



المركز الوطني للبحث والتطوير/برنامج بحوث البادية

AZRAQ OASIS RESTORATION PROJECT

Development of a Decision Support System (DSS) for Azraq Oasis

Final Technical Report
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INTRODUCTION

1.1 Project context of the Azraq DSS

Many studies have been carried out over the last 10 to 20 years on the Azraq Basin and its Oasis near Azraq town. From water resource assessments to ground water modeling and more recently also attempts to consult and involve the local population. The Chapter in this report on Background and (with more detail) Annex 1 to this report will refer to the technical studies already done and that have been important inputs for the work described in this report.

This report is focusing on scenarios and a Decision Support System (DSS) to assess these scenarios that will assist in making the right technical and political decisions for the best sustainable use of the Azraq aquifer in a way that will limit abstraction beyond natural recharge and safe yields, while enhancing local livelihoods in the area.

The development of the Azraq DSS and related best water use scenarios forms part of a larger effort made by the Regional Water Resources and Dryland (REWARD) Program that is carried out by the IUCN Regional Office for West Asia (IUCN-ROWA) with a wide range of partners in different countries of the region. The REWARD demonstration projects focus on developing management plans for watersheds (Jenin/Palestine), river basins or sub-catchments (Zarqa/Jordan, Dhamar/Yemen), Nile Water Districts/Egypt and the groundwater basin Azraq. All demonstration projects follow a similar approach combining stakeholder-led participatory planning approaches with the development of Decision Support Tools. DSS development for Azraq therefore is part of a larger effort in the region in developing practical and highly user-friendly tools that allow planners and decision-makers at both local and national levels to make best and underpinned choices for the best use of scarce and often multi-interest water resources.

1.4 Objectives of the project

The long-term goal and project purpose of the Azraq Restoration Project are the following:

Long-term Goal: A substantial part of the Oasis/Ramsar site restored, while balancing water uses, maintaining ecosystem services and addressing long term access and rights to water by underprivileged groups in the targeted communities.

Project Purpose: Capacities Build in systemic and participatory approaches to planning, restoration, development and management of the restoration of Azraq Oasis, being tested and demonstrated at the intermediate and local level by promoting increased participation and representation of stakeholders mainly end-users in planning and decision making processes (improved local water governance).

These objectives will be achieved by five component results as mentioned in Table 1.

Table 1. Component Results of the Azraq Restoration Project

| | |
|-----------------|---|
| Result 1 | Capacities build in effective and trusting management/coordination systems that are functional to sustain the effective water management at local and Oasis level. |
| Result 2 | All relevant stakeholders (GOs, NGOs, private sector, CBOs and end-users) empowered in participatory water resource planning and management and enabled to engage in planning and decision making and in implementing the master plan and undertake similar activities in the country and the wider region. |
| Result 3 | Systemic analysis tools developed to enhance the communication and information flow between the stakeholders and support the development of the Azraq Oasis restoration master plan. |
| Result 4 | A Master plan designed with all concerned parties for the rehabilitation of Azraq Oasis based on a joint participatory planning framework and supported by a set of systemic tools (possibly a DSS) |
| Result 5 | Pilot projects in the targeted areas developed and implemented to test solutions for the restoration of Azraq oasis - based on the priorities of the stakeholders - that will pave the way for up scaling when implementing the master plan. |
| Result 6 | Information and knowledge acquired in this project shared and communicated at the national and regional level. |

This report will specifically deal with Component Result 3. Work done for the first two Component Results and experienced gained in pilot projects (Result 5) will inform activities necessary for Result 3. In turn the achievements of Result 3 will be critical for attaining Result 4, the designing of a Master Plan for the rehabilitation of the Azraq Oasis.

In other words the Azraq restoration project will be developing a practical Decision Support System (DSS) to enhance environmental flows (water regime) around the Azraq Oasis, taking into account the need to restore (partially) the RAMSAR wetland, and to secure sufficient abstraction of ground water for drinking water of Amman as well as for sustainable agricultural and domestic water use, without exceeding natural recharge of the aquifer.

1.3 Institutional project arrangements

To achieve the project goal, bilateral agreements were signed between the Regional Office for West Asia of the International Union for Conservation of Nature (IUCN-ROWA) and the Badia Research Program (BRP) on one hand, and between IUCN-ROWA and the Arab Women Organization (AWO) on the other hand to implement the project activities. Those three partners started working together with the local community and other related national and international organizations.

The role of the BRP is participating in the overall project process and workshops, while specifically contributing to the project through reviewing previous studies made on the Azraq Basin and Oasis, participating in the data collection and analysis and developing a simple and practical Decision Support System (DSS) as a user friendly computer-based system that is accessible to all related interested bodies. The DSS would support management decisions for a future management and restoration plan of the Azra Oasis. Simultaneously, supporting the primary data collection, the AWO' role is to empower the local stakeholders in the overall process of making sure that their knowledge, insights, concerns and priorities are well taken into account, first in the design of the DSS and hence in the decision-making processes necessary for the good management of the ground water resources of Azraq. Overall leadership, coordination, facilitation of project processes, budget management and reporting to donors is with IUCN-ROWA.

Meanwhile, and for the purpose of the project, two committees were formed to provide feedback and direction to the project methodology and the conceptual design of the DSS. The first one is a steering committee headed by the Ministry of Environment with members from all key stakeholders (Ministry of Water & Irrigation, Ministry of Agriculture, RSCN, Ministry of Planning and International Affairs, and Ministry of Interior). The steering committee is updated continuously while it provides inputs and feedback to the implementing bodies. A technical advisory committee was formed by the BRP involving specialists from BRP' and from other national organizations in the domains of water, agriculture and research aspects.

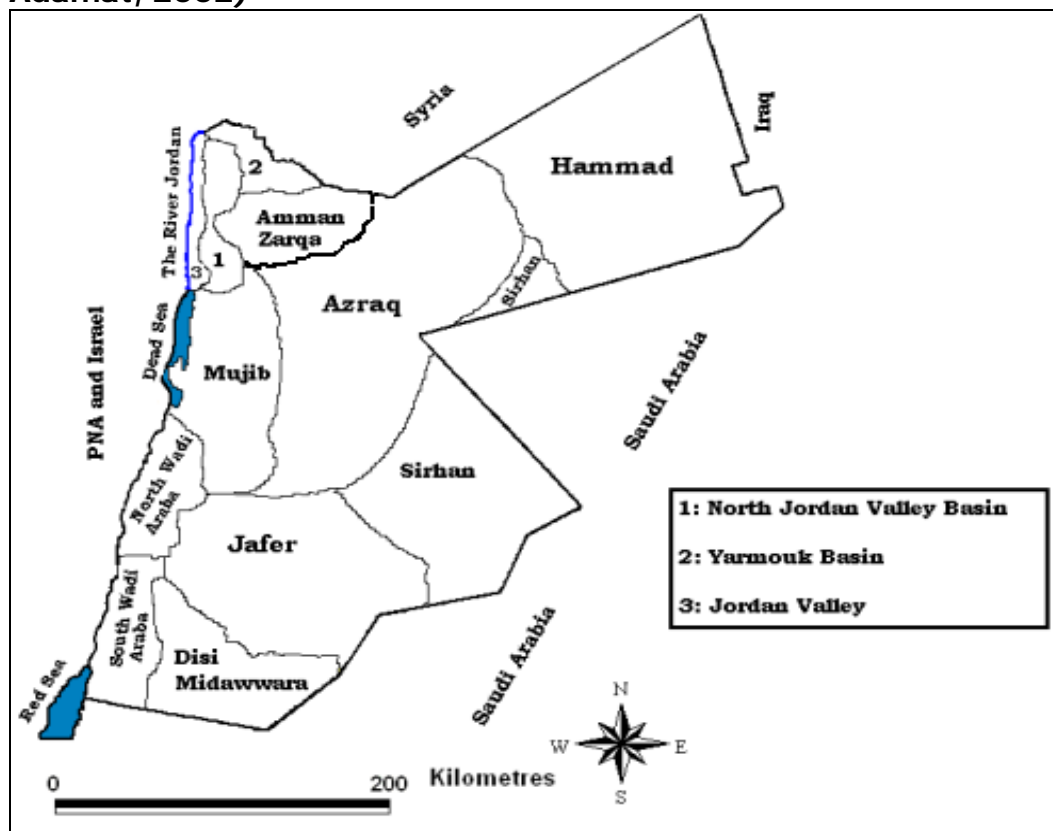
The technical advisory committee role is to evaluate the work done by the BRP on the DSS. Furthermore, BRP has signed contracts with 2 technical persons to implement the project activities delegated to BRP. One of them has a PhD in GIS and groundwater modeling and has a contract for four months to assist in modeling issues building a data base, developing the necessary GIS-base and design the DSS. The person has a Bsc in Agriculture and was hired for two months to assist in data collection with the government organizations. In addition, two employees from the BRP' staff were trained at the Jordanian Royal Geographic Center (JRGC) to upgrade their capabilities in the use of the GIS and data entry.

