UNIVERSITY OF EXETER
Centre for Water Systems

AQUASTRESS

SYSTEM DYNAMICS MODELLING:

THE MERGUELLIL VALLEY WATER SYSTEM

by

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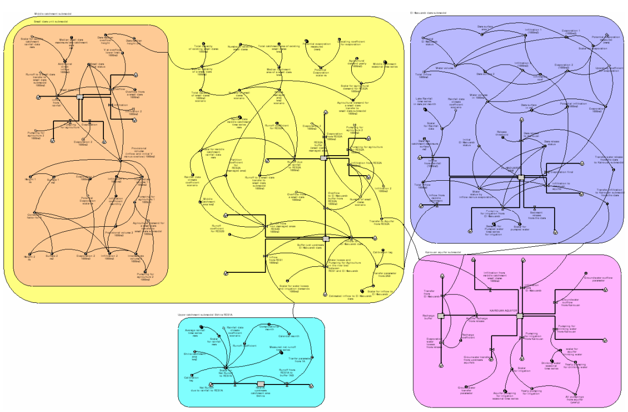

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ABSTRACT

System Dynamics Modelling is a methodology for studying and managing complex feedback systems, typically used when formal analytical models do not exist, but system simulation can be developed by linking a number of feedback mechanisms. They are particularly useful for building, understanding and presenting models to non-engineers. This report presents the procedure for developing conceptual and System Dynamic Modelling in participatory interdisciplinary context, for a complex hydrological system, the Merguellil valley catchment in Tunisia. The model is being used for studying various water management scenarios for 35 small and one large dam in the Merguellil valley, and their impact to aquifer recharge, under different climatic conditions.

Keywords: *System Dynamics Modelling, Hydrological System, Aquifer Recharge, Water Management, Complex Systems*

Table of Contents

1. Introduction

This report is the second on the application of System Dynamics Modelling for the simulation of complex water systems, presenting in detail research on the subject, performed at the Centre for Water Systems (CWS), University of Exeter. The first report (Vamvakeridou-Lyroudia & Savic 2008a) can also be downloaded from the CWS website www.ex.ac.uk/cws.

System Dynamics Modelling (SDM) is a methodology for studying and managing complex feedback systems, typically used when formal analytical models do not exist, but system simulation can be developed by linking a number of feedback mechanisms. Forrester (1961) introduced system thinking and SDM in the early 60's as a modelling and simulation methodology for long-term decision-making in dynamic industrial management problems. Since then, SDM has been applied to various business policy and strategy problems (Barlas 2002, Sterman 2000). Consequently it has proven to be very useful for the simulation and study of complex environmental (Ford 1999, Mulligan and Wainwright 2004, Mazzoleni et al 2004) and water systems (Simonovic 2003, Chung et al 2008) in an integrated way.

Constructing, examining, and modifying System Dynamics Models (SDM) follows an iterative approach. Starting from conceptual qualitative models, simple quantitative models with few feedback loops and little detail are built, so as to allow the construction of an initial working numerical simulation model (Atanasova 2006). The working model can then be modified and improved as necessary to show the desired level of detail and complexity (Haraldsson & Sverdrup 2004).

AQUASTRESS-Mitigation of Water Stress through new Approaches to Integrating Management, Technical, Economic and Institutional Instruments (AQUASTRESS 2005) is an EC FP6 IP project (2005-2009), comprising 35 international partners and 8 case studies, which differ considerably both in technical and spatial/societal terms. Some of the case studies involve agriculture/irrigation/water allocation issues, while others focus on urban/industrial water quantity/quality problems, the locations ranging from Northern Europe to Northern Africa. Most case studies involve re-cycling/re-use and/or re-allocation of water, whose water quality in turn varies over time and space.

Additional complications arise by occasionally incomplete data and by the need of introducing interactive participatory processes at every stage, leading to application-driven investigations. Each case study is considered to be a highly complex water system, where water management options technically available (e.g. water re-use, groundwater management, aquifer recharge, desalination etc), links, interactions and consequences, all aiming at water stress mitigation, are interlinked and hard to simulate separately, i.e. without taking into account their internal connections. Therefore in order to establish a common ground as well as a common approach from the engineering point of view, conceptual modelling has been applied in a number of case studies in Bulgaria, Tunisia, Cyprus, Morocco and Portugal (AQUASTRESS 2006a).

Further on, SDM has been developed and applied for two case studies, which have been considered suitable for such application, namely for Bulgaria (Kremikovtzi water system) and Tunisia (Merguellil valley water system). They have been selected for different reasons:

The Kremikovtzi water system is a very complex one, involving industrial water use and recycling, as well as shortages in fresh water resources. SDM has been developed and applied, aiming at defining feasible operational scenarios under varying climatic conditions and water shortages. This case study has been the prototype for SDM application and software tool within AQUASTRESS. Results and full description of this SDM case study exist in literature (Vamvakeridou et al 2007, Dimova et al 2007, Vamvakeridou and Savic 2008a) and other AQUASTRESS reports (AQUASTRESS 2008a-Deliverable 3.3.4).

The Merguellil valley water system in Tunisia is the second case study selected for full SDM development and application. The decision to develop SDM for Tunisia was taken by participatory process, involving technical (engineering) experts and local stakeholders, taking into account that this specific case study had a good potential and interest for SDM development, in order to investigate alternative water resources, such as rainfall harvesting through small dams and aquifer recharge, for a whole valley-Merguellil in Tunisia, with the objective of mitigating the pressure on natural water resources. Moreover long data series exist for the site, a fact that made possible to calibrate the model.

This report presents the SDM for the Merguellil valley water system, i.e. the procedure for developing conceptual modelling and SDM in participatory interdisciplinary context for this case study. The model was developed at the Centre for Water Systems (University of Exeter), while data and information were provided by IRD (Institut pour la Recherche et le Development) in Montpellier, France, who had long experience working in the specific region of Tunisia in various hydrology projects. Thus, this report represents a combined effort and collaboration between the two institutions (CWS and IRD).

In order to build a model using standard SDM techniques system components have to be described as interlinked compartments (stocks), flows (directed links) and converters (influences) (Ford 1999). Over the years several SDM specialized software visual environments have been developed (Mulligan and Wainwright 2004), which enable the implementation and use of such models in a straightforward way, without the limitations of conventional programming languages, making the model accessible and understandable even to non-programmers. In this way SDM visual environments can be considered as suitable tools for developing models in a gradual, interactive and participatory way.

Mathematically all (or most) existing SDM visual environments are similar (AQUASTRESS 2005 Report WP 4.2.1, AQUASTRESS 2006b). SIMILE (Muetzelfeldt & Massheder 2003, www.simulistics.com) has been selected as the primary software platform for implementing the quantitative (numerical) model for the two case studies within AQUASTRESS, for two reasons: (a) it efficiently supports breaking the model into sub-models, thus facilitating the development process of very complex systems, and (b) it can automatically produce model documentation (code) in C++, thus making the model potentially re-usable for further specialized applications, if necessary. SDM as described here, has been included as a software tool for i3S the software library for AQUASTRESS (Vamvakeridou-Lyroudia & Savic, 2008b)

2. SDM application procedure

Within AQUASTRESS a continuous interactive process is applied, between two different groups of participants. The first group consists of "experts", who define, describe and suggest various "technical options" to be potentially applied for solving a problem (i.e. mitigating water stress) in specific case studies. It should be pointed out, that the group of experts is interdisciplinary, including non-engineers (i.e. from socio-economic disciplines). This fact alone adds to the complexity of the procedure, as far as mutual understanding is concerned. The second group comprises local "stakeholders", who present the case study to the experts, together with initial suggestions for solving the problem, listen to further suggestions, react to them by accepting/ rejecting/modifying them and finally implement the “solution”. Obviously this process is strongly interactive, requiring mutual communication and understanding at all stages (Magnuszewski et al 2005).

As it has already been mentioned in the previous section, SDM has been applied for modelling the complex water system of the Merguellil valley water system (Tunisia case study), according to the following step-by-step procedure:

1. Initially all (case study specific) technically available water management options available for improving water use and mitigating water stress for the Tunisia case study (along with other AQUASTRESS case studies), have been defined and formally conceptualized in SDM terms by IRD (Institut pour la Recherche et de Developement) and the University of Exeter (UNEXE). This phase was completed in July, 2006 (AQUASTRESS 2006a).

2. Problem identification at system level for the water quantity and quality for the Merguellil water system, together with the description of a dynamic hypothesis explaining the cause of the problem has been performed. This step requires interactive cooperation between “experts” and “stakeholders”, and taken place through various meetings and good local knlowledge by IRD.

3. The conceptual (qualitative) model (diagram for each system/case study is built, by combining and linking several technical options, again through an interactive procedure. (Completed Nov. 2006) The generic conceptual diagram for the Merguellil valley water system water system (AQUASTRESS, 2006a) is considered to be the “building blocks” for the water system simulation.

4. Consequently case study specific initial quantitative models (more than one- as it will be explained in detail in the following section for water quantity modelling) for Merguellil (including numerical data and parameters), have been developed, in SDM visual environment/mode (SIMILE graphics environment) by UNEXE, in cooperation with IRD (acting as stakeholder leader for Tunisia), which have been consequently revised and agreed upon by consecutive meetings. The first model was set up in June 2007, during a AQUASTRESS/case study meeting in Sofia (June 22, 2007), in fully participatory “live” process: An expert (UNEXE) was drawing the components in SIMILE environment, while other experts and stakeholders were providing information, descriptions, opinions and discussion.

5. The SDM model was updated and revised repeatedly, by technical meetings, exchange of information and discussions between the case study stakeholder leader (IRD) and UNEXE. . This step took about a year, till June 2008, when the SDM reached its final form.

6. The final SDM models are being for generating alternative scenarios, exploring factors, policies and impacts, aiming at supporting the decision making process, as it is presented in detail in this report (July 2008).

Schematically the procedure for the application of SDM for Merguellil is shown in Figure 1.

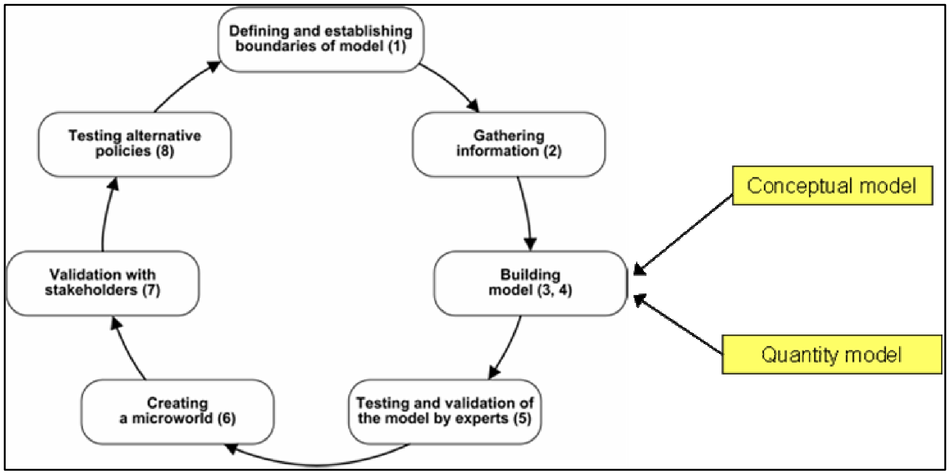

Figure 1: Schematic representation of SDM development

3. Merguellil (Tunisia): Short description of the case study.

The Merguellil wadi basin is located in the central Tunisia (Figure 2), a region characterized by a semiarid climate. The water stress in this catchment is mainly due to imbalance between a limited and highly variable resource and an ever increasing demand, essentially for agriculture and drinking water. The studied area spreads on a surface of about 1325 km² with El Haouareb dam, which was priming in 1989, as outlet.

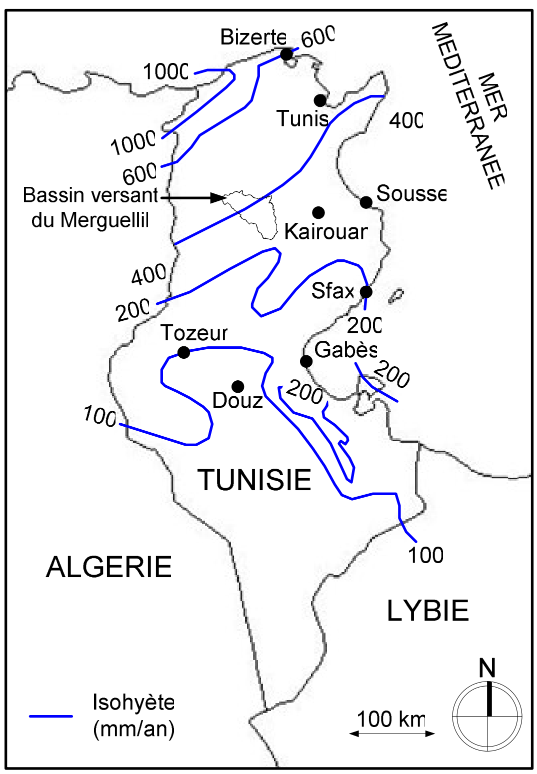

Figure 2: The Merguellil valley in Tunisia showing also the mean average year rainfall in mm (from Lacombe 2007)

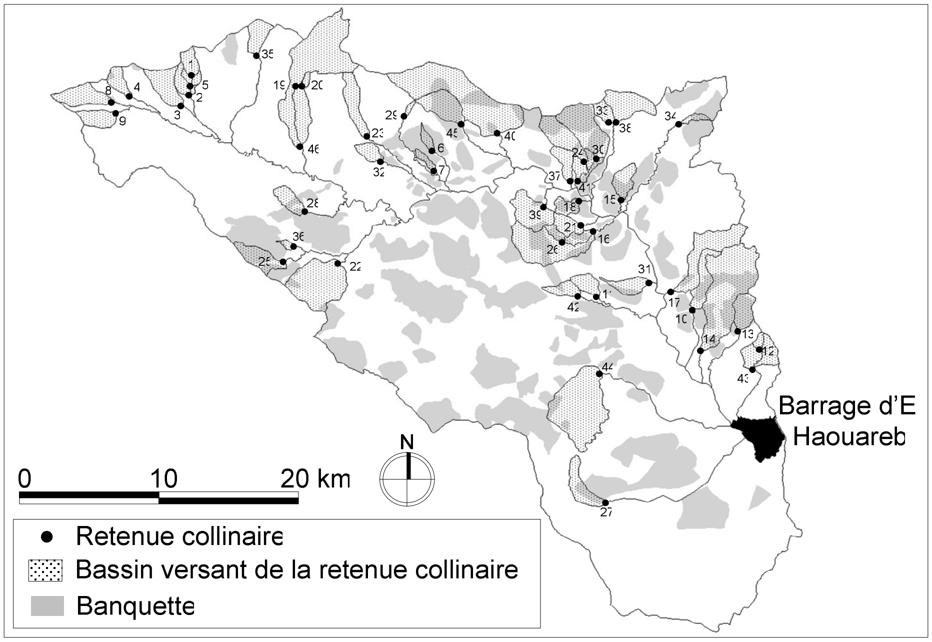

Figure 3: The Merguellil valley and its small mountain dams (from Lacombe 2007)

The basin was submitted to several works of soil and water conservation since the sixties with an important contribution in the late eighties. These practices, that currently cover nearly ¼ of the surface of the basin, are classified in two categories: the practices on basin slopes constituted essentially by contour ridges (200 Km²) and the practices on the hydrographical network by implantation of small hilly dams draining about 170 Km² (Figure 3).

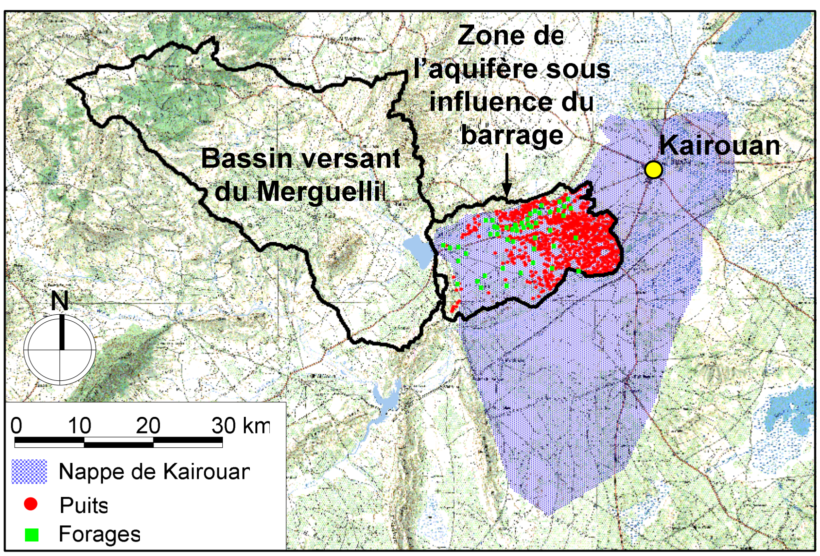

Figure 4: Kairouan plain aquifer and the zone influenced by El Haouareb (from Lacombe 2007)

Four interconnected aquifer systems (Kairouan plain aquifers-Figure 4), which spread on about 600 Km², constitute the main underground reservoirs in relation with the Merguellil wadi. Important withdrawals, which increased progressively since the beginning of the seventies, are made in these aquifers for water supplies, agricultural use and tourist industry. These withdrawals are responsible for a decrease of the water table of 30 m in certain points. While the rainfall varies from 200 to 500 mm a year (Figure 2), two extreme events took place in 1969/70 and 1989/90.

The annual mean inflows at the stations of Haffouz (675 Km^2) and Sidi Boujdaria (890 Km^2) have been estimated respectively to 16.7 and to 32 millions m^3 (for the period 1974-1982), whereas the annual inflows to the El Haouareb dam were evaluated to only 23 millions m^3 between 1989 and 1998.

Two factors may have contributed to the decrease of the inflows of this basin: on the one hand the reduction of the precipitations inputs, and on the other hand the human action consequent to the different works of water and soils conservation. A study of the annual variability of several variables (local and spatial) built from the daily rains has been undertaken using statistical approaches (Kingumbi 2006). Moreover, the changes in hydrological behaviour of the Merguellil catchment due to the Water and Soil Conservation Works (WSCW) were characterized, as a function of the rainfall-runoff variability (Lacombe 2007).

The main objective of the SDM development for Merguellil is the investigation of different scenarios for studying the impact of climate change, and the water and soil conservation works (WSCW-small dams) and El Haouareb, on the Kairouan plain aquifer and its recharge, as it is presented in detail in the following sections.

4. Selection of technical options and their conceptual diagrams

The water stress in the Merguellil catchment is a problem of imbalance between a limited and highly variable resource and an ever increasing demand, essentially for agriculture and drinking water. Actions may concern the supply and/or the demand. The most realistic action about the demand is linked with the water pricing. The water supply will face a long-term decrease, because of conservation works in the Merguellil upstream catchment. The most obvious proposal for improving the water resource is then to save water from evaporation in the El Haouareb dam through a more dynamic and efficient management.

Based on this, the technical option defined as “Alternative water resources / Rainfall harvesting" (AQUASTRESS 2006a) will be applied for the Merguellil catchment’s water system, combined with the option “Water table management" in order to compare different scenarios for managing water resources and recharging the aquifer. Specifically:
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- Option “Rainfall harvesting”: Impact of rainfall harvesting on surface runoff was considered in Tunisia at different spatial scales: at the scale of the bench terrace, at the scale of the small sub-catchment, at the scale of the Merguellil upstream catchment. At this last scale, explanations of the observed decrease in streamflow during the last decades significantly differ. The most reasonable assumption is that the major role is taken by the increasing number of conservation works.
- Option “Water table management”: In Tunisia, the change in surface runoff in the Merguellil upstream catchment induces a change in the volume stored in the big El Haouareb dam and, as a consequence, a new distribution of water in the Kairouan plain.

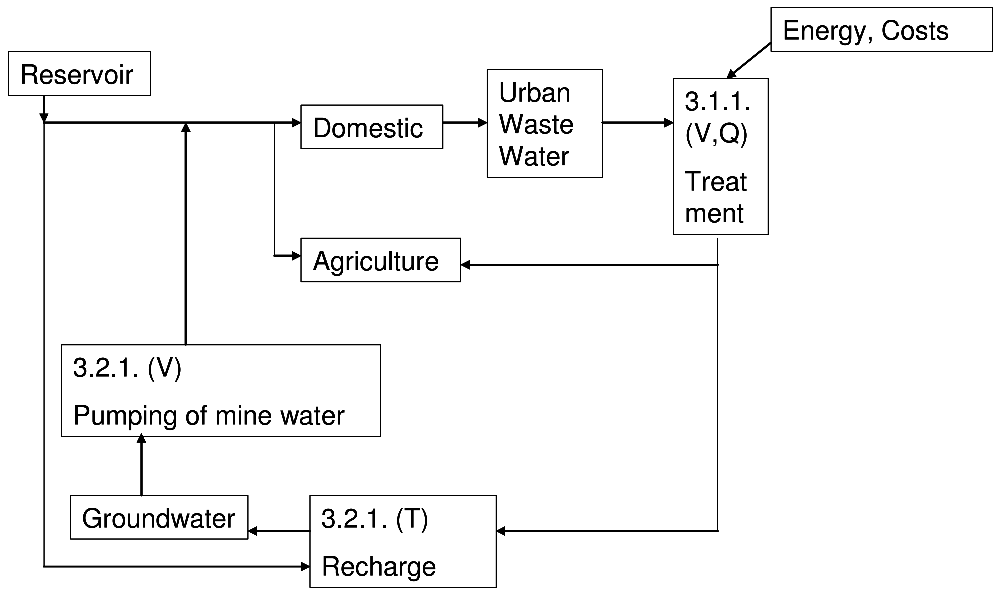

Figure 5: Conceptual model for the technical option “Water table management (3.2.1)”

As it has already been mentioned in previous reports (AQUASTRESS, 2006a) , the conceptual models (diagrams) of technically available water management options for all case studies within AQUASTRESS are the “building blocks” for each system (case study). Indeed, prior to any SDM or numerical modelling, all technically available water management options for all project case studies had to be selected, code named and schematically represented in a similar way, in terms which can be understood even by non-engineers.

The conceptual diagrams are independent of any specific software environment. They are schematic layouts representing the functionality of generic water management options, thus serving as introductory tools to the conceptual and SDM specific models for each case study. Although simple, these diagrams mainly conform to the semantics of SDM models. They contain: (a) stocks (compartments) representing water sources and water users, (b) directed arrows linking the components, and (c) “converters” i.e. processes affecting the volume (V), quality (Q) or mass transfer/conveyance (T) of water.

The conceptual model, shown in Figure 5 shows the option “Water table management”, which is related to the Merguellil water system.

5. Conceptual model

The Merguellil system conceptual model (Figure 6) has been developed by IRD, using the stocks (compartments), directed arrows (flows) and converters, as described in section 3. It has been initially developed in October 2006 and is described in detail in AQUASTRESS, 2006a. A brief description is also presented here.

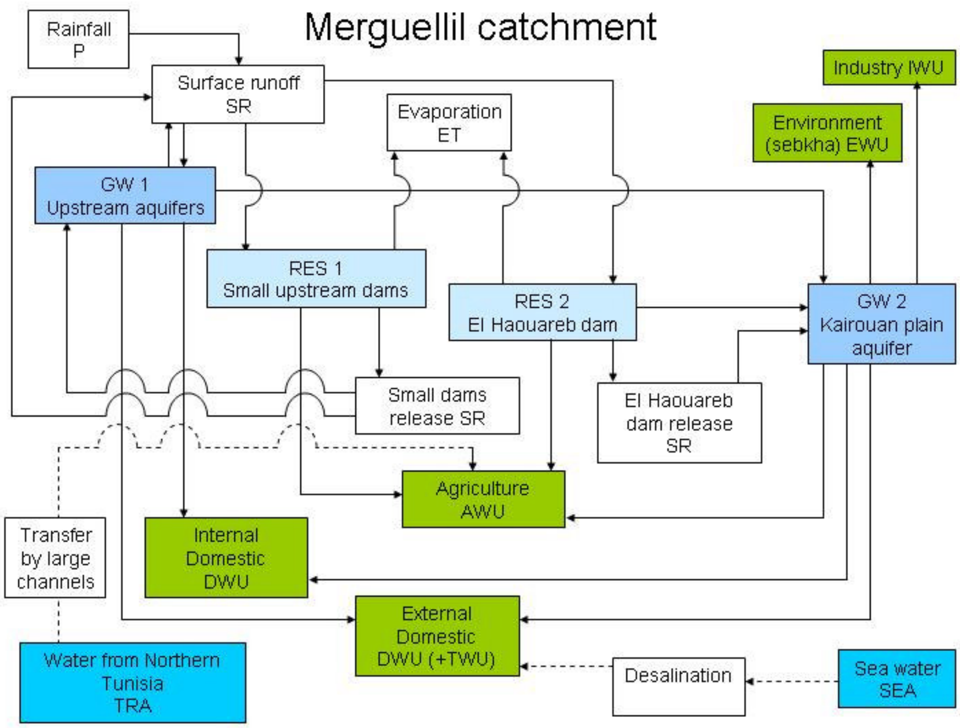

Figure 6. Conceptual Model of the Merguellil catchment water system (Tunisia)

Water stocks are (1) three small interconnected aquifers in the upstream catchment, keeping in mind that the extreme upstream of the catchment has no groundwater resource at all; (2) an increasing number of small dams built for conservation of soil and water; (3) the large El Haouareb dam, (4) the very thick alluvial aquifer of the Kairouan plain.

Aquifers are exploited for agriculture at a very local scale and for the drinking water supply. This exploitation modifies the hydraulic exchanges between aquifers and wadi (ephemeral river) Merguellil, and its tributaries. One aquifer is even largely overexploited.
The small dams for conservation of soils and water were built in order to protect the three largest dams reaching the Kairouan plain against a rapid silting up. When they are young, they stop a large part of the rainfall on the spot, for the benefit of the local agriculture, dierectly fed from rainwater, but significantly reducing the water accumulation in large reservoirs. The El Haouareb dam loses between 50 and 66 % of its water through karstic fissures, and so recharges the aquifer beneath the dam. Because of this infiltration and of climatic fluctuations, the reservoir has often dried up and wadi Merguellil nearly never flows in the plain.

Additional water stocks in the area are external. National authorities consider the possibility of transferring by pipes water from the north-western Tunisia, where the rainfall is much higher. Another project under consideration is the connection between the main dams of the country. In both cases, the result would be a smoothing of level variation in the El Haouareb dam and a decrease in the number of days without any water in the reservoir. Last, desalination plants along the coast line would lighten the drinking water demand fromthe Merguellil aquifers: a large part is exported out of the region for the supply of the large cities and tourism facilities on the seaside.

Flows between the river network and the upstream aquifers have changed. The increase in groundwater exploitation, or even the overexploitation, has probably completely erased the groundwater contribution to the Merguellil base flow and a part of the surface flow probably feeds the depleted aquifers.

Exchanges between the El Haouareb reservoir and the underlying aquifer are always for the benefit of the aquifer. This flow is added to the groundwater flow in this aquifer from its own upstream and ends into the karst of the El Haouareb sill. Part of the karst flow comes up to the surface through fissure springs and creates an unexpected artificial lake at the foot of the dam. This water runs for several hundreds of metres before infiltrating in the plain. The rest of the karst groundwater flow pours directly into the plain aquifer.

When the level of the El Haouareb dam exceeds a fixed limit (e.g. 211 m in 2005/6), a water release is ordered. Depending on the release duration, the artificial river goes on a few kilometres downstream and infiltrates in the plain, although this is a very rare event; except small ordinary releases for silt clearance, a release for recharge only occurred five times in 17 years and only two had a volume over 3 Mm3.

The main water use for groundwater is agriculture (AWU). In the upstream Merguellil catchment, several farmers install mobile pumps when there is enough water in the small reservoirs or in the rivers. All other irrigating farmers take their water from wells and boreholes. In the Kairouan plain, irrigation is much more developed than upstream. A small part of the El Haouareb dam water is pumped for agriculture and feeds the large El Haouareb irrigation scheme. A few private farmers illegally pump in the karstic spring at the foot of the dam, others have their own well or borehole or negociate the access to water with a neighbour. Illicit wells also exist in the public irrigation schemes in order to balance an unsatisfying distribution.

Groundwater is also pumped for supplying the drinking water (DWU) in the region or to the coast towns. The main urban centres are fed by Sonede, the national company that takes water from a very few sites. The smallest rural towns are fed locally with the help of the Ministry of Agriculture.

For the conceptual model, rainfall is more interesting when it becomes a surface runoff. The impact of the conservation works is still discussed. According to the coupled modelling of surface and groundwater flow in the upstream catchment (Kingumbi, 2006), the present impact would be very limited. Moreover, the surface runoff reaching the main courses is later reduced by losses to underlying aquifers.

The surface runoff results from the heaviest rainy events, so that in most of the catchment the flow generally lasts a few hours or days and only the largest rivers may present a continuous or rather continuous flow. Depending on their respective heads, the hydrographic network and the aquifers may exchange a significant flow. Intensity and direction of such a flow varies with time: the river base flow is sustained by the aquifer contribution when losses in karstic or porous media may reduce the river flow. Exchanges between the river network and aquifers can be natural or enhanced by the human intervention, as in the case of a dam release.

Irrigation is now well developed, in particular in the Kairouan plain. Calculations of water balance performed at the plot scale indicate that such a return is possible but there is no evidence of a significant infiltration of irrigation water that could already have reached the water table.

Evaporation strongly affects large and small lakes. It can be estimated by hydrodynamic and geochemical-isotopic approaches. These two complementary views must be compared. Previous results already exist for small lakes and for the El Haouareb dam (Kingumbi et al 2004). In this last case, IRD is now renewing calculations with the most recent years and by crossing hydrodynamics and geochemistry.

Pumpings or releases from the El Haouareb dam are not precisely measured but they can be checked with the time series of the dam level. Besides natural phenomena (infiltration and evaporation) that represent respectively 52 and 29 % of the dam volume, pumping is weak (only 12 %). The water demand for agriculture is obviously linked with climatic conditions: a dry year corresponds to a worse filling of the reservoir and a higher demand downstream, which leads to crisis situations solvable only by an increased pumping from the aquifer.

Quality problems are not now the most important question in the Merguellil catchment. In its southern neighbour, the Zeroud catchment, that also leads to the Kairouan plain, the Sidi Saad reservoir is characterized by a very high mineralization. The geological context explains the difference between the two catchments. Interactions between the two catchments may intervene through a natural process, the groundwater flow to the north through the Aïn el Beidha aquifer, and through an artificial process, the future connection of the largest Tunisian dams.

The water uses in the Merguellil catchment are various. Agriculture (AWU) represents about 80 % of the water demand in the countries of the southern and eastern sides of the Mediterranean basin. This is obviously the first term, where water could be saved or give a better added value. But interactions with technical, social and economic considerations are complex. For instance, the conversion to drip irrigation may save some water but it is often parallel with an extension or intensification of irrigation. The domestic water supply (DWU) is the most important use in terms of urgency. Because of the demographic growth and of the rise in the standard of living, this part of the water demand is still increasing. It is provided through centralized systems or through small autonomous units in case of remote communities. The water demand for Tourism (TWU) could be linked with the domestic use because the water supply is often provided by the same networks. The main differences are probably the high seasonality of the consumption and new uses, as the golf courses. Industry (IWU) may be locally important but it represents at the regional or national scales a water demand much smaller than agriculture and drinking water. Industry may sometimes be satisfied with poor quality water, which allows the recycling of waste water. As everywhere, the environmental demand (EWU) exists in semi-arid areas but it is often badly taken into account by managers who favour other uses.

6 System Dynamics Model

6.1 Initial and intermediate SDM models

As it has already been mentioned in Section 2, the initial SDM for Merguellil was developed in June 2007, and is based on the conceptual model described in Section 5. All the upstream reservoirs are combined in a single stock. The same holds for the upstream aquifers. External water sources have been ignored, while an additional stock (buffer) is needed in order to simulate time delays and lags within the system, between the dam releases and the recharge of the Kairouan aquifer. Rainfall time series is the one parameter (converter) affecting practically all the components of the system.

This initial model (Figure 7) although still low in detail, shows the main interconnections among system components and has been included in a previous report (AQUASTRESS 2007). It was developed using the SIMILE graphics environment as mentioned in Section 1.

