irrigation management and development the Government has formalized a policy framework that includes:

- Transferring the operation and production of large- and medium-size irrigation schemes to the farmers and giving them full responsibility for water management on the irrigation system below the minor canals level through establishment of voluntary water users associations (WUAs).
- Fostering sustainable productivity of the large schemes through rehabilitation, combined with financial and institutional reform.
- Grouping, rehabilitating and handing over the relatively small size pump schemes in the Blue Nile and the White Nile. These schemes were originally established and run by the government. Recently, and in accordance with the economic reforms, these schemes were handed over to the private sector represented by individual farmers, cooperatives or private companies.

Finances

Financing irrigation operation and maintenance O&M through fees collected from the beneficiaries of the irrigation system was first introduced in Sudan with the introduction of the modern irrigation system at the El Zeidab scheme in 1909 when a private foreign company erected a pump station to irrigate local farmers' land for an agreed irrigation fee. After the success of the experiment for the first two seasons, a bad crop yield in 1911/12 meant that the farmers were unable to pay their irrigation fees. The company experienced heavy losses and decided to pull out of the scheme.

Experience from El Zeidab scheme was used in selecting the form of production relationship between the government, the Sudan Plantation Syndicate and the farmers when any agriculture project is commissioned as well as the Gezira scheme. To avoid the inability of some farmers to pay irrigation fees in case of bad crop yields, a "sharing system" between the three parties was adopted. This system continued until 1981 when it was replaced by what is known as the "individual account system" in which each individual farmer is treated separately in terms of cost and profit. The objective was to create some incentive for the individual farmers to increase their productivity. The new account system failed to achieve break-even productivity. The individual account system was also applied in all the irrigation schemes run by the government at that time. Payment of irrigation fees by the farmers continued in all Government schemes from 1981 to 1995. During this period irrigation fees collected were very low, averaging about 50 percent only. The non-recovered part of the water supply costs is borne by the government.

Starting from 1995, and as part of the liberalization of the economy, the Government withdrew from financing the cost of irrigation services, among other things. Farmers were left to pay irrigation fees to the newly established Irrigation Water Corporation (IWC), which uses these fees directly to provide water supply services to the farmers. Instead of the IWC setting up its own mechanism for collecting the fees directly from the farmers, it relies on the Agricultural Corporations (AC) managing the scheme to collect the fees from the farmers. Because these ACs were also facing considerable financial difficulties, part of the water fees collected may not reach the IWC and part of the collected fees paid to IWC is delayed for sometime as it is used for financing other urgent activities. The result of this is the inability of IWC to have the required budget that enables it to provide its services in a sustainable manner. This led to the accumulation of sediment in the irrigation canals, deterioration of the water regulation structures, machinery and pumps.

By the year 2000 the IWC was dissolved and the MIWR is again responsible for the O&M of the irrigation canals up to the minor off-takes. The Ministry of Finance and National Economy provides the MIWR with the annual budgets for operation and maintenance.

Policies

In 1992, the national economy was reoriented towards a free economy, a policy shift that impacted the agricultural sector profoundly. The government withdrew from the direct financing of agriculture, provision of inputs and services. The Government within its policy of withdrawal from provision of goods and services handed over all the small- and medium-size irrigation schemes under its control to the farmers. The handing over policy was not successful because farmers were ill-prepared and most of the schemes were in need of rehabilitation. Since 1992, the cropped areas and the productivity of many schemes have sharply declined.

Agricultural sectoral policies for the irrigated sub-sector include the following:

- To extend the market economy to all crops to allow the farmer to choose a suitable crop mix.
- To provide support to the Agricultural Research Institutions so as to explore suitable technologies for improving crop production and productivity. In addition, to provide support to agricultural extension and services.
- To encourage the private sector to provide agricultural inputs for the agricultural sector.

- To encourage exports through improvement of quality so as to meet international standards.
- Establishment of specialized crop committees for main crops like cotton with the objective of achieving all necessary coordination between the concerned authorities.
- Farmers participate in agricultural policy formulation.

The Sudan Comprehensive National Strategy for the Agricultural Sector (1992-2002) put food security, sustained agricultural development, efficient resource utilization and yield enhancement on the top of the agenda. Little has been done, however, to improve the accessibility to food of the poor, the vulnerable and the marginalized strata of society.

There are a number of factors that affect the governance in Sudan. The government has limited resources compared to other countries, which in itself creates a major obstacle for improving the governance in each of the dimensions reflected in the Worldwide Governance Indicators WGI. Even with this resource restriction, the WGI show some improvements in some dimensions and it has been steady on the others.

Dimensions relevant and important to the water sector such as Government effectiveness and regulatory quality have made improvements. This is a reflection of the work and improvements made on the national level and that has some spill-over effect on the work and performance made by the Ministry of Irrigation and Water Resources in the past few years (WDI, 2007 & Governance Matters 2007).

9.5 Conclusions

Chad has suffered the consequences of a persistent drought that has speeded up the desertification process and reduced the surface area of agro-pastoral land. Lack of water has a major impact on people’s lives, not only in terms of practicalities like sanitation, but – as with any scarce resource – conflict is never far behind. Besides extraction, drought and climate change have contributed to groundwater level decline in Chad. There is a lack of detailed studies regarding the country’s groundwater resources; although some research has been done concerning the geology and hydrogeology around the country

Throughout history, most of the attention regarding water resources in Egypt was given to the Nile. However, in recent decades growing water demand driven mainly by population growth has lead to the adoption of water policies taking into account alternative water resources. The main issues facing Egypt's development include, among others: (a) partial utilization of its land area territories (less than 10%); (b) unbalanced population distribution and continuous immigration from rural to urban areas; (c) a decreasing per capita share in water and agricultural land; and (d) lack of proper water supply and sanitation in the rural and desert areas.

In recent years a rapid increase in population and water consumption rates for domestic, industrial and agricultural purposes have had a significant impact on the country’s water resources mostly ground aquifers which suffered serious depletion and deterioration. A lot of agriculture, industrial and domestic developments encouraged the Libyan authorities to continue studying the water resources in the basins in detail and to seek more information from other neighbouring countries sharing the basins.

Sudan is a country that is half desert or semi-desert, which translates into a high water resources importance. The country as a whole has substantial water resources from the Nile basin and groundwater. However, there are significant differences at the regional level and between seasons and years. Even with the water resources from the Nile and aquifers, Sudan often suffers from shortages of water for human consumption and agriculture as a result of natural conditions and underdevelopment. Water consumption in Sudan is mainly for agriculture (96% according to some estimates). Surface water provides most of the water resources for consumption; however, groundwater is growing quickly as a source of clean drinking water. Combating and mitigating the pollution of water resources has taken place recently with many enterprises and companies installing wastewater treatment plants. There is still a lack of monitoring in regards to groundwater resources, even though they are increasingly important in providing clean drinking water in many regions of Sudan.

Section 10. Summary, Conclusions, and the Pathway to the SAP

10.1 Summary

This SADA represents the technical data-gathering element of the GEF MSP to strengthen cooperative management of the NSAS. The primary objective was to identify transboundary threats in the region and provide the technical basis on which to initiate the implementation planning to be conducted in the Strategic Action Program (SAP) phase of the project. Transboundary threats were identified through causal chain analysis involving stakeholders in the region (Section 8). The causal chain analysis identified some 55 problems. After careful screening and scoping, five of these problems were given high priority and transboundary relevance, as described in Section 5.

The priority issues identified in Section 5 represented the most likely potential threats to water resources and ecosystems in the Nubian region. It remained unclear, however the risk these threats pose and to what extent these may occur due to transboundary causes or from causes due to national uses in the aquifer. As a result, a regional groundwater model was developed for this project (Section 4). This model was developed in close collaboration with national program coordinators and technical staff from the four Nubian countries. A key element in the development of this model was an emphasis on data sharing, collaborative decision making, and transparency in the modelling process.

The modelling results are summarized in Section 4 and the full modelling report is provided in Annex 4. The modelling study determined that the risk of transboundary declines in aquifer levels is low, even for well fields located near national borders. There is, however, sufficient uncertainty in the model, caused by the lack of hydrogeologic data in the region, that continued data collection in the region is necessary. An unequivocal result of the modelling study is that localized declines in aquifer levels will occur.

How the modelling results relate to priority risks is described in Section 5 and summarized in Table 12. Of the four priority risks, Declining water levels were determined to be high in risk due to national activities, but low in risk as a transboundary threat. Closely linked to declining water levels was the risk of damage to ecosystems and loss of biodiversity. Water quality deterioration may be a risk caused by national activities, but is not important as a transboundary risk. Changes in groundwater regime were determined not to be a significant risk, due to either national or transboundary activities.

10.2 Conclusions and Pathway to the SAP

The SADA process revealed two critically important aspects relevant to the management of the Nubian aquifer: (1) it is still early enough in the development of the NSAS that priority threats have not yet, according to national reports, resulted in ecosystem impairment; and (2) the risk of transboundary causes for these threats is low. These findings provide the Nubian countries the unique opportunity to *prevent* rather than *mitigate* resource impairment.

From a management standpoint, the modelling results indicate that member countries can develop their water resources without significant concern either that they will affect neighboring countries or that neighboring countries will affect their water resources. Modelling was based on limited data and these data limitations resulted in sufficient uncertainty in drawdown predictions that continued monitoring is necessary, both to provide additional data to improve modelling efforts and to provide direct evidence that transboundary drawdown does not occur.

From the standpoint of governance, the Joint Authority provides the regional legal and institutional mechanisms necessary to formalize future plans for regional cooperation that will be defined in the next phase of the project, the Strategic Action Program. These mechanisms will be addressed in the Legal and Institutional component of the project.

The Strategic Action Program will build on the results of these SADA findings and will provide an implementation plan for addressing the priority threats defined in Section 5. While the vision and scope of the SAP have yet to be defined, the key element that stands out from the SADA is the opportunity for preventing transboundary effects of abstraction through a cooperative monitoring and data sharing program. Among the many advantages of such a program are the following:

- Builds on previous success in cooperative efforts in the region.
- Verifies that transboundary declines in water level do not occur.
- Improves the quality modelling predictions.
- Provides opportunities for capacity equalization.
- Provides data relevant to preventing impairments due to national activities.