1. SITUATIONAL BACKGROUND ON THE AZRAQ BASIN AND OASIS

2.1. About the Azraq Basin

Azraq Basin is one of the largest groundwater basins in Jordan (12,400 km² which is equivalent to about 12 % of the total area of the Kingdom). It is located between 55 to 230 North and 250 to 400 East (Palestine co-ordinates) in the central/north eastern part of the country. Figure 1 provides a map of the different aquifers in Jordan

Fig1. Groundwater basins in Jordan (Modified from Allison *et al.*, 1998; Al-Adamat, 2002)



The Azraq Basin is located partially within basalt formations (i.e. Tertiary and Quaternary periods, between 13.7 Ma to less than 0.5 Ma) and partly within Tertiary and Quaternary sediments, that contain a shallow aquifer system of Pleistocene age. Rainfall on the Jabel Druze Mountains in Syria - 80km to the north with maximum elevation of 1,400 m a.s.l. - is then main source of groundwater recharge. The aquifer discharged naturally by springs southwards in the Azraq depression where they were feeding the Azraq Oasis (Murakami, 1995). This natural discharge by springs has now almost stopped.

Various studies were carried out on the basin by several researchers on recharge, safe yield and actual abstraction. Findings of these studies are summarized in Table 2.

The natural recharge is around 20 Million Cubic Meters (MCM)/year (as estimated by spring discharge at Azraq using Penman evaporation formula and assuming a steady state flow; UNDP, 1966). Others estimate safe yields between 24 and 33 MCM/year (see Table 2 below). Currently, the total annual abstraction is around 56 MCM/year. In case of a safe yield of 24 MCM/year this would mean a 32 MCM/year deficit.

Table 2. Abstraction and Recharge Rates of the Azraq upper Aquifer

| Author | Year | Abstraction rate (MCM/year) | Recharge Rates (MCM/year) | Safe Yield (MCM/year) |
|--|------|--|---------------------------|----------------------------------|
| Humphries | 1982 | | 33.1 | |
| UNDP | 1966 | | 18.1 | |
| Noble | 1994 | ➤ 43 (legal and illegal pumping) | | |
| Water Authority of Jordan (WAJ), | 1989 | | 34 | |
| Al-Kharabsheh | 2000 | 55 | | |
| National Information Centre (NIC)/Jordan | 1997 | 53.9 | | |
| Humphries | 1988 | | 33.1 | 24 |
| Al Hadidi | 2009 | 54 (23 MCM for domestic use and 30 MCM for agr. Use) | | 33 (domestic + agricultural use) |

The basin supplies ground water for both domestic and agricultural use within and outside the basin. For example it supplies water for two major cities in Jordan (i.e. Amman and Zarqa) in addition to the inhabitants who are living within the Basin borders for drinking and agricultural purposes.

Water pumping from Azraq basin started in early eighties and mainly in the Southern part of the Basin near the town of Azraq. Ten years of the starting pumping (early nineties), withdrawal had reached 39 MCM/ year for all uses. At the beginning,

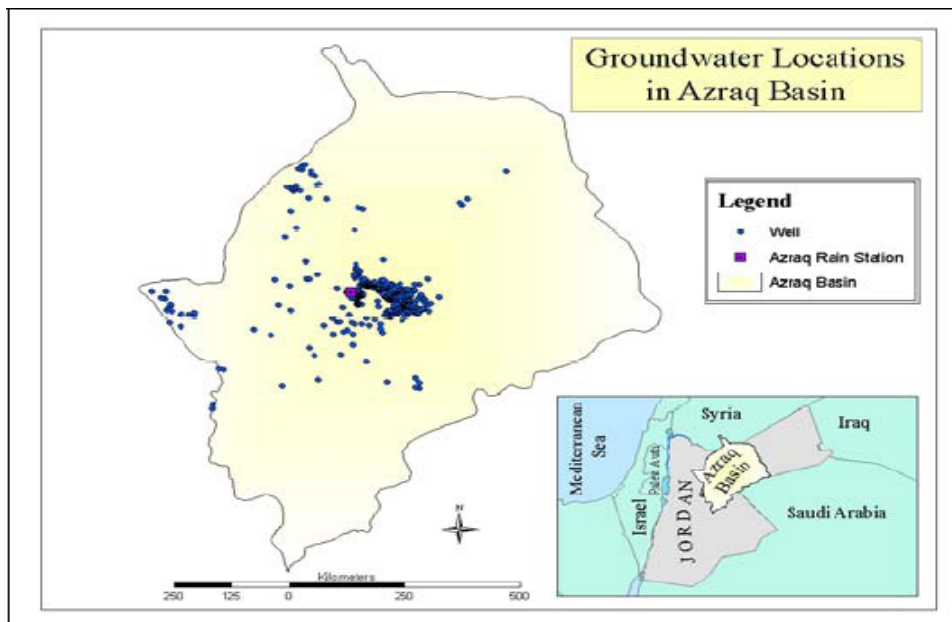
The pumped water was direct to Amman and Zarqa main cities where it was estimated at that time about 15 Million Cubic Meter (MCM)/year goes to these two cities..

In the Northern part of the Basin, agricultural activities were becoming more important in the late eighties and early nineties after a government decision that allowed digging wells in the upper aquifer to start cultivating the land in the areas which is extending to the border with Syria. According to the Jordan Ministry of Environment in 2006, the agriculture area in the basin had increased by 30 times in the last 10 years as a means for investors from outside the area to register and appropriate land. As a consequence, ground water abstraction started to exceed the above mentioned safe yields, causing the static ground water table in the basin to drop dramatically at a rate of 80 to 90 cm/year (IUCN, 2009).

2.2 About the Azraq Oasis

Azraq Oasis forms the heart of the Azraq basin and it is located around the mudflats at the southern downstream borders of the basin. The Oasis is part of Azraq basin which extend from Syrian borders to the Saudi Territories. Figure 2 presents well distribution Azraq Basin well and it is evident that there is huge concentration of wells in the Oasis itself (both legal and illegal)

Fig. 2. Wells distribution within the central part of Azraq basin



Throughout history the Oasis has attracted many civilizations, and it is still one of the few and unique wetlands in the region. It has an international importance due to the environmental biodiversity and was and is still considered as strategic location for immigrant bird routes from Africa to Europe and vice versa. The Ministry of

Environment (MoE) and the Royal Society for the Conservation of Nature (RSCN) gave attention to this area as a site of global importance, and in 1977 the oasis received the status of a RAMSAR site. This was at the time that the Oasis was still naturally fed by springs and a very shallow ground water table until a couple of years ago, where the surface springs have been disappeared because of the over pumping of ground water which was resulted in a rapid decline of the ground water table, subsequently, a strong reduction of the spring water flow has been occurred, the almost disappearance of the lakes and as a consequence the oasis disappeared almost entirely at the end of 1992. This was further aggravated by a decline in rainfall which resulted in desertification and drought with serious impacts on water resources and agriculture.

This has led to water disappearing from the oasis with dramatic consequences on bird migration. This has urged a government response to global pressure to revive the oasis. As a consequence, in 1994, the Jordan Government represented by the Ministry of the Environment and RSCN started pumping ground water into lakes to create an artificially maintained wetland/Oasis through an agreement with the Ministry of Water and Irrigation. At this moment in time a small part of the Oasis wetlands (less than 5%) is still preserved by RSCNs that manages the Azraq Nature Reserve, the remnants of the Ramsar site. Thus the ecology of the region that has served as a place of rest for migrating birds and other wildlife has been heavily endangered.

2.3. Other negative impacts from groundwater over pumping

The heavy pumping water from the basin, for unsustainable and often large-scale agricultural activities and for the supply of drinking water to Amman and Zarqa cities. Apart from the drying-out of the Oasis, considered as an alarming environmental disaster, the ground water over abstraction has had other also very important environmental, social and economic negative impacts.

Hydrological measurements of groundwater level and quality using a network of monitoring wells indicated that groundwater table level are dropping significantly in addition to the deterioration of water quality. During the last twenty years water table level has declined with 17 m, while the water salinity has increased from 250 ppm to 450 ppm (Al Hadidi, 2009). These facts have major implications for future investments in the area in terms of agriculture production, desertification, bird migration, and ecosystem degradation.

This situation has indeed affected the cultural, historical, social, tourist, environmental, water and economic activities in the area.