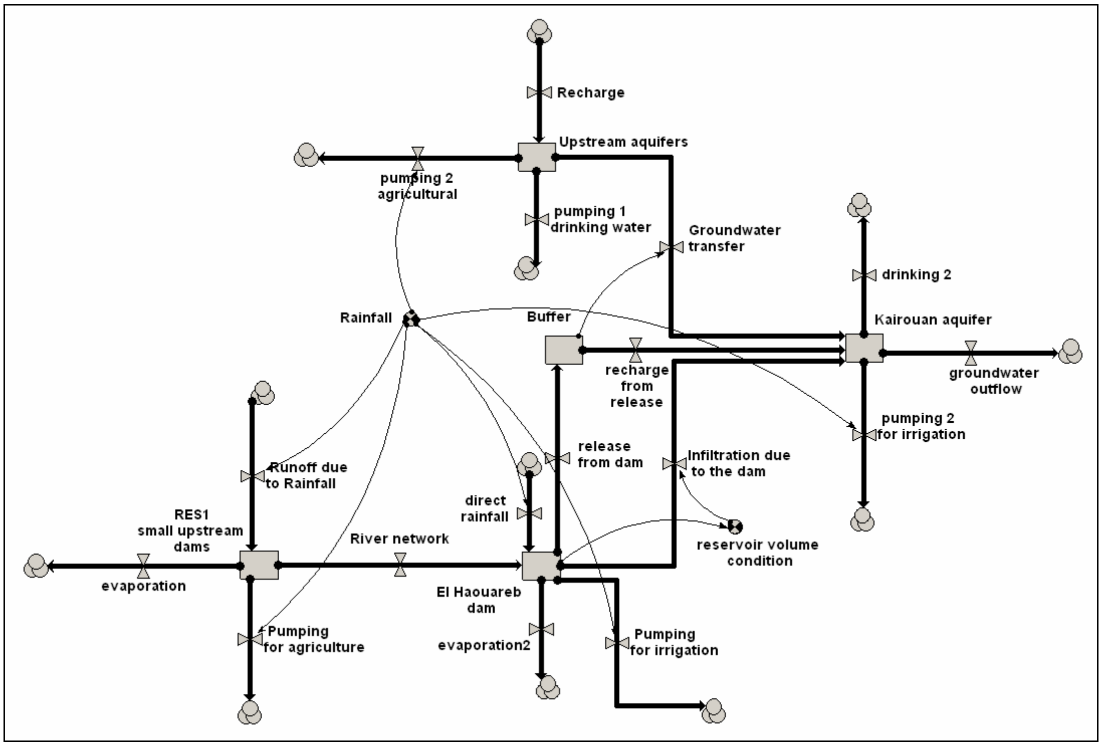

Figure 7: Initial SDM for Merguellil catchment water system (June 2007)

In the following months a more detailed version of the SDM has been developed, after a technical meeting and collaboration between UNEXE and IRD (October 2007), which is shown in Figure 8.

In this second intermediate version, the whole Merguellil system/model is divided in four subsystems. In SDM terms and glossary these subsystems are called submodels.

(a) Upper Skhira submodel
(b) Middle catchment submodel (containing the small dams)
(c) El Haouareb submodel
(d) Kairouan aquifer submodel

The submodels are shown in Figure 8 from left to right. The division in four main submodels has been retained for the final SDM, and they will be explained in detail in Section 6.2. They are also mentioned here, for the intermediate SDM, in order to show the gradual progression towards the final SDM development.

The numerical (quantitative) population of the model started with this intermediate SDM (Figure 8), on which also the data needed have been determined. Then IRD (C. Leduc-case study leader for Tunisia) started collecting and providing data to UNEXE (L.S. Vamvakeridou-Lyroudia), who in turn used them for calibration and the first scenarios. During this process, which was interactive and lasted for several months, the model was gradually enhanced and reviewed, until it reached its final form.

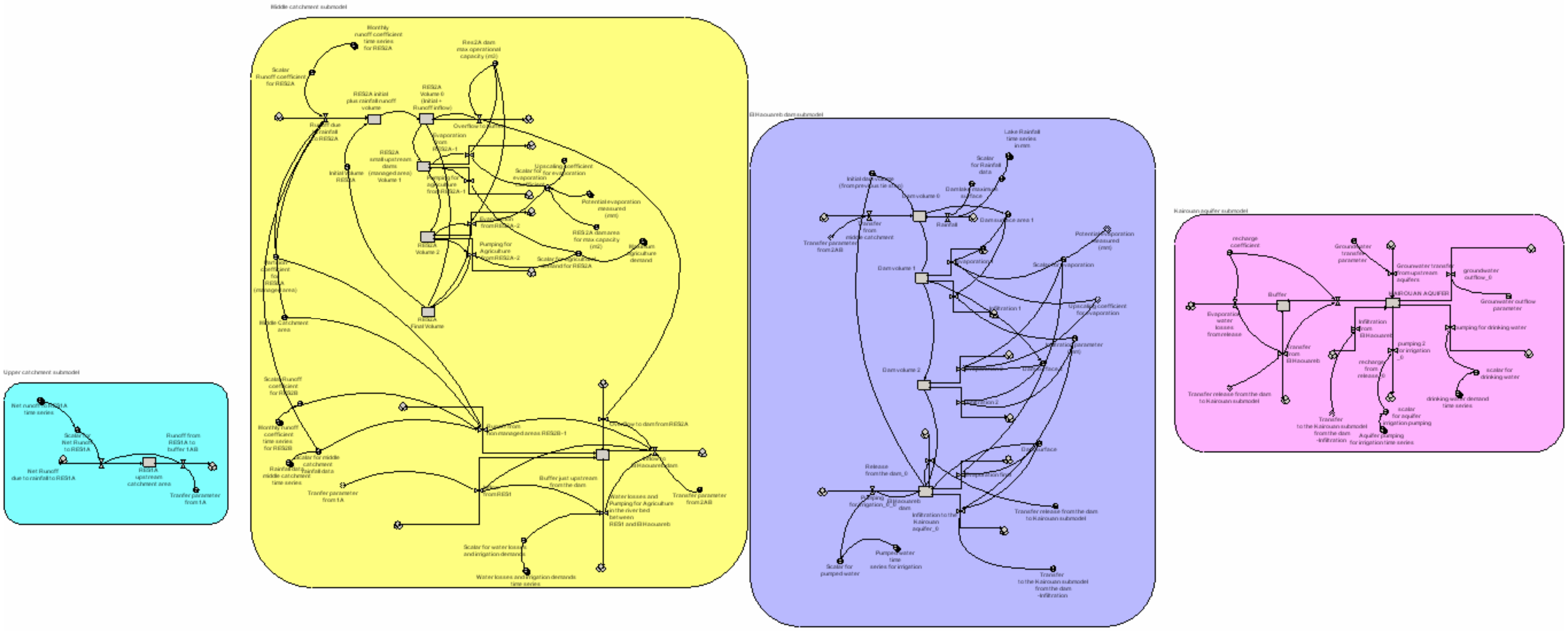

Figure 8: Intermediate SDM for Merguellil (October 2007)

6.2 Final SDM model and its components

The SDM model was finalized in June 2008, during the final stages and fine-tuning of the calibration process.

The division in four submodels, which started at the intermediate phase has been retained. Therefore, in the final, as in the intermediate SDM, the system is divided in four main submodels, as it has already been mentioned in the previous section.

(a) Upper Skhira submodel (light blue-bottom left)
(b) Middle catchment submodel (containing the small dams) (yellow-up left)
(c) El Haouareb submodel (darker blue-up right)
(d) Kairouan aquifer submodel (pink-down left)

The middle catchment submodel contains the simulation of the water and soil conservation works (small dams) in the catchment upstream the El Haouareb dam. It is practically the most complicated submodel, and the one presenting the most difficulties in simulating scenarios. After various trials it was decided to encapsulate a separate subsystem/submodel in it, which represents the simulation of a "typical" small dam unit. Therefore a subsystem is included in the middle catchment submodel (in orange), called "small dam unit".

Obviously, water flow in the catchment takes place from the upper catchment (Skhira), to the middle catchment, then to El Haouareb and ends at the Kairouan aquifer downstream from El Haouareb. At the intermediate SDM this sequence has been retained in the graphics (Figure 8), so as to make the SDM look more "realistic". However, as the number of components kept growing, it was not feasible to keep this sequence in the graphics, while also providing a diagram that would be printable in a single page. So the submodels have been re-arranged graphically.

It should be mentioned that the submodels are interconnected. Some of the interconnections show on the diagram, but several others do not. They are simulated as "shadow" or "ghost" variables in the model, in order to avoid an overcomplicated graph with many connecting lines – a serious problem with complicated SDM, as Merguellil. Mathematically, they are similar.

The final SDM is shown in Figure 9. The submodels and components are presented in detail in the following paragraphs.

The SDM simulations for Merguellil run on a monthly time step and all the components representing rate of flow are expressed in $1000m^3$ /month.

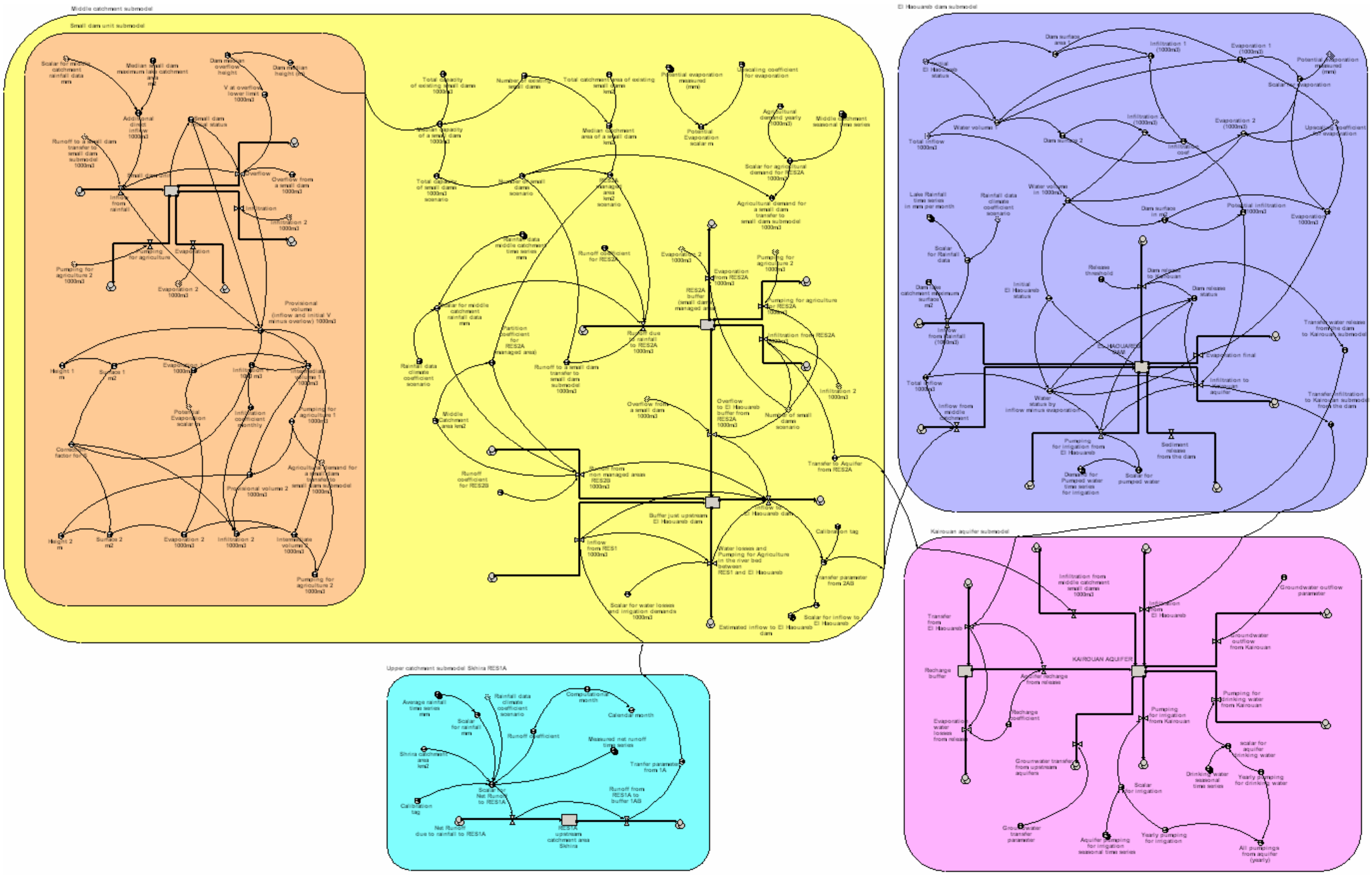

Figure 9: Total final SDM for Merguellil catchment system

Skhira upper catchment submodel

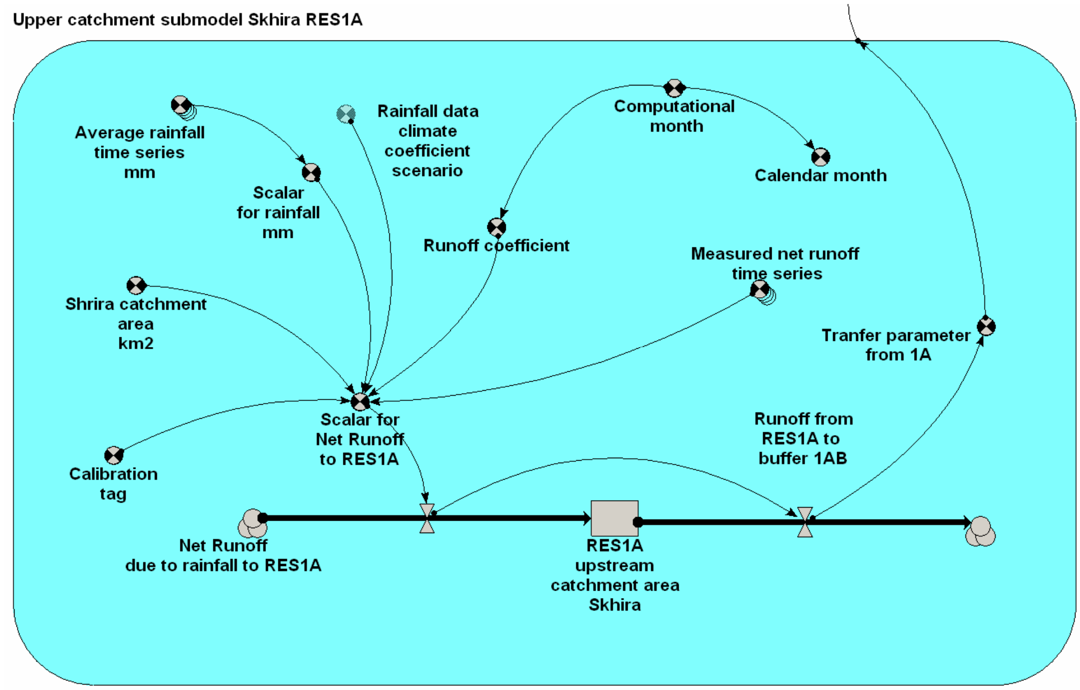

Figure 10: Skhira upper catchment submodel

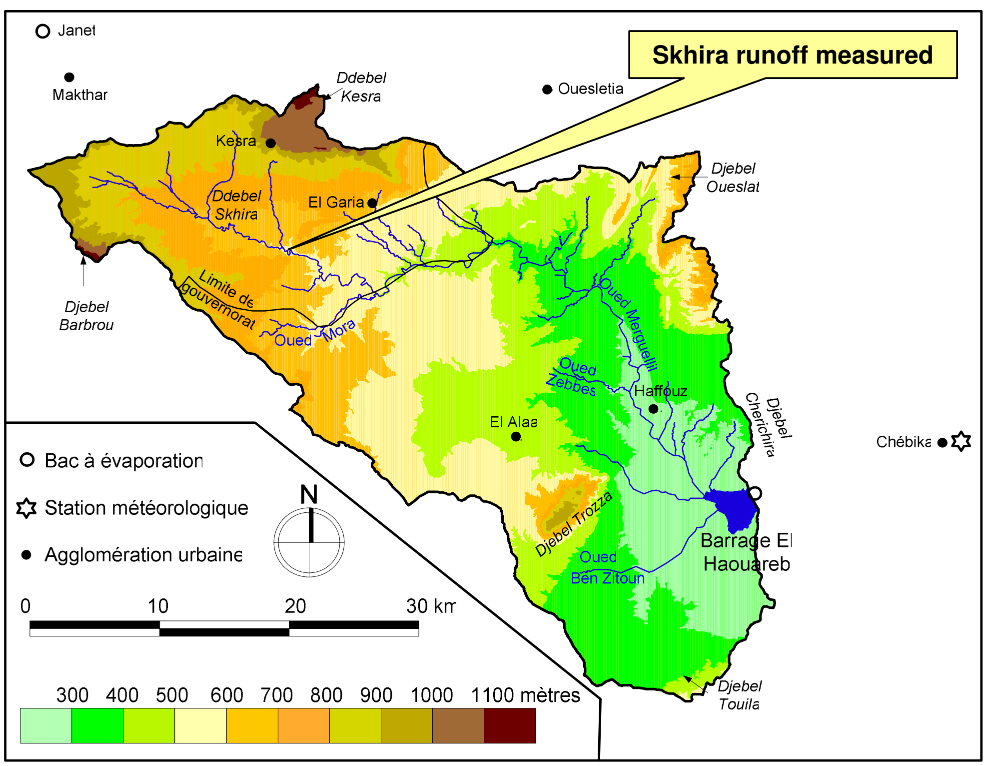

Figure 11: Geophysical map of the Merguellil valley catchment showing the upper catchment-Skhira (from Lacombe, 2007)

The Skhira upper catchment submodel (Figure 10) is the most upstream part of Merguellil valley system. It simulates the mountainous upper part of the catchment (Figure 11)

The upper catchment area is 194 km^2 and ends downstream at a point where runoff measurements have been collected. This SDM submodel of the upper catchment (Skhira) has been designed with the sole purpose of providing runoff inflows to the middle catchment submodel. No more components are needed, because the upper catchment is not directly involved in the SDM management scenarios for the middle catchment.

Therefore it contains only 1 stock, a buffer, called conventionally RES1A (Figure 10). From RES1A surface runoff is transferred to the middle catchment through the appropriate transfer parameter shown in the model.

RES1A can transfer either measured values for calibration of the model, or synthetic runoff values, estimated through rainfall and a runoff coefficient. The model can switch from one mode (calibration) to another (scenarios) by turning on/off (1/0) the "Calibration tag" parameter shown in Figure 10. If the calibration tag is turned on (value=1), then the "measured runoff time series" are transferred to the middle catchment. In the case of scenarios (calibration turned off-value =0), runoff values are estimated through the "average rainfall time series" and the rule for runoff coefficient. The parameter "rainfall data coefficient scenario" enables the user to introduce different multiplication factors (e.g. 0.8, 0.5) to the rainfall data, so as to simulate varying climatic conditions (essentially drought) for different scenarios.

The actual runoff measurements for RES1A range from 1989 to 2001, while rainfall data range from 1989 to 2006. So, in order to use more recent rainfall data and synthetic rainfall time series calibration was needed. The calibration was based in the common period (1989-2001) between runoff and rainfall time series. During the calibration process different rules for the runoff coefficient have been tried. The ideal case, pointed out by IRD with prior knowledge of the area, would be to differentiate the runoff coefficient according to the intensity of the daily rainfall. However this could not be done using monthly data, as was the case with this model. So, different rules have been tried, based on the monthly rainfall and/or the calendar month. The final rule adopted, which had the best fitting is using an average coefficient (11%) for all months and 20% for September. This rule was used for the scenarios.

It is worth mentioning that all parameters called "Scalar" within the SDM have been introduced for computational reasons, namely to retrieve the proper value from a time series. This is a special programming requirement for this type of software and can be seen in all instances in the Merguellil SDM model, where time series are involved as data. It is explained here, because it is the first time it appears (Figure 10) and will not be explained at the other submodels.

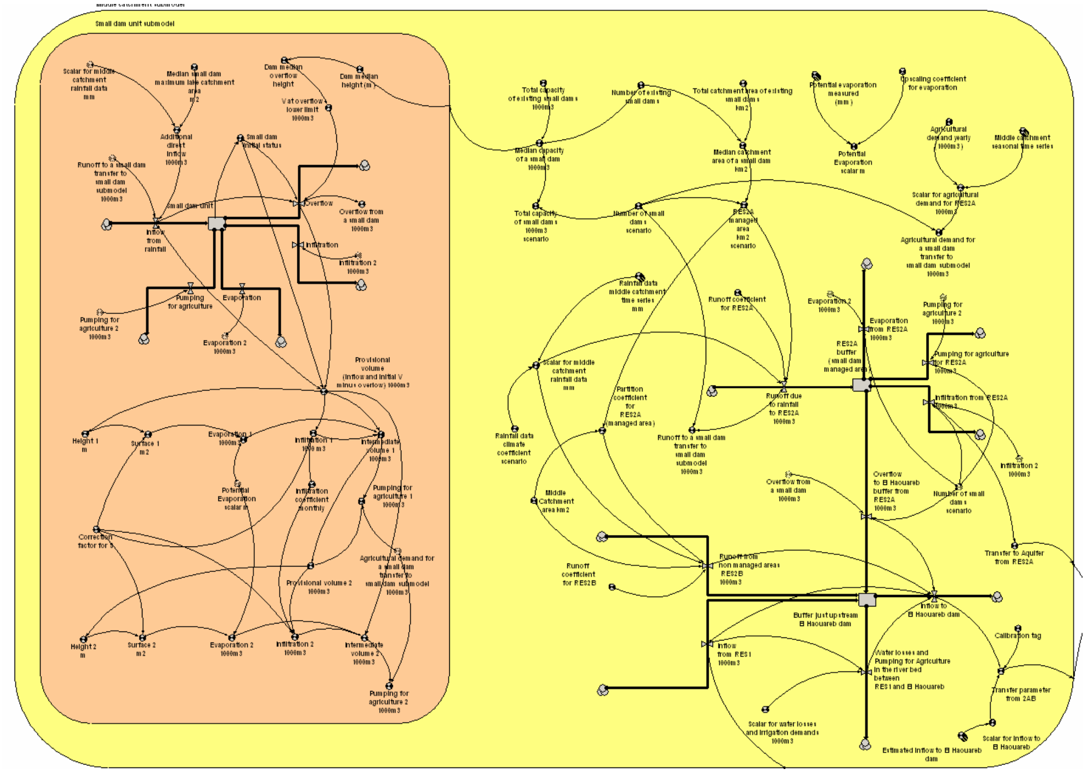

Figure 12: Middle catchment submodel Total view

<u>Middle catchment submodel</u>

The middle catchment submodel simulates the catchment between Shrira measuring station and El Haouareb dam (Figure 11). The total area of the middle catchment is 984 km^2.

This submodel is shown in Figure 12. It contains another submodel called “Small dam unit”, simulating mathematically the behaviour of a typical “small dam”.

This submodel has several components and as a result it is complicated and hard to read as total view in a single page graph, as in Figure 12. This picture is included only in order to give a total picture of the subsystem. Parts of it are explained in detail in the following paragraphs and figures.

As it has already been mentioned in Section 3 and shown in Figure 3, surface runoff in the middle catchment is partially managed and controlled by a number of soil and water conservation works (conventionally called “small dams”). These small dams operate as follows:

Inflow from surface runoff from the catchment area of every small dam comes into each small dam reservoir. There is also additional direct inflow from rain on the small dam reservoir area. If water level in the small dam exceeds the overflow level, then overflow occurs and the excessive water overflows. The remaining water in the small dam is used for irrigation by pumping (agricultural demand). There are also evaporation and infiltration losses. Infiltration losses from the small dams are considered to flow into the Kairouan aquifer downstream.

Currently, there are 35 small dams in the middle catchment (Lacombe 2007, Kikumbi 2006). It should be mentioned that there is also a small number of small dams in the upper Skhira catchment, but those have not been taken into consideration for the middle catchment SDM. Detailed data about the small dams are presented in the next Section. The total capacity of the small dams is currently 6618.3 x $1000m^3$, while the total managed area of the catchment is 183.83 km^2. It should be mentioned that the total capacity of the small dams cannot be considered a constant parameter, because their capacity is reduced in time, because of sediments.

The SDM model for a small dam unit is presented in Figure 13.

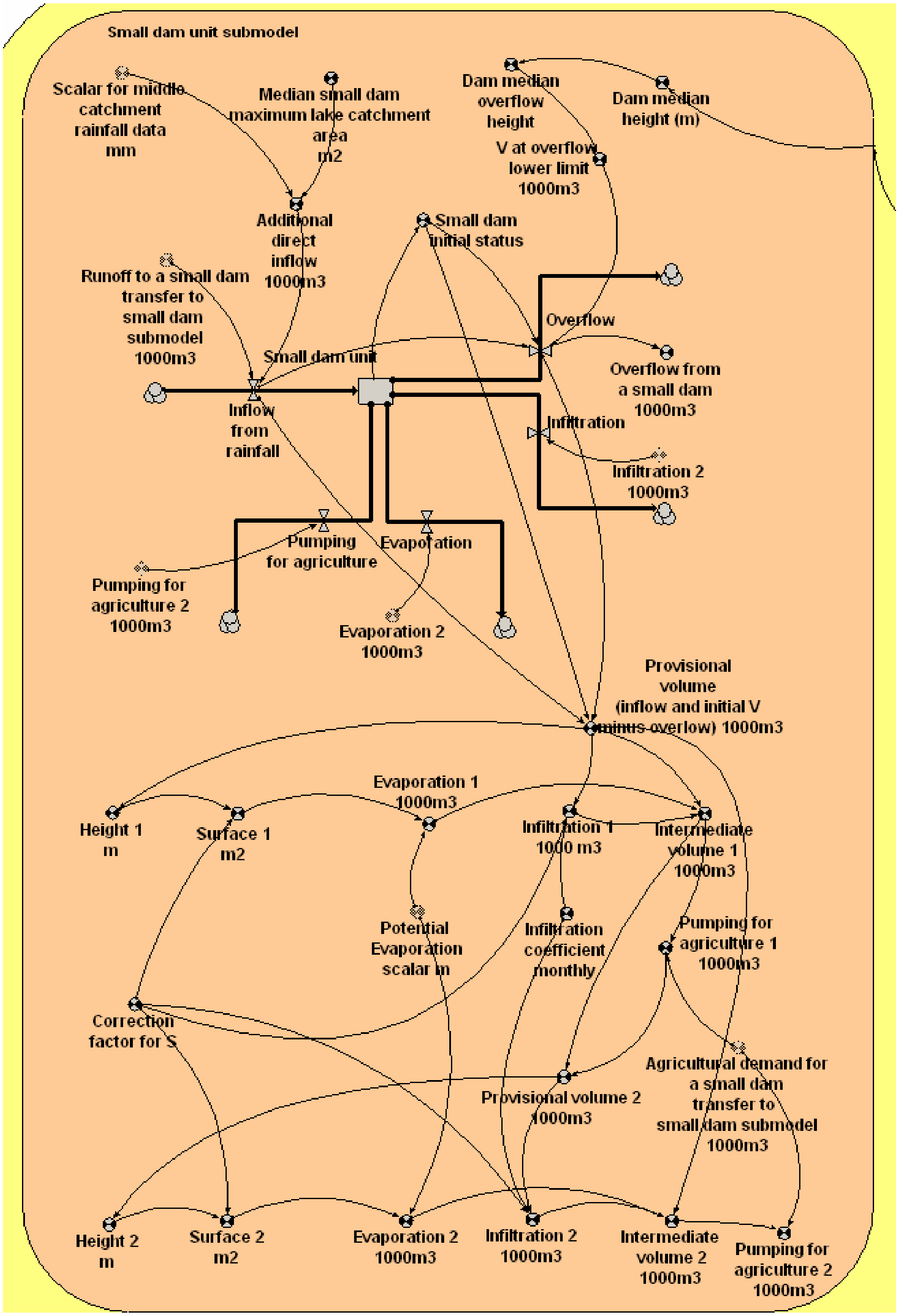

Figure 13: “Small dam unit” submodel

Over the various scenarios, it is needed for the user to be able to modify the number of small dams and consequently the managed area of the middle catchment submodel. Therefore the following modelling assumption has been made:

A computational submodel has been created, labelled as "small dam unit", simulating the behaviour of a median (or average) small dam. Once the properties of this "typical" small dam are defined by simulation, the overall contribution of the small dams in the middle catchment SDM submodel can be calculated.

It is assumed that the "small dam unit" has the following characteristics:

- Capacity = (Total small dams capacity)/(Number of small dams in the scenario)
- Surface runoff = (Total surface runoff)/(Number of small dams in the scenario)
- Pumping for agriculture=(Total demand)/(Number of small dams in the scenario)
- Total overflow from the catchment=(Overflow from a small dam)*(Number of small dams in the scenario)

The "small dam unit" is connected to the middle catchment through input and output parameters. The core of the submodel is the "Small dam unit" stock, seen in the centre of Figure 13. The "small dam unit" receives inflows from:
(a) Surface runoff through the "runoff to a small dam parameter"
(b) Additional direct inflow from rain on the dam lake maximum surface.

The dam maximum height is estimated through a relationship between volume and surface, as discussed in the following section about data. If the water volume corresponding to the initial status of the dam and the inflow, exceeds the maximum water volume, then there is "overflow from a small dam", a parameter transferred to the middle catchment submodel, representing the excess water volume from the small dam unit.

Water losses occur for the remaining water in the small dam through

- Evaporation (based on measured evaporation time series at El Haouareb)
- Infiltration (through an infiltration parameter) to the Kairouan aquifer
- Pumping for agriculture (based on demands for irrigation for the middle catchment)

It should be mentioned that all losses are estimated iteratively, by two iterations (e.g. Evaporation 1, Evaporation 2 in Figure 13), in order to take into account the changes to the water surface and volume within a month. This numerical assumption is considered necessary, because of the monthly time step of the simulation, which is very large for direct estimation.

As far as output from the "small dam units" submodel is concerned, it is connected to the middle catchment submodel, returning the "outflow from a small dam" and the "infiltration" parameters.

It should be pointed out, that, evidently, the characteristics and parameters of the "small dam unit" vary, according to the number of the small dams in the middle catchment. Therefore this submodel enables the user to examine multiple scenarios with a different number of small dams in the middle catchment with the same SDM model.

The proper middle catchment submodel is presented in Figure 14

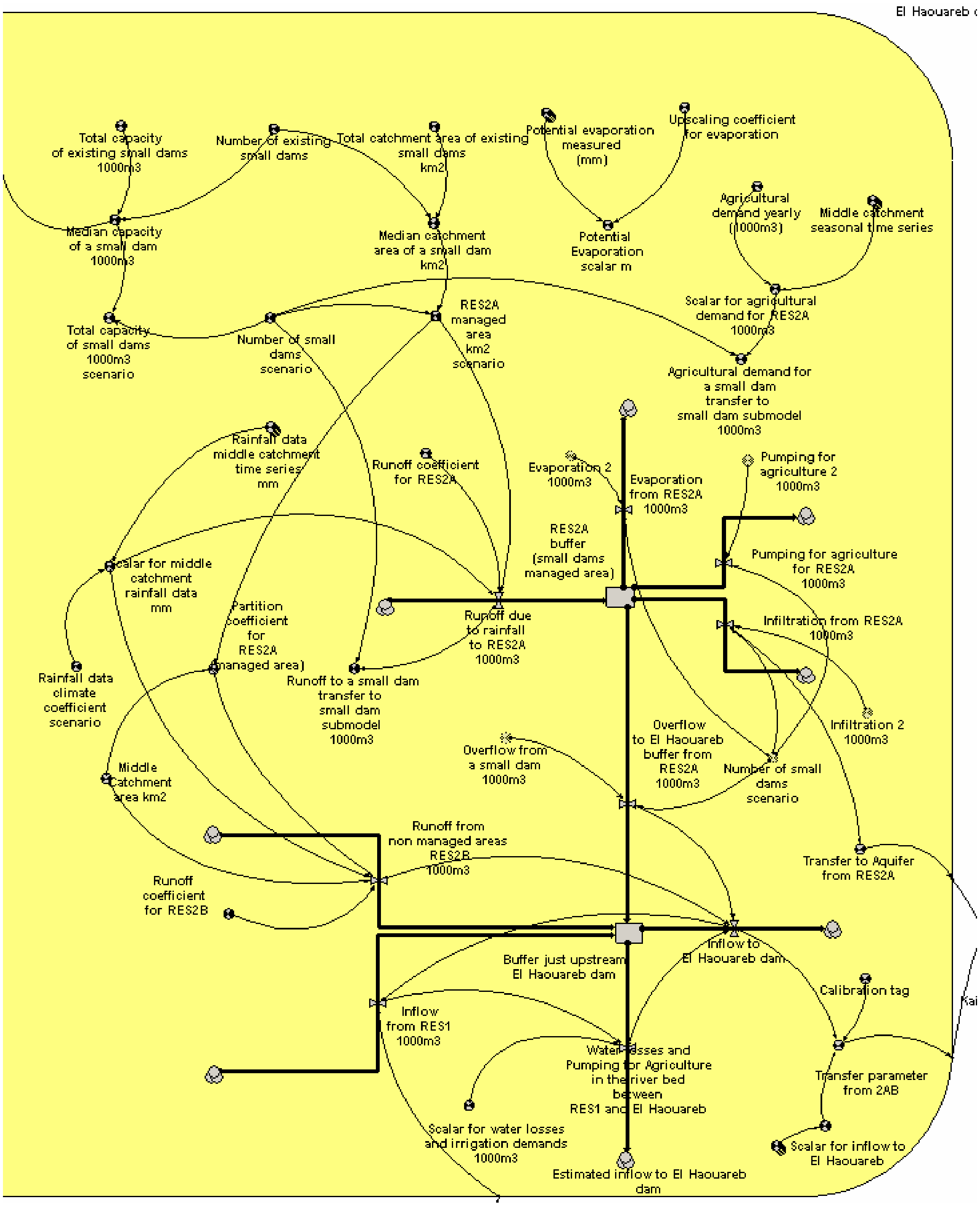

Figure 14: Middle catchment main submodel

The total catchment area of the middle catchment is 989km2, while the managed area (existing small dams) is 183.83km2 (RES2A). For different scenarios of small dams (more/less than 35) the managed area is modified automatically by the model, while the non-managed area (RES2B) is always estimated as the difference between the total and the managed area for each scenario.