The history of regional cooperation demonstrated by the Joint Authority and CEDARE efforts, combined with the technical results of this SADA, provide an excellent basis on which to build the Strategic Action Program and protect the Nubian aquifer from transboundary threats.

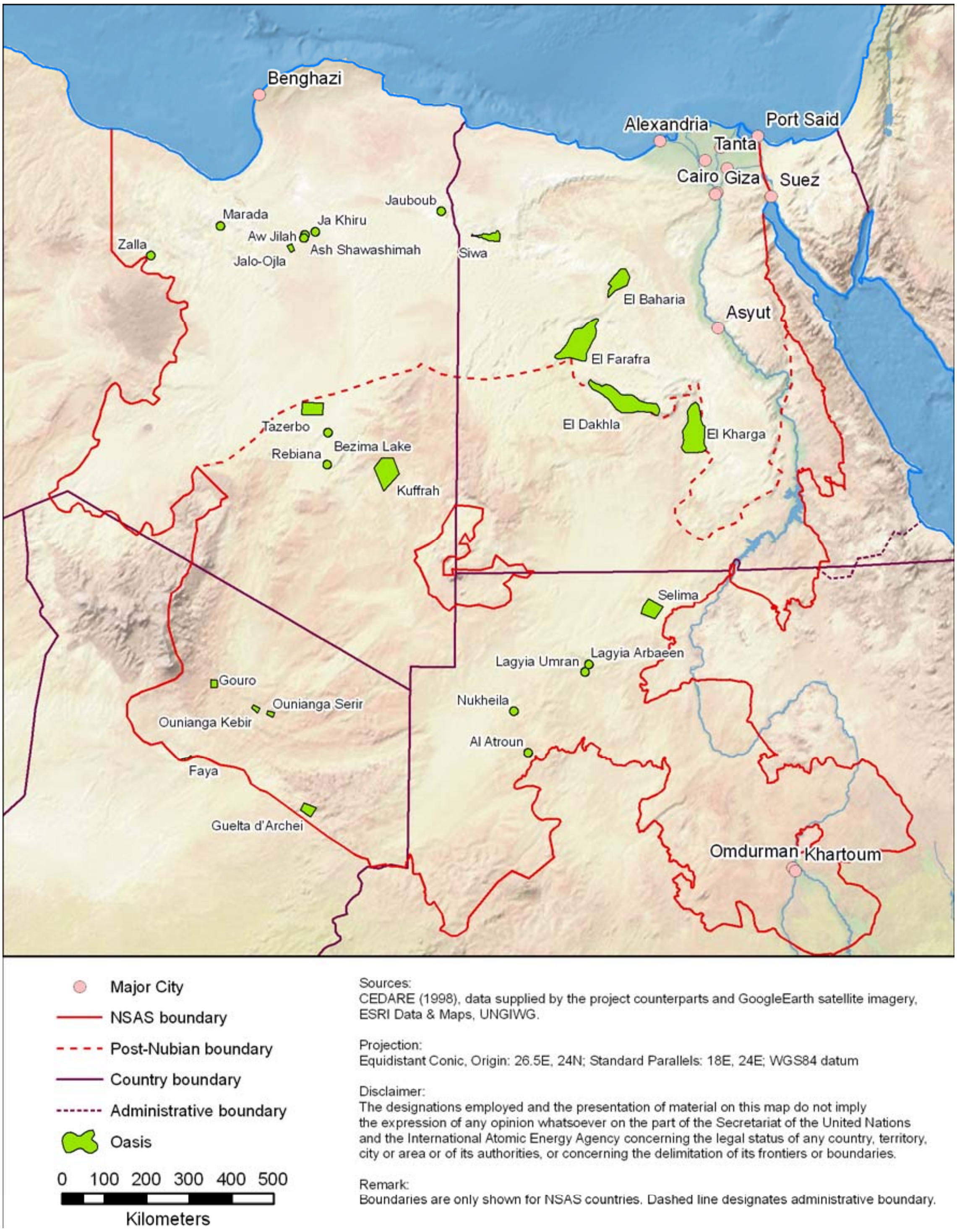


Figure 1. The Nubian Sandstone Aquifer System, including locations of known oases and the boundary of the Post Nubian Aquifer.

Source: 09–a Oases.png

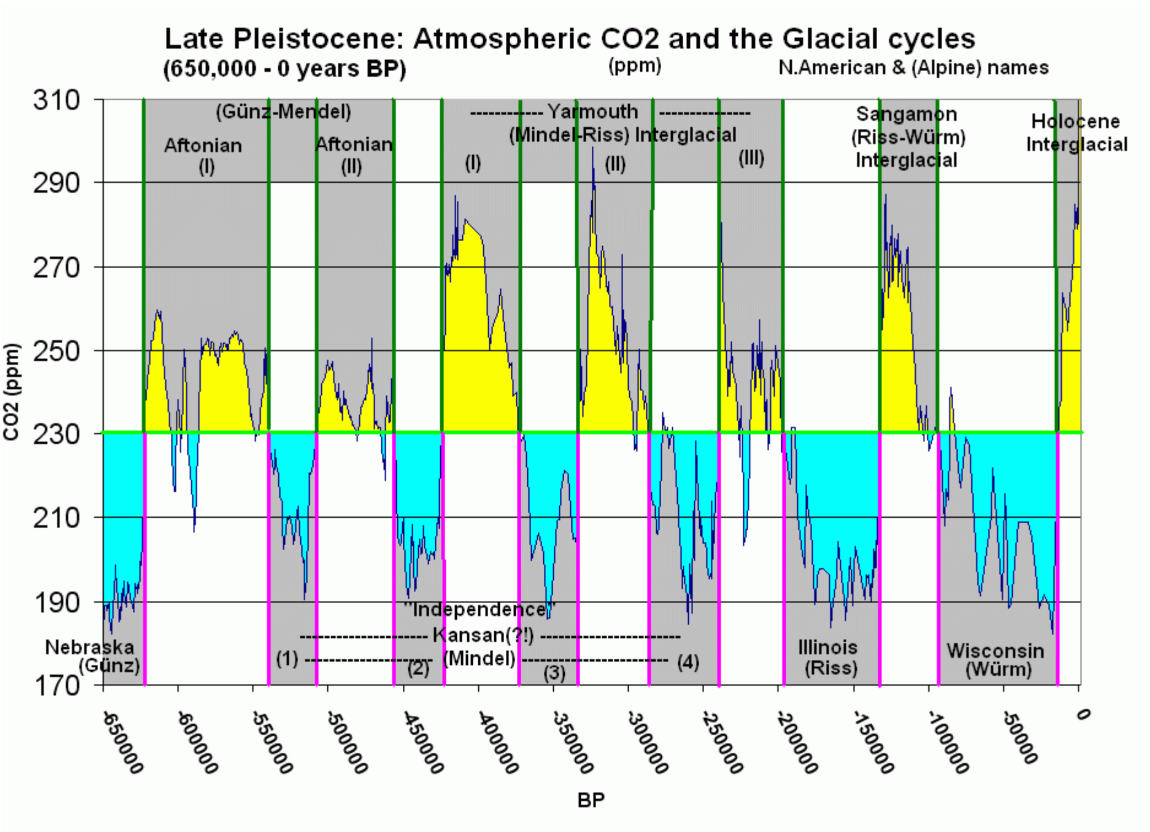


Figure 2. Carbon dioxide from Arctic ice cores which provide a proxy for glacial and inter-glacial cycles.

Source: Requires citation.

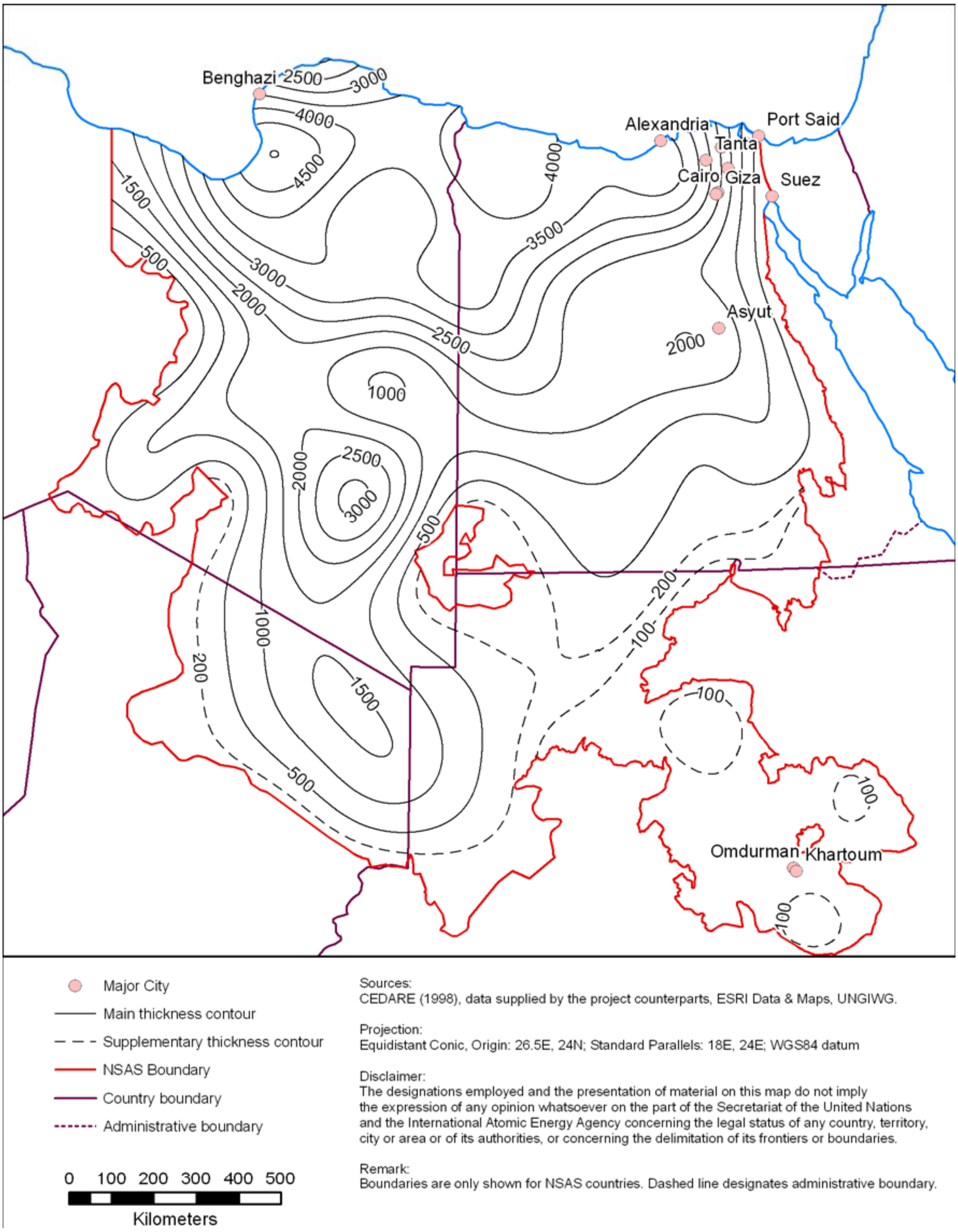


Figure 3. Aquifer thickness inferred from surface topography minus basement elevation.