According to the Jordan Department of Statistics (DoS) the total number of population the Azraq basin in 1994 was 27,434 citizens (14,775 males and 12,659 females). Those people live in 49 towns, villages and settlements. The majority of the population lives in the northern part of the Azraq basin with an 18,241 inhabitants in 43 towns, villages, and settlements. The estimated annual growth of the population in Jordan is 3.5%,

which means that in 2002 the population of the Azraq Basin can be estimated at 37,389 citizens.

Traditionally, the major income source for the majority of the population in the wider Basin is livestock. However, in the Oasis area, and notably to the east, southeast and northeast of Azraq town, an increasing number of farmers is shifting to agriculture. They are planting vegetables as they claim that it generates a rapid profit in the planting season that starts in April and ends in late November. Other farmers cultivate olive or other fruits, with some having a small farm of vegetable adjacent to the tree farm. Farm size varies from one farmer to another as it highly depends on land availability and the financial situation of the farmer. The vegetable farm size ranges from around 100 dunums to a few hundreds dunums, while the size of the trees farms range from around 100 trees to more than 40,000 trees.

Most of this agriculture is highly inefficient in water use and cannot be considered sustainable. Due to the over pumping from basin especially for agriculture related activities, water tables are dropped significantly at a rate of 80-90 cm/ year (IUCN, 2009). Consequently there is severe ecosystem degradation in the area with people now losing most of their products and large cropping areas being irreversibly damaged due to lack of water, salinity and soil deterioration. Of course this has important negative impact on local livelihoods in the area

In short the findings of this study show that the upper shallow aquifer system suffers from severe negative impact (salinity and lowering water tables and quality). This can be further aggravated by salt water intrusion, especially if the water levels sink below 500 meter above the mean sea level which is the static water level of Qa'a-Azraq area.

2. OVERALL PROJECT APPROACH

3.1 Participatory approach

A participatory approach was adopted in this project where the objective of participation is the empowering of people in terms of their acquiring the skills, knowledge and experience to take greater responsibility for their development. This in contrast to many main-stream projects where participation is seen as a process whereby local people cooperate or collaborate with externally introduced development projects and participation is mainly an instrument whereby such projects can be more effectively implemented.

In this project, the participatory approach is inspired by the EMPOWERS Guidelines for Local Water Governance based on a Participatory Planning Cycle and a Stakeholder Dialogue and Concerted Action (SDCA) approach, involving different levels of stakeholders related to the project from local communities to national authorities (Moriarty et al, 2007). More information on the planning cycle and on SDCA is given in sections 3.2 and 3.3.

To meet project objectives, the participation process has utilized different means and techniques (meetings, information days, PRA, cooperative structures, focus groups, etc.). A step-by step method was adopted involving all stakeholders related to the topic (see section 3.3). An initial capacity building process was undertaken to introduce the different actors to the issues and methods to be used, through:

- *workshops,*
- *Seminars,*
- *Brain storms,*
- *Field visits*

A field visit was made within Jordan to Rajif Village in the south of Jordan and to Beni Sueif in Egypt, with the aim to gain experiences from others that have gone through similar processes and to learn from their know-how, while witnessing success stories when all stakeholders are involved in the decision making process. These visits resulted in building confidence and trust between all Azraq stakeholders (local communities-locals-governance-facilitators and implementing parties).

3.2. Stakeholder Dialogue and Concerted Action

As mentioned earlier, the methodology which is adopted for this project was based on an intensive consultation process with the relevant stakeholders with together a multi-disciplinary background. The aim was to involve these relevant parties in an open dialogue to find common basic ground for a shared problem analysis, vision and as a result shared proposals for solutions. Therefore, several meetings (workshops, brainstorm and discussions) were undertaken with the stakeholders to formulate a

conceptual framework and work plan for the restoration of the Oasis.

Key Stakeholders involved

- Local Community' Representatives: Mayor of Azraq, Municipality 'Staff of Azraq Town, Cooperative presidents (Males and Females), teachers, lawyers, *Mukhtars*, religious people, farmers and civil society' leaders.
- Ministries at three levels: local, intermediate and national of Ministries of Interior, Water and Irrigation, Agriculture, Health, Environment, Department of Land and Survey
- NGOs such as RSCN, Mercy Corps, GTZ, InWent as well as representatives of several donor agencies (Italy, Netherlands)

Project Partners

- Badia Research Program (BRP)/themNational Centre for Research and Development
- Arab Women Organization (AWO)
- International Union for Conservation of Nature (IUCN) (project holder)
- Relevant stakeholders and local community

The local community was a key actor in the stakeholder process since their involvement from the beginning gave the methodology a logical and concrete sense and tangible outputs because they are living in the heart of the oasis and they are fully aware of what the situation is and what could happen in the future if the situation does not improve. It is worthwhile to mention that the local Azraq inhabitants and government agencies have high capabilities for analysis and assessment of the local situation. It was notably with their assistance that the problem analysis was made and the vision defined (see section 3.3).

Several advantages have resulted from the dialogue. First of all the open and respectful dialogue has been highly instrumental to find a common ground among all stakeholders to address the problem and to find solutions. Secondly it has built trust between local actors and the decision makers for joint action in the future, since they will all be part of any future decision or project initiative that will reflect positively on the oasis. For example the local actors began to suggest projects that will help to limit the amount of pumped water through rational interventions in order to reach the envisioned safe yield level within 12 years from now. For this to be realized a reduction of 5% of groundwater pumping annually is proposed by initiating pilot agricultural projects (demonstrations) in partnership with the farmers. Particular emphasis would be given to It is also proposed too changes in cropping patterns to crops that require less water such as Jojoba, so as to comply with national and international water requirements. Comparisons will be made between what is going on now and changed cropping

patterns, while also new crops may be suggested from other similar areas. The dialogue process most importantly has led in concert with local authorities to changes in thoughts, vision and attitudes of the local community. Subsequently this will help the BRDC to develop more easily the DSS model. Some important ideas have been given by the local people and these have been taken into account and will support the development of the DSS conceptual design.

Last but not least, it needs to be mentioned here that on the basis of prior efforts that were facilitated by IUCN in 2007, the actual Azraq Restoration Project - with support from GTZ - has made it possible to institutionalize the Azraq Stakeholder Forum that is hosted by the MoWI. The Forum has obtained formal recognition and functions according to a legal frame work headed by Prince Faisal on behalf of the Royal Water Committee. The DSS described in this report is to support the Forum and will be instrumental to decide on future pilots projects to be implemented by the Forum, such as a salt intrusion study.

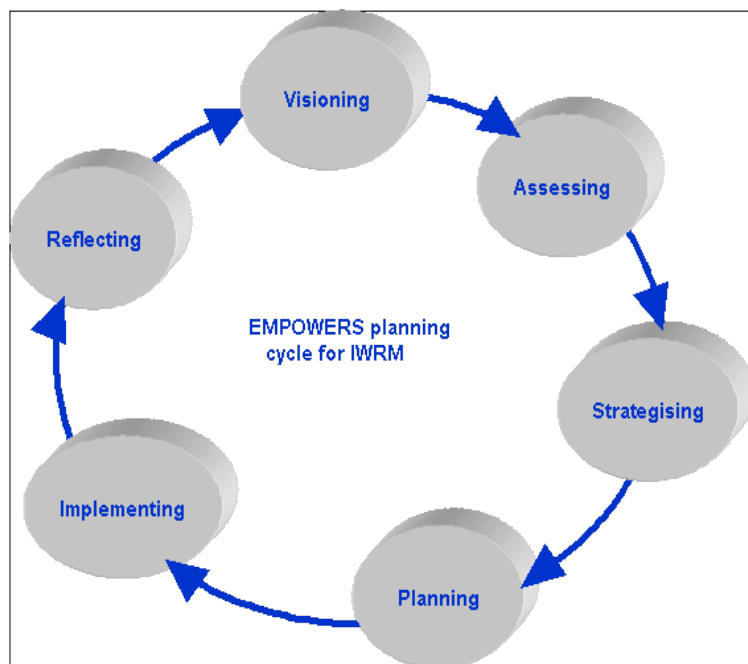
3.3 Participatory Planning Cycle

Embedded by the SDCA process described in the above section 3.2, a Participatory Water Planning Cycle, developed and tested by the EMPOWERS Project in Balqa Jordan, Jenin, Palstine and Beni Sueif, Egypt (Moriarty et al, 2007b) was used to define shared a shared vision, collect qnd assess relevant information, build scenarios and strategies. As depicted in Fig 3 below, this Planning Cycle is build up of six iterative. Most of them have found application in the Azraq Restoration Project.