There are two stocks in this submodel. The first stock (RES2A buffer) simulates the collective effect of the small dams units; it simply represents the entities of each small dam, multiplied by the number of small dams in each scenario. The RES2A buffer sends outflows to the El Haouareb dam buffer and to the Kairouan aquifer through infiltration.

The second buffer "just upstream El Haouareb dam" sums up all inflows and outflows prior to El Haouareb. In terms of inflows there is inflow from RES1 (Shkira) upper catchment submodel, runoff from non managed areas (RES2B), which is different for each small dam scenario, and "Overflow" from the small dams.

In terms of outflows, there are "Water losses and Pumping for Agriculture" in the river bed between Skhira (RES1) and El Haouareb. The remaining water is transferred as Inflow to El Haouareb dam.

The rainfall time series used for the middle catchment are different from the upper submodel, because they have been calculated through different pluviometric stations, as explained in more detail in the next section about data.

It should be mentioned that measured data for inflow to El Haouareb, as a monthly time series do exist from 1989 to 2006. These data have been used for the calibration of the middle catchment model. Therefore, as in the Skhira submodel, a special "calibration tag" has been added, so as to enable the user to switch from calibration to scenario mode.

El Haouareb dam submodel

The El Haouareb dam submodel is presented in Figure 15. This submodel simulates the dam itself, i.e. the inflows and outflows from the dam, as well as the releases from El Haouareb to the downstream Kairouan aquifer.

The core of this submodel, as the name implies, is the El Haouareb dam stock, simulating the reservoir status. The reservoir receives water (inflows) from the middle catchment, through a transfer parameter from the middle catchment submodel and directly from rainfall. There are losses due to evaporation and infiltration, as well as pumping for irrigation directly from the reservoir and sediment releases. The latter, although included in the model for the calibration period (there existed historic data), it was set to zero for the scenarios. The reason for this assumption is that it was thought simpler to include all releases in a single outflow and study a single set of rules, than splitting them.

Again, in a similar way to the middle catchment "small dam unit", evaporation and infiltration are estimated in two iterations, in order to take into account the modification of water volume and surface in the reservoir within a single simulation time step (monthly). This assumption lead to the addition of several parameters at the upper part of the submodel graph (Figure 15) (i.e. Evaporation 1, Evaporation 2 etc) that make the graph more complicated.

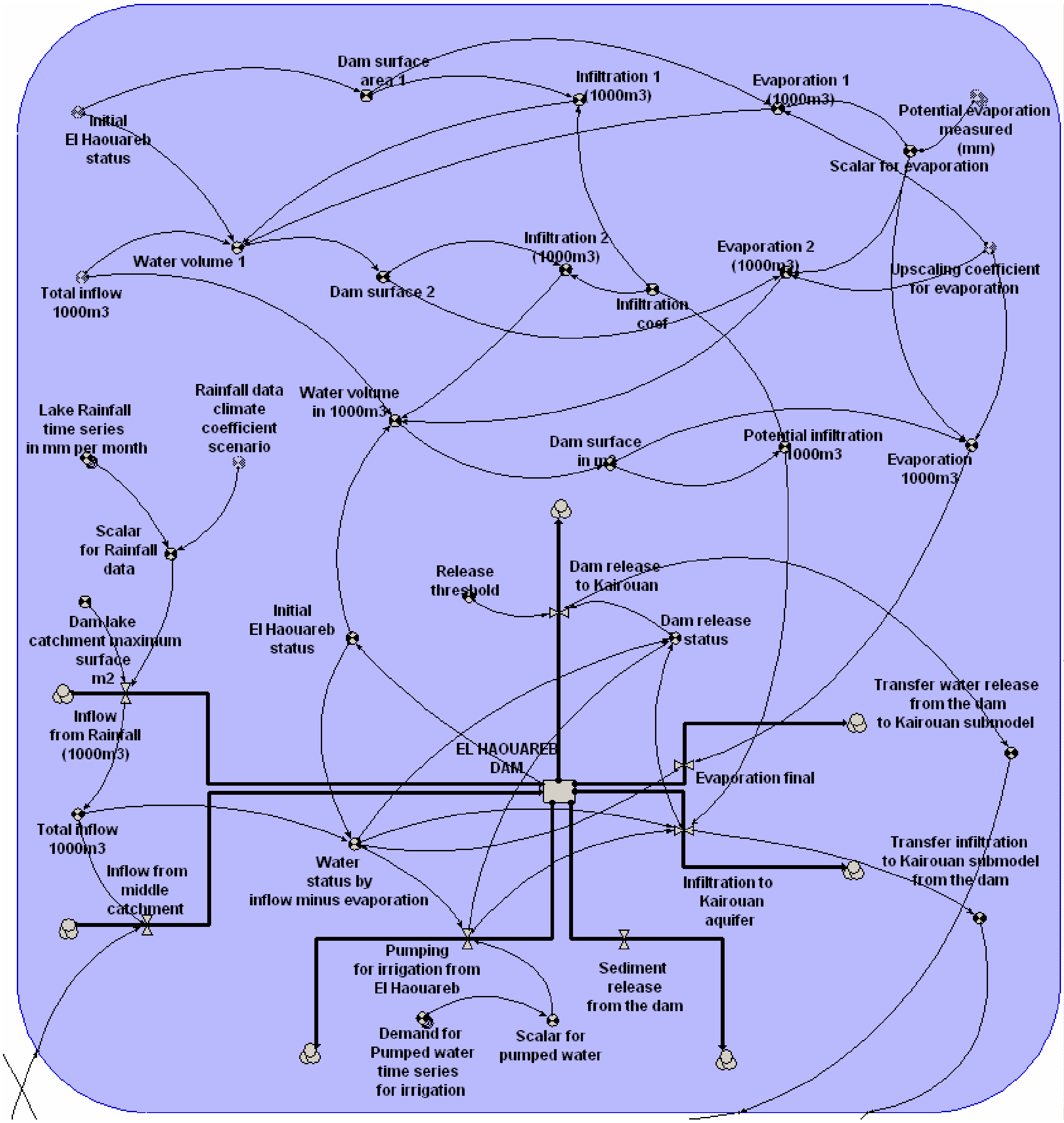

Figure 15: El Haouareb dam submodel

There are two separate water transfers from El Haouareb to the Kairouan aquifer downstream.

The first water transfer is water release from the dam. This takes place when the water volume in the reservoir exceeds a certain threshold (e.g. 15000 or 20000 x 1000 m^3).In this case, excessive water is released downstream, feeding the Kairouan aquifer. Within SDM the water “release threshold” is an important parameter for investigation, determining operational policy for El Haouareb, which has been modified over different scenarios.

The second type of water transfer refers to infiltration, which depends on the amount of water in the dam, and more specifically on the water surface. Infiltration losses end up directly to the Kairouan aquifer (i.e. there are no further water losses).

Kairouan aquifer submodel

The Kairouan aquifer submodel is shown in Figure 16. It is the final submodel, simulating the operation of Kairouan aquifer, downstream El Haouareb.

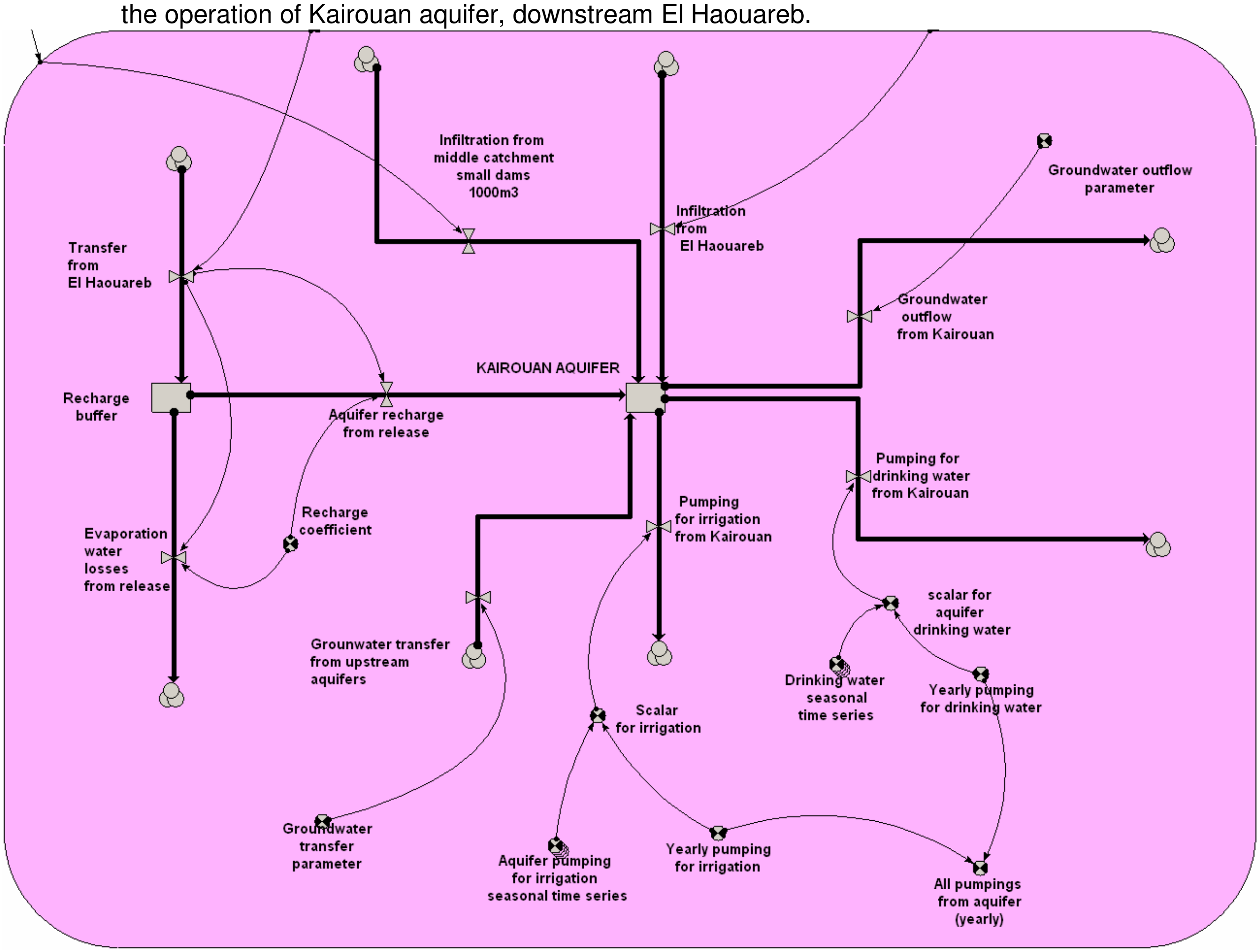

Figure 16: Kairouan aquifer submodel

The Kairouan plain aquifer is situated downstream El Haouareb dam (Figure 4). It covers a large area, part of which is influenced and recharged through El Haouareb (by water release and infiltration). The SDM of Kairouan refers only to the part recharged by Merguellil catchment and El Haouareb. However several parameters and existing data (i.e. water pumping for agriculture, or drinking water uptakes) refer to the whole Kairouan plain aquifer (a much larger area). Consequently there are uncertainties as to the values of these parameters within the model, and the Kairouan aquifer submodel is the most affected one.

The Kairouan aquifer is represented as a “stock”, which can be seen in Figure 16. The status and the water balance in this stock are the ultimate targets for the whole SDM, as far as results are concerned.

The Kairouan “stock” system component receives inflows and increases its status (i.e. is being recharged) by:

(a) Releases from El Haouareb dam (“transfer from El Haouareb” flow), after losses estimated at about 30%. This procedure is simulated by the entity called “recharge buffer” in Figure 16.
(b) Infiltration from El Haouareb, a transfer from the submodel “El Haouareb”
(c) Infiltration from middle catchment small dams, a transfer from the submodel “middle catchment”
(d) Groundwater transfer from upstream aquifers, an external inflow controlled by the “Groundwater transfer parameter”, estimated at 5.2Mm^3/year (or 433.33 x 1000 m^3/month).

Outflows, reducing the Kairouan aquifer status, are due to:

(a) Groundwater outflow from Kairouan to salt lake (Sebkha), controlled by the “Groundwater outflow parameter”, which is considered steady throughout the year. It is estimated at around 7.5Mm^3/year, or 625 x 1000 m^3/month
(b) Pumping for drinking water
(c) Pumping for irrigation

The available data for the last two outflows (pumping for drinking water and irrigation) refer to the whole of Kairouan aquifer, a much larger area than the one simulated through this SDM model. Total pumping from the whole Kairouan plain is estimated at 53x10Mm3/year, and growing every year. About 31.33 Mm^3/year (in 2004) refer to drinking water and the remaining supplies agricultural demands (irrigation).

There is no reliable method for estimating the percentage of this demand coming from the Kairouan aquifer area influenced by El Haouareb. Therefore, for the SDM model presented here the following assumption has been made:

The model will estimate at each scenario the *maximum water volume available yearly for pumping* from the “Kairouan” stock (i.e. the part of Kairouan aquifer linked to El Haouareb and Merguellil), so as to maintain the status (water volume/water table level) steady (or quasi steady, under different climatic conditions and operational policies. All results and comparisons presented in the following sections refer to this water quantity.

7 Model Data

All numerical data used for the Merguellil SDM have been provided by IRD (C. Leduc, JWT for Tunisia). Some data have been used as they were, but there have been cases where some further data process was needed by UNEXE (L.S.Vamvakeridou-Lyroudia), before they could be entered as data for simulation.

In this report data are presented only in their processed form, as they were used for the calibration and/or the SDM scenarios. Data collection and process started in October 2007 and ended in June 2008. All data Tables are included in Appendix A.

Rainfall data

Monthly rainfall data, in mm, from 1989 to 2006, have been used from the following stations: Kesra, Ouslatia, El Ala, Haffouz, El Haouareb and Makhtar (Table A1). Some data were initially on daily basis, and they have been further processed on monthly basis for the needs of the model. The last two columns in the same table (Table A1) present the average monthly rainfall time series for the upper and the middle catchment respectively. For the submodel "El Haouareb", the measurement from El Haouareb alone have been used.

The average rainfall time series for the upper catchment have been estimated with the following weighting factors: 50% Makhtar and 50% Kesra. The average rainfall time series for the middle catchment have been estimated with the following weighting factors: 1/7 Kesra, 1/7 Ouslatia, 2/7 El Ala, 2/7 Haffouz, 1/7 El Haouareb. However, in the case of missing data, weighting factors have been adjusted accordingly. At the top of Table A1, all initial and adjusted weighting factors are presented, with different colours. The same colours are used in the average time series, so as to point out the weighting factor combinations that produced them.

All available rainfall data have been used for calibration of the upper and middle catchment. However, only the last three years (2003-2006), i.e. the most recent available data, have been used for the scenarios.

Surface runoff time series

The monthly surface runoff time series, from 1974 to 2001, for Skhira (RES1) are presented in Table A2. These series have been calculated by aggregation of the daily values provided initially. Only the period from 1989-2001 (in yellow in Table A2) has been used for calibration, because it's the common period with the other data series.

As it has already been mentioned in the previous section, during the calibration process different rules for the runoff coefficient have been tried. The ideal case, pointed out by IRD with prior knowledge of the area, would be to differentiate the runoff coefficient according to the intensity of the daily rainfall. However this could not be done using monthly data, as was the case with this model. So, different rules have been tried, based on the monthly rainfall and/or the calendar month. The final rule adopted, which had the best fitting is using an average coefficient (11%) for all months and 20% for September. This coefficient is increased, compared to the initial uniform runoff coefficient (11%) suggested initially by IRD.

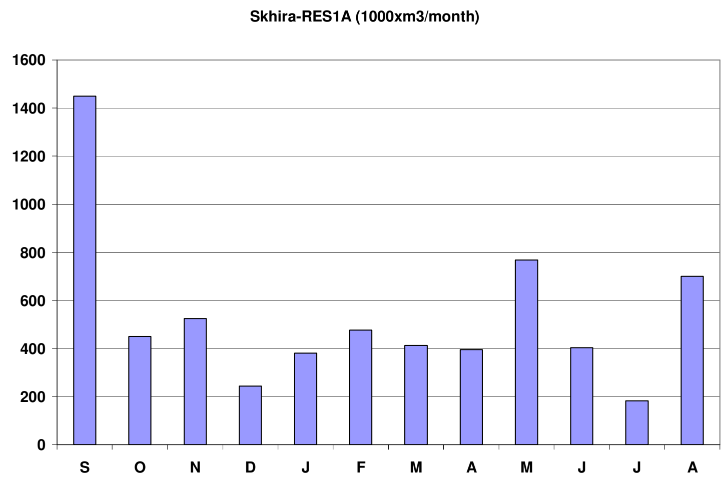

Figure 17: Average measured monthly runoff for Skhira

As it can be seen from Table A2 and in Figure 17, the monthly runoff for September is much higher than the other months, leading to the trials for the rule that was adopted in the end for the model.

The other measured runoff data series represents the inflows to El Haouareb dam, from 1989 to 2006. It is presented in Table A3 in 1000m^3/month. For the model this series represents the total surface runoff for the middle catchment and it has been used for calibration of the middle catchment and the El Haouareb submodel.

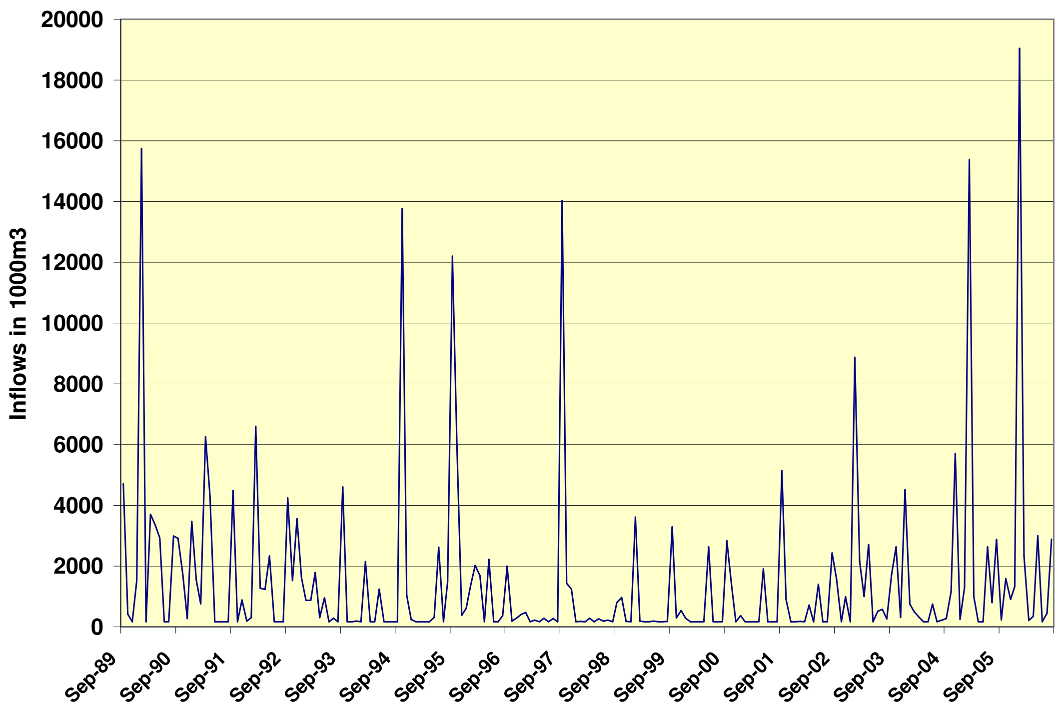

Figure 18: Monthly inflows (1000m3) to El Haouareb dam

The same time series is shown in Figure 18. As it can be seen, the instances with large monthly inflows, leading to water releases from the dam are few.

Apart from these two surface runoff series, there exist no other measured runoff data for the area and the model. The runoff coefficient for the middle catchment has been taken as 3.3%. This value is increased compared to the initial 2.5% for the recent years, suggested by IRD. This value was estimated during calibration of the middle catchment as giving better results for the estimated inflows to El Haouareb, compared to the measured ones for the period 2003-2006.

Evaporation time series
Pan evaporation measurements exist for El Haouareb on a daily and monthly basis, for the period 1989-2006 and are presented in Table A4. These have been considered as representative for the whole catchment. The scale coefficient to account for the transfer from pan to reservoir was taken to be 0.79.

Evaporation losses for the middle catchment and El Haouareb are estimated according to the actual water surface area both at the small dam unit and El Haouareb. As it has already been mentioned in the previous section, the numerical estimation is iterative, so as to simulate better the actual process, which uses daily values and daily water surface. Thus, in all cases in the model, an initial estimation of evaporation losses is being made (Evaporation 1) based on the dam initial status, the surface inflow and the direct rainfall. This initial estimation is being used for an initial water balance for the reservoir, from which a better estimation of the actual water volume (and surface) is obtained, leading in turn in a better approximation for evaporation (Evaporation 2). For the small dams this second estimation (Evaporation 2) is used as the final one, whereas for El Haouareb a third iteration is carried out, before the evaporation is considered final. This procedure is clearly shown in the SDM models for the “small dam unit” submodel (Figure 13) and for the “El Haouareb” submodel (Figure 15).

The evaporation losses at the “Kairouan aquifer” submodel, after water release from El Haouareb have been estimated to be 30%, leading to the value 0.70 for the “Recharge coefficient” parameter in the model.

Infiltration

There are no direct infiltration measurements anywhere in the Merguellil valley. Consequently all infiltration parameters in the model are based on estimations.

For the small dams in the middle catchment an infiltration coefficient LK=0.0016 per day has been adopted, leading to the following formula for infiltration losses:

$$IS = 0.5\ H\ S\ (LK) \qquad (1)$$

where IS are the daily infiltration losses from small dams (in m), H is the water height of the small dam (in m) and S the water surface of the small dam (in m). In order to obtain monthly values, this daily estimation of infiltration losses is multiplied by the number of days in the month. For the SDM the number of days has been taken as 30 for all months. Moreover, an iterative process, similar to the iterative process for the estimation of evaporation was introduced (initial estimation as Infiltration 1, consequently corrected iteratively to Infiltration 2), so as to overcome the dependence on daily values for the water surface and height.

Infiltration losses from El Haouareb have been estimated as 8.5mm/day/m^2. This coefficient obviously relates to the actual water surface. In order to convert to monthly values (duration of 30 days), the following equation has been used:

$$ID = 30 \times 8.5 \times S/1000 \qquad (2)$$

where ID are the infiltration losses in m3, S is the water surface at the dam. In a similar way to the evaporation estimation, described in the previous paragraph, a triple iteration has been applied, so as to cope with the fluctuating actual water surface. However, after the third approximation to the infiltration value has been estimated, there is a difference:

This third approximation is considered as "potential evaporation" (Figure 15), by that meaning that it will not occur, unless there is enough water in the dam. So, a further comparison of this value takes place, with the remaining water volume in the reservoir, after evaporation and pumping for irrigation are subtracted, and the smaller of the two values (potential evaporation, compared to remaining water volume in the reservoir) is adopted as the infiltration recharge to the Kairouan aquifer.

At the most downstream submodel "Kairouan aquifer" there are infiltration inflows from the small dams in the middle catchment, from El Haouareb dam and from upstream aquifer. The latter has been estimated at 5.2Mm^3/year (or 433.33 x 1000 m^3/month). There are also infiltration losses from Kairouan to salt lake (Sebkha), which are considered to be steady throughout the year. They are estimated at around 7.5Mm^3/year, or 625 x 1000 m^3/month.

Pumping

Pumping for agriculture from the small dams varies between 200000m^3/year and 400000m^3/year. The seasonal distribution (%) per month and crop is given in Table A5.

This seasonal distribution has been adopted both for the middle catchment and the Kairouan aquifer.

Detailed monthly data about pumping for irrigation from El Haouareb do exist for the period 1989-2006 and are presented in Table A6. They have been used for the El Haouareb submodel.

Pumping for agriculture and water losses from the river bed, for the middle catchment, between RES1 and El Haouareb (Figure 14) have been combined. They are estimated between 30-50 l/s, if there is water in the river bed (between 77.76 and 129.6 1000m^3/month). For the SDM they have been assumed to be 100 m^3/month and to be constant throughout the year.

Pumping for drinking water and irrigation for the whole of Kairouan aquifer, a much larger area than the one simulated through this SDM model, are estimated at about 53x10Mm^3/year, and growing every year. About 31.33 Mm^3/year (in 2004) are for drinking water and the remaining supplies agricultural demands (irrigation).

There is no reliable method for estimating the percentage of this demand coming from the Kairouan aquifer area influenced by El Haouareb, which is much smaller than the whole plain (Figure 4). Therefore, for the SDM model they have not been used as data. Instead, the following assumption has been made: The model will estimate for each scenario the *maximum water volume available yearly for pumping* from the "Kairouan" stock (i.e. the part of Kairouan aquifer linked to El Haouareb and Merguellil), so as to maintain the status (water volume/water table level) steady (or quasi steady, under different climatic conditions and operational policies.

Small dams

As it has already been mentioned in the previous section there exist 35 small dams in the middle catchment, shown in Figure 3. There are more small dams in the upper Skhira catchment, but they have not been taken into consideration for the SDM.
Data for the small dams have been collected and compared from two sources: Lacombe (2007) and Kikumbi (2004). The latter, being an older reference, does not contain three new dams, constructed between 2002 and 2005. However there are some small differences even for older dams. For the SDM the Lacombe (2007) has been adopted, as the most recent one.

Full data are given in Table A7. The first column in the table refers to the No of each small dam, shown in Figure 3. According to the table, the total capacity of the 35 small dams is 6618.3 x $10^3 m^3$ and their respective total catchment area (total managed area for the middle catchment submodel RES2A) 183.83km^2.

For the "small dam unit" submodel, the following equations have been adopted as representing the volume (V in m^3)-area (S in m^2)-water height (H in m) relationships:

$$V=1037\ H^{2.37} \quad (3)$$

$$S = m * 2.37 * 1037 * H^{1.37} \quad (4)$$

The correction factor m=0.703253, appearing in Equation 4 has been introduced during calibration for compatibility, i.e. in order to adjust the water surface area, when there is an overflow (set as 30000m^2). Overflow height has been set at 1m below the maximum water height. This parameter has been calibrated, using an initial estimation, that on average the release by each small dam is 13200m^3/year. In fact, using the "1m below" rule for overflow, gives on average 12400m^3/year water release for a small dam, for the calibration period 2003-2006 (most recent years). However, by increasing it to 1.5m, the average release was close to 20000m^3/year, over the same period. Increasing accuracy to a first decimal place (i.e. 1.1, 1.2m) was considered "out of scale", from the engineering point of view: There exist no sufficient data and/or accuracy for justifying this choice. Therefore, the rule "1m below maximum water height" has been maintained for the model.

The lake/reservoir surface for direct rainfall has been set at 45000m^2.

It should be pointed out that simulation and calibration of the small dams in the SDM for Merguellil has been the hardest and most original part of the model. To the authors' best knowledge, no similar case exists in literature. It is therefore one of the most innovative aspects of the whole case study within AQUASTRESS, on an international level.

El Haouareb dam and reservoir

The time series available for water volume, inflows, outflows, evaporation, water release, water sediment release and irrigation from the dam, range from 1989 to 2006, and they are presented on a monthly basis in Table A8. These data have been used for the calibration of the model, while data for the last 3 years (2003-2006) for irrigation and evaporation have also been used for the scenarios.

Due to the fact that sediments continuously alter the water surface area-volume relationship, it was decided that the relative equation should be estimated using only the most recent data. Therefore data from 2002 (Table A9) have been used for fitting curves, as follows (surface S in m^2, volume V in 1000m^3):

$$S = -0.00001V^2 + 7.8277V + 482292 \quad \text{for} \quad V>21681.038$$

$$S= -0.0002V^2 + 23.425V + 220529 \quad \text{for} \quad 3538.095< V \leq 21681.038 \qquad (5)$$

$$S= -0.0243V^2 + 153.98V + 57846 \quad \text{for} \quad V\leq 3538.095$$

Equation 5 has been applied, as a rule within the SDM model, for calculating the water surface out of water volume, for El Haouareb dam, in all instances, where water surface estimation was needed, namely for evaporation and infiltration.

Direct rainfall water volume has been estimated using the dam lake maximum volume, i.e. at full capacity. Initially (October 2007) the area corresponding to the level H=212m was used (745 ha). After secondary calibration considerations and further discussions it was replaced (March 2008) with the maximum area Smax=1563.7ha, as the steady area receiving direct rainfall.

When water volume in El Haouareb exceeds a specific amount called in the model conventionally “release threshold” there is water release from the dam to the Kairouan aquifer, where the exceeding volume is released. The “release threshold” parameter is one of the parameters to be investigated through different scenarios. For the historical data and calibration period it was set at 20Mm^3. As it was already mentioned in the previous section describing the SDM components, sediment release has been included in the total water release.

It should be pointed out that calibration of the “release threshold” parameter and a workable rule, through existing historical records, is practically impossible. In recent years there have been only two major monthly water release outflows from the dam, in February and March 2006, as shown in Table A8. In the first case the water volume in the dam (dam status for the SDM) was 27.437Mm^3, and 1.18Mm^3 were released. In the second case, the next month, the water volume was much less (20.829Mm^3) and 6.05Mm^3 were released (5.674Mm^3 directly to Kairouan for recharge and 0.376Mm^3 for “sediment release”). Therefore there doen not seem to be any specific rule for water release, nor any specific threshold. So, it was considered better for the SDM to focus on different “water release scenarios”, in order to demonstrate the impact to Kairouan aquifer.

8. Scenarios and results

The SDM model for Merguellil presented in Section 6.2 has been used in order to simulate the Merguellil valley system and run various scenarios. All scenario results are included in Appendix B.

It should be mentioned that a result template has been developed in the model, that enables the user to automatically get all results from each scenario, tabulated and arranged according to contents. The result tables can then be copy/pasted to EXCEL for saving, combining, studying and comparing.

The result template within the SDM is shown in Figure 19.

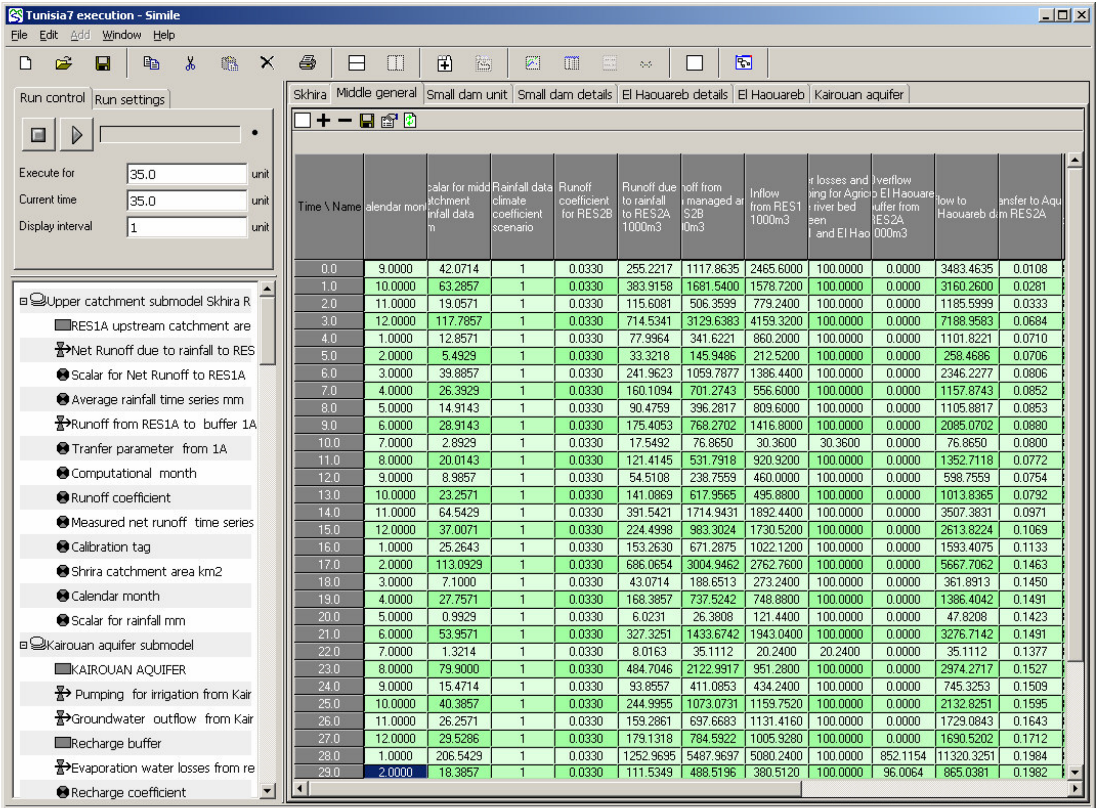

Figure 19: Sample of result template from the SDM for Merguellil

Each run/simulation produces automatically seven tables/spreadsheets, where practically all the varying and important parameters of the model can be seen.