Source: 06a – aquifer thickness.png.

Country	Nubian system (Palaeozoic and Mesozoic sandstone aquifers) Area (km^2)	Fresh water volume in storage (km^3)	Post Nubian system (Miocene aquifers) Area (km^2)	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. Summary of estimated storage in the Nubian Aquifer

Source: Reprinted from Technical Baseline Report Page 9, cited Salem and Pallas, 2001.

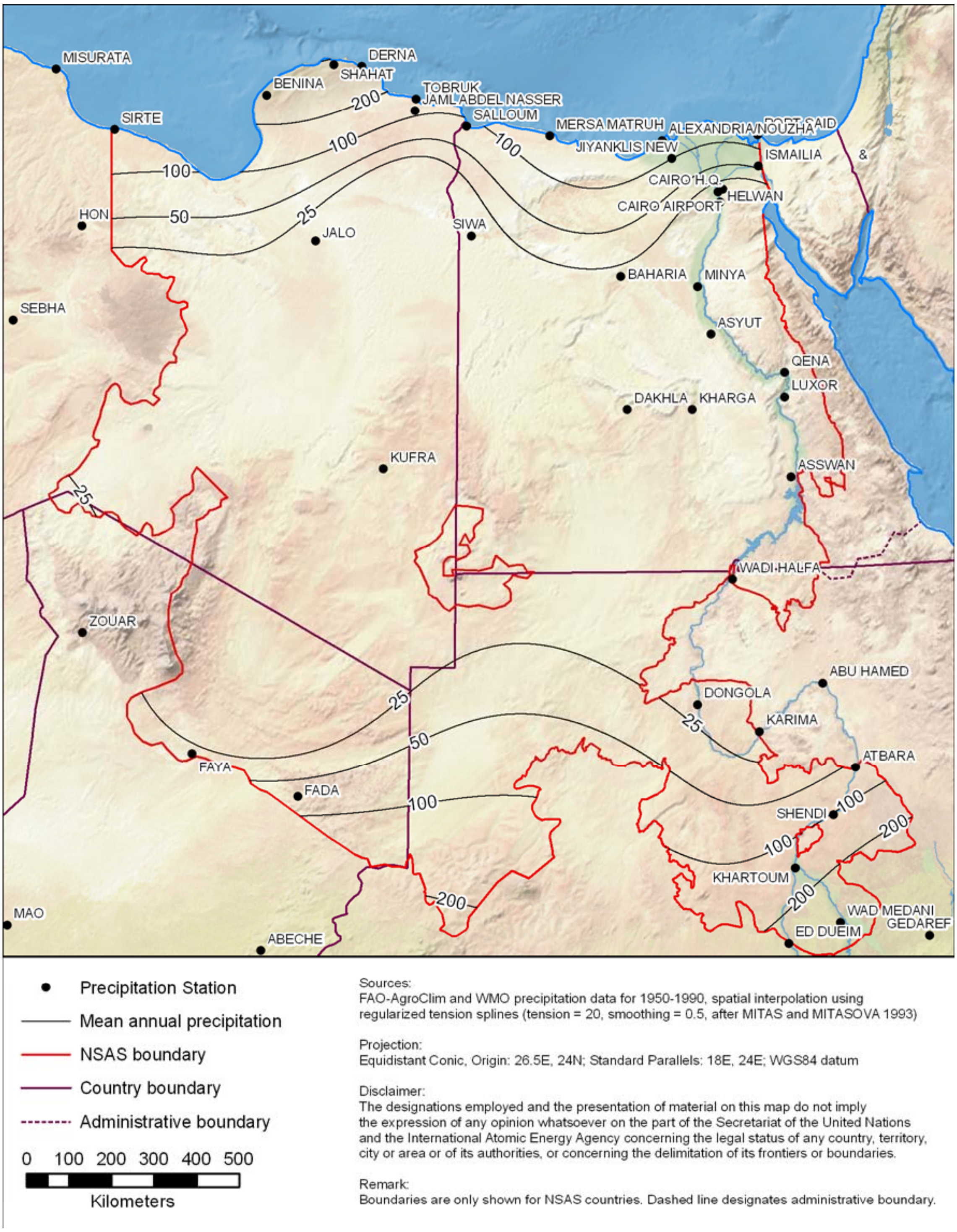


Figure 4. Annual Rainfall in the NSAS.

Source: 04 – Rainfall.png.

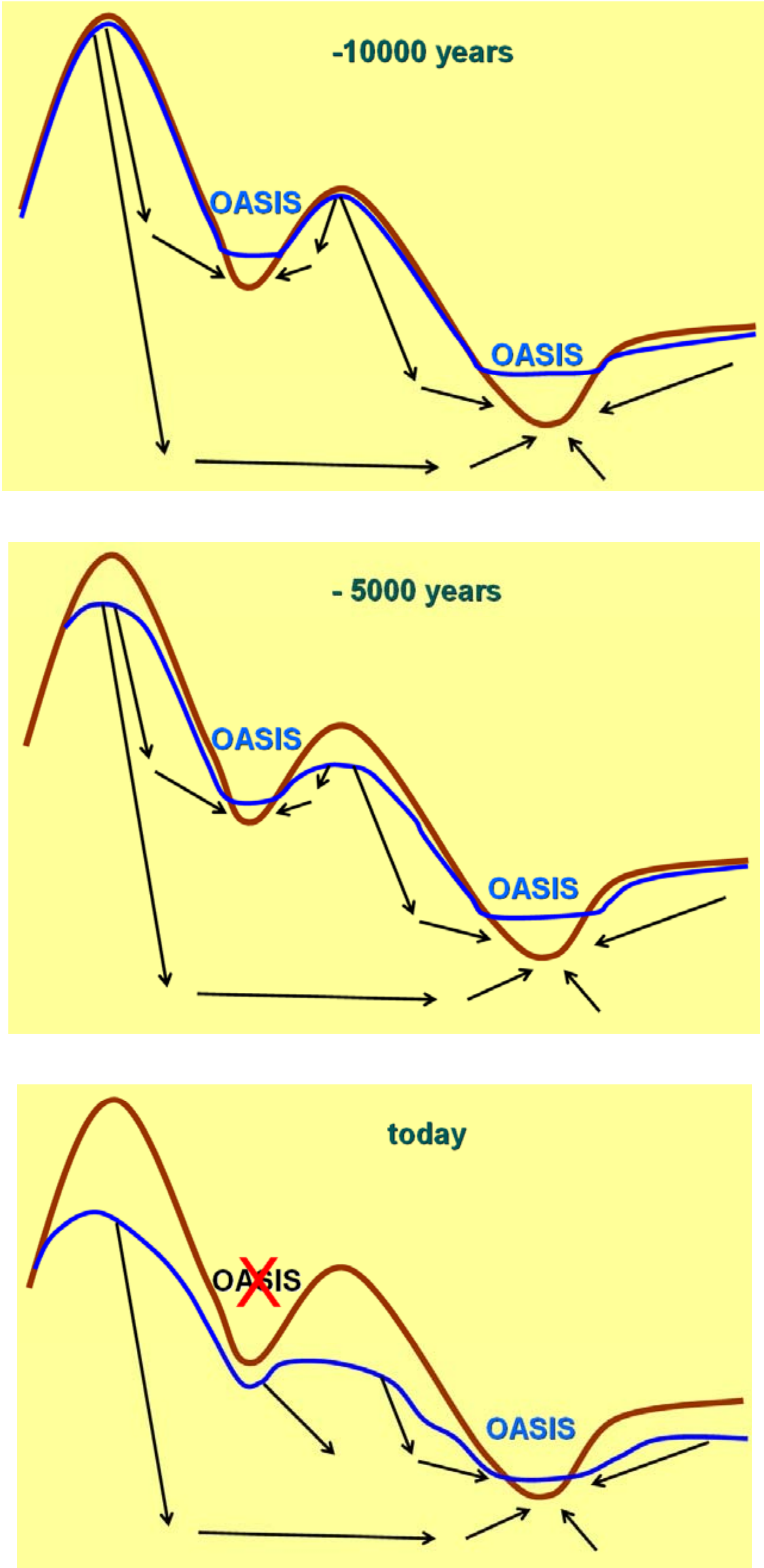


Figure 5. Changes in flowpaths and occurrence of oases in response to natural drainage.

Source: image files.