Fig.3. the EMPOWERS Planning Cycle for IWRM

Outcomes from these activities have led to a detailed and shared problem diagnosis in the Azraq Oasis and subsequently the identification of a long-term vision for the restoration of the Azraq Oasis that is shared by most if not all of the directly involved stakeholders from local communities to government agencies and other interested parties.

All stakeholders agreed that important ecosystem degradation has occurred in



the Azraq Oasis because of internal and external factors (c.f. earlier Azraq platform, 2007). Internal factors relate among others to over pumping within the oasis area, unclear water rights, non-sustainable agriculture, while the external factors have to do with climate change and over pumping in the larger area of the Azraq basin (outside the oasis area) and the drilling of wells and building of dams in the upper catchment on Syrian Territory. In view of this problem diagnosis the stakeholder parties have defined a vision for the Oasis:

Vision for Azraq: "The restoration of Azraq Oasis" by reducing within 12 years groundwater pumping down to safe yield levels in compliance with the Ministry of Water and Irrigation Policy.

For more information on how the Visioning Step is carried out readers are referred to the Report of Arab Women Organization (AWO) on the participatory stakeholder consultations and empowerment of local communities and local-level government staff (AWO Report, 2010) as well as Moriarty *et al* (2007b).

For the purpose of how the development of the Azraq DSS took place the below will elaborate in more detail on the Assessment Step. Further information on strategizing and scenario building (Step 3) is provided in Chapter 4 of this report on the development of the DSS itself. An indication of planned activities is given in Chapter 5, while section 3.4 will elaborate more on how processes have been documented.

The Assessment Step

A mechanism for getting related data has been formulated, where data was obtained and analyzed from three domains:

- (1) *Available published and unpublished data (meta-data)*
- (2) *Opinion and experience from other areas and*
- (3) *Data Gaps analysis*

The kind if necessary data was identified in view of the initial vision developed and based on consultations with relevant stakeholders particularly the local community. Subsequently fieldwork activities have been carried out through Participatory Rapid Appraisal (PRA) technical sessions; unstructured interviews (one to one) were used to collect the primary data, while workshops with the stakeholders at different levels were held (local, intermediate and national level).

Themes of the discussion were developed based on local conditions, local community opinions and lesson learned from other area in the region. The main information collection was focusing on issues related to:

- *water resource issues*
- *social aspects*
- **Restoration and agricultural activities.**

On the basis of the identification and collection of data and other information it was decided what kind of information and data is required for the development of a conceptual framework in order to develop a Decision Support System (DSS) to identify options and guide decisions for the best management of the Azraq Oasis and to support a sound decision-making processes. How the DSS was designed is further discussed in Chapter 4.

The highly participatory character of data identification, collection, analysis and even inputting of data needs to be emphasized here. It represents a quite unique feature of how this DSS has been developed. Indeed, including the community involvement and perspective will ensure decision makers at national levels that the insights, need and priorities of the community is taken into account, while in addition such an inclusive process has facilitated the empowerment of local people with regard to their roles and responsibilities. This involvement of local communities and local government staff has also ensured that relevant information at the local level is collected and taken into account in the further analysis processed with help of this DSS.

3.4. Sub-Regional Events; learning from others

Several workshops, seminars and study tours were conducted to serve the project objectives. They were very helpful to consolidate the positive energy created by the SDCA and participatory planning cycle process. These events were:

- A training workshop organized by the IUCN REWARD team and attended by all relevant parties. It was held in Amman on 1-4 March 2009 with the aim to build capacities in Pro-Poor Participatory Planning of Ecosystem Services and Management. Useful information was gained from this event through new concepts, know-how exchange, getting new insights in participatory approaches, getting new skills and capacity building.
- Strategic Alignment meeting held in May, 2009, organized by Regional Water Resources & Dry lands Program (REWARD) and convened in Sharm El Sheikh, Egypt. The meeting focused at dry land watershed ecosystems, climate change resilience, institutional learning and regional networking in the West Asia and Mediterranean region. The workshop explored how these new dimensions can be integrated and be given more emphasis in the work of REWARD, its field projects and its Regional Water Resource System Networks. The first two days of the workshop were used to reflect on these new dimensions and to see how they can be practically integrated in on-going work. The last day has been used to strengthen the organization of the regional networks on specific water

resource/dry land ecosystems. The work of the workshop is documented in a strategic background publication to share with a broader audience the thoughts, insights and practical propositions to enhance the work and ambitions of REWARD (Leban and Fityani, 2009).

- The third event was a regional workshop on implementation of RAMSAR Convention, held at Arab League, Cairo, Egypt in June, 2009 The visit was organized by IUCN and CEDARE
- A field visit was also made to Beni Swaif in Egypt from 26-30 June,2010. The aim of the visit was to get experience on the Egyptian government endeavors on how they manage the water resources based on consultations with all stakeholders especially the local communities using the Decision Support Tools. Lessons and experience learned (national and regional), opinions and inputs of all relevant parties have been integrated together and have contributed to constitute the conceptual framework of the DSS. Experiences gained from the visit to Beni Swaif in Egypt gave this project huge positive reflection on the development of the Azraq Oasis DSS methodology, where, a holistic participatory approach involving all stakeholders and particularly the local farmers has been adopted. The approach was to use a DST for managing the irrigation system in Beni Swaif furrow system using an advanced automatic informative network system to monitor the levels of the water in the channels. The success of such system is the connection among several stations linked with a main station on a hourly – timing- basis. However, the system in Bani Swaif was built on the basis of all related parties participation to solve and organizing the surface water distribution in channels. The system, lessons learned and experience gained from Bani Swaif has had major positive impact on the methodology adopted in Azraq 'Oasis in terms of how all stakeholders are part of the process and getting involved to obtain success stories, in spite of the fact that the two cases are totally different in terms of technical problems addressed but the approach is similar.

4. DSS DEVELOPMENT PROCESS

4.1 DSS Conceptual Framework

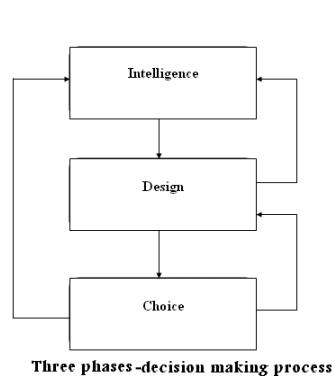
To align with the participatory approach, a step by –step method was used in this project to develop the conceptual framework for the DSS. The conceptual framework was built based in three main phases (steps/see Figure 4). These phases are:

(1) Intelligence phase: identification, collection and verification of data (primary and secondary)

(2) Design phase: building the data base by feeding both primary and secondary data in the computer

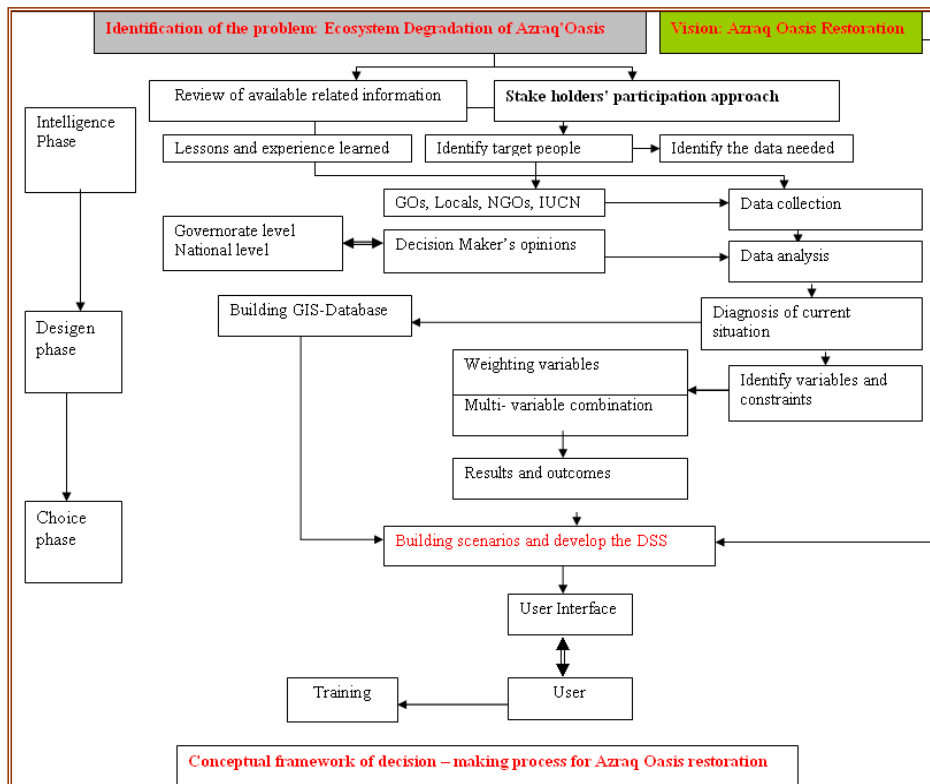
(3) Choice phase: building of a user-friendly computer interface to make choices between the final suggested alternatives, scenarios and potential solutions (management options).