The seven spreadsheets/tables are labelled as follows:

- Skhira
- Middle general
- Small dam unit
- Small dam details
- El Haouareb details
- El Haouareb
- Kairouan aquifer

As their names imply the spreadsheets show numerical results arranged per submodel. The spreadsheets defined as “details” contain results from the iterative processes for the estimation of evaporation and infiltration at the small dams and El Haouareb.

All spreadsheets will be updated at each run automatically, but, obvioiusly, it is not necessary to print out or study all the spreadsheets a scenario that changes a limited number of parameters. The same approach will be used for this report. The results from one simulation run will be printed out in full, but for the other scenarios only spreadsheets (or parts of spreadsheets) will be included, as needed.

Scenario 1-Basis for reference

The first scenario is based on the historical data for the most recent period (2003-2006). The results are presented in full in Tables B1.1 to B1.7.

All the main assumptions about this scenario have been included in the previous section about Model Data.

As it can be seen from Table B1.5, the maximum water volume available for pumping from the Kairouan aquifer, both for drinking and irrigation is 14Mm^3/year, in order to sustain the level of the Kairouan aquifer.

Scenario 2- Reducing the release threshold from El Haouareb

This scenario sets the release threshold for Ek Haouareb at 15Mm3 (instead of 20Mm3). The detailed results for El Haouareb and Kairouan are presented in Tables B2.1 and B2.2 respectively.

As it can be seen by the results, the sustainable pumping from the Aquifer has increased (compared to Scenario 1) to 16 Mm3/year. The yearly releases from El Haouareb have also increased, but the infiltration has decreased to 12.1Mm3/year (from 12.9Mm3/year in Scenario 1-Table B1.5).

Scenario 3 - Increasing the managed area in the middle catchment

This scenario increases the number of small dams in the middle catchment from 35 to 40. This assumption automatically increases the managed area in the middle catchment and the capacity of the small dams by 14%. The objective is to determine the "release threshold" from El Haouareb, that maintains the same sustainable pumping capacity from Kairouan aquifer, as the original (basis) scenario 1.

Detailed results from this scenario are presented in Tables B3.1 to B3.4. As it can be seen in Table B3.3 the water release threshold had to be lowered to 10Mm3, in order to maintain the same quantity of pumping at Kairouan as the base scenario 1 (14Mm^3/year), without reducing the Kairouan aquifer status.

Scenario 4 – Reducing the rainfall to 85% of the original and maintaining pumping

This reduction of rainfall simulates roughly a climate change scenario. Rainfall has benn reduced overall the Merguellil valley system (rainfall climate coefficient 0.85), while the number of small dams is kept at the original number (35). The objective is again to determine the "release threshold" from El Haouareb, that maintains the same sustainable pumping capacity from Kairouan aquifer, as the original (basis) scenario 1.

Detailed results from this scenario are presented in Tables B4.1 to B4.5. As it can be seen in Table B4.4 the water release threshold had to be lowered to 6.5Mm3, in order to maintain the same quantity of pumping at Kairouan as the base scenario 1 (14Mm^3/year), without reducing the Kairouan aquifer status.

There are further important remarks about this scenario: The irrigation demands from El Haouareb are not adequately fulfilled, if the water release threshold is so low. Indeed, by looking at Table 4.4, there are several months, where the available water for irrigation from the dam is equal to zero (i.e. the dam remains practically empty after the releases and the evaporation losses). The average pumping for irrigation from El Haouareb is reduced from 4.7Mm^3/year on average in Scenario 1, to just 2.7Mm^3/year on average in this scenario, a 43% reduction, compared to the base scenario. This remark agrees with recent observations (2008), when El Haouareb was practically empty.

Scenario 5 - Reducing the rainfall to 85% of the original and reducing pumping

Scenario 5 is a variation on Scenario 4. the rainfall is again reduced to 85% of the original, but the water release threshold is increased to 15 Mm^3 ,a reasonable assumption, in order to avoid some (not all) the irrigation deficits from the reservoir. The objective is now to estimate the available water quantity for sustainable pumping from Kairouan.

Results for this scenario are different from the previous one only for El Haouareb and Kairouan and they are presented in Tables B5.1 and B5.2 respectively.

In this scenario irrigation demands from El Haouareb can be fulfilled, but there is only one (very small) water release to El Haouareb, and the total water quantity available for sustainable pumping fron Kairouan aquifer is reduced to only 10Mm^3/year, a 29% reduction, compared to the basis scenario.

9 Conclusions

A System Dynamics Model (SDM) has been developed for the Merguellil valley system, so as to study the impacts of climate change, water management through small dams (rainfall harvesting) and aquifer recharge policies for the Kairouan aquifer. This model has been applied for Merguellil in order to investigate technical options relevant to WP3.1.

The SDM model was developed by UNEXE (L.S.Vamvakeridou-Lyroudia), with the help of IRD (C.Leduc – case study leader for Tunisia), who provided numerical data and assistance in the setting up of the model, in one year.

This report has presented the procedure and background for developing the SDM, as well as the final SDM in detail, together with all the numerical data used for the calibration and the scenarios, together with detailed numerical application results.

Five different scenarios for the system are presented in detail, demonstrating the impacts of different water release thresholds at El Haouareb dam, number of small dams constructed in the middle catchment and rainfall reduction. Briefly, the results can be summarized as follows:

- The maximum available water quantity from El Kairouan, due to El Haouareb is 14Mm^3/year, under existing operational conditions and normal (average) rainfall.
- The water quantity available from Kairouan could increase to 16Mm3/year, under average rainfall conditions, if the water release threshold at Kairouan is lowered to 15Mm^3.
- If the managed area in the middle catchment is increased by 14%, by the construction of more small dams, then the water release threshold has to be lowered to 10Mm^3, in order to maintain the same quantity of pumping at Kairouan (14Mm^3/year), without reducing the Kairouan aquifer status.
- If the rainfall is reduced to 85% or the normal average value, then the water release threshold has to be lowered to 6.5Mm^3, in order to maintain the same quantity of pumping at Kairouan (14Mm^3/year), without reducing the Kairouan aquifer status, but the water available for irrigation from El Haouareb will be also reduced by 43% compared to current operational conditions.
- In order to fulfill the water needs for irrigation from El Haouareb, in the case of reduced rainfall (85%), the water threshold release from El Haouareb should be 15Mm3 and the water available for pumping at Kairouan will be reduced by 29%.

Obviously, it is possible to run several additional scenarios with various combinations of rainfall reduction and/or pumping from Kairouan and/or water releases from El Haouareb, but this would only lead to endless result pages. The results and conclusions presented here are considered enough for providing adequate information on the impacts of different operational policies and/or climatic conditions for the Merguellil valley system.

The SDM model presented in this report is available and free for downloading from www.ex.ac.uk/cws .

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Appendix A

Data tables

Table A1: Monthly rainfall data for Merguellil (in mm)

	Haffouz	El Ala	El Haouareb	Kesra	Ouslatia	Makthar	Middle catchment Average rainfall	Upper catchment average rainfall
All valid	**0.28571429**	**0.2857143**	**0.14285714**	**0.1428571**	**0.1428571**	**0**	**1**	
El Ala out	**0.42857143**	**0**	**0.21428571**	**0.1428571**	**0.2142857**	**0**	**1**	
El Ala+Ouslatia out	**0.42857143**	**0**	**0.28571429**	**0.2857143**	**0**	**0**	**1**	
Kesra+Makthar out	**0.28571429**	**0.2857143**	**0.14285714**	**0**	**0.2857143**	**0**	**1**	
Ouslatia out	**0.28571429**	**0.2857143**	**0.14285714**	**0.2857143**	**0**	**0**	**1**	
Haffouz+El Ala+Ouslatia out	**0**	**0**	**0.71428571**	**0.2857143**	**0**	**0**	**1**	
Kesra out	**0.28571429**	**0.2857143**	**0.14285714**	**0**	**0.2857143**	**0**	**1**	
Upper catchment all valid	**0**	**0**	**0**	**0.5**	**0**	**0.5**	**1**	
Upper catchment Makthar out	**0**	**0**	**0**	**1**	**0**	**0**	**1**	
Upper catchment all out	**0**	**0**	**0**	**0**	**1**	**0**	**1**	
16/09/1989 00:00	22.50		0.00	37.00	28.60	31.30	21.06	34.15
16/10/1989 00:00	49.00		0.00	34.00	33.60	24.10	33.06	29.05
16/11/1989 00:00	18.00		0.00	14.00	18.00	23.00	13.57	18.50
16/12/1989 00:00	51.00		0.00	18.00	27.00	4.80	30.21	11.40
16/01/1990 00:00			0.00	212.60	231.90	178.40	80.06	195.50
16/02/1990 00:00			0.00	0.00	0.00	0.00	0.00	0.00
16/03/1990 00:00			58.00	104.50	85.50	66.10	45.68	85.30
16/04/1990 00:00			76.50	36.50		58.10	32.29	47.30
16/05/1990 00:00			31.00	56.00		69.50	24.86	62.75
16/06/1990 00:00			0.00	2.00		11.60	0.57	6.80
16/07/1990 00:00			0.00	20.00		73.50	5.71	46.75
16/08/1990 00:00			60.70	42.00	42.50	64.10	28.11	53.05
16/09/1990 00:00	43.20		0.00	42.50	17.00	28.50	28.23	35.50
16/10/1990 00:00	45.00		0.00	33.00	28.00	30.20	30.00	31.60
16/11/1990 00:00	36.00		0.00	72.50	30.30	78.70	32.28	75.60
16/12/1990 00:00	35.00		0.00	50.50	0.00	89.90	22.21	70.20
16/01/1991 00:00	28.00		39.60	53.00	86.70	78.60	46.64	65.80
16/02/1991 00:00	18.50		43.60	42.50	54.00	62.30	34.91	52.40
16/03/1991 00:00	79.50		179.20	60.00	77.30	105.10	97.61	82.55
16/04/1991 00:00	18.60		26.30	22.00	36.10	100.30	24.49	61.15
16/05/1991 00:00	6.10		28.20	18.00	24.30	26.90	16.44	22.45
16/06/1991 00:00	12.50		10.00	3.50	0.00	19.30	8.00	11.40
16/07/1991 00:00	0.00		0.00	0.00	8.00	0.00	1.71	0.00
16/08/1991 00:00	0.00		0.00	3.00	0.00	41.50	0.43	22.25
16/09/1991 00:00	43.30		20.50	29.20	56.00	44.10	39.12	36.65
16/10/1991 00:00	50.00		54.10	24.00	15.10	40.60	39.69	32.30
16/11/1991 00:00	23.00		19.00	20.50	20.70	49.10	21.29	34.80
16/12/1991 00:00	1.20		0.00	29.00	27.00	48.90	10.44	38.95
16/01/1992 00:00	42.00		43.00	56.00	45.00	47.70	44.86	51.85
16/02/1992 00:00	89.00		86.90	83.00	104.50	83.60	91.01	83.30
16/03/1992 00:00	38.00		28.20	52.50	32.00	55.50	36.69	54.00
16/04/1992 00:00	52.30		63.50	90.00	64.00	91.60	62.59	90.80
16/05/1992 00:00	52.50		28.40	53.00	40.00	69.80	44.73	61.40
16/06/1992 00:00	18.50		15.70	11.00	9.50	10.50	14.90	10.75
16/07/1992 00:00	0.00		0.00	3.50	0.00	4.50	0.50	4.00
16/08/1992 00:00	0.00		4.10	4.50	14.00	0.00	4.52	2.25
16/09/1992 00:00	53.50		26.10	82.00	14.50	32.40	43.34	57.20
16/10/1992 00:00	15.50		14.90	32.50	21.00	48.60	18.98	40.55
16/11/1992 00:00	75.00		45.60	129.50	108.00	139.20	83.56	134.35
16/12/1992 00:00	104.00		86.40	102.50	80.00	86.10	94.87	94.30
16/01/1993 00:00	0.00		0.00	16.50	16.30	30.80	5.85	23.65

16/02/1993 00:00	22.00		19.70	63.00	47.50	50.80	32.83	56.90
16/03/1993 00:00	37.50		28.90	82.00	79.30	73.70	50.97	77.85
16/04/1993 00:00	0.00		0.00	11.00	2.50	10.00	2.11	10.50
16/05/1993 00:00	9.50		21.30	50.50	23.80	58.40	20.95	54.45
16/06/1993 00:00	0.00		0.00	9.00	0.00	12.20	1.29	10.60
16/07/1993 00:00	0.00		0.00	5.00	0.00	0.00	0.71	2.50
16/08/1993 00:00	3.50		3.30	19.50	7.00	15.60	6.49	17.55
16/09/1993 00:00	68.80		33.60	28.00	19.30	32.90	44.82	30.45
16/10/1993 00:00	4.60		25.60	8.50	10.50	10.90	10.92	9.70
16/11/1993 00:00	21.00		3.90	19.00	12.70	24.70	15.27	21.85
16/12/1993 00:00	9.00		19.40	29.00	6.80	42.00	13.61	35.50
16/01/1994 00:00	0.00		0.00	21.00	23.80	70.20	8.10	45.60
16/02/1994 00:00	37.00		19.50	102.00	12.50	107.30	37.29	104.65
16/03/1994 00:00	8.30		13.50	12.00	7.00		9.66	12.00
16/04/1994 00:00	11.10		5.90	26.00	13.50		12.63	26.00
16/05/1994 00:00	37.00		23.50	8.00	10.50		24.29	8.00
16/06/1994 00:00	0.00		0.00	3.00	2.60		0.99	3.00
16/07/1994 00:00	0.00		0.00	3.00	0.00		0.43	3.00
16/08/1994 00:00	0.00		0.00	0.00	0.00		0.00	0.00
16/09/1994 00:00	58.50		0.00	46.00	47.30	55.40	41.78	50.70
16/10/1994 00:00	34.50		12.40	36.50	66.60	65.80	36.93	51.15
16/11/1994 00:00	0.00		2.00	7.00	24.00	3.50	6.57	5.25
16/12/1994 00:00	0.00		0.00	2.00	4.70	5.50	1.29	3.75
16/01/1995 00:00	0.00		0.50	31.50	17.20	100.80	8.29	66.15
16/02/1995 00:00	0.00		0.00	4.00	0.70	4.00	0.72	4.00
16/03/1995 00:00	8.00		9.10	47.50	21.40	49.70	16.75	48.60
16/04/1995 00:00	3.00		6.70	26.60	20.50	39.20	10.91	32.90
16/05/1995 00:00	0.00		0.00	4.50	0.00	1.20	0.64	2.85
16/06/1995 00:00	26.10		17.60	57.00	24.20	68.20	28.29	62.60
16/07/1995 00:00	7.00		0.30	22.00	29.50	0.00	12.53	11.00
16/08/1995 00:00	9.50		12.10	24.00	39.80	34.00	18.62	29.00
16/09/1995 00:00	119.90	92.00	37.30	122.50	104.50	147.80	99.27	135.15
16/10/1995 00:00	69.10	49.50	117.50	30.00	49.20	49.50	69.62	39.75
16/11/1995 00:00	46.50	40.50	43.00	45.00	46.00	48.50	45.43	46.75
16/12/1995 00:00	30.40	39.20	46.90	17.50	48.30	38.50	35.93	28.00
16/01/1996 00:00	47.70	55.60	40.30	93.50	66.60	65.40	56.71	79.45
16/02/1996 00:00	38.30	49.80	25.80	76.50	99.70	80.10	54.24	78.30
16/03/1996 00:00	51.60	60.80	41.80	64.50	44.30	49.30	49.78	56.90
16/04/1996 00:00	15.30	19.10	18.40	36.50	16.60	43.90	19.27	40.20
16/05/1996 00:00	21.80	33.00	11.10	77.00	71.00	54.60	37.94	65.80
16/06/1996 00:00	32.50	29.50	26.20	20.00	14.00	27.80	25.40	23.90
16/07/1996 00:00	11.50	10.00	3.30	4.50	3.50	0.00	7.03	2.25
16/08/1996 00:00	35.30	20.70	21.30	99.50	17.80	72.10	37.72	85.80
16/09/1996 00:00	52.50	21.00	31.60		51.90		40.34	51.90
16/10/1996 00:00	4.90	9.00	5.10		8.50		7.13	8.50
16/11/1996 00:00	1.50	0.00	0.00		1.20		0.77	1.20
16/12/1996 00:00	9.00	14.20	5.30		17.10		12.27	17.10
16/01/1997 00:00	37.00	29.90	32.90	105.00	59.20	120.60	50.59	112.80
16/02/1997 00:00	0.00	4.80	4.60	22.00	13.40	31.80	7.00	26.90
16/03/1997 00:00	7.10	9.20	9.10	27.00	12.90	14.60	11.61	20.80
16/04/1997 00:00	54.10	73.10	37.40	67.30	46.60	68.90	50.80	68.10
16/05/1997 00:00	1.50	0.00	1.50	16.50	12.20	17.70	5.94	17.10
16/06/1997 00:00	2.00	24.50	3.40	14.50	10.10	8.60	5.82	11.55
16/07/1997 00:00	0.00	0.00	0.00	5.00	0.00	5.10	0.71	5.05
16/08/1997 00:00	31.00	15.50	5.50	72.50	63.40	66.00	38.41	69.25
16/09/1997 00:00	176.20	133.10	160.50	136.50	178.10	103.90	167.57	120.20
16/10/1997 00:00	80.20	51.90	62.10	55.00	67.40	42.80	69.98	48.90
16/11/1997 00:00	25.50	26.00	13.90	52.00	45.50	51.90	31.09	51.95
16/12/1997 00:00	14.00	9.00	8.00	36.00	16.50	50.10	16.39	43.05
16/01/1998 00:00	9.00	12.50	6.60	28.00	40.30	42.20	17.91	35.10
16/02/1998 00:00	2.00	5.70	1.40	26.00	10.00	28.70	7.01	27.35

16/03/1998 00:00	17.50	20.10	20.60	32.00	18.10	65.80	20.36	48.90
16/04/1998 00:00	40.00	38.50	43.70	29.00	21.50	27.00	35.26	28.00
16/05/1998 00:00	27.00	38.60	14.00	22.80	10.70	26.60	20.12	24.70
16/06/1998 00:00	12.00	32.30	2.70	25.50	13.40	32.40	12.24	28.95
16/07/1998 00:00	0.00	0.00	0.00	2.00	0.00	0.00	0.29	1.00
16/08/1998 00:00	11.00	15.70	1.50	19.00	17.50	22.80	11.50	20.90
16/09/1998 00:00	19.30	19.00	0.00	86.50	93.20	79.10	40.60	82.80
16/10/1998 00:00	41.00	37.00	50.90	48.50	27.00	38.40	41.19	43.45
16/11/1998 00:00	15.20	11.90	7.80	28.50	23.90	79.60	17.38	54.05
16/12/1998 00:00	3.00	1.20	2.00	17.00	14.90	29.50	7.34	23.25
16/01/1999 00:00	126.50	118.30	58.20	235.00	160.00	179.00	134.54	207.00
16/02/1999 00:00	0.00	2.00	0.80	15.00	3.80	22.00	3.13	18.50
16/03/1999 00:00	12.00	10.70	12.20	50.00	29.20	58.00	21.16	54.00
16/04/1999 00:00	7.20	9.20	5.90	18.00	17.30	8.00	10.63	13.00
16/05/1999 00:00	29.40	21.80	18.10	22.00	17.60	20.00	23.39	21.00
16/06/1999 00:00	30.30	20.00	6.60	13.00	18.20	32.00	20.16	22.50
16/07/1999 00:00	0.00	2.00	0.00	5.00	5.00	8.00	1.79	6.50
16/08/1999 00:00	1.00	1.50	0.00	18.00	12.00	34.00	5.57	26.00
16/09/1999 00:00	47.90	64.50	25.80	73.00	42.20	57.00	45.53	65.00
16/10/1999 00:00	5.40	5.70	14.20	32.00	10.30	6.00	12.14	19.00
16/11/1999 00:00	66.80	134.90	76.80	88.00	86.00	101.00	76.09	94.50
16/12/1999 00:00	10.20	13.80	11.70	49.00	30.70	75.00	20.46	62.00
16/01/2000 00:00	0.00	1.50	5.80	7.00	2.20	8.00	2.71	7.50
16/02/2000 00:00	0.00	10.30	0.80	17.00	5.00	24.00	3.67	20.50
16/03/2000 00:00	7.90	8.40	8.60	6.00	22.50	5.00	10.91	5.50
16/04/2000 00:00	28.90	13.70	19.00	15.00	29.80	27.00	24.99	21.00
16/05/2000 00:00	35.70	64.30	32.40	77.00	60.00	121.00	46.10	99.00
16/06/2000 00:00	36.40	32.20	17.90	23.00	14.50	5.00	25.83	14.00
16/07/2000 00:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16/08/2000 00:00	6.80	12.50	0.00	12.00	5.00	13.00	5.70	12.50
16/09/2000 00:00	49.10	34.60	10.70	70.00	46.50	108.00	43.30	89.00
16/10/2000 00:00	31.50	41.30	13.70	51.00	148.00	30.00	55.44	40.50
16/11/2000 00:00	1.60	2.50	3.00	7.00	1.50	9.00	2.65	8.00
16/12/2000 00:00	5.40	6.20	0.40	46.00	11.10	37.00	11.35	41.50
16/01/2001 00:00	16.80	13.40	5.60	46.00	24.10	77.00	20.14	61.50
16/02/2001 00:00	0.20	0.00	1.20	23.00	13.80	48.00	6.59	35.50
16/03/2001 00:00	5.80	2.10	5.00	32.00	15.70	38.00	11.49	35.00
16/04/2001 00:00	6.40	1.70	3.40	25.00	16.80	24.00	10.64	24.50
16/05/2001 00:00	79.90	63.10	52.60	94.00	78.00	95.00	75.66	94.50
16/06/2001 00:00	0.20	0.00	0.00	0.00	0.00	0.00	0.09	0.00
16/07/2001 00:00	9.00	4.60	2.30	1.00	0.70	0.00	4.64	0.50
16/08/2001 00:00	4.00	0.00	5.50	4.00	2.80	3.00	4.06	3.50
16/09/2001 00:00	57.00	31.40	37.60	52.00	75.00	48.00	55.99	50.00
16/10/2001 00:00	14.30	6.00	16.50	10.00		4.00	11.01	7.00
16/11/2001 00:00	14.40	2.00	4.30	8.00		14.00	7.59	11.00
16/12/2001 00:00	5.80	0.00	9.70	16.00		11.00	7.61	13.50
16/01/2002 00:00	0.00	5.50	0.70	4.00		13.00	2.81	8.50
16/02/2002 00:00	0.00	0.50	0.70	9.00		14.00	2.81	11.50
16/03/2002 00:00	45.40	9.60	29.30	37.00		15.00	30.47	26.00
16/04/2002 00:00	12.40	21.60	25.30	43.00		30.00	25.61	36.50
16/05/2002 00:00	38.90	37.70	45.20	61.00		56.00	45.77	58.50
16/06/2002 00:00	6.60	2.90	0.50	2.00		0.00	3.36	1.00
16/07/2002 00:00	1.80	6.00	4.40	17.00		39.00	7.71	28.00
16/08/2002 00:00	37.50	37.50	13.50	40.00		53.00	34.79	46.50
16/09/2002 00:00	18.50	22.70	12.60	63.00	48.60	64.00	30.04	63.50
16/10/2002 00:00	0.00	0.00	0.00	4.00	1.00	9.00	0.79	6.50
16/11/2002 00:00	38.00	43.70	50.60	78.00	90.80	120.00	57.73	99.00
16/12/2002 00:00	14.50	13.00	17.90	25.00	22.80	54.00	18.51	39.50
16/01/2003 00:00	110.50	107.20	76.00	193.00	155.70	229.00	124.58	211.00
16/02/2003 00:00	59.50	49.80	41.60	80.00	64.10	86.00	59.58	83.00
16/03/2003 00:00	13.00	15.00	10.20	22.00	21.10	26.00	15.42	24.00

16/04/2003 00:00	63.70	63.00	42.40	105.00	66.00	128.00	65.53	116.50
16/05/2003 00:00	12.00	19.00	9.30	10.00	11.50	11.00	11.03	10.50
16/06/2003 00:00	11.00	24.50	18.70	19.00	28.00	34.00	17.44	26.50
16/07/2003 00:00	7.00	32.70	16.90	9.00	0.70	6.00	8.06	7.50
16/08/2003 00:00	4.00	19.10	0.00	5.00	4.00	3.00	3.29	4.00
16/09/2003 00:00			39.30	49.00		85.00	42.07	67.00
16/10/2003 00:00	56.00	77.00	41.00	68.00		88.00	63.29	78.00
16/11/2003 00:00	9.00	13.00	5.40	42.00		35.00	19.06	38.50
16/12/2003 00:00	69.00	84.00	86.50	216.00		195.00	117.79	205.50
16/01/2004 00:00	4.30	1.80	2.40	33.00	27.00	52.00	12.86	42.50
16/02/2004 00:00	5.00	3.50	6.30	5.00	6.00	16.00	5.49	10.50
16/03/2004 00:00	43.10	49.40	28.10	65.00	28.50	72.00	39.89	68.50
16/04/2004 00:00	21.20	32.10	18.10	28.00	44.00	27.00	26.39	27.50
16/05/2004 00:00	13.20	13.60	15.60	30.00	7.60	50.00	14.91	40.00
16/06/2004 00:00	19.20	52.50	21.40	56.00	37.80	84.00	28.91	70.00
16/07/2004 00:00	4.00	3.00	1.50	3.00	2.00	0.00	2.89	1.50
16/08/2004 00:00	11.00	41.70	10.00	54.00	25.40	37.00	20.01	45.50
16/09/2004 00:00	7.60	8.40	2.80	11.00	16.60	14.00	8.99	12.50
16/10/2004 00:00	16.00	39.50	10.30	32.00	44.90	17.00	23.26	24.50
16/11/2004 00:00	62.20	86.50	38.90	93.00	75.90	94.00	64.54	93.50
16/12/2004 00:00	18.80	31.00	22.70	90.00	52.40	81.00	37.01	85.50
16/01/2005 00:00	14.70	17.00	5.30	45.00	53.20	56.00	25.26	50.50
16/02/2005 00:00	106.00	173.00	69.40	166.00	135.70	107.00	113.09	136.50
16/03/2005 00:00	5.10	11.20	5.80	8.00	11.80	19.00	7.10	13.50
16/04/2005 00:00	23.60	20.00	27.40	38.00	29.60	36.00	27.76	37.00
16/05/2005 00:00	0.00	0.00	0.50	2.00	2.80	10.00	0.99	6.00
16/06/2005 00:00	44.60	112.00	33.50	129.00	43.10	63.00	53.96	96.00
16/07/2005 00:00	0.00	0.00	4.00	1.00	1.50	1.00	1.32	1.00
16/08/2005 00:00	69.70	116.20	62.60	61.00	130.20	33.00	79.90	47.00
16/09/2005 00:00	22.50	13.00	13.70		11.80		15.47	11.80
16/10/2005 00:00	29.70	35.50	37.70		57.30		40.39	57.30
16/11/2005 00:00	8.90	21.50	11.20		55.90		26.26	55.90
16/12/2005 00:00	19.60	22.50	23.10		49.70		29.53	49.70
16/01/2006 00:00	201.50	172.40	196.00		251.00		206.54	251.00
16/02/2006 00:00	16.00	27.00	5.10		18.80		18.39	18.80
16/03/2006 00:00	2.00	0.00	0.00		8.90		3.11	8.90
16/04/2006 00:00	13.70	18.50	4.70		8.50		12.30	8.50
16/05/2006 00:00	86.10	104.50	53.70		44.50		74.84	44.50
16/06/2006 00:00	10.10	15.00	5.50		4.70		9.30	4.70
16/07/2006 00:00	14.20	43.70	11.70		57.00		34.50	57.00
16/08/2006 00:00	2.50	3.50	53.10		23.00		15.87	23.00

Table A2: Monthly runoff series for the upper catchment (common period with El Haouareb in yellow)

Skhira-RES1A (1000xm3/month)

	S	O	N	D	J	F	M	A	M	J	J	A
1974 - 1975	1738.109	154.224	70.243	22.032	21.946	2918.333	81.907	272.333	171.504	24.538	10.800	4243.795
1975 - 1976	743.904	92.707	2258.323	30.586	1129.507	161.136	449.798	296.784	1951.258	2894.400	1171.325	260.842
1976 - 1977	149.472	1017.792	1602.806	111.283	344.218	63.590	680.400	72.749	21.514	933.206	13.392	22.291
1977 - 1978	364.954	485.827	379.123	8.035	10.714	70.762	87.264	71.539	469.670	55.555	8.035	511.142
1978 - 1979	116.208	46.829	7.776	7.430	8.035	14.602	605.318	2031.264	41.645	16.330	5.357	2541.802
1979 - 1980	714.787	718.675	1887.926	10.714	6.826	92.016	1596.586	94.349	62.294	492.394	5.357	5.357
1980 - 1981	511.834	39.485	17.885	1735.344	343.354	123.638	63.245	82.858	179.453	394.675	24.106	24.106
1981 - 1982	459.562	405.302	5.184	11.837	412.214	23.501	132.192	2394.403	1178.150	400.810	5.357	5.357
1982 - 1983	356.746	963.965	814.493	54.778	130.982	35.683	111.110	5.875	93.744	131.846	5.357	5.357
1983 - 1984	5.184	339.552	9.763	5.357	5.357	38.880	14.256	5.184	11.405	5.184	2.851	6.826
1984 - 1985	556.675	58.320	15.638	223.171	99.446	15.120	20.131	10.368	2060.122	340.675	10.714	10.714
1985 - 1986	935.021	16.330	12.182	18.922	10.714	14.947	1246.406	6.394	1790.122	543.629	1566.778	497.491
1986 - 1987	90.806	770.688	9.504	9.072	8.035	7.258	138.326	27.734	20.304	20.650	944.698	182.390
1987 - 1988	15.466	442.109	10.368	10.714	10.714	10.022	16.502	46.742	4506.451	259.027	7.430	950.918
1988 - 1989	605.491	39.658	367.546	64.195	12.960	20.390	29.203	146.189	319.507	541.901	248.573	728.093
1989 - 1990	2352.586	83.030	15.811	30.931	2629.584	152.842	1552.954	1253.146	1214.179	49.766	443.837	3889.382
1990 - 1991	860.285	281.750	300.067	1730.678	365.126	417.571	1084.493	1520.467	124.243	45.878	9.677	8.035
1991 - 1992	3046.896	34.733	1473.638	101.866	711.850	3940.963	363.830	1013.472	810.691	49.507	8.035	8.035
1992 - 1993	4023.907	420.941	2336.861	1275.091	172.886	584.582	818.035	102.211	708.739	21.254	10.800	48.384
1993 - 1994	2950.387	9.072	7.776	8.035	31.622	1503.360	8.035	7.776	8.381	7.776	8.035	8.035
1994 - 1995	906.682	1776.298	12.960	13.392	13.392	12.096	13.392	12.960	13.392	1910.477	13.392	781.402
1995 - 1996	5069.866	1675.210	189.562	41.818	934.330	1658.880	1185.667	258.077	1981.930	431.222	26.006	310.867
1996 - 1997	1158.192	43.805	8.899	227.318	506.477	86.227	10.368	93.226	11.318	81.562	0.432	2137.622
1997 - 1998	6394.205	625.104	1329.782	270.691	245.549	198.547	139.363	122.515	204.941	3.283	2.506	3.542
1998 - 1999	1275.437	437.098	25.834	5.357	1719.792	214.704	135.043	308.621	88.560	146.189	7.258	843.955
1999 - 2000	2267.741	711.677	469.670	327.024	11.923	12.528	144.547	14.170	1938.384	688.522	189.734	192.586
2000 - 2001	2666.822	896.486	5.184	442.714								
mean	1448.862	449.622	524.601	244.449	380.675	476.622	412.630	395.054	768.535	403.471	182.686	701.089
S.D	1646.962	485.319	768.760	505.799	622.126	976.719	514.995	666.938	1065.456	654.658	407.371	1181.397
Var.coef.	1.137	1.079	1.465	2.069	1.634	2.049	1.248	1.688	1.386	1.623	2.230	1.685