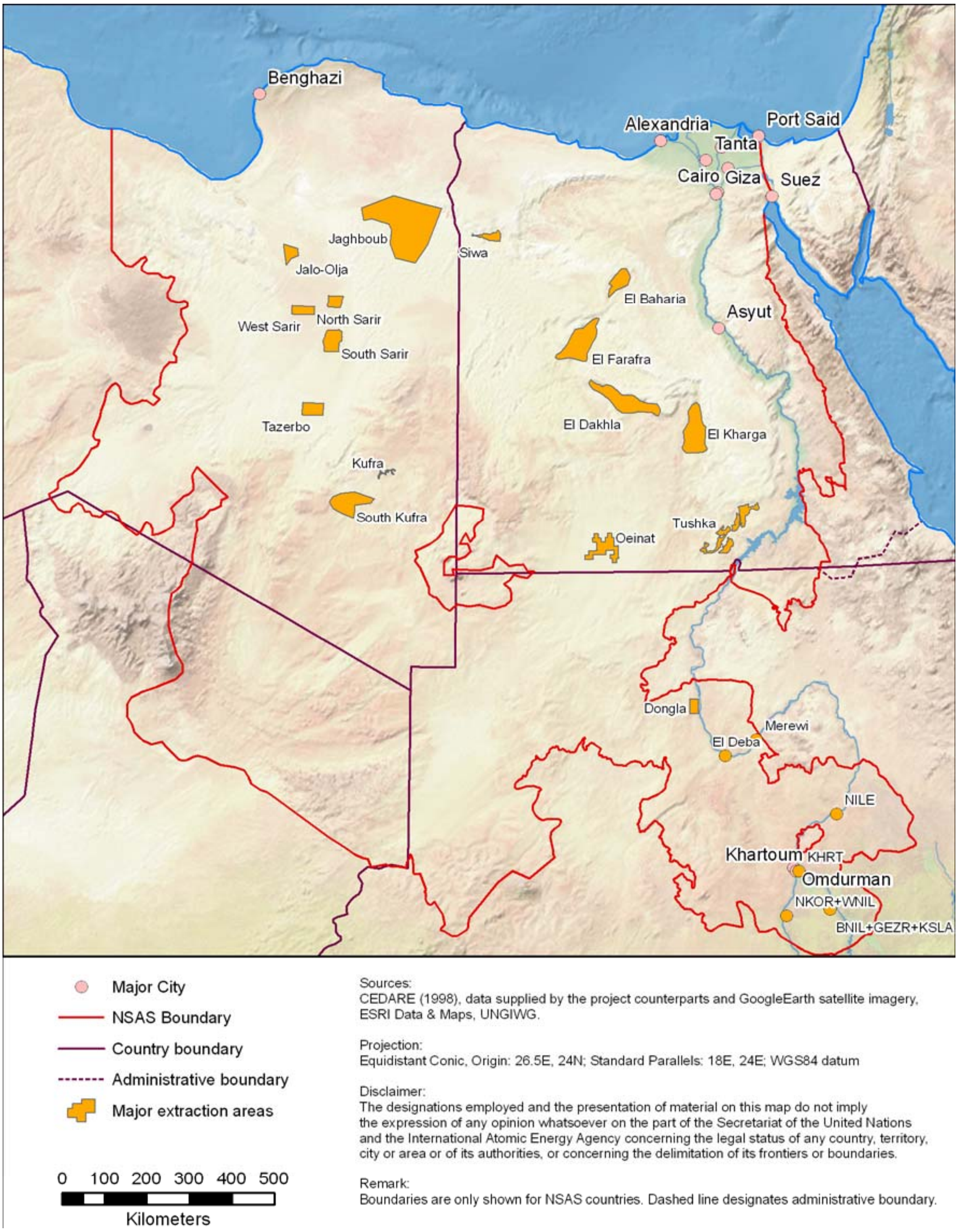


Figure 6. Major abstraction areas in the NSAS.

Source: 10a – ExtrAreas.png.

Country	Development Area	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Egypt	Kharga (Shallow)	37.3	37.1	35.1	35.1	30.8	27.2	26.5	24.7	23.5	23.5	22.3	22.0	21.1	20.3	20.0	19.5	18.3	17.5	15.8	16.5
	Kharga & El Zayat (Deep)	13 .62	20.51,	44.7	66.7	65.0	66.9	61.2	65.6	64.1	63.0	65.8	64.6	69.0	66.3	68.4	66.8	67.7	69.0	69.8	73.8
	Kharga Total	51.0	57.6	79.8	101.8	95.9	94.1	87.7	90.4	88.0	86.5	88.1	86.6	90.0	86.7	88.4	86.2	85.9	86.5	85.6	90.3
	Dakhla (Shallow)	86.0	78.8	78.2	74.0	73.3	70.1	67.0	64.7	63.3	63.4	61.0	55.6	59.9	59.2	57.5	56.1	54.2	52.8	52.1	51.2
	Dakhla & W. Mawhub (Deep)	29.6	29.0	34.5	75.4	103.3	144.2	140.9	135.3	146.6	144.6	142.5	142.0	135.3	131.3	136.7	139.7	142.7	150.0	150.5	150.2
	Dakhla Total	115.6	107.9	112.7	149.4	176.6	214.3	207.9	200.0	210.0	208.0	203.5	197.6	195.2	190.6	194.1	195.8	196.9	202.8	202.5	201.5
	Farafra &. Abu Minqar (Deep)						1.1	1.1	1.1	1.1 0	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
	Bahareya Shallow	28.9	29.3	29.3	29.5	29.2	29.3	30.9	31.0	29.5	28.6	28.0	26.9	24.7	25.0	23.7	22.8	21.6	20.4	19.3	18.4
	Bahareya (Deep)				3.5	5.1	7.5	8.0	9.6	10.3	9.8	10.7	11.1	12.9	13.9	11.6	10.7	14.5	16.2	17.2	15.4
	Bahareva Total	28.9	29.3	29.3	33.0	34.3	36.7	38.8	40.6	39.8	38.5	38.7	38.0	37.6	38.9	35.3	33.4	36.1	36.6	36.5	33.7
	Siwa (Deep)																				
	East Oweinat																				
	Total Egypt	195.4	194.7	221.8	284.1	306.7	346.2	335.5	332.1	338.9	334.0	331.3	323.3	324.0	317.2	318.9	316.6	320.0	327.0	325.6	326.6
Libya	Tazerbo Oasis																				
	Kufra Settlement											5.0	5.2	5.5	5.7	5.9	6.2	26.4	26.6	26.9	27.1
	Kufra Production											25.0	26.4	27.8	139.1	140.5	141.9	143.2	144.6	146.0	147.4
	Kufra Oasis"	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.4	6.8	9.2	11 .60	14.0	16.4	18.8	21.2	23.6	26.0	28.4	30.8
	Total Libya	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	4.4	6.8	39.2	43.2	47.2	161.2	165.2	169.2	193.2	197.3	201.3	205.3
Sudan	Sahara Nubian Basin																				
	Nile Nubian Basin																				
	Total Sudan																				
Grand Total		197.4	196.7	223.8	286.1	308.7	348.2	337.5	334.1	343.3	340.8	370.5	366.5	371.2	478.4	484.1	485.8	513.3	524.3	526.9	531.9