Fig. 4. Phases in the DSS conceptual design



The conceptual framework developed and produced by the BRP is presented in Figure 5.

Fig 5. DSS Conceptual Framework



Following the project participatory and stakeholder process, a series of visits were made as part of the assessment step of the participatory planning cycle to those stakeholders who are directly in charge of water issues in the Azraq area to identify and collect relevant data for the DSS. Subsequently, several joint meetings with these stakeholders were held to arrive at a shared opinion on validity and relevance of information for the DSS.

This assessment process has taken several months of visits, meetings, workshops, brain storming and other sessions. It has resulted in a shared problem statement for the Azraq' Oasis and the identification of a provisional vision which have been integrated in the DSS choice interface. After agreeing on a shared problem statement and vision, available secondary data on the target area (Azraq Oasis) were identified and collected.

Monthly meetings and discussions were organized with the different stakeholders to inform and update on the DSS design process. These meetings took place at three levels; local, middle and national level. Outcomes from these meetings and activities were subject to the steering committee comments and also to advice and feedback from the BRDC Technical Advisory Committee. In general, it must be emphasized here that especially the representatives of the local population and local government authorities have been very supportive and have given valuable inputs and insights to the process of building the conceptual design for the DSS, while being very appreciative about what has been done.

With this up-dating and feed-back process an initial conceptual framework was developed following the above three phases. Once ready the conceptual design was presented first to the BRDC advisory committee and then to the Steering Committee of the Azraq Basin Restoration Project at the Ministry of Environment in Amman. The meeting was attended by representatives of the local population, the sub- governor of Azraq region and the Ministry decision makers.

4.2 Development of the GIS environment for the DSS **The GIS component in the Azraq DSS**

It has been suggested that there will be integration between the Azraq DSS and GIS. It was found from data provided by the related agencies that well coordinates are not completely accurate and can not be implemented within GIS environment and linked with the DSS database, therefore a Google Earth techniques used to overcome this problem, however, it is suggested that future work must be conducted on acquiring the exact location of all wells (Drinking, monitoring, and agriculture (legal and illegal). Also, another fieldwork must be conducted in combination with the use of remote sensing on all farms within the investigated area to build a GIS database for all farms including their physical location and size.

After completing both tasks above, the generated maps will be linked with Google Earth and the DSS, so decision makers can have a better look on the actual situation on the ground when making their decisions.

4.3 Design of the DSS inter-face

Following are the steps of building the DSS into computer environment. First, when clicking on the link of the decision-making support system, the first screen will appear as shown in Figure 6 below.

Figure 6. The DSS Inter-Face User



User is requested to enter the user name and password which you can get them from the person responsible for this system. The users of the DSS are classified into three categories, and they are as follows:

1. The first group "decision makers": users in this group can access two menus of the DSS:
 - a. Decision-making and
 - b. Reporting.
2. The second group "Basic data entry": users in this group are responsible for entering important and accurate data through the input menu. Such data will benefit users from the third group.
3. The third group "General data entry": users in this group are in charge of entering the names of farmers and their data and as well as farming activities in the Azraq Basin.

The system administrator is the one who can distribute users belonging to any group, according to their functions. After you enter a user name and password, you will be diverted to the home page, which contains several menus, and you'll see the appropriate commands and minus according to the type of user group to which you belongs Figure (2). As shown in Figure (7), on the top of the page, you will always see 3 links which are:

- a. Logout: To navigate outside the DSS
- b. Change Password: To change the designated password to something of your own.
- c. Home: To go back the main page of the DSS

Also, on the left corner of the page, you will see your user name.

Figure 7. Page of DSS project' components



On the above main page, there are the following links:

- a. Brief description of the project
- b. The DSS
- c. Previous studies and work methodology (English version)

- d. Work methodology and strategy preparation
- e. The expected outcomes of the project

On the main page, links to Entree, Decision-Making and Reporting are found:

1. Entree Menu

- a. **Crops factor link** (Figure 8): On this page, user could add crops and their class and also define the crop factor based on the growing period into four classes; beginning, rapid growing, middle of the season and crop harvest.

Figure8 .Crop Menue

المحاصيل الزراعية

المحصول

خضراوات

نوع المحصول

إضافة

إلغاء

ملاحظة : قيمة المعامل يجب أن تكون بين 0 – 99.999

| الرقم | المحصول | نوع المحصول | معامل المحصول (بداية الزراعة) | معامل المحصول (النمو السريع) | معامل المحصول (منتصف الموسم) | معامل المحصول (الحصاد) | التعديل |
|-------|-------------|-------------|-------------------------------|------------------------------|------------------------------|------------------------|---------|
| 049 | اسكواش غموي | أخرى | 0.710 | 0.985 | 1.010 | 0.810 | Edit |
| 048 | اسكواش | أخرى | 0.650 | 0.925 | 0.950 | 0.750 | Edit |
| 047 | يقطين | خضراوات | 0.700 | 0.975 | 1.000 | 0.800 | Edit |
| 046 | بطيخ أصفر | أخرى | 0.500 | 0.825 | 0.850 | 0.600 | Edit |
| 045 | فجل | أخرى | 0.750 | 0.875 | 0.900 | 0.850 | Edit |
| 044 | سبانخ | خضراوات | 0.850 | 0.975 | 1.000 | 0.950 | Edit |
| 043 | بصل | أخرى | 0.650 | 1.025 | 1.050 | 0.750 | Edit |
| 042 | خس | خضراوات | 0.850 | 0.975 | 1.000 | 0.950 | Edit |

- b. **Farmer link** (Figure 9): On this page, you can enter data about farmers such as their names, national ID number, telephone and farm area You can modify such data whenever there is a need to do so, and also you can sort the names in any manner that suit you.

Figure 9. Farmers' details

المزارعين

| | |
|---|---------------------|
| <input type="text"/> | اسم المزارع |
| حقل اختياري <input type="text"/> | الرقم الوطني |
| حقل اختياري <input type="text"/> | الهاتف |
| <input type="text"/> <input type="text"/> | مساحة أرضه الحقيقية |

| التعديل | مساحة الأرض الحقيقية بالمتر المربع | الهاتف | الرقم الوطني | اسم المزارع | الرقم |
|----------------------|------------------------------------|--------|--------------|----------------|-------|
| Edit | 400000.0 | | | سامر الجاصر | 0005 |
| Edit | 22000.0 | | | عطية أبو غلبون | 0004 |
| Edit | 40000.0 | | | سليمان عتيق | 0003 |

- c. **Wells link** (Figure 10): On this page, you can data about wells such as well code, well name, well type (Drinking, agriculture (legal), agriculture (illegal) and monitoring), well depth and well ownership (in case you choose farmer ownership, you will be diverted to the farmer list that have been entered in the farmer link to link the well with its owner). If you choose to select the well type as drinking well, automatically, the ownership will be government. If the well is owned by an organization that is not listed, refer to the system administrator to add it.

Figure 10. Wells' information

الآبار الجوفية

| | |
|--|-----------|
| <input type="text"/> | كود البئر |
| <input type="text"/> | اسم البئر |
| <input type="radio"/> غرب <input type="radio"/> زراعي مرخص <input type="radio"/> زراعي غير مرخص <input type="radio"/> مرافقة | نوع البئر |
| <input type="text"/> متر | العمق |
| <input type="radio"/> مزارع <input checked="" type="radio"/> جهة مالكة <div style="border: 1px solid black; padding: 5px; margin-top: 5px;"> حكومي هيئة قرية جنوب الأزرق قاعدة موقع السلطي الجوية </div> | الملكية |

إلغاء
إضافة

| الرقم | كود البئر | اسم البئر | النوع | العمق | نوع الملكية | المالك | التعديل |
|-------|-----------|-------------|-------|-------|-------------|--------|---------|
| 9 | F 9933 | زهرة الازرق | غرب | 77.00 | جهة مالكة | حكومي | Edit |

d. **Crops growing link:** On this page (Figure 11), you can add the necessary data about crops, where you have to choose the farmer name, the crop type, the duration of each growing period of the crop to match it with the crop factor, the cropped area, soil type, the date of planting, the date for harvesting, evapotranspiration, allowed pumping, irrigation system efficiency. After entering all data, you may calculate the optimum amount of irrigation water for each crop you entered for that farmer.