Table A3: Measured inflows to El Haouareb reservoir (1000m3)

Measured inflows to El Haouareb reservoir (1000 m3)

		S	O	N	D	J	F	M	A	M	J	J	A
1989 -	1990	4723	421	168	1526	15745	168	3711	3353	2931	168	168	2997
1990 -	1991	2918	1730	276	3479	1552	758	6256	4310	168	168	168	168
1991 -	1992	4483	168	884	188	302	6602	1279	1236	2345	168	168	168
1992 -	1993	4241	1530	3555	1618	872	877	1790	303	961	168	291	172
1993 -	1994	4614	168	168	192	168	2148	168	168	1244	168	168	168
1994 -	1995	168	13765	1046	245	168	168	168	168	316	2621	168	1498
1995 -	1996	12194	5981	388	617	1375	2025	1683	168	2223	168	168	367
1996 -	1997	2008	191	291	418	477	168	219	168	283	168	273	168
1997 -	1998	14028	1437	1243	168	180	168	291	168	266	190	219	168
1998 -	1999	801	975	178	168	3609	193	168	168	190	168	168	183
1999 -	2000	3299	297	541	292	168	168	168	168	2637	168	168	168
2000 -	2001	2834	1433	168	373	168	168	168	168	1908	168	168	168
2001 -	2002	5139	910	168	168	179	168	717	168	1401	168	168	2439
2002 -	2003	1568	168	985	168	8873	2163	1004	2708	168	519	580	265
2003 -	2004	1728	2632	315	4513	755	502	325	168	168	754	168	230
2004 -	2005	275	1167	5700	258	1291	15377	997	168	168	2636	806	2875
2005 -	2006	234	1593	906	1332	19035	2327	212	345	3007	168	459	2887
	mean	3838.510	2033.466	998.944	924.954	3230.514	2008.881	1136.881	829.859	1199.083	514.114	263.534	887.778
	S.D	3879.217	3329.887	1462.445	1268.304	5768.258	3808.461	1611.635	1310.890	1091.308	811.519	182.922	1142.694
	Var.coef.	1.011	1.638	1.464	1.371	1.786	1.896	1.418	1.580	0.910	1.578	0.694	1.287

Table A4: Measured pan evaporation at El Haouareb (in mm)

Pan evaporation (mm)-Potential evaporation

	S	O	N	D	J	F	M	A	M	J	J	A
1989 - 1990	191	153	90	77	54	71	111	137	220	207	273	268
1990 - 1991	191	153	90	79	106	118	217	231	292	268	218	131
1991 - 1992	104	74	59	56	62	71	118	106	186	270	305	303
1992 - 1993	310	156	116	101	52	48	111	208	237	279	349	319
1993 - 1994	208	145	91	72	85	97	136	148	235	294	304	379
1994 - 1995	220	104	98	73	75	93	119	143	254	229	312	236
1995 - 1996	184	115	91	72	51	65	84	129	203	229	290	250
1996 - 1997	205	135	107	86	68	91	149	140	231	288	301	236
1997 - 1998	129	162	69	76	59	74	126	157	203	259	328	259
1998 - 1999	192	118	78	64	47	77	109	179	247	276	295	303
1999 - 2000	195	140	99	66	53	95	107	155	183	253	338	305
2000 - 2001	221	141	119	107	93	96	177	189	212	327	367	334
2001 - 2002	211	150	100	88	59	90	146	171	197	305	318	258
2002 - 2003	195	165	90	58	64	81	123	143	230	297	344	283
2003 - 2004	179	174	63	49	76	114	100	131	186	230	340	365
2004 - 2005	213	166	88	67	53	59	117	125	238	293	360	274
2005 - 2006	208	127	108	74	54	61	134	183	214	281	350	278
mean	197.193	139.807	91.402	74.389	65.396	82.472	128.430	157.361	221.652	269.662	317.202	281.304
S.D	42.144	25.803	16.995	14.883	16.635	19.263	31.186	32.317	28.481	31.665	36.926	56.670
Var.coef.	0.214	0.185	0.186	0.200	0.254	0.234	0.243	0.205	0.128	0.117	0.116	0.201

Table A5: Seasonal distribution of agricultural water demands

Percentage of water use per month for irrigation

Type of demand	Total percentage	September	October	November	December	January	February	March	April	May	June	July	August
	%	%	%	%	%	%	%	%	%	%	%	%	%
Market gardening	**32**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	8.000	8.000	16.000
Olive trees	**25**	8.333	0.000	0.000	0.000	0.000	0.000	0.000	8.333	0.000	0.000	8.333	0.000
Fruit trees	**43**	2.688	2.048	0.000	0.000	0.000	0.000	2.048	2.688	7.167	9.598	9.598	7.167
Total	**100**	**11.021**	**2.048**	**0.000**	**0.000**	**0.000**	**0.000**	**2.048**	**11.021**	**7.167**	**17.598**	**25.932**	**23.167**

Table A6: Pumping for irrigation from El Haouareb

Pumping from the dam for irrigation **1000 m3**

	S	O	N	D	J	F	M	A	M	J	J	A
1989 - 1990	0	0	0	0	0	0	0	0	0	0	0	0
1990 - 1991	0	0	0	0	0	0	0	0	0	0	0	0
1991 - 1992	0	0	0	0	0	0	0	0	0	0	0	0
1992 - 1993	0	0	0	0	0	0	0	0	0	0	0	0
1993 - 1994	0	0	0	56	742	331	536	810	459	0	0	0
1994 - 1995	0	0	10	420	407	290	444	501	71	0	0	0
1995 - 1996	0	20	5	5	0	6	21	52	35	211	225	108
1996 - 1997	92	111	99	256	187	217	587	158	159	398	291	9
1997 - 1998	42	40	0	204	85	439	700	243	171	694	459	166
1998 - 1999	85	49	193	459	0	70	595	489	122	115	0	14
1999 - 2000	0	106	40	0	38	398	0	0	0	54	267	0
2000 - 2001	0	0	156	594	160	0	0	0	2	154	0	0
2001 - 2002	152	305	226	575	274	93	89	28	96	197	108	13
2002 - 2003	411	644	369	230	51	73	468	316	357	759	1130	553
2003 - 2004	431	679	244	172	356	579	806	293	266	472	608	182
2004 - 2005	330	155	98	205	296	367	751	843	722	723	1185	420
2005 - 2006	643	498	410	227	67	81	965	1315	335	634	675	154
mean	168.14	200.55	142.31	261.72	204.87	226.50	458.60	388.30	214.93	339.22	380.61	124.57
S.D	199.43	233.04	136.05	205.42	203.77	189.89	349.54	384.09	204.35	289.67	394.80	162.92
Var.coef.	1.19	1.16	0.96	0.78	0.99	0.84	0.76	0.99	0.95	0.85	1.04	1.31
%	5.41	6.45	4.58	8.41	6.59	7.28	14.74	12.48	6.91	10.91	12.24	4.01

Table A7: Middle catchment small dams

Middle catchment small dams		Lacombe, 2007			Kikumbi, 2004	
No		Construction year	Capacity 1000m3	Catchment area (ha)	Capacity 1000m3	Catchment area (ha)
6	Garia 1	1968	19	94	25	114
7	Garia 2	1968	25	84	19	64
10	Abda	1969	37	377	37	287
11	Ben Houria	1970	17	219	17	208
12	Marrouki	1973	56	60	56	63
13	Salem Thabet	1973	63	318	63	205
14	Dabi	1980	60	1861	26	564
15	Bouksab	1985	55	279	55	320
16	Maiz	1986	44.5	1233	500	1300
17	Hoshas	1989	130	782	130	1050
18	Fidh Ben Naceur	1990	81	182	100	169
21	Fidh Ali	1991	127	237	127	412
22	Mora	1992	650	1163	650	1250
23	Faden Bouras	1992	94	408	94	391
24	Gatar	1992	150	502	150	450
25	Habsa	1992	45	388	50	450
26	Mbarek	1992	53	97	53	95
27	Ben Zitoun	1993	50	387	50	250
28	Fidh Zitoun	1993	40	259	40	100
29	Hafar	1993	30	37	30	130
30	Mahbes	1993	180	821	180	820
31	Ain Faouar	1994	66	257	66	290
32	Ain Sadoun	1994	0	183	18	172
33	Ain Smili 1	1994	35	526	130	720
34	Sidi Sofiane	1994	40	79	40	101
36	Absa	1995	35	49	35	82
37	Gtatis	1995	106	238	106	212
38	Ain Smili 2	1996	130	168	35	164
39	Gassaa	1997	104.8	558	104	480
40	Kraroub	1997	1590	2074	1270	1930
41	Nmel	1997	1055	1602	1000	1550
42	El Hamrat	1998	160	190	120	400
43	Ghouil	2002	153	477		
44	Hamam	2002	850	1684		
45	Oued Thal	2005	350	510		

Total	**35**			**6681.3**	**18383**		
Total		Without 43-46		5328.3	15712	5376	14793

Table A8: Time series historical data for El Haouareb

Date	mean level	mean area	mean volume	rainfall	Pan Evaporation	Rainfall (S=744.7 ha, cote 212 m)	Pumping in the dam for irrigation	Dam release for sediment cleaning	Dam release for infiltration downstream	Estimation of inflow to the dam reservoir
	m	ha	Mm^3	mm	mm	10^3m^3	10^3m^3	10^3m^3	10^3m^3	10^3m^3
01/09/1989	203.77	279	8.791	0	191	0	0	0	0	4723
01/10/1989	203.59	270	8.280	0	153	0	0	0	0	421
01/11/1989	203.23	253	7.376	0	90	0	0	0	0	168
01/12/1989	203.41	261	7.816	0	77	0	0	0	0	1526
01/01/1990	204.65	327	12.218	0	54	0	0	0	0	15745
01/02/1990	207.12	459	21.190	0	71	0	0	0	0	168
01/03/1990	207.08	457	21.027	58	111	432	0	0	0	3711
01/04/1990	207.84	501	24.724	77	137	570	0	0	0	3353
01/05/1990	207.99	510	25.508	31	220	231	0	0	0	2931
01/06/1990	207.81	499	24.553	0	207	0	0	0	0	168
01/07/1990	207.32	471	22.145	0	273	0	0	0	0	168
01/08/1990	207.76	497	24.339	61	268	452	0	0	0	2997
01/09/1990	207.90	505	25.019	0	191	0	0	0	0	2918
01/10/1990	208.15	519	26.344	0	153	0	0	0	0	1730
01/11/1990	207.76	496	24.311	0	90	0	0	0	0	276
01/12/1990	207.65	490	23.780	0	79	0	0	0	0	3479
01/01/1991	207.88	504	24.915	40	106	295	0	0	0	1552
01/02/1991	207.95	508	25.273	44	118	325	0	0	0	758
01/03/1991	208.62	547	27.467	179	217	1335	0	0	0	6256
01/04/1991	209.48	597	30.860	26	231	196	0	0	0	4310
01/05/1991	209.48	597	30.825	28	292	210	0	0	0	168
01/06/1991	209.06	573	28.349	10	268	74	0	0	0	168
01/07/1991	208.56	543	25.632	0	218	0	0	0	0	168
01/08/1991	208.06	514	22.981	0	131	0	0	0	0	168
01/09/1991	208.23	524	23.868	21	104	153	0	0	0	4483
01/10/1991	208.18	521	23.594	54	74	403	0	0	0	168
01/11/1991	207.90	504	22.165	19	59	141	0	0	0	884
01/12/1991	207.75	494	21.463	0	56	0	0	0	0	188
01/01/1992	207.46	474	20.084	43	62	320	0	0	0	302
01/02/1992	207.60	482	20.770	87	71	647	0	476	0	6602

01/03/1992	208.48	538	25.176	28	118	210	0	0	0	1279
01/04/1992	208.28	527	24.139	64	106	473	0	0	0	1236
01/05/1992	208.34	531	24.477	28	186	211	0	146	0	2345
01/06/1992	208.25	525	23.948	16	270	117	0	0	0	168
01/07/1992	207.77	495	21.552	0	305	0	0	0	0	168
01/08/1992	207.27	461	19.169	4	303	31	0	0	0	168
01/09/1992	206.87	434	17.335	26	310	194	0	0	0	4241
01/10/1992	207.55	480	20.485	15	156	111	0	0	0	1530
01/11/1992	207.99	509	22.664	46	116	340	0	588	0	3555
01/12/1992	207.91	504	22.237	86	101	643	0	45	0	1618
01/01/1993	207.98	509	22.537	0	52	0	0	0	326	872
01/02/1993	207.91	504	22.225	20	48	147	0	0	0	877
01/03/1993	207.81	497	21.709	29	111	215	0	0	0	1790
01/04/1993	207.63	485	20.863	0	208	0	0	0	2804	303
01/05/1993	206.36	402	15.313	21	237	159	0	0	2491	961
01/06/1993	205.90	373	13.519	0	279	0	0	0	0	168
01/07/1993	205.43	348	11.902	0	349	0	0	0	0	291
01/08/1993	205.03	325	10.538	3	319	25	0	0	0	172
01/09/1993	205.28	338	11.381	34	208	250	0	0	74	4614
01/10/1993	205.45	349	11.968	26	145	191	0	0	0	168
01/11/1993	205.11	330	10.780	4	91	29	0	0	0	168
01/12/1993	204.81	312	9.807	19	72	144	56	0	0	192
01/01/1994	204.40	287	8.560	0	85	0	742	0	0	168
01/02/1994	204.15	274	7.867	20	97	145	331	8	0	2148
01/03/1994	204.19	276	7.948	14	136	101	536	0	0	168
01/04/1994	203.46	237	6.218	6	148	44	810	0	0	168
01/05/1994	202.62	151	3.769	24	235	175	459	3448	0	1244
01/06/1994	202.00	100	2.333	0	294	0	0	0	0	168
01/07/1994	202.00	100	2.333	0	304	0	0	0	0	168
01/08/1994	202.09	107	2.574	0	379	0	0	0	0	168
01/09/1994	202.00	100	2.333	0	220	0	0	0	0	168
01/10/1994	206.38	391	13.485	12	104	92	0	1131	0	13765
01/11/1994	206.93	428	14.938	2	98	15	10	0	0	1046
01/12/1994	206.55	400	13.524	0	73	0	420	0	0	245
01/01/1995	206.12	369	11.962	1	75	4	407	0	0	168
01/02/1995	205.71	342	10.599	0	93	0	290	0	0	168

01/03/1995	205.31	318	9.303	9	119	68	444	0	0	168
01/04/1995	204.79	287	7.700	7	143	50	501	0	0	168
01/05/1995	204.36	261	6.431	0	254	0	71	0	0	316
01/06/1995	204.55	273	6.999	18	229	131	0	291	0	2621
01/07/1995	204.41	264	6.595	0	312	2	0	0	0	168
01/08/1995	204.46	267	6.833	12	236	90	0	11	0	1498
01/09/1995	206.14	374	11.673	37	184	278	0	370	1228	12194
01/10/1995	208.26	516	18.202	118	115	875	20	89	1082	5981
01/11/1995	208.49	533	19.311	43	91	320	5	0	0	388
01/12/1995	208.39	526	18.775	47	72	349	5	0	0	617
01/01/1996	208.31	521	18.397	40	51	300	0	0	0	1375
01/02/1996	208.44	530	19.036	26	65	192	6	0	0	2025
01/03/1996	208.48	533	19.247	42	84	311	21	0	0	1683
01/04/1996	208.32	521	18.447	18	129	137	52	0	0	168
01/05/1996	208.19	512	17.763	11	203	83	35	14	0	2223
01/06/1996	207.93	493	16.509	26	229	195	211	0	0	168
01/07/1996	207.43	453	14.314	3	290	25	225	0	0	168
01/08/1996	206.88	411	12.117	21	250	159	108	0	0	367
01/09/1996	206.80	404	11.719	32	205	235	92	6	0	2008
01/10/1996	206.62	390	11.066	5	135	38	111	0	0	191
01/11/1996	206.24	362	9.768	0	107	0	99	0	0	291
01/12/1996	205.92	338	8.720	5	86	39	256	0	0	418
01/01/1997	205.59	315	7.703	33	68	245	187	0	0	477
01/02/1997	205.47	307	7.338	5	91	34	217	0	0	168
01/03/1997	204.98	273	5.935	9	149	68	587	0	0	219
01/04/1997	204.64	248	5.007	37	140	279	158	0	0	168
01/05/1997	204.33	226	4.200	2	231	11	159	0	0	283
01/06/1997	203.89	191	3.192	3	288	25	398	0	0	168
01/07/1997	203.26	135	2.195	0	301	0	291	0	0	273
01/08/1997	202.91	80	1.726	6	236	41	9	0	0	168
01/09/1997	206.23	352	9.217	161	129	1195	42	55	0	14028
01/10/1997	207.96	484	13.691	62	162	462	40	0	0	1437
01/11/1997	207.96	484	13.685	14	69	104	0	0	0	1243
01/12/1997	207.68	460	12.488	8	76	60	204	0	0	168
01/01/1998	207.36	434	11.151	7	59	49	85	0	0	180
01/02/1998	207.02	406	9.796	1	74	10	439	0	0	168

01/03/1998	206.53	369	8.076	21	126	153	700	0	0	291
01/04/1998	206.10	337	6.716	44	157	325	243	0	0	168
01/05/1998	205.74	305	5.635	14	203	104	171	0	0	266
01/06/1998	205.24	270	4.274	3	259	20	694	0	0	190
01/07/1998	204.57	213	2.593	0	328	0	459	0	0	219
01/08/1998	203.94	156	1.400	2	259	11	166	0	0	168
01/09/1998	202.81	63	0.496	0	192	0	85	5	0	801
01/10/1998	204.28	187	1.927	51	118	379	49	0	0	975
01/11/1998	204.05	164	1.433	8	78	58	193	0	0	178
01/12/1998	202.72	56	0.410	2	64	15	459	0	0	168
01/01/1999	203.26	105	1.427	58	47	433	0	8	0	3609
01/02/1999	204.92	243	3.429	1	77	6	70	0	0	193
01/03/1999	204.55	211	2.535	12	109	91	595	0	0	168
01/04/1999	203.81	144	1.234	6	179	44	489	0	0	168
01/05/1999	202.11	9	0.056	18	247	135	122	10	0	190
01/06/1999	202.00	0	0.000	7	276	49	115	0	0	168
01/07/1999	202.00	0	0.000	0	295	0	0	0	0	168
01/08/1999	202.12	9	0.069	0	303	0	14	0	0	183
01/09/1999	204.14	177	2.263	26	195	192	0	0	0	3299
01/10/1999	204.45	202	2.297	14	140	106	106	0	0	297
01/11/1999	204.21	180	1.764	77	99	572	40	0	0	541
01/12/1999	204.38	196	2.153	12	66	87	0	0	0	292
01/01/2000	204.18	177	1.705	6	53	43	38	0	0	168
01/02/2000	203.03	80	0.627	1	95	6	398	0	0	168
01/03/2000	202.00	0	0.000	9	107	64	0	0	0	168
01/04/2000	202.00	0	0.000	19	155	141	0	0	0	168
01/05/2000	202.40	33	0.381	32	183	241	0	0	0	2637
01/06/2000	204.41	199	2.221	18	253	133	54	4	0	168
01/07/2000	202.84	66	0.555	0	338	0	267	0	0	168
01/08/2000	202.00	0	0.000	0	305	0	0	0	0	168
01/09/2000	203.62	127	1.001	11	221	80	0	0	0	2834
01/10/2000	204.36	194	2.111	14	141	102	0	0	0	1433
01/11/2000	204.48	205	2.374	3	119	22	156	0	0	168
01/12/2000	203.82	145	1.235	0	107	3	594	0	0	373
01/01/2001	202.36	28	0.210	6	93	42	160	0	0	168
01/02/2001	202.00	0	0.000	1	96	9	0	0	0	168

01/03/2001	202.00	0	0.000	5	177	37	0	0	0	168
01/04/2001	202.00	0	0.000	3	189	25	0	0	0	168
01/05/2001	203.76	133	1.238	53	212	392	2	0	0	1908
01/06/2001	202.84	66	0.534	0	327	0	154	0	0	168
01/07/2001	202.00	0	0.000	2	367	17	0	0	0	168
01/08/2001	202.00	0	0.000	6	334	41	0	0	0	168
01/09/2001	203.69	138	1.444	38	211	280	152	4	0	5139
01/10/2001	205.83	295	4.669	17	150	123	305	10	0	910
01/11/2001	205.32	254	3.307	4	100	32	226	0	0	168
01/12/2001	204.79	205	2.093	10	88	72	575	0	0	168
01/01/2002	204.38	163	1.293	1	59	5	274	0	0	179
01/02/2002	203.32	75	0.481	1	90	5	93	0	0	168
01/03/2002	202.94	56	0.365	29	146	218	89	0	0	717
01/04/2002	202.39	20	0.123	25	171	188	28	0	0	168
01/05/2002	204.53	172	1.573	45	197	337	96	1	0	1401
01/06/2002	203.26	82	0.584	1	305	4	197	0	0	168
01/07/2002	202.66	34	0.215	4	318	33	108	0	0	168
01/08/2002	203.64	117	1.101	14	258	101	13	5	0	2439
01/09/2002	205.24	247	3.114	13	195	94	411	2	0	1568
01/10/2002	204.77	202	2.048	0	165	0	644	0	0	168
01/11/2002	204.57	182	1.645	51	90	377	369	0	0	985
01/12/2002	204.18	134	0.932	18	58	133	230	0	0	168
01/01/2003	205.42	256	4.911	76	64	566	51	0	0	8873
01/02/2003	207.52	418	8.983	42	81	310	73	0	0	2163
01/03/2003	207.85	444	10.210	10	123	76	468	0	0	1004
01/04/2003	208.01	458	10.919	42	143	316	316	0	0	2708
01/05/2003	207.64	428	9.438	9	230	69	357	0	0	168
01/06/2003	207.15	387	7.553	19	297	139	759	0	0	519
01/07/2003	206.42	331	5.184	17	344	126	1130	0	0	580
01/08/2003	205.72	270	3.274	0	283	0	553	0	0	265
01/09/2003	205.44	243	2.440	39	179	293	431	0	0	1728
01/10/2003	205.47	245	2.526	41	174	305	679	0	0	2632
01/11/2003	205.87	281	3.553	5	63	40	244	0	0	315
01/12/2003	206.55	336	5.708	87	49	644	172	0	0	4513
01/01/2004	207.11	384	7.397	2	76	18	356	0	0	755
01/02/2004	206.80	360	6.378	6	114	47	579	0	0	502

01/03/2004	206.33	324	4.919	28	100	209	806	0	0	325
01/04/2004	205.95	290	3.782	18	131	135	293	0	0	168
01/05/2004	205.48	245	2.532	16	186	116	266	0	0	168
01/06/2004	205.11	213	1.685	21	230	159	472	0	0	754
01/07/2004	203.72	104	0.579	2	340	11	608	0	0	168
01/08/2004	202.35	25	0.258	10	365	74	182	0	0	230
01/09/2004	204.57	152	0.710	3	213	21	330	2	0	275
01/10/2004	203.53	83	0.279	10	166	77	155	0	0	1167
01/11/2004	205.88	274	3.851	39	88	290	98	6	0	5700
01/12/2004	206.42	308	4.946	23	67	169	205	0	0	258
01/01/2005	206.35	300	3.972	5	53	39	296	0	0	1291
01/02/2005	208.54	486	13.122	69	59	517	367	145	0	15377
01/03/2005	209.64	580	17.797	6	117	43	751	0	0	997
01/04/2005	209.16	535	15.153	27	125	204	843	0	0	168
01/05/2005	208.57	478	12.259	1	238	4	722	0	0	168
01/06/2005	208.25	447	10.748	34	293	249	723	0	0	2636
01/07/2005	207.93	420	9.408	4	360	30	1185	0	0	806
01/08/2005	206.74	335	6.661	63	274	466	420	0	0	2875
01/09/2005	208.26	449	10.833	14	208	102	643	0	0	234
01/10/2005	207.96	421	9.456	38	127	281	498	0	0	1593
01/11/2005	207.81	411	8.933	11	108	83	410	0	0	906
01/12/2005	207.65	399	8.340	23	74	172	227	0	0	1332
01/01/2006	209.27	527	15.475	196	54	1460	67	127	0	19035
01/02/2006	211.45	712	27.437	5	61	38	81	0	1179	2327
01/03/2006	210.43	634	20.829	0	134	0	965	376	5674	212
01/04/2006	209.49	546	15.401	5	183	35	1315	0	0	345
01/05/2006	209.20	517	13.880	54	214	400	335	0	0	3007
01/06/2006	209.04	501	13.075	6	281	41	634	0	0	168
01/07/2006	208.41	435	10.241	12	350	87	675	0	0	459
01/08/2006	207.97	396	8.540	53	278	395	154	2	0	2887

Table A9: Level-Surface-Volume data for El Haouareb dam

Level	Volume	Surface	
m	1000m3	m2	
204.00	1.00	58000	
205.00	1192.36	206958	
206.00	3538.10	299008	1st breaking point
207.00	6908.70	375200	
208.00	11115.73	456660	
209.00	16055.71	540537	
210.00	21681.04	633063	2nd Breaking point
211.00	28251.04	686200	
212.00	35401.04	744700	
213.00	43141.04	803200	
214.00	51471.04	861700	
215.00	60371.04	920200	
216.00	69871.04	978700	
217.00	79951.04	1037200	
218.00	90611.04	1095700	
219.00	101861.04	1145200	
220.00	113701.04	1212700	
221.00	126121.04	1271200	
222.00	139121.04	1329700	
223.00	152711.04	1388200	
224.00	166891.04	1446700	
225.00	181641.04	1505200	
226.00	196991.04	1563700	

Appendix B

Results

Table B1.1 Skhira upper catchment

Skhira upper catchment

Scenario 1 As it is

Time	Calendar month	Rainfall Skhira upper catchment	Runoff coefficient	Runoff to middle catchment	Rainfall data climate coefficient
		mm		1000m3	
0	9	67	0.2	2465.6	1
1	10	78	0.11	1578.72	1
2	11	38.5	0.11	779.24	1
3	12	205.5	0.11	4159.32	1
4	1	42.5	0.11	860.2	1
5	2	10.5	0.11	212.52	1
6	3	68.5	0.11	1386.44	1
7	4	27.5	0.11	556.6	1
8	5	40	0.11	809.6	1
9	6	70	0.11	1416.8	1
10	7	1.5	0.11	30.36	1
11	8	45.5	0.11	920.92	1
12	9	12.5	0.2	460	1
13	10	24.5	0.11	495.88	1
14	11	93.5	0.11	1892.44	1
15	12	85.5	0.11	1730.52	1
16	1	50.5	0.11	1022.12	1
17	2	136.5	0.11	2762.76	1
18	3	13.5	0.11	273.24	1
19	4	37	0.11	748.88	1
20	5	6	0.11	121.44	1
21	6	96	0.11	1943.04	1
22	7	1	0.11	20.24	1
23	8	47	0.11	951.28	1
24	9	11.8	0.2	434.24	1
25	10	57.3	0.11	1159.752	1
26	11	55.9	0.11	1131.416	1
27	12	49.7	0.11	1005.928	1
28	1	251	0.11	5080.24	1
29	2	18.8	0.11	380.512	1
30	3	8.9	0.11	180.136	1
31	4	8.5	0.11	172.04	1
32	5	44.5	0.11	900.68	1
33	6	4.7	0.11	95.128	1
34	7	57	0.11	1153.68	1
35	8	23	0.11	465.52	1

Table B1.2a Middle catchment-Part a

Middle catchment general

Scenario 1

Time	Calendar month	Rainfall middle catchment	Rainfall data climate coefficient	Runoff coefficient	Runoff to small dams RES2A	Runoff from non managed areas RES2B	Inflow from Skhira upper catchment RES1	Water losses and pumping from river bed between RES1 and El Haouareb
		mm			1000m3	1000m3	1000m3	1000m3
0	9	42.0714	1	0.033	255.2217	1117.8635	2465.6	100
1	10	63.2857	1	0.033	383.9158	1681.54	1578.72	100
2	11	19.0571	1	0.033	115.6081	506.3599	779.24	100
3	12	117.7857	1	0.033	714.5341	3129.6383	4159.32	100
4	1	12.8571	1	0.033	77.9964	341.6221	860.2	100
5	2	5.4929	1	0.033	33.3218	145.9486	212.52	100
6	3	39.8857	1	0.033	241.9623	1059.7877	1386.44	100
7	4	26.3929	1	0.033	160.1094	701.2743	556.6	100
8	5	14.9143	1	0.033	90.4759	396.2817	809.6	100
9	6	28.9143	1	0.033	175.4053	768.2702	1416.8	100
10	7	2.8929	1	0.033	17.5492	76.865	30.36	30.36
11	8	20.0143	1	0.033	121.4145	531.7918	920.92	100
12	9	8.9857	1	0.033	54.5108	238.7559	460	100
13	10	23.2571	1	0.033	141.0869	617.9565	495.88	100
14	11	64.5429	1	0.033	391.5421	1714.9431	1892.44	100
15	12	37.0071	1	0.033	224.4998	983.3024	1730.52	100
16	1	25.2643	1	0.033	153.263	671.2875	1022.12	100
17	2	113.0929	1	0.033	686.0654	3004.9462	2762.76	100
18	3	7.1	1	0.033	43.0714	188.6513	273.24	100
19	4	27.7571	1	0.033	168.3857	737.5242	748.88	100
20	5	0.9929	1	0.033	6.0231	26.3808	121.44	100
21	6	53.9571	1	0.033	327.3251	1433.6742	1943.04	100
22	7	1.3214	1	0.033	8.0163	35.1112	20.24	20.24
23	8	79.9	1	0.033	484.7046	2122.9917	951.28	100
24	9	15.4714	1	0.033	93.8557	411.0853	434.24	100
25	10	40.3857	1	0.033	244.9955	1073.0731	1159.752	100
26	11	26.2571	1	0.033	159.2861	697.6683	1131.416	100
27	12	29.5286	1	0.033	179.1318	784.5922	1005.928	100
28	1	206.5429	1	0.033	1252.9695	5487.9697	5080.24	100
29	2	18.3857	1	0.033	111.5349	488.5196	380.512	100
30	3	3.1143	1	0.033	18.8925	82.7485	180.136	100
31	4	12.3	1	0.033	74.6166	326.8185	172.04	100
32	5	74.8429	1	0.033	454.026	1988.6204	900.68	100
33	6	9.3	1	0.033	56.4174	247.1067	95.128	95.128
34	7	34.5	1	0.033	209.2905	916.686	1153.68	100
35	8	15.8714	1	0.033	96.2823	421.7135	465.52	100