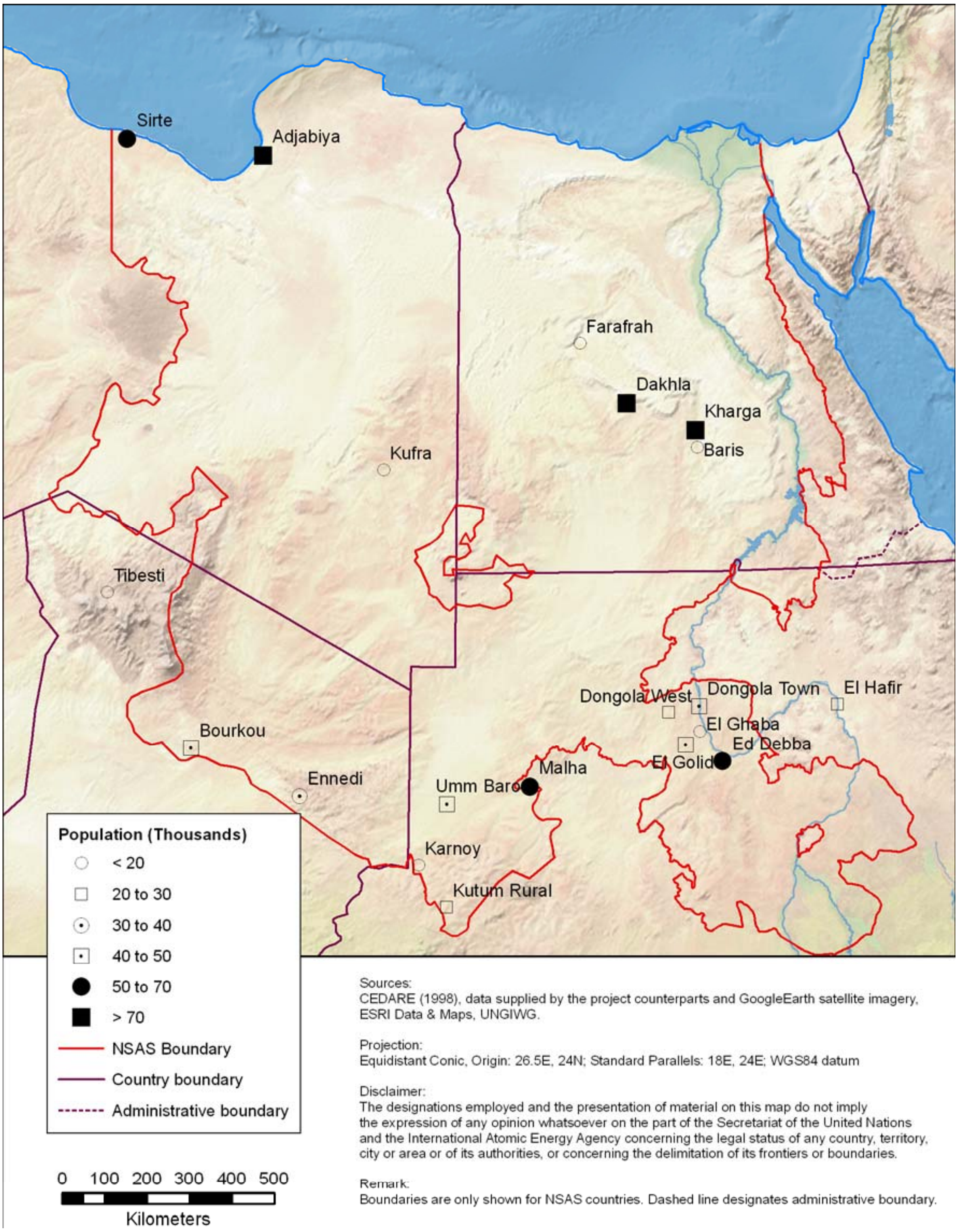
Country	Development Area	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Egypt	Kharga (Shallow)	16.3	14.2	12.5	11.0	9.8	6.0	5.6	5.2	4.7	4.3	3.9	3.7	3.5	3.3	3.1	2.9	2.6	2.2	1.9
	Kharga & El Zayat (Deep)	77.0	83.2	88.7	93.6	98.1	107.9	110.6	113.3	115 .94	118.6	121.3	122.3	123.2	124.2	125.1	126.1	122.6	119.1	115.6
	Kharga Total	93.3	97.4	101.1	104.6	107.8	113.9	116.2	118.4	120.7	122.9	125.2	126.0	126.7	127.5	128.2	129.0	125.2	121.3	117.5
	Dakhla (Shallow)	51.0	52.9	54.7	56.5	58.2	60.6	62.1	63.5	65.0	65.0	67.9	67.4	66.9	66.3	65.8	65.3	62.8	60.2	57.7
	Dakhla & W. Mawhub (Deep)	171.5	179.6	185.9	190.7	194.4	212.1	211.1	210.1	209.1	209.1	207.1	205.9	204.7	203.4	202.2	201.0	215.9	230.7	245.6
	Dakhla Total	222.4	232.5	240.6	247.2	252.6	272.7	273.2	273.6	274.1	274.1	275.0	273.3	271.5	269.8	268.0	266.3	278.6	290.9	303.2
	Farafra &. Abu Minqar (Deep)	1.1	10.1	18.9	27.3	35.5	39.0	42.0	45.0	48.0	51.5	54.0	57.0	60.0	61.0	61.5	79.7	142.0	131.1	155.4
	Bahareya Shallow	17.7	18.2	19.0	20.2	21.5	20.1	22.4	24.7	27.0	29.3	31.6	31.6	31.5	31.5	31.4	31.4	28.5	25.6	25.0
	Bahareya (Deep)	16.2	17.1	17.7	18.4	19.1	20.1	20.6	21.2	21.7	22.3	22.8	23.3	23.7	24.2	24.6	25.1	28.1	31.0	31.7
	Bahareva Total	33.9	35.3	36.8	38.6	40.6	40.2	43 .04	45.9	48.7	51.6	54.4	54.8	55.2	55.7	56.1	56.5	56.6	56.6	56.7
	Siwa (Deep)																20.0	20.0	20.0	20.0
	East Oweinat											10.5	10.5	10.5	10.5	10.5	10.5	20.5	30.5	30.5
	Total Egypt	350.7	375.4	397.4	417.7	436.6	465.8	474.4	482.9	491.4	501.4	519.1	521.5	524.0	524.4	524.4	562.0	642.2	650.4	683.2
Libva	Tazerbo Oasis									1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
	Kufra Settlement	27.3	27.6	27.8	28.0	28.3	28.5	28.7	29.0	29.2	29.4	29.7	29.9	30.1	30.4	30.6	30.8	31.1	31.9	32.2
	Kufra Production	148.7	150.1	151.2	152.9	154.2	155.6	157.0	158.4	159.7	161.1	162.5	163.9	165.2	166.6	168.0	169.4	170.7	175.5	176.9
	Kufra Oasis"	33.2	35.6	38.0	40.4	42.8	45.2	47.6	50.0	52.4	54.8	57.2	59.6	62.0	64.4	66.8	69.2	71.2	73.0	75.0
	Total Libya	209.3	213.3	217.3	221.3	225.3	229.3	233.3	237.3	242.9	246.9	250.9	254.9	258.9	262.9	266.9	270.6	274.5	282.0	285.6
Sudan	Sahara Nubian Basin																			6.7
	Nile Nubian Basin																			400.0
	Total Sudan																			406.7
Grand Total		560.0	588.6	614.7	639.0	661.9	695.1	707.7	720.2	734.3	748.3	770.0	776.4	782 .90	787.3	791.3	832.6	917.3	932.4	1,375.5

Country	Development Area	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Egypt	Farafra	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Siwa	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	65.9	
	Wadi El Fareigh																				
	Total Egypt	66.8	66.8	66.8	66.8	66.8	66.8	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	66.7	0.8
Libya	Jalo																				
	Marada Oasis																				
	North Sarir																				
	South Sarir																				
	West Sarir																				
	Tazerbo Oasis	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.6	2.8	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Jabal Akhdar	20.0	22.1	23.1	24.3	25.5	26.7	28.1	29.4	32.4	35.6	39.2	43.2	54.0	67.5	84.3	105.4	131.0	160.0	172.0	176.0
	Total Libya*	22.0	24.1	25.1	26.3	27.5	28.7	30.1	31.4	35.0	38.4	42.2	46.2	57.0	70.5	87.3	108.4	134.0	163.0	175.0	179.0
Grand Total		88.8	90.8	91.9	93.1	94.2	95.5	96.8	98.1	101.7	105.1	108.9	112.9	123.7	137.1	154.0	175.1	200.7	229.7	241.7	179.8

Country	Development Area	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Egypt	Farafra	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
	Siwa	65.9	83.7	101.2	118.3	135.3	155.0	171.0	187.0	203.0	219.0	235.0	242.2	249.4	256.6	263.8	271.0	271.0	271.0	288.1
	Wadi El Fareigh															12.0	25.0	37.0	50.0	57.2
	Total Egypt	66.7	84.5	102.0	119.1	136.1	155.8	171.8	187.8	203.8	219.7	235.7	242.9	250.1	257.3	276.5	296.7	308.7	321.7	346.0
Libya	Jalo	33.8	35.0	36.4	37.9	39.4	41.0	42.6	44.3	46.1	*47.9*	49.0	50.0	52.5	55.1	57.9	60.8	63.8	67.0	70.0
	Marada Oasis	3.2	3.2	315.0	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2	3.2
	North Sarir	7.1	75.0	86.1	85.1	71.6	71.3	51.7	59.9	49.2	65.3	66.8	42.1	42.2	40.2	38.0	36.0	35.0	18.0	18.0
	South Sarir	82.1	114.6	141.8	139.5	91.4	143.6	142.3	131.2	106.1	130.4	129.7	96.5	91.4	9509.0	93.0	92.4	9150.0	53.1	53.1
	West Sarir														41.8	70.6	81.2	82.7	94.7	95.1
	Tazerbo Oasis	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
	Jabal Akhdar	181.0	186.0	191.0	196.0	20000.0	220.0	240.0	260.0	280.0	300.0	320.0	340.0	360.0	380.0	400.0	400.0	375.0	350.0	323.0
	Total Libya*	310.1	416.7	461.4	464.6	408.5	482.1	482.7	*501.5*	487.5	549.7	571.6	534.8	552.3	618.4	665.6	676.5	654.1	589.0	565.4
Grand Total		376.8	501.2	563.4	583.7	544.6	637.9	654.5	689.3	691.3	769.4	807.4	777.7	802.4	875.7	942.1	973.2	962.8	910.6	911.4

Table 2. Summary of known abstraction from NSAS to the year 1998 from the Nubian (top) and Post-nubian (bottom) formations.

Source: CEDARE Volume II Hydrogeology, Tables 5.5 and 5.11.



Note: This needs editing.

Figure 7. Population in the NSAS.

Source: 11 – Pop.png. See Table 3.3 for data sources.

Chad: BET Prefecture in 2010 (projected).	
Location	Population
Borkou	64,695
Ennedi	48,443
Tibesti	13,388
Total	***126,526***

Libya: Kalij region 1991.	
Location	Population
Ajdabiya	90,000
Sirte	62,000
Kufra	17,000
Total	***169,000***

Sudan: Locality council populations 2010 (projected).		
Location		Population
Northern State	El Hafir	22,620
	Dongola Town	48,164
	Dongola West	25,097
	El Golid	49,516
	El Debba	64,814
	El Ghaba	14,916
	Subtotal	***225,127***
North Darfur	Malha	50,774
	Es Sayah	27,449
	Kutum Rural	24,746
	Umm Baro	44,977
	Karnoi	15,597
	Subtotal	***163,543***
Total		***388,670***

Egypt: New Valley 2006.	
Location	Population
Dakhla	80,447
Kharga	74,178
Farafrah	12,643
Baris	11,057
Total	***178,325***

Table 3. Population in the NSAS. ***Needs checking and updating.***.

Sources: Chad: SDEA Chapter 1, Table 1.
Libya: Baseline Report, Page 138.
Sudan: National SADA, Page 25.
Sudan: National SADA, Page 75.