Figure 11. Crop information

| | | |
|---|-----------------------|---------------------|
| <p>الحصاد منتصف الموسم النمو السريع بداية الزراعة</p> | <p>أجاص</p> | المحصول |
| <p>معامل المحصول : (Crop Coefficient)</p> | <p>يوم</p> | المساحة المروعة |
| <p>النبحر + النتج (ET₀) : بالملمتر المكعب (mm)</p> | <p>رملة</p> | نوع التربة |
| <p>كفاءة نظام الري : (System Efficiency)</p> | <p>حقل اختياري</p> | البئر المستخدم |
| <p>حساب احتياج المحصول</p> | <p>حقل اختياري</p> | تاريخ بدء الزراعة |
| | <p>متر مكعب</p> | موعد القطف |
| | <p>إضافة الحذف</p> | كمية الصنخ المسموحة |

- e. **Physical Properties link (Wells):** On this page (Figure 12), you can enter the physical properties of wells including static water level, and pumping rate (cubic meter/ hour) and modify these properties whenever there is a change in their values.

Figure 12. Wells physical properties

متغيرات سنوية خاصة بالآبار

| رقم البئر | كود البئر | اسم البئر | قم باختيار البئر لإضافة المتغيرات |
|-----------|-----------|------------------|-----------------------------------|
| 1 | F 1011 | عوي طوفان 1 | Select |
| 2 | F 1013 | عطية 1 | Select |
| 3 | F 1028 | AWSA 1 | Select |
| 4 | F 1029 | AWSA 2 | Select |
| 5 | F 1030 | AWSA 3 | Select |
| 6 | F 1324 | هيئة قرية الأزرق | Select |
| 7 | F 7788 | دامي | Select |
| 8 | F 6565 | طائر المنقاء 3 | Select |
| 9 | F 9933 | زهرة الازرق | Select |

| | |
|---|--------------------|
| <input type="text" value="2009"/> | السنة |
| <input type="text" value=""/> متر | سطح الماء الساكن |
| <input type="text" value=""/> متر مكعب | معدل التصح بالساعة |
| <input type="button" value="إضافة"/> <input type="button" value="إلغاء"/> | |

- f. **Physical Properties link (*Basin*):** On this page(Figure 13), you can enter data about the annual water abstraction from the Basin and the annual recharge if available.

Figure 13. Basin Physical properties

متغيرات سنوية خاصة بالحووض

| | السنة | |
|--|-------|--|
| | 2009 | |
| | | المنبع الآمن |
| | | المنبع لأغراض الشرب خارج الحوض |
| | | المنبع لأغراض الشرب داخل الحوض |
| | | المنبع لأغراض الزراعة (آبار مرخصة) |
| | | المنبع لأغراض الزراعة (آبار غير مرخصة) |
| | | المنبع الجوي (التغذية الصناعية) |
| | | إضافة إنهاء |

| التعديل | المنبع الجوي (التغذية الصناعية) | المنبع لأغراض الزراعة (آبار غير مرخصة) | المنبع لأغراض الزراعة (آبار مرخصة) | المنبع لأغراض الشرب داخل الحوض | المنبع لأغراض الشرب خارج الحوض | المنبع الآمن | السنة |
|----------------------|---------------------------------|--|------------------------------------|--------------------------------|--------------------------------|--------------|-------|
| Edit | 0 | 18000000 | 25000000 | 1000000 | 17000000 | 24000000 | 2009 |

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g. Physical Properties link (Climate): On this page(Figure 14), user can enter data about monthly rainfall and monthly evapotranspiration of the area.

Figure 14. Climate data

المعلومات المناخية لحوض الأزرق

اختر السنة : 2009

| | | | |
|-------|--------------|--|---------------|
| | كانون الثاني | | الشهر |
| | ملمتر مكعب | | معدل التبخر |
| | ملمتر مكعب | | المطول المطري |
| إضافة | إلغاء | | |

| التعديل | المطول المطري | معدل التبخر | الشهر |
|---------|---------------|-------------|--------------|
| Edit | 11.91 | 6.47 | كانون الثاني |
| Edit | 8.18 | 8.50 | غباط |
| Edit | 4.96 | 11.64 | آثار |
| Edit | 4.85 | 17.57 | نيسان |

2. Decision Making Menu

- a. **Crop Water Requirement Link:** On this page (Figure 15), decision makers can estimate the required irrigation water for each crop based on crop type, climate, crop factor farming area and growing stage.

Figure 15. Water irrigation requirements

قم باختيار نوع المحصول : أشجار مثمرة

اختر المحصول من القائمة :

- نجاح
- توت
- خوخ
- زيتون
- عنب
- فستق
- كرز
- لوز

معامل المحصول (Crop Coefficient) :

التبخير + النتح (ET_o) بالمتر المكعب (mm) :

كفاءة نظام الري (System Efficiency) :

مساحة الأرض المزروعة بالمحصول (Area) :

النمو السريع :

متوسط الموسم :

الخصاب :

بداية الزراعة :

دوم

حساب الاحتياج

النتيجة : 2.346 متر مكعب

- b. **Wells Link:** On this page (Figure 16), decision makers can calculate the water budget for any given year based on entering the safe yield, pumping rate for drinking (outside and inside the basin), and agriculture (legal and illegal wells)

Figure 16. Calculation of water budget

جميع الآبار

$W = (A+F)-(B+C+D+E)$

A = 24 مليون متر مكعب
الصنخ الآمن

F: المشحون الجوي

B: الصنخ لأغراض الشرب خارج الخوض

C: الصنخ لأغراض الشرب داخل الخوض

D: الصنخ لأغراض الزراعة - الآبار المرخصة

E: الصنخ لأغراض الزراعة - الآبار غير المرخصة

حساب المتغير في الموازنة المائتة

النتيجة : **-27650000** متر مكعب

اختر السنة

النسبة المئوية للتطبيق (B) %

النسبة المئوية للتطبيق (C) %

النسبة المئوية للتطبيق (D) %

النسبة المئوية للتطبيق (E) %

كمية المشحون الجوي (F) متر مكعب

3. Reporting Menu: On this menu, user can produce a report for all actions you may have done on this DSS.

4.4 Building scenarios and management options

As for the development of the conceptual design for the DSS workshops and meetings were held with local communities and other relevant parties to debate and agree on possible future scenarios under which management measures need to be taken. With scenarios is meant here the description of situations in a defined future as determined by a set of external factors, such as climate change, population growth, global economy and (in the case of Azraq) contribution of water resources other than the Azra Basin to water demand in Jordan.

Outcomes from these discussions have resulted in several scenarios and possible management options. The scenarios concentrated on two main factors:

- (i) Uncertainty, if sufficient funds can be mobilized for initiating and future projects; and
- (ii) Uncertainty, if adequate cooperation can be organized among local communities and with government authorities.

Management options

In view of the scenarios as constructed as indicated above different management options have been discussed and finally approved by the stakeholders, NRDC Advisory Committee and Azraq Steering Committee

The management options used in the Azraq DSS are designed to be user friendly and easily managed in order to give the decision makers the flexibility of using a single option or multiple options to reduce the pumping rate from the basin in order to reach the projected safe yield. These options are based on using the following basic information (consolidated on the basis of data fed to the data base):

1. Pumping rate (MCM/ Year) for drinking purposes outside the Azraq Basin,
2. Pumping rate (MCM/ Year) for drinking purposes within the Azraq Basin,
3. Pumping rate (MCM/ Year) for agricultural purposes from legal wells,
4. Pumping rate (MCM/ Year) for agricultural purposes from illegal wells,
5. The safe yield for the Azraq Basin (MCM/ Year).

The used management options include:

1. Reducing the pumping rate (%) outside the Azraq Basin for drinking purposes,
2. Reducing the pumping rate (%) within the Azraq Basin for drinking purposes,
3. Reducing the pumping rate (%) for agricultural purposes from legal wells,
4. Reducing the pumping rate (%) for agricultural purposes from illegal wells,
5. Reducing the pumping rate for agricultural purposes through calculating the actual irrigation requirement for each crop,
6. Reducing the pumping rate for agricultural purposes through introducing new crops that require less water for irrigation,
7. Increasing the safe yield of the basin through groundwater recharge projects.

5. Azraq DSS User Groups

The Azraq DSS is accessible – and protected by a user name and a password – for three levels of users:

1. ***Group I***: Decision makers who can access the decision making and reporting menus,
2. ***Group II***: Basic data entree controllers who can enter the basic data about the basin to the system through the entrée menu including climatic data and well data.
3. ***Group III***: General data entrée controllers who enter the data about farmers and the agricultural activities within the basin.

5.1. The GIS component in the Azraq DSS

It has been suggested that there will be integration between the Azraq DSS and GIS. It was found from the available coordinates that, well coordinates are not accurate and far away from the real locations and can not be implemented within GIS environment and

linked with the DSS database. The water Authority provided the coordinates of these wells in Palestine Belt system which has been transformed to latitude/ longitude coordinates.