Table B1.2b Middle catchment-Part b

Middle catchment general

Scenario 1

Time	Calendar month	Overflow to El Haouareb from small dams RES2A	Flow to El Haouareb dam from middle catchment	Transfer to Aquifer from RES2A small dams Infiltration	Number of small dams	Managed area in RES2A	Total capacity of small dams	Potential Evaporation	Agricultural demands	Transfer from 2AB
		1000m3	1000m3	1000m3		km2	1000m3	m	1000m3	1000m3
0	9	0	3483.4635	0.0108	35	183.83	6618.3	0.1414	22.1394	1728
1	10	0	3160.26	0.0281	35	183.83	6618.3	0.1375	4.1697	2632
2	11	0	1185.5999	0.0333	35	183.83	6618.3	0.0498	0	315
3	12	0	7188.9583	0.0684	35	183.83	6618.3	0.0387	0	4513
4	1	0	1101.8221	0.071	35	183.83	6618.3	0.06	0	755
5	2	0	258.4686	0.0706	35	183.83	6618.3	0.0901	0	502
6	3	0	2346.2277	0.0806	35	183.83	6618.3	0.079	4.1697	325
7	4	0	1157.8743	0.0852	35	183.83	6618.3	0.1035	22.1394	168
8	5	0	1105.8817	0.0853	35	183.83	6618.3	0.1469	14.5939	168
9	6	0	2085.0702	0.088	35	183.83	6618.3	0.1817	34.7636	754
10	7	0	76.865	0.08	35	183.83	6618.3	0.2686	51.4303	168
11	8	0	1352.7118	0.0772	35	183.83	6618.3	0.2884	46.5939	230
12	9	0	598.7559	0.0754	35	183.83	6618.3	0.1683	22.1394	275
13	10	0	1013.8365	0.0792	35	183.83	6618.3	0.1311	4.1697	1167
14	11	0	3507.3831	0.0971	35	183.83	6618.3	0.0695	0	5700
15	12	0	2613.8224	0.1069	35	183.83	6618.3	0.0529	0	258
16	1	0	1593.4075	0.1133	35	183.83	6618.3	0.0419	0	1291
17	2	0	5667.7062	0.1463	35	183.83	6618.3	0.0466	0	15377
18	3	0	361.8913	0.145	35	183.83	6618.3	0.0924	4.1697	997
19	4	0	1386.4042	0.1491	35	183.83	6618.3	0.0988	22.1394	168
20	5	0	47.8208	0.1423	35	183.83	6618.3	0.188	14.5939	168
21	6	0	3276.7142	0.1491	35	183.83	6618.3	0.2315	34.7636	2636
22	7	0	35.1112	0.1377	35	183.83	6618.3	0.2844	51.4303	806
23	8	0	2974.2717	0.1527	35	183.83	6618.3	0.2165	46.5939	2875
24	9	0	745.3253	0.1509	35	183.83	6618.3	0.1643	22.1394	234
25	10	0	2132.8251	0.1595	35	183.83	6618.3	0.1003	4.1697	1593
26	11	0	1729.0843	0.1643	35	183.83	6618.3	0.0853	0	906
27	12	0	1690.5202	0.1712	35	183.83	6618.3	0.0585	0	1332
28	1	852.1154	11320.3251	0.1984	35	183.83	6618.3	0.0427	0	19035
29	2	96.0064	865.0381	0.1982	35	183.83	6618.3	0.0482	0	2327
30	3	0	162.8845	0.1946	35	183.83	6618.3	0.1059	4.1697	212
31	4	0	398.8585	0.1915	35	183.83	6618.3	0.1446	22.1394	345
32	5	357.1046	3146.405	0.1926	35	183.83	6618.3	0.1691	14.5939	3007
33	6	0	247.1067	0.185	35	183.83	6618.3	0.222	34.7636	168
34	7	0	1970.366	0.1824	35	183.83	6618.3	0.2765	51.4303	459
35	8	0	787.2335	0.177	35	183.83	6618.3	0.2196	46.5939	2887

Table B 1.3 Small dam unit

Small dam unit

Scenario 1

Time	Calendar month	Number of small dams	Median small dam capacity	Median small dam height	Median height for starting overflow	Small dam capacity at overflow	Small dam lake and surrounding surface for direct rainfall	Inflow from runoff	Direct inflow from rainfall	Small dam initial status	Overflow from a small dam	Evaporation from a small dam	Infiltration from a small dam	Pumping for agriculture from a small dam
			1000m3	m	m	1000m3	m2	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	35	189.094	8.9943	7.9943	143.0095	45000	5.5243	1.8932	0	0	0.6757	0.0002	0.6326
1	10	35	189.094	8.9943	7.9943	143.0095	45000	8.3099	2.8479	6.109	0	1.1529	0.0006	0.1191
2	11	35	189.094	8.9943	7.9943	143.0095	45000	2.5023	0.8576	15.994	0	0.4604	0.0008	0
3	12	35	189.094	8.9943	7.9943	143.0095	45000	15.4661	5.3004	18.8928	0	0.5455	0.0016	0
4	1	35	189.094	8.9943	7.9943	143.0095	45000	1.6882	0.5786	39.1122	0	0.8633	0.0016	0
5	2	35	189.094	8.9943	7.9943	143.0095	45000	0.7213	0.2472	40.514	0	1.2888	0.0016	0
6	3	35	189.094	8.9943	7.9943	143.0095	45000	5.2373	1.7949	40.1921	0	1.2206	0.0018	0.1191
7	4	35	189.094	8.9943	7.9943	143.0095	45000	3.4656	1.1877	45.8827	0	1.6458	0.0019	0.6326
8	5	35	189.094	8.9943	7.9943	143.0095	45000	1.9584	0.6711	48.2557	0	2.3324	0.0019	0.417
9	6	35	189.094	8.9943	7.9943	143.0095	45000	3.7967	1.3011	48.1339	0	2.9229	0.002	0.9932
10	7	35	189.094	8.9943	7.9943	143.0095	45000	0.3799	0.1302	49.3136	0	4.0516	0.0018	1.4694
11	8	35	189.094	8.9943	7.9943	143.0095	45000	2.628	0.9006	44.3008	0	4.2302	0.0017	1.3313
12	9	35	189.094	8.9943	7.9943	143.0095	45000	1.1799	0.4044	42.2663	0	2.4258	0.0016	0.6326
13	10	35	189.094	8.9943	7.9943	143.0095	45000	3.0538	1.0466	40.7905	0	1.946	0.0017	0.1191
14	11	35	189.094	8.9943	7.9943	143.0095	45000	8.4749	2.9044	42.8241	0	1.168	0.0021	0
15	12	35	189.094	8.9943	7.9943	143.0095	45000	4.8593	1.6653	53.0333	0	0.9423	0.0023	0
16	1	35	189.094	8.9943	7.9943	143.0095	45000	3.3174	1.1369	58.6133	0	0.7721	0.0025	0
17	2	35	189.094	8.9943	7.9943	143.0095	45000	14.8499	5.0892	62.293	0	1.0021	0.0032	0
18	3	35	189.094	8.9943	7.9943	143.0095	45000	0.9323	0.3195	81.2267	0	1.9748	0.0032	0.1191
19	4	35	189.094	8.9943	7.9943	143.0095	45000	3.6447	1.2491	80.3814	0	2.1416	0.0033	0.6326
20	5	35	189.094	8.9943	7.9943	143.0095	45000	0.1304	0.0447	82.4977	0	3.9537	0.0031	0.417
21	6	35	189.094	8.9943	7.9943	143.0095	45000	7.085	2.4281	78.2989	0	4.9901	0.0033	0.9932
22	7	35	189.094	8.9943	7.9943	143.0095	45000	0.1735	0.0595	81.8253	0	5.8136	0.003	1.4694
23	8	35	189.094	8.9943	7.9943	143.0095	45000	10.4914	3.5955	74.7723	0	4.6999	0.0033	1.3313
24	9	35	189.094	8.9943	7.9943	143.0095	45000	2.0315	0.6962	82.8247	0	3.5341	0.0033	0.6326
25	10	35	189.094	8.9943	7.9943	143.0095	45000	5.3029	1.8174	81.3825	0	2.2312	0.0034	0.1191
26	11	35	189.094	8.9943	7.9943	143.0095	45000	3.4478	1.1816	86.1491	0	1.9316	0.0036	0
27	12	35	189.094	8.9943	7.9943	143.0095	45000	3.8773	1.3288	88.8432	0	1.3565	0.0037	0

28	1	35	189.094	8.9943	7.9943	143.0095	45000	27.1206	9.2944	92.6892	0	1.1924	0.0051	0
29	2	35	189.094	8.9943	7.9943	143.0095	45000	2.4142	0.8274	127.907	0	1.3584	0.0052	0
30	3	35	189.094	8.9943	7.9943	143.0095	45000	0.4089	0.1401	129.785	0	2.9499	0.0051	0.1191
31	4	35	189.094	8.9943	7.9943	143.0095	45000	1.6151	0.5535	127.26	0	3.9827	0.005	0.6326
32	5	35	189.094	8.9943	7.9943	143.0095	45000	9.8274	3.3679	124.808	0	4.8261	0.0053	0.417
33	6	35	189.094	8.9943	7.9943	143.0095	45000	1.2212	0.4185	132.755	0	6.1801	0.0051	0.9932
34	7	35	189.094	8.9943	7.9943	143.0095	45000	4.5301	1.5525	127.216	0	7.5884	0.005	1.4694
35	8	35	189.094	8.9943	7.9943	143.0095	45000	2.084	0.7142	124.236	0	5.9048	0.0048	1.3313

Table B1.4 El Haouareb

El Haouareb

Scenario 1

Time	Calendar month	Rainfall	Rainfall data climate coefficient scenario	Inflow from Rainfall	Inflow from middle catchment	Initial El Haouareb status	Evaporation	Pumping for Irrigation	Infiltration to Kairoouan aquifer	Dam release status	Release threshold	Dam release to Kairouan
		mm		1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	39.3	1	614.5341	1728	2440	426.8469	431	769.719	3154.9682	20000	0
1	10	41	1	641.117	2632	3154.9682	460.2703	0	853.8406	5113.9743	20000	0
2	11	5.4	1	84.4398	315	5113.9743	160.5594	244	822.6372	4286.2176	20000	0
3	12	86.5	1	1352.6005	4513	4286.2176	160.0893	172	1054.5793	8765.1495	20000	0
4	1	2.4	1	37.5288	755	8765.1495	240.82	356	1022.803	7938.0553	20000	0
5	2	6.3	1	98.5131	502	7938.0553	341.7741	579	967.7148	6650.0796	20000	0
6	3	28.1	1	439.3997	325	6650.0796	283.2011	0	914.13	6217.1482	20000	0
7	4	18.1	1	283.0297	168	6217.1482	354.1185	293	872.5501	5148.5093	20000	0
8	5	15.6	1	243.9372	168	5148.5093	466.3607	266	809.3235	4018.7623	20000	0
9	6	21.4	1	334.6318	754	4018.7623	556.1297	0	780.4792	3770.7853	20000	0
10	7	1.5	1	23.4555	168	3770.7853	778.3073	0	738.8994	2445.0341	20000	0
11	8	10	1	156.37	230	2445.0341	713.3147	182	630.8141	1305.2752	20000	0
12	9	2.8	1	43.7836	275	1305.2752	310.4614	0	470.48	843.1174	20000	0
13	10	10.3	1	161.0611	1167	843.1174	280.0562	155	544.5656	1191.5567	20000	0
14	11	38.9	1	608.2793	5700	1191.5567	250.3213	98	918.1809	6233.3337	20000	0
15	12	22.7	1	354.9599	258	6233.3337	184.7807	205	890.2148	5566.2982	20000	0
16	1	5.3	1	82.8761	1291	5566.2982	147.2422	296	896.7462	5600.1859	20000	0
17	2	69.4	1	1085.2078	15377	5600.1859	285.1499	367	1560.0347	19850.209	20000	0
18	3	5.8	1	90.6946	997	19850.209	546.8077	751	1508.5573	18131.539	20000	0
19	4	27.4	1	428.4538	168	18131.539	550.034	843	1420.3409	15914.618	20000	0
20	5	0.5	1	7.8185	168	15914.618	952.8163	722	1292.2464	13123.373	20000	0
21	6	33.5	1	523.8395	2636	13123.373	1171.2176	723	1290.2773	13098.718	20000	0
22	7	4	1	62.548	806	13098.718	1317.3967	1185	1181.2101	10283.659	20000	0
23	8	62.6	1	978.8762	2875	10283.659	1019.5673	420	1201.098	11496.87	20000	0
24	9	13.7	1	214.2269	234	11496.87	718.3125	643	1114.7133	9469.071	20000	0
25	10	37.7	1	589.5149	1593	9469.071	438.0983	498	1113.4762	9602.0114	20000	0
26	11	11.2	1	175.1344	906	9602.0114	358.5085	410	1071.4915	8843.1458	20000	0
27	12	23.1	1	361.2147	1332	8843.1458	245.2413	227	1069.732	8994.3871	20000	0
28	1	196	1	3064.852	19035	8994.3871	298.9651	67	1787.063	28941.211	20000	8941.2109

29	2	5.1	1	79.7487	2327	20000	297.4346	81	1573.8914	20454.423	20000	454.4227
30	3	0	1	0	212	20000	613.4022	965	1477.5889	17156.009	20000	0
31	4	4.7	1	73.4939	345	17156.009	772.942	1315	1363.3548	14123.206	20000	0
32	5	53.7	1	839.7069	3007	14123.206	910.5691	335	1373.448	15350.896	20000	0
33	6	5.5	1	86.0035	168	15350.896	1100.8721	634	1264.5722	12605.455	20000	0
34	7	11.7	1	182.9529	459	12605.455	1248.3347	675	1151.2671	10172.806	20000	0
35	8	53.1	1	830.3247	2887	10172.806	1024.5825	154	1189.6391	11521.909	20000	0

Table B1.5 Kairouan aquifer

Kairouan aquifer

Scenario 1

Time	Calendar month	Transfer from El Haouareb	Recharge coefficient	Aquifer recharge from release	Infiltration from middle catchment	Infiltration from El Haouareb	Groundwater transfer from upstream aquifers	Kairouan aquifer initial status	Groundwater outflow from Kairouan	Pumping for drinking water	Pumping for irrigation
		1000m3		1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	0	0.7	0	0.0108	769.719	433.333	150000	625	583.3333	774.8788
1	10	0	0.7	0	0.0281	853.8406	433.333	149219.85	625	583.3333	145.9394
2	11	0	0.7	0	0.0333	822.6372	433.333	149152.78	625	583.3333	0
3	12	0	0.7	0	0.0684	1054.5793	433.333	149200.45	625	437.5	0
4	1	0	0.7	0	0.071	1022.803	433.333	149625.93	625	437.5	0
5	2	0	0.7	0	0.0706	967.7148	433.333	150019.64	625	437.5	0
6	3	0	0.7	0	0.0806	914.13	433.333	150358.26	625	583.3333	145.9394
7	4	0	0.7	0	0.0852	872.5501	433.333	150351.53	625	583.3333	774.8788
8	5	0	0.7	0	0.0853	809.3235	433.333	149674.28	625	583.3333	510.7879
9	6	0	0.7	0	0.088	780.4792	433.333	149197.9	625	729.1667	1216.7273
10	7	0	0.7	0	0.08	738.8994	433.333	147840.91	625	729.1667	1800.0606
11	8	0	0.7	0	0.0772	630.8141	433.333	145858.99	625	729.1667	1630.7879
12	9	0	0.7	0	0.0754	470.48	433.333	143938.26	625	583.3333	774.8788
13	10	0	0.7	0	0.0792	544.5656	433.333	142858.94	625	583.3333	145.9394
14	11	0	0.7	0	0.0971	918.1809	433.333	142482.65	625	583.3333	0
15	12	0	0.7	0	0.1069	890.2148	433.333	142625.92	625	437.5	0
16	1	0	0.7	0	0.1133	896.7462	433.333	142887.08	625	437.5	0
17	2	0	0.7	0	0.1463	1560.0347	433.333	143154.77	625	437.5	0
18	3	0	0.7	0	0.145	1508.5573	433.333	144085.78	625	583.3333	145.9394
19	4	0	0.7	0	0.1491	1420.3409	433.333	144673.55	625	583.3333	774.8788
20	5	0	0.7	0	0.1423	1292.2464	433.333	144544.16	625	583.3333	510.7879
21	6	0	0.7	0	0.1491	1290.2773	433.333	144550.76	625	729.1667	1216.7273
22	7	0	0.7	0	0.1377	1181.2101	433.333	143703.62	625	729.1667	1800.0606
23	8	0	0.7	0	0.1527	1201.098	433.333	142164.08	625	729.1667	1630.7879
24	9	0	0.7	0	0.1509	1114.7133	433.333	140813.71	625	583.3333	774.8788
25	10	0	0.7	0	0.1595	1113.4762	433.333	140378.69	625	583.3333	145.9394
26	11	0	0.7	0	0.1643	1071.4915	433.333	140571.39	625	583.3333	0
27	12	0	0.7	0	0.1712	1069.732	433.333	140868.04	625	437.5	0

28	1	8941.211	0.7	6258.848	0.1984	1787.063	433.333	141308.78	625	437.5	0
29	2	454.4227	0.7	318.0959	0.1982	1573.8914	433.333	148725.72	625	437.5	0
30	3	0	0.7	0	0.1946	1477.5889	433.333	149988.74	625	583.3333	145.9394
31	4	0	0.7	0	0.1915	1363.3548	433.333	150545.58	625	583.3333	774.8788
32	5	0	0.7	0	0.1926	1373.448	433.333	150359.25	625	583.3333	510.7879
33	6	0	0.7	0	0.185	1264.5722	433.333	150447.1	625	729.1667	1216.7273
34	7	0	0.7	0	0.1824	1151.2671	433.333	149574.3	625	729.1667	1800.0606
35	8	0	0.7	0	0.177	1189.6391	433.333	148004.86	625	729.1667	1630.7879
Yearly		6010.6092		4207.4264		12987.227				6999.9999	7000.0001

Table B1.6a: Small dam details-Part a

Small dam details

Scenario 1

Time	Calendar	Inflow from rainfall	Small dam unit initial status	Overflow from small dam	Provisional volume	Height 1	Surface 1	Evaporation 1	Infiltration 1
		1000m3	1000m3	1000m3	1000m3	m	m2	1000m3	1000m3
0	9	7.4175	0	0	7.4175	2.2937	5389.86	0.7622	0.0003
1	10	11.1577	6.109	0	17.2667	3.2762	8784.12	1.2075	0.0007
2	11	3.3599	15.994	0	19.354	3.4378	9383.1	0.467	0.0008
3	12	20.7665	18.8928	0	39.6592	4.6532	14205.5	0.5499	0.0016
4	1	2.2668	39.1122	0	41.379	4.7373	14558.3	0.8741	0.0017
5	2	0.9684	40.514	0	41.4825	4.7423	14579.4	1.313	0.0017
6	3	7.0321	40.1921	0	47.2242	5.0089	15713.9	1.2414	0.0019
7	4	4.6532	45.8827	0	50.5359	5.1542	16341.8	1.6912	0.002
8	5	2.6295	48.2557	0	50.8852	5.1692	16407	2.4108	0.002
9	6	5.0978	48.1339	0	53.2317	5.2685	16840.1	3.0599	0.0021
10	7	0.51	49.3136	0	49.8236	5.1234	16208.2	4.3535	0.002
11	8	3.5287	44.3008	0	47.8295	5.0359	15830	4.5646	0.0019
12	9	1.5842	42.2663	0	43.8506	4.8547	15054.8	2.5333	0.0018
13	10	4.1004	40.7905	0	44.8909	4.9029	15260.3	2.0012	0.0018
14	11	11.3794	42.8241	0	54.2035	5.3088	17017.2	1.183	0.0022
15	12	6.5246	53.0333	0	59.558	5.5241	17969.6	0.9511	0.0024
16	1	4.4543	58.6133	0	63.0676	5.6592	18574.3	0.7777	0.0025
17	2	19.9391	62.293	0	82.2321	6.3296	21653.3	1.0093	0.0033
18	3	1.2518	81.2267	0	82.4785	6.3376	21690.8	2.0049	0.0033
19	4	4.8938	80.3814	0	85.2751	6.4274	22113	2.1837	0.0034
20	5	0.175	82.4977	0	82.6727	6.3439	21720.3	4.0839	0.0033
21	6	9.513	78.2989	0	87.8119	6.5074	22490.9	5.206	0.0035
22	7	0.233	81.8253	0	82.0583	6.324	21626.9	6.1507	0.0033
23	8	14.0869	74.7723	0	88.8592	6.54	22645.5	4.9019	0.0036
24	9	2.7277	82.8247	0	85.5524	6.4362	22154.5	3.6404	0.0034
25	10	7.1203	81.3825	0	88.5028	6.5289	22593	2.2668	0.0035
26	11	4.6293	86.1491	0	90.7784	6.5993	22927	1.9561	0.0036
27	12	5.2061	88.8432	0	94.0493	6.6986	23401	1.368	0.0038
28	1	36.415	92.6892	0	129.1041	7.6566	28103.8	1.1989	0.0052
29	2	3.2415	127.9066	0	131.1481	7.7075	28360.2	1.3667	0.0052
30	3	0.5491	129.7845	0	130.3336	7.6873	28258.2	2.9914	0.0052
31	4	2.1686	127.2595	0	129.4281	7.6647	28144.6	4.0689	0.0052
32	5	13.1953	124.8079	0	138.0032	7.875	29207.9	4.9379	0.0055
33	6	1.6397	132.7549	0	134.3945	7.7874	28763.9	6.3853	0.0054
34	7	6.0826	127.2161	0	133.2987	7.7606	28628.1	7.9157	0.0053
35	8	2.7982	124.2359	0	127.0342	7.6045	27842.5	6.1148	0.0051

Table B1.6b: Small dam details-Part b

Small dam details

Scenario 1

Time	Calendar	Intermediate Volume 1	Pumping for agriculture 1	Provisional volume 2	Height2	Surface 2	Evaporation 2	Infiltration2	Intermediate volume 2	Pumping for agriculture
		1000m3	1000m3	1000m3	m	m2	1000m3	1000m3	1000m3	1000m3
0	9	6.655	0.6326	6.0225	2.1007	4778.2968	0.6757	0.0002	6.7416	0.6326
1	10	16.0586	0.1191	15.9394	3.1675	8387.2193	1.1529	0.0006	16.1132	0.1191
2	11	18.8862	0	18.8862	3.4025	9251.3342	0.4604	0.0008	18.8928	0
3	12	39.1077	0	39.1077	4.6258	14090.927	0.5455	0.0016	39.1122	0
4	1	40.5033	0	40.5033	4.6947	14379.436	0.8633	0.0016	40.514	0
5	2	40.1678	0	40.1678	4.6783	14310.469	1.2888	0.0016	40.1921	0
6	3	45.9809	0.1191	45.8618	4.9474	15450.211	1.2206	0.0018	46.0018	0.1191
7	4	48.8427	0.6326	48.2101	5.0527	15902.705	1.6458	0.0019	48.8882	0.6326
8	5	48.4723	0.417	48.0553	5.0459	15873.165	2.3324	0.0019	48.5508	0.417
9	6	50.1697	0.9932	49.1764	5.0952	16086.187	2.9229	0.002	50.3068	0.9932
10	7	45.4681	1.4694	43.9987	4.8616	15084.215	4.0516	0.0018	45.7702	1.4694
11	8	43.263	1.3313	41.9317	4.7639	14670.439	4.2302	0.0017	43.5976	1.3313
12	9	41.3155	0.6326	40.683	4.7035	14416.279	2.4258	0.0016	41.4231	0.6326
13	10	42.8879	0.1191	42.7688	4.8038	14839.023	1.946	0.0017	42.9432	0.1191
14	11	53.0183	0	53.0183	5.2595	16801.091	1.168	0.0021	53.0333	0
15	12	58.6045	0	58.6045	5.4866	17802.704	0.9423	0.0023	58.6133	0
16	1	62.2874	0	62.2874	5.6295	18441.101	0.7721	0.0025	62.293	0
17	2	81.2195	0	81.2195	6.2966	21498.796	1.0021	0.0032	81.2267	0
18	3	80.4703	0.1191	80.3512	6.2681	21365.635	1.9748	0.0032	80.5005	0.1191
19	4	83.0881	0.6326	82.4555	6.3369	21687.317	2.1416	0.0033	83.1302	0.6326
20	5	78.5855	0.417	78.1686	6.1957	21028.2	3.9537	0.0031	78.7159	0.417
21	6	82.6024	0.9932	81.6092	6.3093	21558.363	4.9901	0.0033	82.8185	0.9932
22	7	75.9043	1.4694	74.4349	6.0691	20441.606	5.8136	0.003	76.2417	1.4694
23	8	83.9538	1.3313	82.6225	6.3423	21712.701	4.6999	0.0033	84.156	1.3313
24	9	81.9086	0.6326	81.276	6.2984	21507.444	3.5341	0.0033	82.0151	0.6326
25	10	86.2325	0.1191	86.1134	6.454	22238.363	2.2312	0.0034	86.2682	0.1191
26	11	88.8186	0	88.8186	6.5388	22639.565	1.9316	0.0036	88.8432	0
27	12	92.6775	0	92.6775	6.6572	23203.052	1.3565	0.0037	92.6892	0
28	1	127.9001	0	127.9001	7.6264	27952.034	1.1924	0.0051	127.9066	0
29	2	129.7762	0	129.7762	7.6734	28188.322	1.3584	0.0052	129.7845	0
30	3	127.337	0.1191	127.2179	7.6092	27865.75	2.9499	0.0051	127.3787	0.1191
31	4	125.3541	0.6326	124.7215	7.5458	27548.348	3.9827	0.005	125.4404	0.6326
32	5	133.0598	0.417	132.6429	7.7444	28546.594	4.8261	0.0053	133.1718	0.417
33	6	128.0038	0.9932	127.0106	7.6039	27839.499	6.1801	0.0051	128.2093	0.9932
34	7	125.3777	1.4694	123.9083	7.525	27444.368	7.5884	0.005	125.7054	1.4694
35	8	120.9143	1.3313	119.5831	7.413	26886.451	5.9048	0.0048	121.1246	1.3313

Table B1.7a: El Haouareb dam details-Part a

El Haouareb details details

Scenario 1

Time	Calendar month	Inflow from rainfall	Inflow from middle catchment	Total inflow	Initial El Haouareb status	Dam surface area 1	Infiltration 1	Evaporation 1		Dam surface area 2	Infiltration 2	Evaporation 2
		1000m3	1000m3	1000m3	1000m3	m2	1000m3	1000m3	1000m3	m2	1000m3	1000m3
0	9	614.5341	1728	2342.5341	2440	2.89E+06	736.656	408.5119	3637.366	3.03E+06	772.875	428.597
1	10	641.117	2632	3273.117	3154.9682	3.02E+06	769.5137	414.8131	5243.758	3.38E+06	861.5548	464.4287
2	11	84.4398	315	399.4398	5113.9743	3.35E+06	854.4879	166.7759	4492.15	3.22E+06	820.3904	160.1209
3	12	1352.6005	4513	5865.6005	4286.2176	3.17E+06	809.0113	122.8111	9219.996	4.20E+06	1069.7396	162.3907
4	1	37.5288	755	792.5288	8765.1495	4.10E+06	1046.742	246.4564	8264.48	4.00E+06	1021.1835	240.4387
5	2	98.5131	502	600.5131	7938.0553	3.94E+06	1004.3823	354.7242	7179.462	3.78E+06	964.9174	340.7861
6	3	439.3997	325	764.3997	6650.0796	3.67E+06	937.0291	290.2953	6187.155	3.58E+06	912.4077	282.6675
7	4	283.0297	168	451.0297	6217.1482	3.58E+06	914.0095	370.9445	5383.224	3.41E+06	869.1298	352.7303
8	5	243.9372	168	411.9372	5148.5093	3.36E+06	856.3701	493.4707	4210.606	3.16E+06	804.8223	463.767
9	6	334.6318	754	1088.6318	4018.7623	3.11E+06	794.168	565.8836	3747.343	3.06E+06	779.0301	555.0971
10	7	23.4555	168	191.4555	3770.7853	3.06E+06	780.3405	821.9587	2359.942	2.86E+06	729.0328	767.9146
11	8	156.37	230	386.37	2445.0341	2.89E+06	737.1088	833.5111	1260.784	2.13E+06	544.0548	615.2086
12	9	43.7836	275	318.7836	1305.2752	2.17E+06	554.4498	365.8717	703.7373	1.54E+06	393.1411	259.4269
13	10	161.0611	1167	1328.0611	843.1174	1.70E+06	434.5089	223.4568	1513.213	2.35E+06	599.7805	308.4518
14	11	608.2793	5700	6308.2793	1191.5567	2.07E+06	527.3925	143.7817	6828.662	3.71E+06	946.4689	258.0334
15	12	354.9599	258	612.9599	6233.3337	3.59E+06	914.8736	189.8991	5741.521	3.48E+06	888.4993	184.4246
16	1	82.8761	1291	1373.8761	5566.2982	3.45E+06	879.0431	144.3354	5916.796	3.52E+06	897.927	147.4361
17	2	1085.2078	15377	16462.208	5600.1859	3.45E+06	880.8744	161.01	21020.51	6.25E+06	1592.6333	291.1084
18	3	90.6946	997	1087.6946	19850.209	6.07E+06	1547.1207	560.7857	18830	5.91E+06	1506.3052	545.9913
19	4	428.4538	168	596.4538	18131.539	5.80E+06	1477.7499	572.2659	16677.98	5.56E+06	1416.728	548.6349
20	5	7.8185	168	175.8185	15914.618	5.43E+06	1383.8185	1020.3355	13686.28	5.04E+06	1284.3516	946.9952
21	6	523.8395	2636	3159.8395	13123.373	4.94E+06	1258.4236	1142.3031	13882.49	5.07E+06	1293.313	1173.9731
22	7	62.548	806	868.548	13098.718	4.93E+06	1257.2805	1402.2376	11307.75	4.60E+06	1172.5919	1307.7848
23	8	978.8762	2875	3853.8762	10283.659	4.40E+06	1122.6961	953.0149	12061.82	4.74E+06	1208.6483	1025.9765
24	9	214.2269	234	448.2269	11496.87	4.63E+06	1181.6893	761.4713	10001.94	4.35E+06	1108.7824	714.4907
25	10	589.5149	1593	2182.5149	9469.071	4.24E+06	1082.2438	425.8099	10143.53	4.38E+06	1115.7856	439.007
26	11	175.1344	906	1081.1344	9602.0114	4.27E+06	1088.8918	364.3304	9229.924	4.20E+06	1070.2392	358.0895
27	12	361.2147	1332	1693.2147	8843.1458	4.12E+06	1050.7006	240.8783	9244.782	4.20E+06	1070.9868	245.529
28	1	3064.852	19035	22099.852	8994.3871	4.15E+06	1058.3589	177.0572	29858.82	7.07E+06	1803.1112	301.6499

29	2	79.7487	2327	2406.7487	20000	6.09E+06	1553.024	293.4911	20560.23	6.18E+06	1574.9	297.6252
30	3	0	212	212	20000	6.09E+06	1553.024	644.7181	18014.26	5.78E+06	1472.9063	611.4583
31	4	73.4939	345	418.4939	17156.009	5.64E+06	1437.0341	814.7138	15322.75	5.33E+06	1357.8933	769.8456
32	5	839.7069	3007	3846.7069	14123.206	5.11E+06	1304.2539	864.6948	15800.96	5.41E+06	1378.8679	914.1624
33	6	86.0035	168	254.0035	15350.896	5.33E+06	1359.134	1183.1928	13062.57	4.92E+06	1255.6037	1093.0646
34	7	182.9529	459	641.9529	12605.455	4.84E+06	1234.2823	1338.3493	10674.78	4.48E+06	1141.8784	1238.1545
35	8	830.3247	2887	3717.3247	10172.806	4.38E+06	1117.231	962.2206	11810.68	4.69E+06	1196.7041	1030.6673

Table B1.7b: El Haouareb dam details-Part B

El Haouareb details details

Scenario 1

Time	Calendar month	Water volume	Dam surface	Evaporation	Water status by inflow minus evaporation	Dam release status	Release threshold	Dam release to Kairouan aquifer	Potential infiltration	Pumping for irrigation from El Haouareb	Infiltration to Kairouan aquifer
		1000m3	m2	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	3581.0621	3.02E+06	426.8469	4355.6872	3154.9682	20000	0	769.719	431	769.719
1	10	5102.1017	3.35E+06	460.2703	5967.8149	5113.9743	20000	0	853.8406	0	853.8406
2	11	4532.9028	3.23E+06	160.5594	5352.8547	4286.2176	20000	0	822.6372	244	822.6372
3	12	8919.6878	4.14E+06	160.0893	9991.7288	8765.1495	20000	0	1054.5793	172	1054.5793
4	1	8296.0561	4.01E+06	240.82	9316.8583	7938.0553	20000	0	1022.803	356	1022.803
5	2	7232.865	3.80E+06	341.7741	8196.7943	6650.0796	20000	0	967.7148	579	967.7148
6	3	6219.4041	3.58E+06	283.2011	7131.2782	6217.1482	20000	0	914.13	0	914.13
7	4	5446.3178	3.42E+06	354.1185	6314.0594	5148.5093	20000	0	872.5501	293	872.5501
8	5	4291.8572	3.17E+06	466.3607	5094.0858	4018.7623	20000	0	809.3235	266	809.3235
9	6	3773.267	3.06E+06	556.1297	4551.2644	3770.7853	20000	0	780.4792	0	780.4792
10	7	2465.2934	2.90E+06	778.3073	3183.9334	2445.0341	20000	0	738.8994	0	738.8994
11	8	1672.1406	2.47E+06	713.3147	2118.0893	1305.2752	20000	0	630.8141	182	630.8141
12	9	971.4908	1.85E+06	310.4614	1313.5974	843.1174	20000	0	470.48	0	470.48
13	10	1262.9461	2.14E+06	280.0562	1891.1223	1191.5567	20000	0	544.5656	155	544.5656
14	11	6295.3336	3.60E+06	250.3213	7249.5146	6233.3337	20000	0	918.1809	98	918.1809
15	12	5773.3697	3.49E+06	184.7807	6661.513	5566.2982	20000	0	890.2148	205	890.2148
16	1	5894.8112	3.52E+06	147.2422	6792.9321	5600.1859	20000	0	896.7462	296	896.7462
17	2	20178.652	6.12E+06	285.1499	21777.2438	19850.209	20000	0	1560.0347	367	1560.0347
18	3	18885.607	5.92E+06	546.8077	20391.096	18131.539	20000	0	1508.5573	751	1508.5573
19	4	16762.63	5.57E+06	550.034	18177.9584	15914.618	20000	0	1420.3409	843	1420.3409
20	5	13859.089	5.07E+06	952.8163	15137.6197	13123.373	20000	0	1292.2464	722	1292.2464
21	6	13815.927	5.06E+06	1171.2176	15111.9951	13098.718	20000	0	1290.2773	723	1290.2773
22	7	11486.889	4.63E+06	1317.3967	12649.8691	10283.659	20000	0	1181.2101	1185	1181.2101
23	8	11902.91	4.71E+06	1019.5673	13117.9678	11496.87	20000	0	1201.098	420	1201.098
24	9	10121.824	4.37E+06	718.3125	11226.7843	9469.071	20000	0	1114.7133	643	1114.7133
25	10	10096.793	4.37E+06	438.0983	11213.4876	9602.0114	20000	0	1113.4762	498	1113.4762
26	11	9254.8171	4.20E+06	358.5085	10324.6373	8843.1458	20000	0	1071.4915	410	1071.4915
27	12	9219.8447	4.20E+06	245.2413	10291.1192	8994.3871	20000	0	1069.732	227	1069.732
28	1	28989.478	7.01E+06	298.9651	30795.274	28941.211	20000	8941.2109	1787.063	67	1787.063