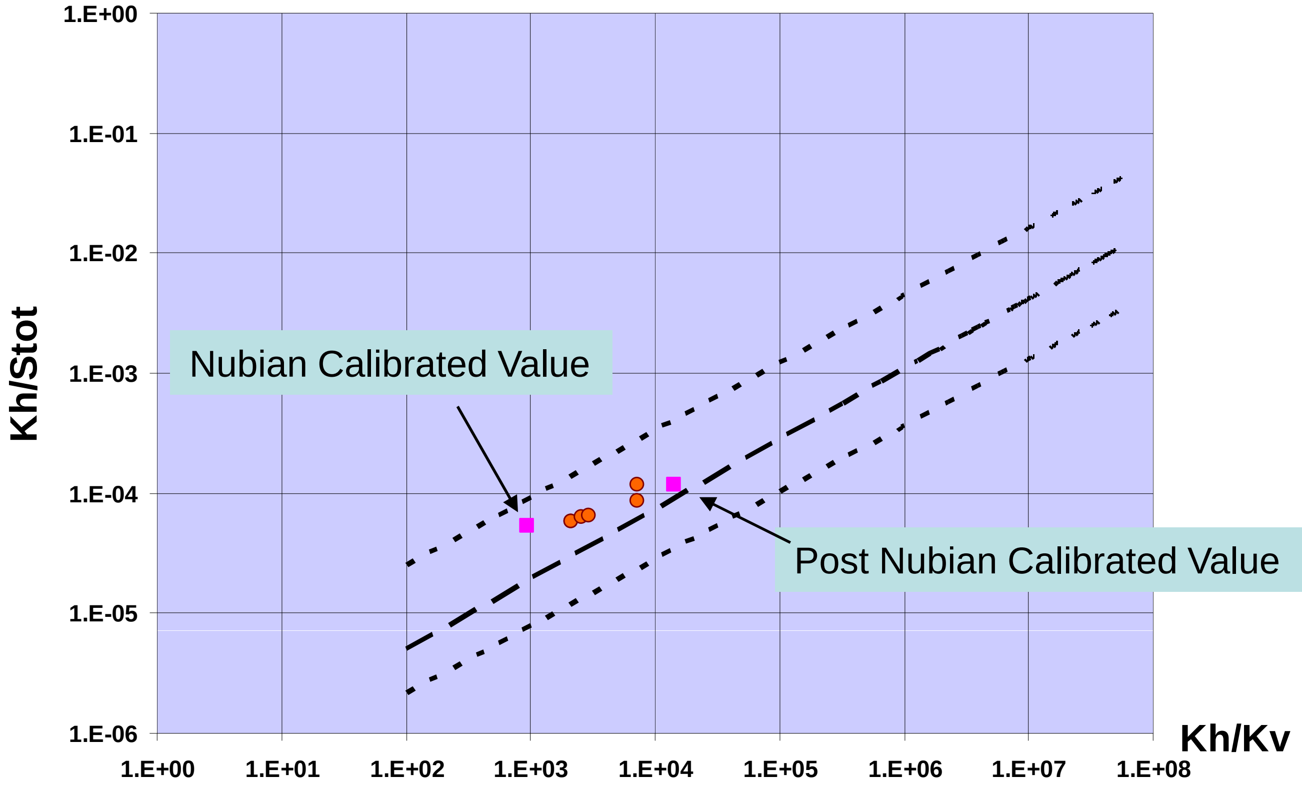


Figure 8. Calibration parameters for the regional model.

Source: images.

Table 5.5 - Groundwater Abstraction from the Nubian Aquifer System in Development Areas (mcm/year)																					
Country	Development Area	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
Egypt	Kharga Total	1.61	1.82	2.53	3.22	3.04	2.98	2.78	2.86	2.78	2.74	2.79	2.74	2.85	2.75	2.80	2.73	2.72	2.74	2.71	2.86
	Dakhla Total	3.66	3.42	3.57	4.73	5.60	6.79	6.59	6.34	6.65	6.59	6.45	6.26	6.19	6.04	6.15	6.21	6.24	6.43	6.42	6.38
	Frafra Total	0.03	0.03	0.03	0.03	0.03	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
	Bahareya Total	0.91	0.93	0.93	1.05	1.09	1.16	1.23	1.29	1.26	1.22	1.22	1.21	1.19	1.23	1.12	1.06	1.14	1.16	1.15	1.07
	Siwa	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.09	2.12	2.12	2.12	2.12	2.12	2.12	2.12	2.12
	East Oweinat																				
Libya	Tazerbo Oasis	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Kufra Total	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.14	0.22	1.24	1.37	1.50	5.11	5.24	5.36	6.12	6.25	6.38	6.50
	Jalo	0.16	0.17	0.19	0.21	0.23	0.25	0.28	0.33	0.40	0.49	0.95	0.96	0.98	0.99	1.00	1.01	1.02	1.02	1.03	1.03
	Marada Oasis	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.04	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	South Sarir																0.44	1.13	1.81	2.35	3.14
	West Sarir																				
	Jabal Akhdar	0.63	0.70	0.73	0.77	0.81	0.85	0.89	0.93	1.03	1.13	1.24	1.37	1.71	2.14	2.67	3.34	4.15	5.07	5.45	5.58
Sudan	umdurman,north,khartoum																				
	nile																				
	sahra																				
	Total	9.24	9.30	10.21	12.24	13.02	14.33	14.06	14.05	14.52	14.66	16.24	16.25	16.79	20.63	21.35	22.53	24.90	26.86	27.86	28.94
Country	Development Area	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	
Egypt	Kharga Total	2.96	3.09	3.21	3.31	3.42	3.61	3.68	3.75	3.82	3.90	3.97	3.99	4.02	4.04	4.06	4.09	3.97	3.84	3.72	
	Dakhla Total	7.05	7.37	7.62	7.83	8.00	8.64	8.66	8.67	8.69	8.69	8.71	8.66	8.60	8.55	8.49	8.44	8.83	9.22	9.61	
	Frafra Total	0.08	0.35	0.62	0.89	1.15	1.26	1.36	1.45	1.55	1.66	1.73	1.83	1.92	1.96	1.97	2.55	4.52	4.18	4.95	
	Bahareya Total	1.07	1.12	1.16	1.22	1.29	1.27	1.36	1.45	1.57	1.63	1.76	1.77	1.78	1.80	1.81	1.82	1.82	1.82	1.82	
	Siwa Total	2.09	2.65	3.21	3.75	4.29	4.91	5.42	5.93	6.43	6.94	7.45	7.67	7.90	8.13	8.36	9.22	9.22	9.22	9.76	
	East Oweinat old											0.33	0.33	0.33	0.33	0.33	0.33	0.65	0.97	0.97	
	East Oweinat new																				
	Wadi El Fareigh															0.38	0.79	1.17	1.58	1.81	
Libya	Tazerbo Total	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	
	Kufra Total	6.63	6.76	6.89	7.01	7.14	7.27	7.39	7.52	7.65	7.77	7.90	8.03	8.16	8.28	8.41	8.54	8.65	8.89	9.00	
	Jalo	1.07	1.11	1.15	1.20	1.25	1.30	1.35	1.40	1.46	1.52	1.55	1.58	1.66	1.75	1.83	1.93	2.02	2.12	2.22	
	Marada Oasis	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	
	North Sarir	0.22	2.38	2.73	2.70	2.27	2.26	1.64	1.90	1.56	2.07	2.12	1.34	1.34	1.28	1.20	1.14	1.11	0.57	0.57	
	South Sarir	2.60	3.63	4.49	4.42	2.90	4.55	4.51	4.16	3.36	4.13	4.11	3.06	2.90	3.01	2.95	2.93	2.90	1.68	1.68	
	West Sarir														1.32	2.24	2.57	2.62	3.00	3.01	
	Jabal Akhdar	5.74	5.89	6.05	6.21	6.34	6.97	7.61	8.24	8.87	9.51	10.14	10.77	11.41	12.04	12.68	12.68	11.88	11.09	10.24	
Sudan	west umdurman+north+khartoum																			12.70	
	nile																				
	sahara																			0.21	
	Total	29.69	34.54	37.33	38.75	38.23	42.24	43.17	44.67	45.20	48.05	50.02	49.28	50.27	52.73	54.96	57.26	59.61	58.43	72.51	
Country	Development Area	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2020	2030	2040	2050	2060			
Egypt	Kharga Total	3.96	3.95	3.95	3.95	3.95	3.95	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49	3.49			
	Dakhla Total	8.75	8.75	8.75	8.75	8.75	8.75	10.30	10.30	10.30	10.30	10.30	11.85	11.85	11.85	11.85	11.85	11.85			
	Frafra Total	5.05	5.05	5.05	5.05	5.05	5.05	9.02	9.02	9.02	9.02	9.02	12.99	12.99	12.99	12.99	12.99	12.99			
	Bahareya Total	1.78	1.78	1.78	1.78	1.78	1.78	2.71	2.71	2.71	2.71	2.71	3.64	3.64	3.64	3.64	3.64	3.64			
	Siwa Total	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76	9.76			
	East Oweinat old	0.97	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17			
	East Oweinat new							22.27	22.27	22.27	22.27	22.27	44.39	44.39	44.39	44.39	44.39	44.39			
	Wadi El Fareigh	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81	1.81			
	darb40							3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17	3.17			
	tushka							4.20	4.20	4.20	4.20	4.20	6.18	6.18	6.18	6.18	6.18	6.18			
Libya	Tazerbo Total	0.19	0.19	0.19	0.22	0.25	2.14	3.03	4.49	3.66	3.67	3.67	3.73	12.01	12.17	12.33	12.49	12.64			
	Kufra Total	8.49	8.52	8.56	9.28	9.32	9.44	9.51	9.57	9.66	9.66	9.98	11.28	12.68	12.90	13.15	13.47	13.94			
	Kufra GMMR													19.42	19.42	19.42	19.42	19.42			
	Ouienat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.92	7.92	7.92	7.92	7.92			
	Jalo	2.06	2.06	2.06	2.06	2.06	2.06	1.05	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90	3.90			
	Marada Oasis	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13			
	North Sarir	2.85	2.85	2.85	2.85	2.85	2.85	1.58	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85			
	South Sarir	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.38	2.54	2.85	2.85	2.85	2.85	2.85	2.85			
	West Sarir	2.74	2.27	2.38	3.60	4.89	3.71	3.85	2.52	3.85	4.15	4.12	4.12	11.41	11.41	11.41	11.41	11.41			
	Jabal Akhdar	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09	11.09			
	Jaghboub							1.50	1.50	1.50	1.50	1.50	3.01	3.01	3.01	3.01	3.01	3.01			
Sudan	west umdurman+north+khartoum	40.05	41.03	42.04	43.08	44.15	45.25	46.39	47.55	48.75	49.98	51.25	52.55	67.94	88.78	117.27	156.63	156.63			
	nile	1.16	1.19	1.21	1.23	1.26	1.28	1.31	1.34	1.36	1.39	1.42	1.44	1.75	2.12	2.58	3.12	3.12			
	sahra	2.17	2.21	2.25	2.29	2.33	2.37	2.41	2.45	2.50	2.54	2.58	2.67	3.67	5.04	6.92	9.51	9.51			
	Total	105.88	108.67	109.88	112.97	115.46	117.46	154.59	160.14	162.00	163.14	164.92	200.08	261.08	284.04	315.28	358.25	358.89			
Libya	other?	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85	2.85			

Table 4. Listing of input abstraction rates for modelling. ***Needs checking, updating, and re-drafting.*.**

Source: Total_NSAS_Extraction.xls.