Therefore, in order to integrate the well location with the DSS, the wells file provided by the water Authority of Jordan was divided into 3 files:

1. Monitoring wells,
2. Drinking wells,
3. Agriculture wells.

However, an attempt was made to use the Google earth and Remote sensing techniques to correct the locations of these wells and the farms (Drinking, monitoring, and agriculture (legal and illegal). This work has led to build a Geographic Information System (GIS) database for the locations of all farms and wells and their physical location and size. Three shape files were generated using ARC GIS9.3 and then exported to KML (**Keyhole Markup Language**) format.

KML is an XML notation for expressing geographic annotation and visualization within Internet-based, two-dimensional maps and three-dimensional Earth browsers. KML was developed for use with [Google Earth](#), which was originally named Keyhole Earth Viewer.

The KML format links the data files with Google Erath, so, whenever the link on the DSS is selected, the KML file will open Google Erath and display the desired wells (Monitoring, drinking or agriculture) on the Google Earth Satellite imageries

In the current DSS system, only some selected wells were used, but in the future, the system could be developed to have more wells and better database to be shown on the Google Erath imageries.

Also, in the future, the DSS system could be developed to have the farm locations map with its database, but this work need an intensive fieldwork to collect the appropriate data about farms within the basin and their coordinates.

After completing both tasks above, the generated maps were linked with Google Earth and the DSS, so decision makers can have a better look on the actual situation on the ground when making their decisions.

6. RECOMMENDED FOLLOW-UP

This Chapter will propose a number of activities and projects that either could make use of the here described DSS, could further strengthen or capitalize on it, or could be logical outcomes of the DSS and subsequent management decision process for the restoration of Azraq.

6.1 Activities directly related to final / further DSS development

- The conceptual design which is already produced was subject to review and feedback by technical people, decision makers and planners from the national related agencies before being adopted
- GIS layers or maps for wells used for both drinking and agriculture (legal and illegal) and also for farms in the area (vegetables, fruits and olives). These maps will be linked with Google Earth to give decision makers a better view of the situation in the area and to benefit from Google Earth services (measuring distances and areas). Google Earth also update the available images for the region from time to time which will allow users to compare the situation on the ground at a certain time with the situation at another time, especially the farming activities in the area.
- An initiative by GTZ through the Ministry of Water and Irrigation for developing a monitoring network of wells will be funded. This will assist in practicing the fluctuation of the balance of recharge-discharge from the Oasis. Resulting data should be incorporated in above GIS layers for the Azraq DSS.

6.2 Community project proposals

In order to achieve the project vision, stakeholders, particularly the local community suggested the following projects:

- *Demonstration pilot projects (Jojoba species, Palm trees propagation etc...),*
- *Reduce the groundwater pumping to reach the safe yield,*
- *Close illegal wells.*
- *Control the pumping process within a limited amount,*
- *Estimate the exact water irrigation requirements,*
- *Adopting a drip irrigation system,*
- *Adopting water harvesting projects,*
- *Monitoring wells (establish a centralized-digital network of wells to show the change of water quantity and quality),*
- *Maintain the domestic water network,*
- *Initiate income-generating projects (Revolving fund, in house- grey water use, Salt refinery, Tourism, Handicrafts).*

6.3 Other proposed projects to reverse degradation in the Azraq Oasis

- Lesson learned from restoration of terrestrial ecosystems in the Jordan Badia based on Community Participation and Stewardship, will provide another positive dimension to the Azraq Restoration Project.
- Proposals are currently in development which eventually will support the Azraq restoration process such as:
 - ✓ The Jawa restoration project based on directions from HRH Prince Al Hassan Bin Talal to restore the ancient water harvesting system.
 - ✓ The development of criteria for water harvesting sites in collaboration with Al Albayt University based on GIS, Remote sensing and Indigenous knowledge. This proposal is supported by HE the General Secretary of the Ministry of Water and Irrigation and fund raising is in the pipeline.
- A number of governmental, private and international organizations started to take action to limit the negative impact on the water situation in the basin, for example:
 - ✓ the Royal Court granted a local community fund for establishing a new Eco-tourist site.
 - ✓ Project initiatives implemented and funded by GTZ and Mercy Corps provide for generating incomes for local communities.
- BRP in collaboration with AWO and IUCN and other national and international organizations are contributing to attenuate this devastating situation with some projects that are now being implemented and others in preparation to reverse the degradation in the Oasis. These projects are:
 - ✓ *Rangeland Ecological Restoration of the Northern Badia, Based on Community Participation and Stewardship.*
 - ✓ *The aim is to restore the deteriorated ecosystems in the Badia region in cooperation with the local communities to manage the restored ecosystems on a sustainable basis. The project is funded by the UNCC for 15-20 years*
 - ✓ *National Carrier Pipeline with Al Albayt University: the aim is to develop a design for groundwater basins network and characterize the quality of the surface and groundwater*

7. CONCLUSION

This report describes how in a very participatory way a Decision Support System (DSS) has been developed for guiding important technical and political decisions on the best way to manage and use the ground water reserves of the Azraq Aquifer. It must be emphasized here that, contrary to many other examples of DSS development, the local population and local government officials in Azraq Oasis have had a key role in making sure that the right kind of data are identified and collected and that their own interests

and priorities, next to those of the big cities and those at a more national level, are taken into account in the conceptual framework for the DSS and as a result in the design itself of the DSS. In short the DSS proposed here transmits the rich discussions ideas and knowledge of a very wide group of interested and relevant stakeholders from the Community, District, Governorate and National level.

It is wished that – in view of the dramatic over-abstraction of the aquifer, especially for highly unsustainable agricultural practices implemented at a large scale – this DSS may be helpful in identifying, analyzing and comparing the different management options for better and more sustainable use of the Azraq Aquifer, one of the few if not the only aquifer in Jordan with substantial natural recharge. It is equally wished that national policy and decision-makers have the courage to use the objective information that can be made available by using this DSS in the way it is intended for to make the necessary rational choices to preserve not only the natural recharge and the existence of this invaluable aquifer, but also to take the necessary measures to preserve what is left from a very unique wetland, still recognized as a Ramsar site.

Annexes

Annex 1. Detailed information on the Azraq Basin

Annex 2. References cited

Annex1. Detailed information on the Azraq Basin

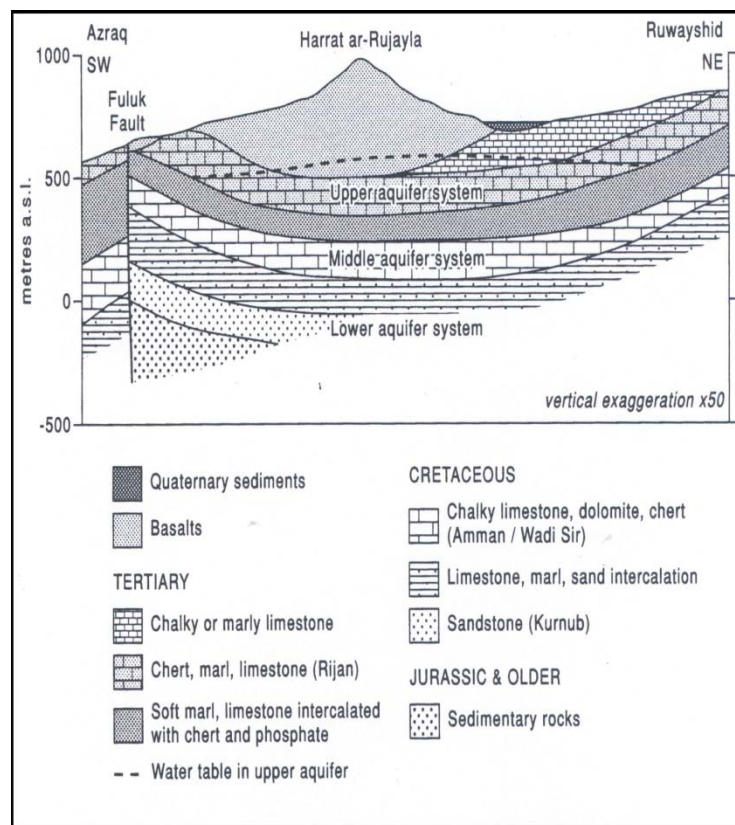
A. Aquifer Characteristics

Azraq basin is considered one of the most important water sources in Jordan groundwater in the Northern part NE Part of the basi The Basin is located in the Northern and central parts of Jordan. Groundwater in the Azraq basin is founded in the three aquifer systems complexes (Figure 1), Upper, Middle and Lower Aquifers (Dottridge, 1998); the aquitard and the Muwaqqar (B3) marls separate the Upper and Middle aquifer systems, through which significant leakage is thought to occur. Most of the pumped water is from the shallow aquifer system, which is over exploited. The basin has developed rapidly in the last ten years where significant parts of grazing lands are used for agriculture. According to Jordan Ministry of Environment figures in 2006, the agriculture area had increased by 30 times in the last 10 years. This is mainly due to use of the agriculture as a mean to register land and investors tendency from outside basin to invest in agriculture. At the end of 1992 and as a direct result of the over pumping from the basin to agricultural activities and to supply Amman and Zarqa cities the natural springs in the basin dried out. This had lead to dry the oasis which considered as an alarming environmental disaster. The safe yield of Azraq basin is ranges from 24 million m³ /year. Currently, the total annual abstraction is around 56 million m³ /year (36.7 MCM for agriculture and 15.6 MCM to supply Amman and Zarqa cities); this resulted in 32 million m³ /year deficit. Due to the over pumping from basin, water elevation dropped significantly. The static water level is dropping at a rate of 80-90 cm/ yearn occurs in three aquifer.