29	2	20534.224	6.17E+06	297.4346	22109.3141	20454.423	20000	454.4227	1573.8914	81	1573.8914
30	3	18127.636	5.79E+06	613.4022	19598.5978	17156.009	20000	0	1477.5889	965	1477.5889
31	4	15446.764	5.35E+06	772.942	16801.5608	14123.206	20000	0	1363.3548	1315	1363.3548
32	5	15676.883	5.39E+06	910.5691	17059.3439	15350.896	20000	0	1373.448	335	1373.448
33	6	13256.231	4.96E+06	1100.8721	14504.0273	12605.455	20000	0	1264.5722	634	1264.5722
34	7	10867.375	4.51E+06	1248.3347	11999.0732	10172.806	20000	0	1151.2671	675	1151.2671
35	8	11662.759	4.67E+06	1024.5825	12865.5483	11521.909	20000	0	1189.6391	154	1189.6391

Table B2.1 El Haouareb-Scenario 2

El Haouareb

Scenario 2

Time	Calendar month	Rainfall	Rainfall data climate coefficient scenario	Inflow from Rainfall	Inflow from middle catchment	Initial El Haouareb status	Evaporation	Pumping for Irrigation	Infiltration to Kairoouan aquifer	Dam release status	Release threshold	Dam release to Kairouan
		mm		1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	39.3	1	614.5341	1728	2440	426.8469	431	769.719	3154.9682	15000	0
1	10	41	1	641.117	2632	3154.9682	460.2703	0	853.8406	5113.9743	15000	0
2	11	5.4	1	84.4398	315	5113.9743	160.5594	244	822.6372	4286.2176	15000	0
3	12	86.5	1	1352.6005	4513	4286.2176	160.0893	172	1054.5793	8765.1495	15000	0
4	1	2.4	1	37.5288	755	8765.1495	240.82	356	1022.803	7938.0553	15000	0
5	2	6.3	1	98.5131	502	7938.0553	341.7741	579	967.7148	6650.0796	15000	0
6	3	28.1	1	439.3997	325	6650.0796	283.2011	0	914.13	6217.1482	15000	0
7	4	18.1	1	283.0297	168	6217.1482	354.1185	293	872.5501	5148.5093	15000	0
8	5	15.6	1	243.9372	168	5148.5093	466.3607	266	809.3235	4018.7623	15000	0
9	6	21.4	1	334.6318	754	4018.7623	556.1297	0	780.4792	3770.7853	15000	0
10	7	1.5	1	23.4555	168	3770.7853	778.3073	0	738.8994	2445.0341	15000	0
11	8	10	1	156.37	230	2445.0341	713.3147	182	630.8141	1305.2752	15000	0
12	9	2.8	1	43.7836	275	1305.2752	310.4614	0	470.48	843.1174	15000	0
13	10	10.3	1	161.0611	1167	843.1174	280.0562	155	544.5656	1191.5567	15000	0
14	11	38.9	1	608.2793	5700	1191.5567	250.3213	98	918.1809	6233.3337	15000	0
15	12	22.7	1	354.9599	258	6233.3337	184.7807	205	890.2148	5566.2982	15000	0
16	1	5.3	1	82.8761	1291	5566.2982	147.2422	296	896.7462	5600.1859	15000	0
17	2	69.4	1	1085.2078	15377	5600.1859	285.1499	367	1560.0347	19850.209	15000	4850.2091
18	3	5.8	1	90.6946	997	15000	475.6924	751	1312.3615	13548.641	15000	0
19	4	27.4	1	428.4538	168	13548.641	475.1195	843	1226.8908	11600.084	15000	0
20	5	0.5	1	7.8185	168	11600.084	812.8783	722	1102.4571	9138.5673	15000	0
21	6	33.5	1	523.8395	2636	9138.5673	1013.4899	723	1116.5159	9445.401	15000	0
22	7	4	1	62.548	806	9445.401	1134.0624	0	1016.8281	8163.0585	15000	0
23	8	62.6	1	978.8762	2875	8163.0585	939.2067	420	1106.4294	9551.2985	15000	0
24	9	13.7	1	214.2269	234	9551.2985	660.0301	643	1024.2678	7672.2275	15000	0
25	10	37.7	1	589.5149	1593	7672.2275	404.8557	498	1028.9863	7922.9005	15000	0
26	11	11.2	1	175.1344	906	7922.9005	331.6279	410	991.1524	7271.2545	15000	0
27	12	23.1	1	361.2147	1332	7271.2545	227.9146	227	994.1538	7515.4007	15000	0

28	1	196	1	3064.852	19035	7515.4007	294.4759	67	1760.2288	27493.548	15000	12493.548
29	2	5.1	1	79.7487	2327	15000	260.2979	81	1377.3803	15688.071	15000	688.0705
30	3	0	1	0	212	15000	528.0862	965	1272.0762	12446.838	15000	0
31	4	4.7	1	73.4939	345	12446.838	657.8821	0	1160.4063	11047.043	15000	0
32	5	53.7	1	839.7069	3007	11047.043	824.7488	335	1244.0017	12490	15000	0
33	6	5.5	1	86.0035	168	12490	992.1169	634	1139.6451	9978.241	15000	0
34	7	11.7	1	182.9529	459	9978.241	1119.6175	675	1032.5587	7793.0177	15000	0
35	8	53.1	1	830.3247	2887	7793.0177	932.5041	154	1082.7271	9341.1112	15000	0

Table B2.2 Kairouan aquifer-Scenario 2

Kairouan aquifer

Scenario 2

Time	Calendar month	Transfer from El Haouareb	Recharge coefficient	Aquifer recharge from release	Infiltration from middle catchment	Infiltration from El Haouareb	Groundwater transfer from upstream aquifers	Kairouan aquifer initial status	Groundwater outflow from Kairouan	Pumping for drinking water	Pumping for irrigation
		1000m3		1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	0	0.7	0	0.0108	769.719	433.333	150000	625	666.6667	885.5758
1	10	0	0.7	0	0.0281	853.8406	433.333	149025.82	625	666.6667	166.7879
2	11	0	0.7	0	0.0333	822.6372	433.333	148854.57	625	666.6667	0
3	12	0	0.7	0	0.0684	1054.5793	433.333	148818.9	625	500	0
4	1	0	0.7	0	0.071	1022.803	433.333	149181.89	625	500	0
5	2	0	0.7	0	0.0706	967.7148	433.333	149513.09	625	500	0
6	3	0	0.7	0	0.0806	914.13	433.333	149789.21	625	666.6667	166.7879
7	4	0	0.7	0	0.0852	872.5501	433.333	149678.3	625	666.6667	885.5758
8	5	0	0.7	0	0.0853	809.3235	433.333	148807.03	625	666.6667	583.7576
9	6	0	0.7	0	0.088	780.4792	433.333	148174.34	625	833.3333	1390.5455
10	7	0	0.7	0	0.08	738.8994	433.333	146539.36	625	833.3333	2057.2121
11	8	0	0.7	0	0.0772	630.8141	433.333	144196.13	625	833.3333	1863.7576
12	9	0	0.7	0	0.0754	470.48	433.333	141938.26	625	666.6667	885.5758
13	10	0	0.7	0	0.0792	544.5656	433.333	140664.91	625	666.6667	166.7879
14	11	0	0.7	0	0.0971	918.1809	433.333	140184.43	625	666.6667	0
15	12	0	0.7	0	0.1069	890.2148	433.333	140244.38	625	500	0
16	1	0	0.7	0	0.1133	896.7462	433.333	140443.03	625	500	0
17	2	4850.209	0.7	3395.146	0.1463	1560.0347	433.333	140648.23	625	500	0
18	3	0	0.7	0	0.145	1312.3615	433.333	144911.89	625	666.6667	166.7879
19	4	0	0.7	0	0.1491	1226.8908	433.333	145199.27	625	666.6667	885.5758
20	5	0	0.7	0	0.1423	1102.4571	433.333	144682.4	625	666.6667	583.7576
21	6	0	0.7	0	0.1491	1116.5159	433.333	144342.91	625	833.3333	1390.5455
22	7	0	0.7	0	0.1377	1016.8281	433.333	143044.03	625	833.3333	2057.2121
23	8	0	0.7	0	0.1527	1106.4294	433.333	140978.78	625	833.3333	1863.7576
24	9	0	0.7	0	0.1509	1024.2678	433.333	139196.61	625	666.6667	885.5758
25	10	0	0.7	0	0.1595	1028.9863	433.333	138477.12	625	666.6667	166.7879
26	11	0	0.7	0	0.1643	991.1524	433.333	138481.14	625	666.6667	0
27	12	0	0.7	0	0.1712	994.1538	433.333	138614.12	625	500	0

28	1	12493.55	0.7	8745.484	0.1984	1760.2288	433.333	138916.78	625	500	0
29	2	688.0705	0.7	481.6493	0.1982	1377.3803	433.333	148731.02	625	500	0
30	3	0	0.7	0	0.1946	1272.0762	433.333	149898.59	625	666.6667	166.7879
31	4	0	0.7	0	0.1915	1160.4063	433.333	150145.73	625	666.6667	885.5758
32	5	0	0.7	0	0.1926	1244.0017	433.333	149562.42	625	666.6667	583.7576
33	6	0	0.7	0	0.185	1139.6451	433.333	149364.53	625	833.3333	1390.5455
34	7	0	0.7	0	0.1824	1032.5587	433.333	148088.81	625	833.3333	2057.2121
35	8	0	0.7	0	0.177	1082.7271	433.333	146039.34	625	833.3333	1863.7576
Yearly		6010.609		4207.426		12168.927				8000.0001	8000.0002

Table B3.1a Middle catchment-Part a-Scenario 3

Middle catchment general

Scenario 3

Time	Calendar month	Rainfall middle catchment	Rainfall data climate coefficient	Runoff coefficient	Runoff to small dams RES2A	Runoff from non managed areas RES2B	Inflow from Skhira upper catchment RES1	Water losses and pumping from river bed between RES1 and El Haouareb
		mm			1000m3	1000m3	1000m3	1000m3
0	9	42.0714	1	0.033	291.6819	1081.4033	2465.6	100
1	10	63.2857	1	0.033	438.7609	1626.6949	1578.72	100
2	11	19.0571	1	0.033	132.1235	489.8445	779.24	100
3	12	117.7857	1	0.033	816.6104	3027.562	4159.32	100
4	1	12.8571	1	0.033	89.1388	330.4798	860.2	100
5	2	5.4929	1	0.033	38.0821	141.1883	212.52	100
6	3	39.8857	1	0.033	276.5283	1025.2217	1386.44	100
7	4	26.3929	1	0.033	182.9821	678.4016	556.6	100
8	5	14.9143	1	0.033	103.401	383.3565	809.6	100
9	6	28.9143	1	0.033	200.4632	743.2123	1416.8	100
10	7	2.8929	1	0.033	20.0562	74.358	30.36	30.36
11	8	20.0143	1	0.033	138.7594	514.4469	920.92	100
12	9	8.9857	1	0.033	62.2981	230.9686	460	100
13	10	23.2571	1	0.033	161.2422	597.8012	495.88	100
14	11	64.5429	1	0.033	447.4767	1659.0085	1892.44	100
15	12	37.0071	1	0.033	256.5712	951.231	1730.52	100
16	1	25.2643	1	0.033	175.1577	649.3928	1022.12	100
17	2	113.0929	1	0.033	784.0747	2906.9369	2762.76	100
18	3	7.1	1	0.033	49.2244	182.4983	273.24	100
19	4	27.7571	1	0.033	192.4407	713.4691	748.88	100
20	5	0.9929	1	0.033	6.8835	25.5204	121.44	100
21	6	53.9571	1	0.033	374.0858	1386.9135	1943.04	100
22	7	1.3214	1	0.033	9.1615	33.966	20.24	20.24
23	8	79.9	1	0.033	553.9481	2053.7482	951.28	100
24	9	15.4714	1	0.033	107.2637	397.6773	434.24	100
25	10	40.3857	1	0.033	279.9949	1038.0737	1159.752	100
26	11	26.2571	1	0.033	182.0412	674.9131	1131.416	100
27	12	29.5286	1	0.033	204.7221	759.0019	1005.928	100
28	1	206.5429	1	0.033	1431.9652	5308.974	5080.24	100
29	2	18.3857	1	0.033	127.4685	472.5861	380.512	100
30	3	3.1143	1	0.033	21.5914	80.0495	180.136	100
31	4	12.3	1	0.033	85.2761	316.159	172.04	100
32	5	74.8429	1	0.033	518.8868	1923.7595	900.68	100
33	6	9.3	1	0.033	64.4771	239.047	95.128	95.128
34	7	34.5	1	0.033	239.1891	886.7874	1153.68	100
35	8	15.8714	1	0.033	110.0369	407.9589	465.52	100

Table B3.1b Middle catchment-Part b-Scenario 3

Middle catchment general

Scenario 3

Time	Calendar month	Overflow to El Haouareb from small dams RES2A	Flow to El Haouareb dam from middle catchment	Transfer to Aquifer from RES2A small dams Infiltration	Number of small dams	Managed area in RES2A	Total capacity of small dams	Potential Evaporation	Agricultural demands	Transfer from 2AB
		1000m3	1000m3	1000m3		km2	1000m3	m	1000m3	1000m3
0	9	0	3447.0033	0.0124	40	210.0914	7563.7714	0.1414	22.1394	3447.003
1	10	0	3105.4149	0.0323	40	210.0914	7563.7714	0.1375	4.1697	3105.415
2	11	0	1169.0845	0.0382	40	210.0914	7563.7714	0.0498	0	1169.085
3	12	0	7086.882	0.0783	40	210.0914	7563.7714	0.0387	0	7086.882
4	1	0	1090.6798	0.0812	40	210.0914	7563.7714	0.06	0	1090.68
5	2	0	253.7083	0.0808	40	210.0914	7563.7714	0.0901	0	253.7083
6	3	0	2311.6617	0.0923	40	210.0914	7563.7714	0.079	4.1697	2311.662
7	4	0	1135.0016	0.0976	40	210.0914	7563.7714	0.1035	22.1394	1135.002
8	5	0	1092.9565	0.0979	40	210.0914	7563.7714	0.1469	14.5939	1092.957
9	6	0	2060.0123	0.1011	40	210.0914	7563.7714	0.1817	34.7636	2060.012
10	7	0	74.358	0.0922	40	210.0914	7563.7714	0.2686	51.4303	74.358
11	8	0	1335.3669	0.0893	40	210.0914	7563.7714	0.2884	46.5939	1335.367
12	9	0	590.9686	0.0873	40	210.0914	7563.7714	0.1683	22.1394	590.9686
13	10	0	993.6812	0.0916	40	210.0914	7563.7714	0.1311	4.1697	993.6812
14	11	0	3451.4485	0.1121	40	210.0914	7563.7714	0.0695	0	3451.449
15	12	0	2581.751	0.1232	40	210.0914	7563.7714	0.0529	0	2581.751
16	1	0	1571.5128	0.1306	40	210.0914	7563.7714	0.0419	0	1571.513
17	2	0	5569.6969	0.1682	40	210.0914	7563.7714	0.0466	0	5569.697
18	3	0	355.7383	0.1668	40	210.0914	7563.7714	0.0924	4.1697	355.7383
19	4	0	1362.3491	0.1716	40	210.0914	7563.7714	0.0988	22.1394	1362.349
20	5	0	46.9604	0.1638	40	210.0914	7563.7714	0.188	14.5939	46.9604
21	6	0	3229.9535	0.1718	40	210.0914	7563.7714	0.2315	34.7636	3229.954
22	7	0	33.966	0.159	40	210.0914	7563.7714	0.2844	51.4303	33.966
23	8	0	2905.0282	0.1764	40	210.0914	7563.7714	0.2165	46.5939	2905.028
24	9	0	731.9173	0.1744	40	210.0914	7563.7714	0.1643	22.1394	731.9173
25	10	0	2097.8257	0.1842	40	210.0914	7563.7714	0.1003	4.1697	2097.826
26	11	0	1706.3291	0.1897	40	210.0914	7563.7714	0.0853	0	1706.329
27	12	0	1664.9299	0.1975	40	210.0914	7563.7714	0.0585	0	1664.93
28	1	1020.648	11309.8616	0.2268	40	210.0914	7563.7714	0.0427	0	11309.86
29	2	109.7216	862.8197	0.2265	40	210.0914	7563.7714	0.0482	0	862.8197
30	3	0	160.1855	0.2224	40	210.0914	7563.7714	0.1059	4.1697	160.1855
31	4	0	388.199	0.219	40	210.0914	7563.7714	0.1446	22.1394	388.199
32	5	411.8038	3136.2433	0.2202	40	210.0914	7563.7714	0.1691	14.5939	3136.243
33	6	0	239.047	0.2117	40	210.0914	7563.7714	0.222	34.7636	239.047
34	7	0	1940.4674	0.209	40	210.0914	7563.7714	0.2765	51.4303	1940.467
35	8	0	773.4789	0.2031	40	210.0914	7563.7714	0.2196	46.5939	773.4789

Table B 3.2 Small dam unit-Scenario 3

Small dam unit

Scenario 3

Time	Calendar month	Number of small dams	Median small dam capacity	Median small dam height	Median height for starting overflow	Small dam capacity at overflow	Small dam lake and surrounding surface for direct rainfall	Inflow from runoff	Direct inflow from rainfall	Small dam initial status	Overflow from a small dam	Evaporation from a small dam	Infiltration from a small dam	Pumping for agriculture from a small dam
			1000m3	m	m	1000m3	m2	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	40	189.094	8.9943	7.9943	143.0095	45000	7.292	1.8932	0	0	0.7829	0.0003	0.5535
1	10	40	189.094	8.9943	7.9943	143.0095	45000	10.969	2.8479	7.8486	0	1.3215	0.0008	0.1042
2	11	40	189.094	8.9943	7.9943	143.0095	45000	3.3031	0.8576	20.239	0	0.5271	0.001	0
3	12	40	189.094	8.9943	7.9943	143.0095	45000	20.4153	5.3004	23.8715	0	0.6211	0.002	0
4	1	40	189.094	8.9943	7.9943	143.0095	45000	2.2285	0.5786	48.9641	0	0.9838	0.002	0
5	2	40	189.094	8.9943	7.9943	143.0095	45000	0.9521	0.2472	50.7853	0	1.4709	0.002	0
6	3	40	189.094	8.9943	7.9943	143.0095	45000	6.9132	1.7949	50.5116	0	1.3938	0.0023	0.1042
7	4	40	189.094	8.9943	7.9943	143.0095	45000	4.5746	1.1877	57.7193	0	1.8855	0.0024	0.5535
8	5	40	189.094	8.9943	7.9943	143.0095	45000	2.585	0.6711	61.0401	0	2.6815	0.0024	0.3648
9	6	40	189.094	8.9943	7.9943	143.0095	45000	5.0116	1.3011	61.2475	0	3.3783	0.0025	0.8691
10	7	40	189.094	8.9943	7.9943	143.0095	45000	0.5014	0.1302	63.3103	0	4.7354	0.0023	1.2858
11	8	40	189.094	8.9943	7.9943	143.0095	45000	3.469	0.9006	57.9184	0	4.9901	0.0022	1.1648
12	9	40	189.094	8.9943	7.9943	143.0095	45000	1.5575	0.4044	56.1308	0	2.8742	0.0022	0.5535
13	10	40	189.094	8.9943	7.9943	143.0095	45000	4.0311	1.0466	54.6627	0	2.3038	0.0023	0.1042
14	11	40	189.094	8.9943	7.9943	143.0095	45000	11.1869	2.9044	57.33	0	1.3719	0.0028	0
15	12	40	189.094	8.9943	7.9943	143.0095	45000	6.4143	1.6653	70.0466	0	1.1035	0.0031	0
16	1	40	189.094	8.9943	7.9943	143.0095	45000	4.3789	1.1369	77.0197	0	0.9027	0.0033	0
17	2	40	189.094	8.9943	7.9943	143.0095	45000	19.6019	5.0892	81.6295	0	1.1634	0.0042	0
18	3	40	189.094	8.9943	7.9943	143.0095	45000	1.2306	0.3195	105.153	0	2.2958	0.0042	0.1042
19	4	40	189.094	8.9943	7.9943	143.0095	45000	4.811	1.2491	104.299	0	2.4933	0.0043	0.5535
20	5	40	189.094	8.9943	7.9943	143.0095	45000	0.1721	0.0447	107.308	0	4.6217	0.0041	0.3648
21	6	40	189.094	8.9943	7.9943	143.0095	45000	9.3521	2.4281	102.534	0	5.8479	0.0043	0.8691
22	7	40	189.094	8.9943	7.9943	143.0095	45000	0.229	0.0595	107.593	0	6.871	0.004	1.2858
23	8	40	189.094	8.9943	7.9943	143.0095	45000	13.8487	3.5955	99.7207	0	5.5526	0.0044	1.1648
24	9	40	189.094	8.9943	7.9943	143.0095	45000	2.6816	0.6962	110.443	0	4.1869	0.0044	0.5535
25	10	40	189.094	8.9943	7.9943	143.0095	45000	6.9999	1.8174	109.076	0	2.6387	0.0046	0.1042
26	11	40	189.094	8.9943	7.9943	143.0095	45000	4.551	1.1816	115.146	0	2.2826	0.0047	0

27	12	40	189.094	8.9943	7.9943	143.0095	45000	5.1181	1.3288	118.591	0	1.6007	0.0049	0
28	1	40	189.094	8.9943	7.9943	143.0095	45000	35.7991	9.2944	123.432	25.516	1.2654	0.0057	0
29	2	40	189.094	8.9943	7.9943	143.0095	45000	3.1867	0.8274	141.739	2.743	1.4284	0.0057	0
30	3	40	189.094	8.9943	7.9943	143.0095	45000	0.5398	0.1401	141.576	0	3.1048	0.0056	0.1042
31	4	40	189.094	8.9943	7.9943	143.0095	45000	2.1319	0.5535	139.041	0	4.2027	0.0055	0.5535
32	5	40	189.094	8.9943	7.9943	143.0095	45000	12.9722	3.3679	136.965	10.295	4.9295	0.0055	0.3648
33	6	40	189.094	8.9943	7.9943	143.0095	45000	1.6119	0.4185	137.71	0	6.3285	0.0053	0.8691
34	7	40	189.094	8.9943	7.9943	143.0095	45000	5.9797	1.5525	132.537	0	7.8238	0.0052	1.2858
35	8	40	189.094	8.9943	7.9943	143.0095	45000	2.7509	0.7142	130.955	0	6.1119	0.0051	1.1648

Table B3.3 El Haouareb-Scenario 3

El Haouareb

Scenario 3

Time	Calendar month	Rainfall	Rainfall data climate coefficient scenario	Inflow from Rainfall	Inflow from middle catchment	Initial El Haouareb status	Evaporation	Pumping for Irrigation	Infiltration to Kairoouan aquifer	Dam release status	Release threshold	Dam release to Kairouan
		mm		1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	39.3	1	614.5341	3447.0033	2440	475.0257	431	856.5983	4738.9134	10000	0
1	10	41	1	641.117	3105.4149	4738.9134	515.0276	679	955.42	6335.9978	10000	0
2	11	5.4	1	84.4398	1169.0845	6335.9978	181.1232	244	927.997	6236.4019	10000	0
3	12	86.5	1	1352.6005	7086.882	6236.4019	191.572	172	1261.9701	13050.342	10000	3050.3423
4	1	2.4	1	37.5288	1090.6798	10000	258.3912	356	1097.4308	9416.3866	10000	0
5	2	6.3	1	98.5131	253.7083	9416.3866	362.8168	579	1027.2961	7799.4951	10000	0
6	3	28.1	1	439.3997	2311.6617	7799.4951	330.283	806	1066.1034	8348.1701	10000	0
7	4	18.1	1	283.0297	1135.0016	8348.1701	415.7256	293	1024.3505	8033.1253	10000	0
8	5	15.6	1	243.9372	1092.9565	8033.1253	574.642	266	997.235	7532.142	10000	0
9	6	21.4	1	334.6318	2060.0123	7532.142	724.5475	472	1016.8389	7713.3997	10000	0
10	7	1.5	1	23.4555	74.358	7713.3997	949.5799	608	901.4999	5352.1333	10000	0
11	8	10	1	156.37	1335.3669	5352.1333	961.4876	182	850.2838	4850.0989	10000	0
12	9	2.8	1	43.7836	590.9686	4850.0989	529.2363	330	802.0161	3823.5987	10000	0
13	10	10.3	1	161.0611	993.6812	3823.5987	402.0015	155	781.6866	3639.6529	10000	0
14	11	38.9	1	608.2793	3451.4485	3639.6529	253.3261	98	929.2024	6418.8522	10000	0
15	12	22.7	1	354.9599	2581.751	6418.8522	210.4676	205	1013.9664	7926.1291	10000	0
16	1	5.3	1	82.8761	1571.5128	7926.1291	168.6704	296	1027.25	8088.5976	10000	0
17	2	69.4	1	1085.2078	5569.6969	8088.5976	230.9391	367	1263.4512	12882.112	10000	2882.112
18	3	5.8	1	90.6946	355.7383	10000	383.8823	751	1059.0715	8252.4791	10000	0
19	4	27.4	1	428.4538	1362.3491	8252.4791	402.1198	843	1038.3853	7759.7769	10000	0
20	5	0.5	1	7.8185	46.9604	7759.7769	674.7831	0	915.167	6224.6057	10000	0
21	6	33.5	1	523.8395	3229.9535	6224.6057	916.1611	723	1009.2932	7329.9443	10000	0
22	7	4	1	62.548	33.966	7329.9443	981.7997	0	880.3056	5564.353	10000	0
23	8	62.6	1	978.8762	2905.0282	5564.353	837.8154	420	986.9857	7203.4563	10000	0
24	9	13.7	1	214.2269	731.9173	7203.4563	602.6693	643	935.2523	5968.6789	10000	0
25	10	37.7	1	589.5149	2097.8257	5968.6789	382.034	498	970.9825	6805.003	10000	0
26	11	11.2	1	175.1344	1706.3291	6805.003	326.3871	410	975.489	6974.5905	10000	0
27	12	23.1	1	361.2147	1664.9299	6974.5905	228.3036	227	995.8505	7549.581	10000	0

28	1	196	1	3064.852	11309.862	7549.581	260.3128	67	1556.0188	20040.963	10000	10040.963
29	2	5.1	1	79.7487	862.8197	10000	206.1995	81	1091.1161	9564.2528	10000	0
30	3	0	1	0	160.1855	9564.2528	424.3685	0	1022.2367	8277.8331	10000	0
31	4	4.7	1	73.4939	388.199	8277.8331	548.5801	0	967.6139	7223.332	10000	0
32	5	53.7	1	839.7069	3136.2433	7223.332	714.8595	335	1078.2513	9071.1714	10000	0
33	6	5.5	1	86.0035	239.047	9071.1714	857.7054	634	985.2465	6919.27	10000	0
34	7	11.7	1	182.9529	1940.4674	6919.27	1038.597	675	957.8381	6371.2553	10000	0
35	8	53.1	1	830.3247	773.4789	6371.2553	789.6124	154	916.8161	6114.6304	10000	0

Table B3.4 Kairouan aquifer- Scenario 3

Kairouan aquifer

Scenario 3

Time	Calendar month	Transfer from El Haouareb	Recharge coefficient	Aquifer recharge from release	Infiltration from middle catchment	Infiltration from El Haouareb	Groundwater transfer from upstream aquifers	Kairouan aquifer initial status	Groundwater outflow from Kairouan	Pumping for drinking water	Pumping for irrigation
		1000m3		1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	0	0.7	0	0.0124	856.5983	433.333	150000	625	583.3333	774.8788
1	10	0	0.7	0	0.0323	955.42	433.333	149306.73	625	583.3333	145.9394
2	11	0	0.7	0	0.0382	927.997	433.333	149341.24	625	583.3333	0
3	12	3050.342	0.7	2135.24	0.0783	1261.9701	433.333	149494.28	625	437.5	0
4	1	0	0.7	0	0.0812	1097.4308	433.333	152262.4	625	437.5	0
5	2	0	0.7	0	0.0808	1027.2961	433.333	152730.75	625	437.5	0
6	3	0	0.7	0	0.0923	1066.1034	433.333	153128.95	625	583.3333	145.9394
7	4	0	0.7	0	0.0976	1024.3505	433.333	153274.21	625	583.3333	774.8788
8	5	0	0.7	0	0.0979	997.235	433.333	152748.78	625	583.3333	510.7879
9	6	0	0.7	0	0.1011	1016.8389	433.333	152460.32	625	729.1667	1216.7273
10	7	0	0.7	0	0.0922	901.4999	433.333	151339.7	625	729.1667	1800.0606
11	8	0	0.7	0	0.0893	850.2838	433.333	149520.4	625	729.1667	1630.7879
12	9	0	0.7	0	0.0873	802.0161	433.333	147819.15	625	583.3333	774.8788
13	10	0	0.7	0	0.0916	781.6866	433.333	147071.38	625	583.3333	145.9394
14	11	0	0.7	0	0.1121	929.2024	433.333	146932.22	625	583.3333	0
15	12	0	0.7	0	0.1232	1013.9664	433.333	147086.53	625	437.5	0
16	1	0	0.7	0	0.1306	1027.25	433.333	147471.45	625	437.5	0
17	2	2882.112	0.7	2017.478	0.1682	1263.4512	433.333	147869.67	625	437.5	0
18	3	0	0.7	0	0.1668	1059.0715	433.333	150521.6	625	583.3333	145.9394
19	4	0	0.7	0	0.1716	1038.3853	433.333	150659.9	625	583.3333	774.8788
20	5	0	0.7	0	0.1638	915.167	433.333	150148.57	625	583.3333	510.7879
21	6	0	0.7	0	0.1718	1009.2932	433.333	149778.12	625	729.1667	1216.7273
22	7	0	0.7	0	0.159	880.3056	433.333	148650.02	625	729.1667	1800.0606
23	8	0	0.7	0	0.1764	986.9857	433.333	146809.59	625	729.1667	1630.7879
24	9	0	0.7	0	0.1744	935.2523	433.333	145245.13	625	583.3333	774.8788
25	10	0	0.7	0	0.1842	970.9825	433.333	144630.68	625	583.3333	145.9394
26	11	0	0.7	0	0.1897	975.489	433.333	144680.91	625	583.3333	0
27	12	0	0.7	0	0.1975	995.8505	433.333	144881.58	625	437.5	0

28	1	10040.96	0.7	7028.674	0.2268	1556.0188	433.333	145248.46	625	437.5	0
29	2	0	0.7	0	0.2265	1091.1161	433.333	153204.22	625	437.5	0
30	3	0	0.7	0	0.2224	1022.2367	433.333	153666.39	625	583.3333	145.9394
31	4	0	0.7	0	0.219	967.6139	433.333	153767.91	625	583.3333	774.8788
32	5	0	0.7	0	0.2202	1078.2513	433.333	153185.87	625	583.3333	510.7879
33	6	0	0.7	0	0.2117	985.2465	433.333	152978.55	625	729.1667	1216.7273
34	7	0	0.7	0	0.209	957.8381	433.333	151826.45	625	729.1667	1800.0606
35	8	0	0.7	0	0.2031	916.8161	433.333	150063.6	625	729.1667	1630.7879
Yearly		5324.472		3727.131		12047.506				6999.9999	7000.0001