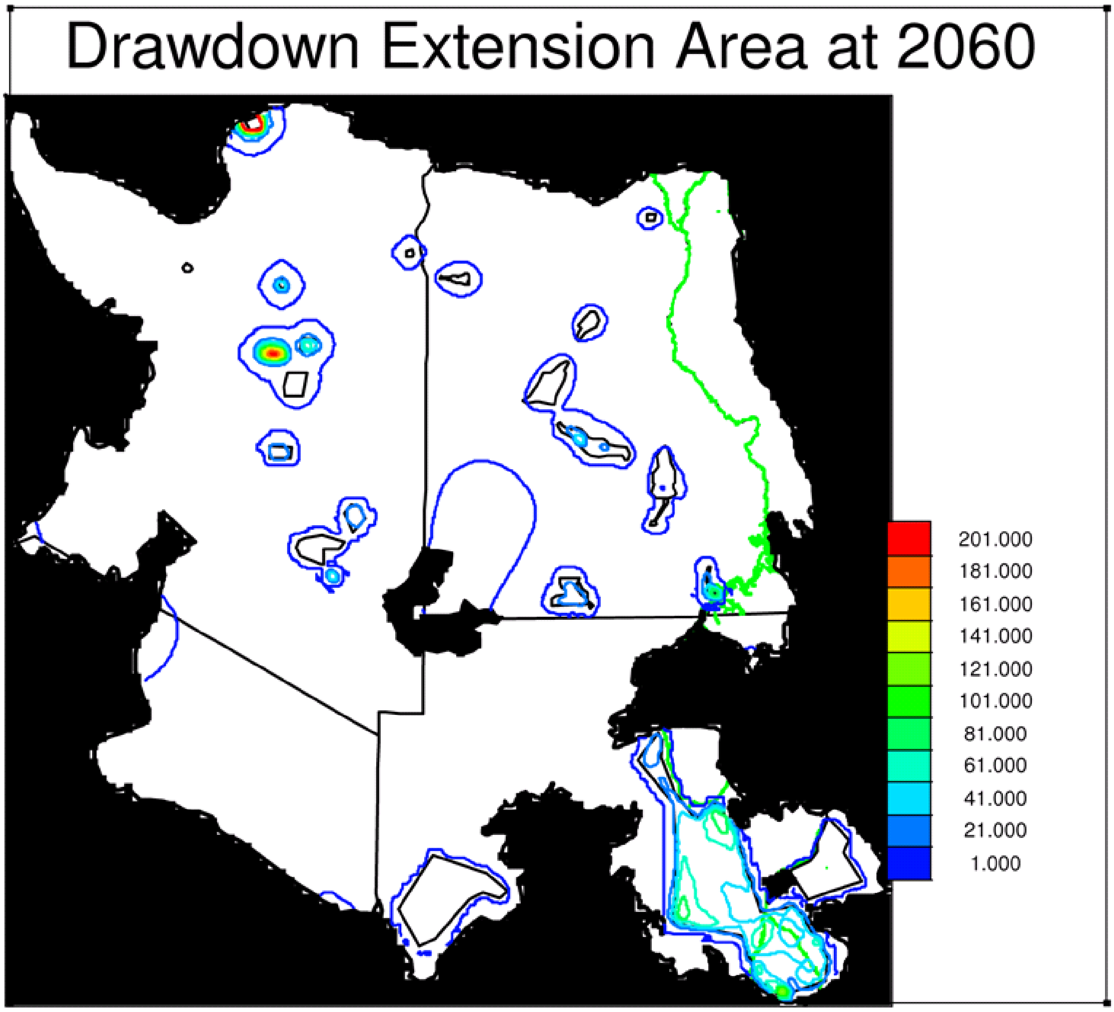


Figure 9. Drawdown in meters predicted in 2060 for the Base Model.

Source: Voss Report Page 36.

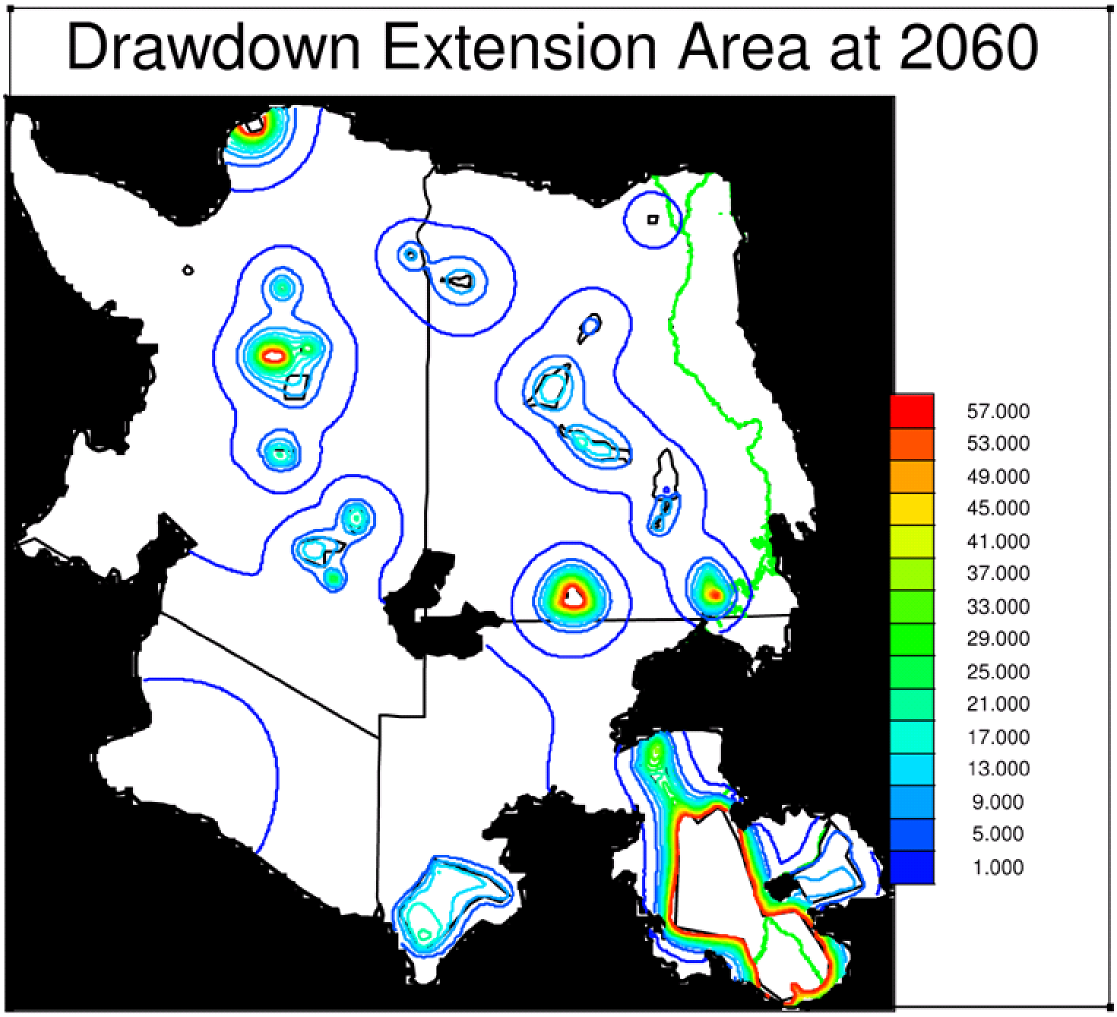
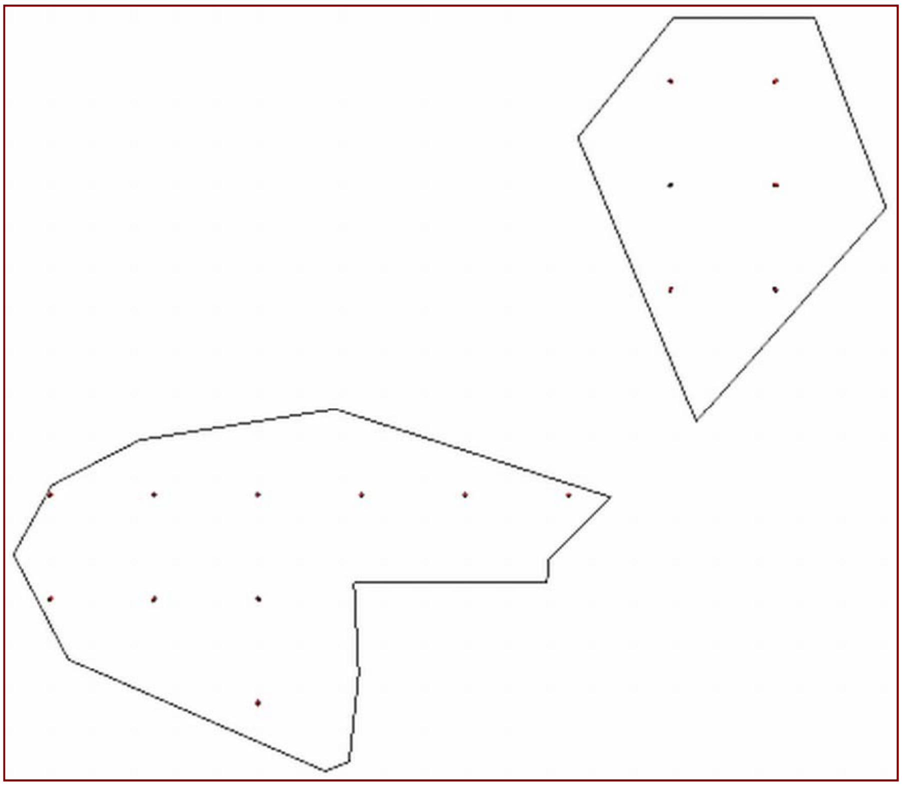
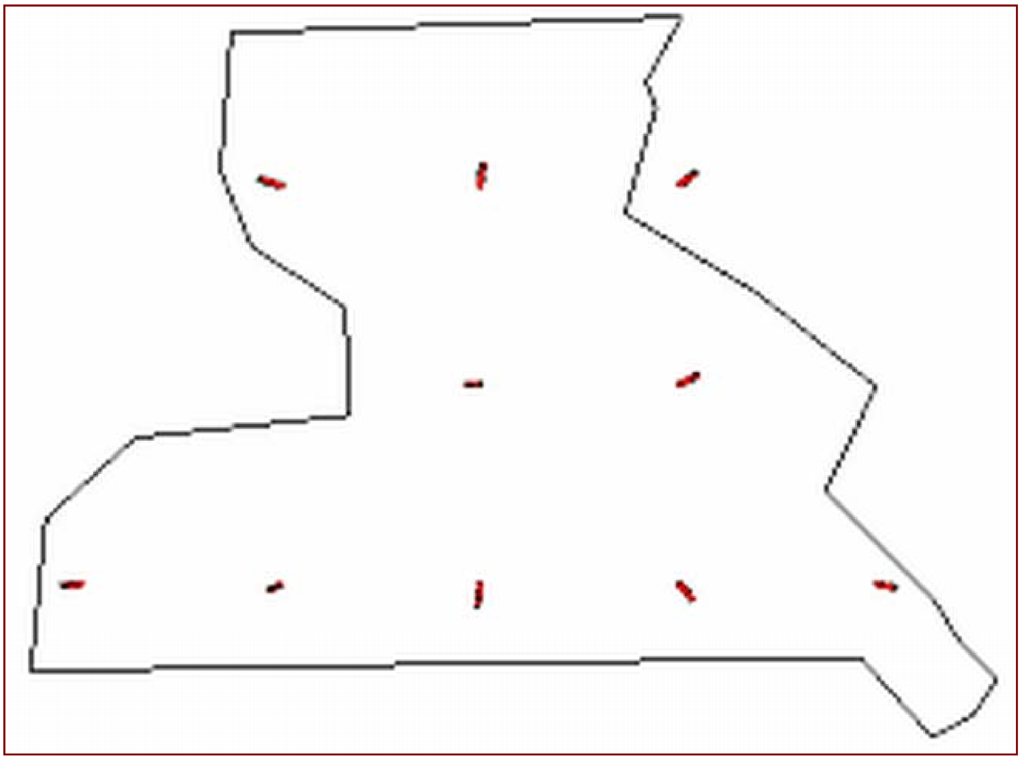