The Middle aquifer dips under the Azraq basin from outcrops in the western highlands of Jordan and into Iraq. There is some uncertainty about the flow pattern, which may approximately follow the dip, converging towards the centre of the basin. The Middle and Lower aquifers are separated by low but variable permeability Marls and marly limestone (Dottridge, 1994).

According to Gibbs (1993), water level declines of between 0.35 to 0.55 meter per year. The increase in aquifer withdrawal has caused an upward migration of more highly mineralized water into the aquifer. The groundwater quality varies within the basin. In the central part, the water in the Amman-Wadi Sir system is mineralized and sulphurous and of generally poor quality, with total dissolved solids concentrations ranging between 800 and 2,500 mg/L. In the western and north-western part of the basin, in the basalt system, the quality is good with total dissolved solids concentrations between 200 and 500 mg/L (USGS, 2000)

Figure 1. Cross section of the main aquifers of the Badia, (Source: Dottridge, 1998)

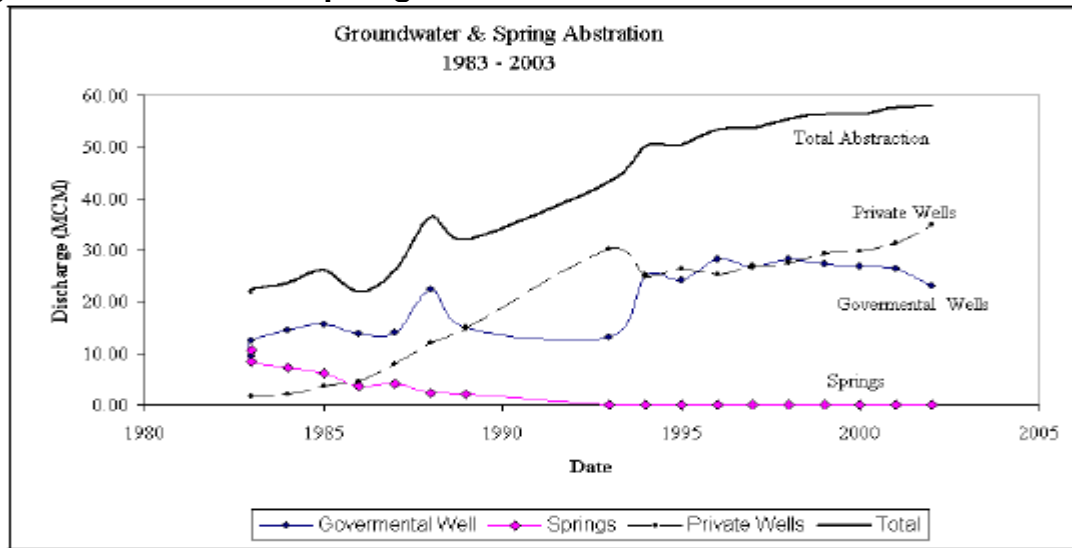


Al-Momani (1996) conducted an isotope study of the upper groundwater System in Azraq Basin. According to the researcher, determination of the stable isotope composition of the groundwater provides an indication for the mean elevation at which this water was recharged. The results of the isotope studies show that the mean elevation of recharge was about 100m a. s. l. for the groundwater in the upper Azraq basin and 1200 m a. s. l. for the groundwater in the lower Azraq basin. The researcher concluded that the results of this study indicate that groundwater is recharged in the area between the Jordanian/ Syrian border. Also, the researcher argued that the basalt aquifer in the upper Azraq basin is very thick.

Due to the over pumping from basin, water elevation dropped significantly (drop in water elevation is around 10 m in the Mazare' area and around 17 m in WAJ wells area). This lead to drop in springs flow and dry up of the Oasis.

Figure 4 shows recorded drop in water elevation. It is worth noting that the majority of Jordan's average annual precipitation comes in the arid and desert zones, 6,375 MCM or 75%. These areas are most at risk from climate change caused increases in temperature and reductions in rainfall. (Hagan, 2009).

Figure 2. Recorded drop in groundwater table level from 1982-2003



B. Aquifer Recharge

A significant deficiency regarding water supply and recharge is limited information on groundwater aquifers. Recharge points are not identified and therefore can neither be protected from damage, nor can opportunities be envisioned to maximize recharge. Groundwater monitoring wells are limited and poorly located, typically along highways for easy access; it is not uncommon to find monitoring wells in the drawdown shadow of others nearby. Knowledge of aquifers is so weak that it is not possible to predict with any accuracy how much water remains. At the same time water quality deterioration indicates that the bottom of the fresh water is being approached in some aquifers.

Mudallal (1967) reviewed the annual recharge from the UNDP (1966) data. Through the use of a flow net analysis aquifer throughput was calculated which equated to a recharge with a value of 30 MCM.

Parker (1970) also reviewed the UNDP data of 1966 and used flow net analysis to estimate the through-flow and the result was 18.1 MCM as an annual recharge.

Humphries (1982) used piezometry from the Azraq well field and through the use of flow-net analysis; the groundwater recharge was estimated at 33.1 MCM.

In 1989, the Water Authority of Jordan (WAJ), used the water budgeting method (daily runoff, interception, infiltration and surface storage processes that occur before the runoff were calculated) using the US Soil Conservation Service's Curve Number method. This resulted in an estimation of the average recharge to the basin of 34 MCM.

C. Aquifer Abstraction

The beginning was in the in 1982, where 15 new wells were drilled as a beginning of a new investment era in the Azraq basin resulting in larger exploitation of the upper or shallow aquifer (abstraction then was estimated at 18 to 22 MCM of water per year) and a growing agricultural economy. The total average pumping rose to 40 MCM/year over the past years (Hagon, 2009).

Al-Kharabsheh (1996) conducted a hydro-geological and hydro-chemical study of the upper aquifer system of the Azraq Basin. The results of this research showed that the upper aquifer system in Azraq basin includes the Quaternary sediments, the basalt and the limestone formations of Wadi Shallala (B5) and Rijam (B4). Also, the aquifer is unconfined and the severe pumping is the greatest problem in the basin and may cause salt water intrusion especially if the water levels sink below 500 meter above the mean sea level which is the static water level of Qaa'-Azraq area. The researcher argued that the water quality in the northern part is better than in the south and south-eastern parts.

In 1992, Al-Beiruti, constructed a mathematical model for the shallow basaltic aquifer system. The researcher calculated that the amount of infiltration from rainfall to groundwater reservoir is about 14.2 MCM. Furthermore, the researcher built some computer programs, performed several case studies, and estimated the response of the aquifer to different pumping scenarios. The researcher concluded that without considering infiltration, 32.5 MCM/year may be extracted from the whole aquifer, of which 15 MCM/year may be extracted from the AWSA well field (Jordan Water Authority wells) up to year 2005. If at least six wet water-years were guaranteed in a 15 years period, pumping may be extended, at the same rate, for an extra five years (until 2010). Increasing the pumping rate up to 36.5 MCM/year will decrease the period of pumping to five years only. If these five years were wet,water-years, pumping at this increased rate may not be extended for more than two years.

Sunna' *et al* (2002) conducted an integrated study over five years funded by the Higher Council of Science and Technology (HCST) under supervision of the Badia Research Program (BRDC). The investigated area is the Azraq basin. The study resulted in several thematic reports on water, land use and sub-surface investigations. Results of the study are located at the HCST and the BRDC. One of the main outputs were maps (Figure 3&4). that prototype vividly the basin in terms of land use, anomalies, potential sites for mining, soil quality and potential sites for extracting water and oil

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