Table B4.1 Skhira upper catchment-Scenario 4

Skhira upper catchment

Scenario 4 85% rainfall

Time	Calendar month	Rainfall Skhira upper catchment	Runoff coefficient	Runoff to middle catchment	Rainfall data climate coefficient
		mm		1000m3	
0	9	67	0.2	2095.76	0.85
1	10	78	0.11	1341.912	0.85
2	11	38.5	0.11	662.354	0.85
3	12	205.5	0.11	3535.422	0.85
4	1	42.5	0.11	731.17	0.85
5	2	10.5	0.11	180.642	0.85
6	3	68.5	0.11	1178.474	0.85
7	4	27.5	0.11	473.11	0.85
8	5	40	0.11	688.16	0.85
9	6	70	0.11	1204.28	0.85
10	7	1.5	0.11	25.806	0.85
11	8	45.5	0.11	782.782	0.85
12	9	12.5	0.2	391	0.85
13	10	24.5	0.11	421.498	0.85
14	11	93.5	0.11	1608.574	0.85
15	12	85.5	0.11	1470.942	0.85
16	1	50.5	0.11	868.802	0.85
17	2	136.5	0.11	2348.346	0.85
18	3	13.5	0.11	232.254	0.85
19	4	37	0.11	636.548	0.85
20	5	6	0.11	103.224	0.85
21	6	96	0.11	1651.584	0.85
22	7	1	0.11	17.204	0.85
23	8	47	0.11	808.588	0.85
24	9	11.8	0.2	369.104	0.85
25	10	57.3	0.11	985.7892	0.85
26	11	55.9	0.11	961.7036	0.85
27	12	49.7	0.11	855.0388	0.85
28	1	251	0.11	4318.204	0.85
29	2	18.8	0.11	323.4352	0.85
30	3	8.9	0.11	153.1156	0.85
31	4	8.5	0.11	146.234	0.85
32	5	44.5	0.11	765.578	0.85
33	6	4.7	0.11	80.8588	0.85
34	7	57	0.11	980.628	0.85
35	8	23	0.11	395.692	0.85

Table B4.2a Middle catchment-Part a-Scenario 4

Middle catchment general

Scenario 4

Time	Calendar month	Rainfall middle catchment	Rainfall data climate coefficient	Runoff coefficient	Runoff to small dams RES2A	Runoff from non managed areas RES2B	Inflow from Skhira upper catchment RES1	Water losses and pumping from river bed between RES1 and El Haouareb
		mm			1000m3	1000m3	1000m3	1000m3
0	9	35.7607	0.85	0.033	216.9384	950.184	2095.76	100
1	10	53.7929	0.85	0.033	326.3285	1429.309	1341.912	100
2	11	16.1986	0.85	0.033	98.2669	430.4059	662.354	100
3	12	100.1179	0.85	0.033	607.354	2660.1925	3535.422	100
4	1	10.9286	0.85	0.033	66.297	290.3788	731.17	100
5	2	4.6689	0.85	0.033	28.3235	124.0563	180.642	100
6	3	33.9029	0.85	0.033	205.668	900.8196	1178.474	100
7	4	22.4339	0.85	0.033	136.093	596.0832	473.11	100
8	5	12.6771	0.85	0.033	76.9045	336.8394	688.16	100
9	6	24.5771	0.85	0.033	149.0945	653.0297	1204.28	100
10	7	2.4589	0.85	0.033	14.9168	65.3352	25.806	25.806
11	8	17.0121	0.85	0.033	103.2023	452.023	782.782	100
12	9	7.6379	0.85	0.033	46.3342	202.9425	391	100
13	10	19.7686	0.85	0.033	119.9239	525.263	421.498	100
14	11	54.8614	0.85	0.033	332.8108	1457.7016	1608.574	100
15	12	31.4561	0.85	0.033	190.8248	835.807	1470.942	100
16	1	21.4746	0.85	0.033	130.2736	570.5944	868.802	100
17	2	96.1289	0.85	0.033	583.1556	2554.2043	2348.346	100
18	3	6.035	0.85	0.033	36.6107	160.3536	232.254	100
19	4	23.5936	0.85	0.033	143.1278	626.8956	636.548	100
20	5	0.8439	0.85	0.033	5.1196	22.4237	103.224	100
21	6	45.8636	0.85	0.033	278.2263	1218.6231	1651.584	100
22	7	1.1232	0.85	0.033	6.8139	29.8445	17.204	17.204
23	8	67.915	0.85	0.033	411.9989	1804.543	808.588	100
24	9	13.1507	0.85	0.033	79.7774	349.4225	369.104	100
25	10	34.3279	0.85	0.033	208.2462	912.1121	985.7892	100
26	11	22.3186	0.85	0.033	135.3932	593.0181	961.7036	100
27	12	25.0993	0.85	0.033	152.2621	666.9033	855.0388	100
28	1	175.5614	0.85	0.033	1065.0241	4664.7742	4318.204	100
29	2	15.6279	0.85	0.033	94.8047	415.2417	323.4352	100
30	3	2.6471	0.85	0.033	16.0586	70.3362	153.1156	100
31	4	10.455	0.85	0.033	63.4241	277.7957	146.234	100
32	5	63.6164	0.85	0.033	385.9221	1690.3273	765.578	100
33	6	7.905	0.85	0.033	47.9548	210.0407	80.8588	80.8588
34	7	29.325	0.85	0.033	177.8969	779.1831	980.628	100
35	8	13.4907	0.85	0.033	81.8399	358.4565	395.692	100

Table B4.2b Middle catchment-Part b-Scenario 4

Middle catchment general

Scenario 4

Time	Calendar month	Overflow to El Haouareb from small dams RES2A	Flow to El Haouareb dam from middle catchment	Transfer to Aquifer from RES2A small dams Infiltration	Number of small dams	Managed area in RES2A	Total capacity of small dams	Potential Evaporation	Agricultural demands	Transfer from 2AB
		1000m3	1000m3	1000m3		km2	1000m3	m	1000m3	1000m3
0	9	0	2945.944	0.0089	35	183.83	6618.3	0.1414	22.1394	2945.944
1	10	0	2671.221	0.0236	35	183.83	6618.3	0.1375	4.1697	2671.221
2	11	0	992.7599	0.0279	35	183.83	6618.3	0.0498	0	992.7599
3	12	0	6095.6145	0.0578	35	183.83	6618.3	0.0387	0	6095.615
4	1	0	921.5488	0.0598	35	183.83	6618.3	0.06	0	921.5488
5	2	0	204.6983	0.0594	35	183.83	6618.3	0.0901	0	204.6983
6	3	0	1979.2936	0.0678	35	183.83	6618.3	0.079	4.1697	1979.294
7	4	0	969.1932	0.0714	35	183.83	6618.3	0.1035	22.1394	969.1932
8	5	0	924.9994	0.0712	35	183.83	6618.3	0.1469	14.5939	924.9994
9	6	0	1757.3097	0.073	35	183.83	6618.3	0.1817	34.7636	1757.31
10	7	0	65.3352	0.0656	35	183.83	6618.3	0.2686	51.4303	65.3352
11	8	0	1134.805	0.0628	35	183.83	6618.3	0.2884	46.5939	1134.805
12	9	0	493.9425	0.061	35	183.83	6618.3	0.1683	22.1394	493.9425
13	10	0	846.761	0.0641	35	183.83	6618.3	0.1311	4.1697	846.761
14	11	0	2966.2756	0.0792	35	183.83	6618.3	0.0695	0	2966.276
15	12	0	2206.749	0.0875	35	183.83	6618.3	0.0529	0	2206.749
16	1	0	1339.3964	0.0929	35	183.83	6618.3	0.0419	0	1339.396
17	2	0	4802.5503	0.1208	35	183.83	6618.3	0.0466	0	4802.55
18	3	0	292.6076	0.1196	35	183.83	6618.3	0.0924	4.1697	292.6076
19	4	0	1163.4436	0.1228	35	183.83	6618.3	0.0988	22.1394	1163.444
20	5	0	25.6477	0.1166	35	183.83	6618.3	0.188	14.5939	25.6477
21	6	0	2770.2071	0.1219	35	183.83	6618.3	0.2315	34.7636	2770.207
22	7	0	29.8445	0.1115	35	183.83	6618.3	0.2844	51.4303	29.8445
23	8	0	2513.131	0.1238	35	183.83	6618.3	0.2165	46.5939	2513.131
24	9	0	618.5265	0.1219	35	183.83	6618.3	0.1643	22.1394	618.5265
25	10	0	1797.9013	0.129	35	183.83	6618.3	0.1003	4.1697	1797.901
26	11	0	1454.7217	0.1331	35	183.83	6618.3	0.0853	0	1454.722
27	12	0	1421.9421	0.1388	35	183.83	6618.3	0.0585	0	1421.942
28	1	0	8882.9782	0.1907	35	183.83	6618.3	0.0427	0	8882.978
29	2	0	638.6769	0.1935	35	183.83	6618.3	0.0482	0	638.6769
30	3	0	123.4518	0.1898	35	183.83	6618.3	0.1059	4.1697	123.4518
31	4	0	324.0297	0.1863	35	183.83	6618.3	0.1446	22.1394	324.0297
32	5	140.026	2495.9313	0.1926	35	183.83	6618.3	0.1691	14.5939	2495.931
33	6	0	210.0407	0.1846	35	183.83	6618.3	0.222	34.7636	210.0407
34	7	0	1659.8111	0.1805	35	183.83	6618.3	0.2765	51.4303	1659.811
35	8	0	654.1485	0.1744	35	183.83	6618.3	0.2196	46.5939	654.1485

Table B 4.3 Small dam unit- Scenario 4

Small dam unit

Scenario 4

Time	Calendar month	Number of small dams	Median small dam capacity	Median small dam height	Median height for starting overflow	Small dam capacity at overflow	Small dam lake and surrounding surface for direct rainfall	Inflow from runoff	Direct inflow from rainfall	Small dam initial status	Overflow from a small dam	Evaporation from a small dam	Infiltration from a small dam	Pumping for agriculture from a small dam
			1000m3	m	m	1000m3	m2	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	35	189.094	8.9943	7.9943	143.0095	45000	6.1982	1.6092	0	0	0.6992	0.0003	0.6326
1	10	35	189.094	8.9943	7.9943	143.0095	45000	9.3237	2.4207	6.4755	0	1.1907	0.0007	0.1191
2	11	35	189.094	8.9943	7.9943	143.0095	45000	2.8076	0.7289	16.9093	0	0.4754	0.0008	0
3	12	35	189.094	8.9943	7.9943	143.0095	45000	17.353	4.5053	19.9696	0	0.5626	0.0017	0
4	1	35	189.094	8.9943	7.9943	143.0095	45000	1.8942	0.4918	41.2636	0	0.8907	0.0017	0
5	2	35	189.094	8.9943	7.9943	143.0095	45000	0.8092	0.2101	42.7572	0	1.3301	0.0017	0
6	3	35	189.094	8.9943	7.9943	143.0095	45000	5.8762	1.5256	42.4448	0	1.2598	0.0019	0.1191
7	4	35	189.094	8.9943	7.9943	143.0095	45000	3.8884	1.0095	48.4657	0	1.6999	0.002	0.6326
8	5	35	189.094	8.9943	7.9943	143.0095	45000	2.1973	0.5705	51.0292	0	2.4109	0.002	0.417
9	6	35	189.094	8.9943	7.9943	143.0095	45000	4.2598	1.106	50.967	0	3.0246	0.0021	0.9932
10	7	35	189.094	8.9943	7.9943	143.0095	45000	0.4262	0.1107	52.3129	0	4.2026	0.0019	1.4694
11	8	35	189.094	8.9943	7.9943	143.0095	45000	2.9486	0.7655	47.1758	0	4.3966	0.0018	1.3313
12	9	35	189.094	8.9943	7.9943	143.0095	45000	1.3238	0.3437	45.1603	0	2.5236	0.0017	0.6326
13	10	35	189.094	8.9943	7.9943	143.0095	45000	3.4264	0.8896	43.6699	0	2.0242	0.0018	0.1191
14	11	35	189.094	8.9943	7.9943	143.0095	45000	9.5089	2.4688	45.8408	0	1.2128	0.0023	0
15	12	35	189.094	8.9943	7.9943	143.0095	45000	5.4521	1.4155	56.6033	0	0.9778	0.0025	0
16	1	35	189.094	8.9943	7.9943	143.0095	45000	3.7221	0.9664	62.4906	0	0.801	0.0027	0
17	2	35	189.094	8.9943	7.9943	143.0095	45000	16.6616	4.3258	66.3754	0	1.0379	0.0035	0
18	3	35	189.094	8.9943	7.9943	143.0095	45000	1.046	0.2716	86.3214	0	2.0462	0.0034	0.1191
19	4	35	189.094	8.9943	7.9943	143.0095	45000	4.0894	1.0617	85.4703	0	2.2197	0.0035	0.6326
20	5	35	189.094	8.9943	7.9943	143.0095	45000	0.1463	0.038	87.7656	0	4.1016	0.0033	0.417
21	6	35	189.094	8.9943	7.9943	143.0095	45000	7.9493	2.0639	83.4279	0	5.1797	0.0035	0.9932
22	7	35	189.094	8.9943	7.9943	143.0095	45000	0.1947	0.0505	87.2647	0	6.0458	0.0032	1.4694
23	8	35	189.094	8.9943	7.9943	143.0095	45000	11.7714	3.0562	79.9914	0	4.887	0.0035	1.3313
24	9	35	189.094	8.9943	7.9943	143.0095	45000	2.2794	0.5918	88.5972	0	3.6771	0.0035	0.6326
25	10	35	189.094	8.9943	7.9943	143.0095	45000	5.9499	1.5448	87.1552	0	2.3206	0.0037	0.1191
26	11	35	189.094	8.9943	7.9943	143.0095	45000	3.8684	1.0043	92.2064	0	2.0087	0.0038	0

27	12	35	189.094	8.9943	7.9943	143.0095	45000	4.3503	1.1295	95.0666	0	1.4102	0.004	0
28	1	35	189.094	8.9943	7.9943	143.0095	45000	30.4293	7.9003	99.1323	0	1.2366	0.0054	0
29	2	35	189.094	8.9943	7.9943	143.0095	45000	2.7087	0.7033	136.22	0	1.4087	0.0055	0
30	3	35	189.094	8.9943	7.9943	143.0095	45000	0.4588	0.1191	138.217	0	3.0603	0.0054	0.1191
31	4	35	189.094	8.9943	7.9943	143.0095	45000	1.8121	0.4705	135.611	0	4.134	0.0053	0.6326
32	5	35	189.094	8.9943	7.9943	143.0095	45000	11.0263	2.8627	133.121	4.0007	4.9284	0.0055	0.417
33	6	35	189.094	8.9943	7.9943	143.0095	45000	1.3701	0.3557	137.659	0	6.3155	0.0053	0.9932
34	7	35	189.094	8.9943	7.9943	143.0095	45000	5.0828	1.3196	132.071	0	7.7638	0.0052	1.4694
35	8	35	189.094	8.9943	7.9943	143.0095	45000	2.3383	0.6071	129.234	0	6.0464	0.005	1.3313

Table B4.4 El Haouareb-Scenario 4

El Haouareb

Scenario 4

Time	Calendar month	Rainfall	Rainfall data climate coefficient scenario	Inflow from Rainfall	Inflow from middle catchment	Initial El Haouareb status	Evaporation	Pumping for Irrigation	Infiltration to Kairoouan aquifer	Dam release status	Release threshold	Dam release to Kairouan
		mm		1000m3	1000m3	1000m3	1000m3	1000 m3	1000m3	1000m3	1000m3	1000m3
0	9	33.405	0.85	522.354	2945.944	2440	458.5406	431	826.8712	4191.8862	6500	0
1	10	34.85	0.85	544.9494	2671.221	4191.8862	486.5905	679	902.6669	5339.7992	6500	0
2	11	4.59	0.85	71.7738	992.7599	5339.7992	169.4569	244	868.2242	5122.6519	6500	0
3	12	73.525	0.85	1149.7104	6095.6145	5122.6519	175.8421	172	1158.3502	10861.785	6500	4361.7845
4	1	2.04	0.85	31.8995	921.5488	6500	216.4761	356	919.4105	5961.5617	6500	0
5	2	5.355	0.85	83.7361	204.6983	5961.5617	301.512	579	853.715	4515.7691	6500	0
6	3	23.885	0.85	373.4897	1979.2936	4515.7691	274.5875	0	886.3267	5707.6382	6500	0
7	4	15.385	0.85	240.5752	969.1932	5707.6382	359.1068	293	884.8414	5380.4585	6500	0
8	5	13.26	0.85	207.3466	924.9994	5380.4585	493.939	266	857.1828	4895.6827	6500	0
9	6	18.19	0.85	284.437	1757.3097	4895.6827	621.4397	472	872.1361	4971.8536	6500	0
10	7	1.275	0.85	19.9372	65.3352	4971.8536	804.229	0	763.5085	3489.3885	6500	0
11	8	8.5	0.85	132.9145	1134.805	3489.3885	869.9863	182	769.3654	2935.7563	6500	0
12	9	2.38	0.85	37.2161	493.9425	2935.7563	476.0364	0	721.3959	2269.4827	6500	0
13	10	8.755	0.85	136.9019	846.761	2269.4827	364.7826	155	709.3149	2024.0481	6500	0
14	11	33.065	0.85	517.0374	2966.2756	2024.0481	223.0804	98	818.2611	4368.0196	6500	0
15	12	19.295	0.85	301.7159	2206.749	4368.0196	185.0073	205	891.3065	5595.1707	6500	0
16	1	4.505	0.85	70.4447	1339.3964	5595.1707	147.7791	296	900.016	5661.2167	6500	0
17	2	58.99	0.85	922.4266	4802.5503	5661.2167	203.148	367	1111.4084	9704.6372	6500	3204.6372
18	3	4.93	0.85	77.0904	292.6076	6500	320.6428	0	884.6035	5664.4517	6500	0
19	4	23.29	0.85	364.1857	1163.4436	5664.4517	348.2676	0	899.324	5944.4894	6500	0
20	5	0.425	0.85	6.6457	25.6477	5944.4894	607.6166	0	824.0731	4545.0931	6500	0
21	6	28.475	0.85	445.2636	2770.2071	4545.0931	820.0803	0	903.4452	6037.0382	6500	0
22	7	3.4	0.85	53.1658	29.8445	6037.0382	910.4145	0	816.2999	4393.3341	6500	0
23	8	53.21	0.85	832.0448	2513.131	4393.3341	768.1529	420	904.9201	5645.4368	6500	0
24	9	11.645	0.85	182.0929	618.5265	5645.4368	548.4381	0	851.0938	5046.5243	6500	0
25	10	32.045	0.85	501.0877	1797.9013	5046.5243	356.6518	498	906.4708	5584.3906	6500	0

26	11	9.52	0.85	148.8642	1454.7217	5584.3906	301.619	410	901.4632	5574.8943	6500	0
27	12	19.635	0.85	307.0325	1421.9421	5574.8943	209.0857	227	912.0228	5955.7604	6500	0
28	1	166.6	0.85	2605.1242	8882.9782	5955.7604	230.7013	67	1379.0164	15767.145	6500	9267.1451
29	2	4.335	0.85	67.7864	638.6769	6500	171.82	81	909.195	6044.4482	6500	0
30	3	0	0.85	0	123.4518	6044.4482	351.6074	0	846.9666	4969.3261	6500	0
31	4	3.995	0.85	62.4698	324.0297	4969.3261	453.1375	0	799.2672	4103.4209	6500	0
32	5	45.645	0.85	713.7509	2495.9313	4103.4209	591.6383	335	892.3918	5494.073	6500	0
33	6	4.675	0.85	73.103	210.0407	5494.073	703.939	0	808.6149	4264.6627	6500	0
34	7	9.945	0.85	155.51	1659.8111	4264.6627	882.9109	0	814.2578	4382.8152	6500	0
35	8	45.135	0.85	705.776	654.1485	4382.8152	694.7066	154	806.6214	4087.4117	6500	0

Table B4.5 Kairouan aquifer-Scenario 4

Kairouan aquifer

Scenario 4

Time	Calendar month	Transfer from El Haouareb	Recharge coefficient	Aquifer recharge from release	Infiltration from middle catchment	Infiltration from El Haouareb	Groundwater transfer from upstream aquifers	Kairouan aquifer initial status	Groundwater outflow from Kairouan	Pumping for drinking water	Pumping for irrigation
		1000m3		1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	0	0.7	0	0.0089	826.8712	433.333	150000	625	583.3333	774.8788
1	10	0	0.7	0	0.0236	902.6669	433.333	149277	625	583.3333	145.9394
2	11	0	0.7	0	0.0279	868.2242	433.333	149258.75	625	583.3333	0
3	12	4361.785	0.7	3053.249	0.0578	1158.3502	433.333	149352	625	437.5	0
4	1	0	0.7	0	0.0598	919.4105	433.333	152934.49	625	437.5	0
5	2	0	0.7	0	0.0594	853.715	433.333	153224.8	625	437.5	0
6	3	0	0.7	0	0.0678	886.3267	433.333	153449.4	625	583.3333	145.9394
7	4	0	0.7	0	0.0714	884.8414	433.333	153414.86	625	583.3333	774.8788
8	5	0	0.7	0	0.0712	857.1828	433.333	152749.89	625	583.3333	510.7879
9	6	0	0.7	0	0.073	872.1361	433.333	152321.36	625	729.1667	1216.7273
10	7	0	0.7	0	0.0656	763.5085	433.333	151056.01	625	729.1667	1800.0606
11	8	0	0.7	0	0.0628	769.3654	433.333	149098.69	625	729.1667	1630.7879
12	9	0	0.7	0	0.061	721.3959	433.333	147316.49	625	583.3333	774.8788
13	10	0	0.7	0	0.0641	709.3149	433.333	146488.07	625	583.3333	145.9394
14	11	0	0.7	0	0.0792	818.2611	433.333	146276.51	625	583.3333	0
15	12	0	0.7	0	0.0875	891.3065	433.333	146319.85	625	437.5	0
16	1	0	0.7	0	0.0929	900.016	433.333	146582.08	625	437.5	0
17	2	3204.637	0.7	2243.246	0.1208	1111.4084	433.333	146853.02	625	437.5	0
18	3	0	0.7	0	0.1196	884.6035	433.333	149578.63	625	583.3333	145.9394
19	4	0	0.7	0	0.1228	899.324	433.333	149542.41	625	583.3333	774.8788
20	5	0	0.7	0	0.1166	824.0731	433.333	148891.98	625	583.3333	510.7879
21	6	0	0.7	0	0.1219	903.4452	433.333	148430.38	625	729.1667	1216.7273
22	7	0	0.7	0	0.1115	816.2999	433.333	147196.39	625	729.1667	1800.0606
23	8	0	0.7	0	0.1238	904.9201	433.333	145291.9	625	729.1667	1630.7879
24	9	0	0.7	0	0.1219	851.0938	433.333	143645.33	625	583.3333	774.8788
25	10	0	0.7	0	0.129	906.4708	433.333	142946.66	625	583.3333	145.9394

26	11	0	0.7	0	0.1331	901.4632	433.333	142932.32		625	583.3333	0
27	12	0	0.7	0	0.1388	912.0228	433.333	143058.92		625	437.5	0
28	1	9267.145	0.7	6487.002	0.1907	1379.0164	433.333	143341.91		625	437.5	0
29	2	0	0.7	0	0.1935	909.195	433.333	150578.95		625	437.5	0
30	3	0	0.7	0	0.1898	846.9666	433.333	150859.18		625	583.3333	145.9394
31	4	0	0.7	0	0.1863	799.2672	433.333	150785.39		625	583.3333	774.8788
32	5	0	0.7	0	0.1926	892.3918	433.333	150034.97		625	583.3333	510.7879
33	6	0	0.7	0	0.1846	808.6149	433.333	149641.76		625	729.1667	1216.7273
34	7	0	0.7	0	0.1805	814.2578	433.333	148313		625	729.1667	1800.0606
35	8	0	0.7	0	0.1744	806.6214	433.333	146406.55		625	729.1667	1630.7879
Yearly		5611.189		3927.832		10591.45					6999.9999	7000.0001

Table B5.1 El Haouareb-Scenario 5

El Haouareb

Scenario 5

Time	Calendar month	Rainfall	Rainfall data climate coefficient scenario	Inflow from Rainfall	Inflow from middle catchment	Initial El Haouareb status	Evaporation	Pumping for Irrigation	Infiltration to Kairoouan aquifer	Dam release status	Release threshold	Dam release to Kairouan
		mm		1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	33.405	0.85	522.354	2945.944	2440	458.5406	431	826.8712	4191.8862	15000	0
1	10	34.85	0.85	544.9494	2671.221	4191.8862	486.5905	679	902.6669	5339.7992	15000	0
2	11	4.59	0.85	71.7738	992.7599	5339.7992	169.4569	244	868.2242	5122.6519	15000	0
3	12	73.525	0.85	1149.7104	6095.6145	5122.6519	175.8421	172	1158.3502	10861.785	15000	0
4	1	2.04	0.85	31.8995	921.5488	10861.785	265.9363	356	1129.4762	10063.82	15000	0
5	2	5.355	0.85	83.7361	204.6983	10063.82	372.6398	579	1055.1094	8345.5056	15000	0
6	3	23.885	0.85	373.4897	1979.2936	8345.5056	332.4728	806	1073.1716	8486.6446	15000	0
7	4	15.385	0.85	240.5752	969.1932	8486.6446	414.393	293	1021.067	7967.953	15000	0
8	5	13.26	0.85	207.3466	924.9994	7967.953	567.2223	266	984.3589	7282.7179	15000	0
9	6	18.19	0.85	284.437	1757.3097	7282.7179	704.259	472	988.3657	7159.8398	15000	0
10	7	1.275	0.85	19.9372	65.3352	7159.8398	920.6414	608	874.0267	4842.4442	15000	0
11	8	8.5	0.85	132.9145	1134.805	4842.4442	920.8223	182	814.3218	4193.0196	15000	0
12	9	2.38	0.85	37.2161	493.9425	4193.0196	504.5072	330	764.5411	3125.1299	15000	0
13	10	8.755	0.85	136.9019	846.761	3125.1299	394.2038	155	766.524	2793.065	15000	0
14	11	33.065	0.85	517.0374	2966.2756	2793.065	233.8706	98	857.8394	5086.6681	15000	0
15	12	19.295	0.85	301.7159	2206.749	5086.6681	192.5047	205	927.4265	6270.2018	15000	0
16	1	4.505	0.85	70.4447	1339.3964	6270.2018	153.3466	296	933.9237	6296.7725	15000	0
17	2	58.99	0.85	922.4266	4802.5503	6296.7725	208.5509	367	1140.9671	10305.231	15000	0
18	3	4.93	0.85	77.0904	292.6076	10305.231	387.7979	751	1069.8741	8466.2575	15000	0
19	4	23.29	0.85	364.1857	1163.4436	8466.2575	401.2347	843	1036.0998	7713.5524	15000	0
20	5	0.425	0.85	6.6457	25.6477	7713.5524	672.3142	0	911.8185	6161.7131	15000	0
21	6	28.475	0.85	445.2636	2770.2071	6161.7131	890.6389	723	981.1765	6782.3684	15000	0
22	7	3.4	0.85	53.1658	29.8445	6782.3684	951.3198	0	852.9766	5061.0823	15000	0
23	8	53.21	0.85	832.0448	2513.131	5061.0823	795.6781	420	937.346	6253.2339	15000	0
24	9	11.645	0.85	182.0929	618.5265	6253.2339	567.9707	643	881.4053	4961.4772	15000	0
25	10	32.045	0.85	501.0877	1797.9013	4961.4772	354.9825	498	902.2281	5505.2556	15000	0
26	11	9.52	0.85	148.8642	1454.7217	5505.2556	300.2923	410	897.4982	5501.051	15000	0
27	12	19.635	0.85	307.0325	1421.9421	5501.051	208.2361	227	908.3168	5886.4727	15000	0
28	1	166.6	0.85	2605.1242	8882.9782	5886.4727	230.2192	67	1376.1347	15701.221	15000	701.2212

29	2	4.335	0.85	67.7864	638.6769	15000	246.7635	81	1305.7625	14072.937	15000	0
30	3	0	0.85	0	123.4518	14072.937	509.6873	965	1227.7561	11493.946	15000	0
31	4	3.995	0.85	62.4698	324.0297	11493.946	632.5124	0	1115.6579	10132.275	15000	0
32	5	45.645	0.85	713.7509	2495.9313	10132.275	779.6357	335	1175.9558	11051.366	15000	0
33	6	4.675	0.85	73.103	210.0407	11051.366	936.4579	634	1075.7095	8688.3419	15000	0
34	7	9.945	0.85	155.51	1659.8111	8688.3419	1113.0466	675	1026.4986	7689.1178	15000	0
35	8	45.135	0.85	705.776	654.1485	7689.1178	834.2545	154	968.6499	7092.1378	15000	0

Table B5.2 Kairouan aquifer-Scenario 5

Kairouan aquifer

Scenario 5

Time	Calendar month	Transfer from El Haouareb	Recharge coefficient	Aquifer recharge from release	Infiltration from middle catchment	Infiltration from El Haouareb	Groundwater transfer from upstream aquifers	Kairouan aquifer initial status	Groundwater outflow from Kairouan	Pumping for drinking water	Pumping for irrigation
		1000m3		1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3	1000m3
0	9	0	0.7	0	0.0089	826.8712	433.333	150000	625	416.6667	553.4849
1	10	0	0.7	0	0.0236	902.6669	433.333	149665.06	625	416.6667	104.2424
2	11	0	0.7	0	0.0279	868.2242	433.333	149855.18	625	416.6667	0
3	12	0	0.7	0	0.0578	1158.3502	433.333	150115.09	625	312.5	0
4	1	0	0.7	0	0.0598	1129.4762	433.333	150769.34	625	312.5	0
5	2	0	0.7	0	0.0594	1055.1094	433.333	151394.7	625	312.5	0
6	3	0	0.7	0	0.0678	1073.1716	433.333	151945.71	625	416.6667	104.2424
7	4	0	0.7	0	0.0714	1021.067	433.333	152306.37	625	416.6667	553.4849
8	5	0	0.7	0	0.0712	984.3589	433.333	152165.69	625	416.6667	364.8485
9	6	0	0.7	0	0.073	988.3657	433.333	152176.94	625	520.8333	869.0909
10	7	0	0.7	0	0.0656	874.0267	433.333	151583.78	625	520.8333	1285.7576
11	8	0	0.7	0	0.0628	814.3218	433.333	150459.62	625	520.8333	1164.8485
12	9	0	0.7	0	0.061	764.5411	433.333	149396.65	625	416.6667	553.4849
13	10	0	0.7	0	0.0641	766.524	433.333	148999.44	625	416.6667	104.2424
14	11	0	0.7	0	0.0792	857.8394	433.333	149053.45	625	416.6667	0
15	12	0	0.7	0	0.0875	927.4265	433.333	149303.04	625	312.5	0
16	1	0	0.7	0	0.0929	933.9237	433.333	149726.38	625	312.5	0
17	2	0	0.7	0	0.1208	1140.9671	433.333	150156.23	625	312.5	0
18	3	0	0.7	0	0.1196	1069.8741	433.333	150793.15	625	416.6667	104.2424
19	4	0	0.7	0	0.1228	1036.0998	433.333	151150.57	625	416.6667	553.4849
20	5	0	0.7	0	0.1166	911.8185	433.333	151024.97	625	416.6667	364.8485
21	6	0	0.7	0	0.1219	981.1765	433.333	150963.73	625	520.8333	869.0909
22	7	0	0.7	0	0.1115	852.9766	433.333	150363.43	625	520.8333	1285.7576
23	8	0	0.7	0	0.1238	937.346	433.333	149218.27	625	520.8333	1164.8485
24	9	0	0.7	0	0.1219	881.4053	433.333	148278.39	625	416.6667	553.4849
25	10	0	0.7	0	0.129	902.2281	433.333	147998.09	625	416.6667	104.2424
26	11	0	0.7	0	0.1331	897.4982	433.333	148187.88	625	416.6667	0
27	12	0	0.7	0	0.1388	908.3168	433.333	148477.17	625	312.5	0
28	1	701.2212	0.7	490.8549	0.1907	1376.1347	433.333	148881.46	625	312.5	0

29	2	0	0.7	0	0.1935	1305.7625	433.333	150244.48	625	312.5	0
30	3	0	0.7	0	0.1898	1227.7561	433.333	151046.26	625	416.6667	104.2424
31	4	0	0.7	0	0.1863	1115.6579	433.333	151561.63	625	416.6667	553.4849
32	5	0	0.7	0	0.1926	1175.9558	433.333	151515.66	625	416.6667	364.8485
33	6	0	0.7	0	0.1846	1075.7095	433.333	151718.63	625	520.8333	869.0909
34	7	0	0.7	0	0.1805	1026.4986	433.333	151212.93	625	520.8333	1285.7576
35	8	0	0.7	0	0.1744	968.6499	433.333	150241.35	625	520.8333	1164.8485
Yearly		233.7404		163.6183		11912.699				5000.0001	5000.0001