Figure 10. Drawdown in meters predicted in 2060 for the Maximum Lateral Extension Model.

Source: Voss Report Page 41.





Needs scale.

Figure 11. Capture zone analysis showing the distance moved by parcels of water after two hundred years of pumping in the Kufra (top) and East Oweinat (bottom) well fields..

Source: images.

Table 5. List of the Primary and Secondary Stakeholders in Each Country.

Country	Primary Stakeholders	Secondary Stakeholders
Chad	Local tribes, NGOs, Farmers, Tourism/ safari workers. Local / National Parliament members.	Ministry of water, Ministry of Foreign Affairs
Egypt	Local Tribes, Agriculture investors, graduates and immigrated farmers, Groundwater user associations, Hotel owners, tourism/ safari workers. Local Popular Council members, Parliament members.	Ministry of Water Resources & Irrigation (Groundwater Sector, Research Institute of Groundwater, Central labs), Egypt Atomic Energy Authority Local Governments. Ministry of Agriculture, Ministry of foreign Affairs.
Libya	Local Tribes, Farmers, Groundwater user associations, Tourism/ safari workers. Local / National Parliament members. NGOs, Agriculture Cooperative Assemblies.	GWA, EGA, GMMRA, GMMRUA, REDWRC, Ministry of Agriculture, Ministry of industry, Utilities, Housing Authority, Ministry of Planning, Ministry of Foreign Affairs and local government
Sudan	Local Citizens, Agriculture investors	Ministry of Irrigation & Water Resources, Ministry of Environment, Ministry of Livestock, Ministry of Interior, Wildlife Department, University of Khartoum, Ministry of Foreign Affairs.

Table 6. Interests of Secondary Stakeholders in the Four Counterpart Countries.

Country	Secondary Stakeholders	Interests	Potential project Impacts	Relative priorities of interest
Chad	Ministry of water,	Provide project management support	+++	++
	Ministry of Foreign Affairs	Participate, facilitate and assist the implementation of the third component of the project	+++	+
	IAEA	Provide Funding, technical assistance and management	+++	+++
	GEF	Provides funding	+++	++
	UNDP	Provide project monitoring	++	++
Egypt	Ministry of Water Resources & Irrigation.	Provide project management support	+++	++
	Egypt Atomic Energy Authority	Facilitate and assist the project management	+	+
	Local Governments	Creating job opportunities	+	+
	Ministry of Agriculture	Access to land for production purposes Currently on land – would like to be part of project	++	+
	Ministry of foreign Affairs	Participate, facilitate and assist the implementation of the third component of the project	+++	+
	IAEA	Provide Funding, technical assistance and management	+++	+++
	GEF	Provides funding	+++	++
	UNDP	Provide project monitoring	++	++
Libya	GWA, EGA, GMMRA, GMMRUA, REDWRC, ,	Provide project management support	+++	++
	Ministry of Agriculture	Access to land for production purposes Currently on land – would like to be part of project	++	+
	Ministry of industry,	Availability of Water resources for industrial development	+	+
	Utilities, Housing Authority	Availability of Water resources for domestic development	+	+
	, Ministry of Planning	Availability of Water resources for development and planning.	+	+
	, Ministry of Foreign Affairs	Participate, facilitate and assist the implementation of the third component of the project	+++	+
	IAEA	Provide Funding, technical assistance and management	+++	+++
	GEF	Provides funding	+++	++
	UNDP	Provide project monitoring	++	++

Table 6 (concluded). Interests of Secondary Stakeholders in the Four Counterpart Countries.

Country	Secondary Stakeholders	Interests	Potential project Impacts	Relative priorities of interest
Sudan	Ministry of Irrigation ,	Provide project management support	+++	++
	Ministry of Agriculture	Access to land for production purposes Currently on land – would like to be part of project	+	+
	Ministry of Environment	Protection of the water resources	+	+
	Ministry of Interior, ,	Good management of water resources has direct contribution to the security	++	+
	Ministry of livestock & Wildlife Department	Access for meat and milk production	+	+
	University of Khartoum	Participate in water resources research development	+	+
	, Ministry of Foreign Affairs	Participate, facilitate and assist the implementation of the third component of the project	+++	+
	IAEA	Provide Funding, technical assistance and management	+++	+++
	GEF	Provides funding	+++	++
	UNDP	Provide project monitoring	++	++

\+ Low ++ Medium +++High

Table 7. Interests of Primary Stakeholders in the Four Counterparts Countries.

Country	Primary Stakeholders	Interests	Potential project Impacts	Relative priorities of interest
Chad	Community from the project Area	Access to land for production purposes	+++	+++
	Farm workers	Currently on land – would like to be part of project	+	++
	Local government	Creating job opportunities	++	++
Egypt	Community from the project Area	Access to land for production purposes	+++	+++
	Farm workers	Currently on land – would like to be part of project	+	++
	Local government	Creating job opportunities	++	++
	Hotel owners, tourism/ safari workers	Currently on land – would like to be part of project	+	++
Libya	Community from the project Area	Access to land for production purposes	+++	+++
	Farm workers	Currently on land – would like to be part of project	++	++
	Local government	Creating job opportunities	+	++
Sudan	Community from the project Area	Access to land for production purposes	+++	+++
	Farm workers	Currently on land – would like to be part of project	+	++
	Local government	Creating job opportunities	++	++

\+ Low ++ Medium +++High

Table 8. Importance/ Influence for the Stakeholders in Egypt.

Influence	Importance			
	+++	++	+	-
+++	Ministry of Water Resources & Irrigation, IAEA, GEF, National/Local Parliament Members			Ministry of Foreign Affairs
++	Ministry of Agriculture, Local Government	UNDP, Ministry of Planning		
+		Groundwater Users Associations	Local Tribes, Hotel Owners, Tourism workers	Egyptian Authority of Atomic Agency
-		Graduate and Immigrated Farmers, Agriculture Investors		

Table 9. Importance/ Influence for the Stakeholders in Libya.

Influence	Importance			
	+++	++	+	-
+++	GWA, GMMRA IAEA, GEF, National/Local Parliament Members			Ministry of Foreign Affairs
++	Ministry of Agriculture, Local Government	UNDP, Ministry of Planning, EGA, REDWRC, Ministry of Industry, Housing Authority		
+		Agriculture cooperative Assemblies	Local Tribes	Authority of Atomic Agency
-		Farmers,		

Table 10. Importance/ Influence for the Stakeholders in Sudan.

Influence	Importance			
	+++	++	+	-
+++	Ministry of Water Resources & Irrigation, IAEA, GEF, National/Local Parliament Members	Ministry of Interior		Ministry of Foreign Affairs
++	Ministry of Agriculture, Ministry of Livestock Local Government	UNDP, Ministry of Planning, Ministry of Environment		
+		Agriculture Investors	Local Tribes, Farmers	University of Khartoum
-				

Table 11. Importance/ Influence for the Stakeholders in Chad.

Influence	Importance			
	+++	++	+	-
+++	Ministry of Water Resources & Irrigation, IAEA, GEF, National/Local Parliament Members			Ministry of Foreign Affairs
++	Ministry of Agriculture, Local Government	UNDP, Ministry of Planning		
+			Local Tribes,	
-		Farmers,		

Table 12. Summary of Priority Risks.

Risk	Rank	Comment
Declining Water Levels	1	The aquifer is highly vulnerable to localized drawdown. There is little indication that the lateral extent of drawdown can extend far enough to cause transboundary effects.
Damage or Loss of Ecosystem and Biodiversity	2	Closely linked with Declining Water Levels. Oases are highly vulnerable to water level declines and practically all well fields are located in or near oases.
Water Quality Deterioration	3	As more water is abstracted from the aquifer, the potential increases for recharged wastewater to cause water quality problems.
Climate Change	4	Depends on timing and magnitude of climate change. Can affect changes in water use patterns. In southern part of region, can affect grasslands.
Changes in Groundwater Regime	5	Modelling indicates that changes in groundwater flow patterns will not occur outside of the very immediate area of well fields.