IMPROVED DROUGHT EARLY WARNING AND FORECASTING TO STRENGTHEN PREPAREDNESS AND ADAPTATION TO DROUGHTS IN AFRICA

DEWFORA

A 7th Framework Programme Collaborative Research Project

Implementation of improved methodologies in comparative case studies

Inception report for each case study

WP6-D6.1

May 2012

Coordinator: Deltares, The Netherlands
Project website: www.dewfora.net
FP7 Call ENV-2010-1.3.3.1
Contract no. 265454

Page intentionally left blank

DOCUMENT INFORMATION

Title	Inception report for each case study
Lead Author	JRC, NFC, WaterNet, IAV, PIK
Contributors	IHE, ECWMF, GFZ, DCER, UEM, WRNA, CSIR, FEUP, WISO
Distribution	<Please select on of three below> PP: Restricted to other programme participants (including the Commission Services) RE: Restricted to a group specified by the consortium (including the Commission Services) CO: Confidential, only for members of the consortium (including the Commission Services)
Reference	WP6-D6.1

DOCUMENT HISTORY

Date	Revision	Prepared by	Organisation	Approved by	Notes
16/05/2012		Gustavo Naumann		Paulo Barbosa	
13/05/2012		Samuel Fournet	PIK		
26/03/2012		Paulo Barbosa	JRC		
26/03/2012		Gustavo Naumann	JRC		
25/03/2012		Doaa Lashien	NFC		
13/02/2012		Samuel Fournet	PIK		
13/02/2012		Bakary Kone	WISO		
30/01/2012		Yasmina Imani	IAV		
16/09/2011	0	David Love	WaterNet	David Love	
30/09/2011	0.1	David Love	WaterNet	David Love	
15/12/2011	0.2	Tsiko, Mulengera and Kileshye Onema	WaterNet	Jean-Marie Kileshye Onema	
19/12/2011	0.3	Mathias Siebert	GFZ	Jean-Marie Kileshye Onema	
21/12/2011	0.4	Berhanu Alemaw	WaterNet	Jean-Marie Kileshye Onema	Chapter 4 needs further discussions with other WPs and partners
23/12/2011	0.5	Jean-Marie Kileshye Onema	WaterNet	Jean-Marie Kileshye Onema	With inputs sourced from CSIR report authored by Archer van Garderen, Landman, Engelbrecht, & Park
12/12/2011		Mohamed Ahmed Ali	NFC		

ACKNOWLEDGEMENT

The research leading to these results has received funding from the European Union's Seventh Framework Programme (FP7/2007-2013) under grant agreement N°265454

Page intentionally left blank

Summary

The DEWFORA project has a clear focus on the testing and implementation of existing and developed methodologies on drought monitoring and forecasting. Basin case studies will be used to provide in depth analysis of drought monitoring, forecasting and early warning in Africa at different spatial scales. The case studies will play an integral role in the project by providing direct interaction with end-users, highlighting the needs for improvement of the existing systems, and challenging the application of the methods developed in the project in real operational settings. Each of the basin case studies has a specific contribution to the project although sharing common objectives to allow comparison across scales and climatic conditions. Four regional case studies will be considered:

- The Eastern Nile Basin (North & Eastern Africa), focusing on improved tools for the forecasting of water availability, the impact of climate change and community scale adaptation.
- The Limpopo Basin (Southern Africa), focusing on improving existing drought monitoring and forecasting capabilities, as well as institutions, policies, guidelines and procedures for management of the scarce water resources in the basin.
- The Oum er-Rbia River Basin (Morocco, Northern Africa), focusing on improving capabilities in the forecasting of agricultural drought and establishing guidelines on adaptation in agricultural practices to reduce vulnerability.
- The Niger Basin (Western Africa), focusing on mid-term climate forecasting and strengthening preparedness to droughts to improve food security and human welfare.

Furthermore, a demonstrative continental pan-African system will also be developed, focusing on a pre-operational drought monitoring and forecasting system, in order to improve current drought and food security predictions at continental scale.

Finally, there will be a study focusing on the inter-comparison of approaches applied in the pilot case studies of the DEWFORA project, and those applied in other EU projects, particularly in Southern Europe.

This report provides a detailed description of each case study as well as a discussion concerning the needed activities, work-plan and time schedule in order to reach the goals of each task. A final report with the results obtained in each regional case study will be delivered on month 28 of the project, while the pan-African system and the inter-comparison study between EU and Africa will provide a number of deliverables during the lifetime of the project.

Page intentionally left blank

TABLE OF CONTENTS

List of figures

LIST of tables

List of abbreviations:

AC	Agricultural Corporations
Ar	Argon (argon dating system)
BCM	Billion cubic meters
Ca	circa (around)
CCD	Climate Change Data
CV	Coefficient of Variation
DFID	Department for International Development
DRI	Desertification Research Institute, Sudan
DM	Drought Management
DPPC	Disaster Prevention and Preparedness committee
DRMFSS	Disaster Risk Management and Food Security Sector
ESP	Extended Stream flow Prediction
ELQG	Extended Linear Quadratic Gaussian
EM-DAT	the International Disasters Database
EWS	Early Warning System
FAO	Food and Agriculture Organization
FTP	File Transfer Protocol
GCM	Global Circulation Model
GDP	Gross Domestic Product
GWRI	Georgia Water Resources Institute
Ha	hectare
HAD	High Aswan Dam
HADA	High Aswan Dam Authority
HAD-DSS	The High Aswan Dam Decision Support System
HIBU	Hydro-meteorological Institute and Belgrade University
ICS	Interconnected System
ITCZ	Inter-Tropical Convergence Zone
LNFDC	Lake Nasser Flood and Drought Control
Ma	Million years ago
MFS	Monitoring, Forecasting and Simulation Project (at NFC)
MDG	Millennium Development Goals
MOARD	the Ministry of Agriculture and Rural Development
MOFED	Ministry of Finance and Economic Development
MW	Mega Watt
MWRI	Ministry of Water Resources and Irrigation
NBHIS	Nile Basin Hydro-meteorological Information System (the NFC data Base)
NBI	Nile Basin Initiative
NCEP	National Centre of Environmental prediction
NCAR	the National Centre of Atmospheric Research
NFC	Nile Forecast Centre
NFS	Nile Forecast System

Nile-DST	Nile Decision Support Tools
NMSA	National Meteorological Services Agency
NMSA	National Meteorological Services Agency
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
OAD	Old Aswan Dam
PSNP	Productive Safety Net Program
PRECIS	Providing Regional Climates for Impacts Studies
PASDEP	Plan for Accelerated and Sustained Development to End Poverty (Ministry of Finance and Economic Development; Ethiopia)
PDUS	Primary Data User System
RCM	Regional Climate Model
RIBASIM-NILE	The River Basin Simulation Model of the Nile Basin upstream the High Aswan Dam
RRC	the Relief and Rehabilitation Commission
SCS	Self-Contained System
SMA	Sudan Meteorological Authority
TWh	Terra Watt Hour
WMO	World Meteorological Organization

Page intentionally left blank

1. INTRODUCTION

1.1 PROJECT CONTEXT

The DEWFORA project has a clear focus on the testing and implementation of existing and developed methodologies on drought monitoring and forecasting. Basin case studies will be used to provide in depth analysis of drought monitoring, forecasting and early warning in Africa at different spatial scales. The case studies will play an integral role in the project by providing direct interaction with end-users, highlighting the needs for improvement of the existing systems, and challenging the application of the methods developed in the project in real operational settings. The pilot case studies selected cover a broad range of African climates and environments (Figure 1-1).

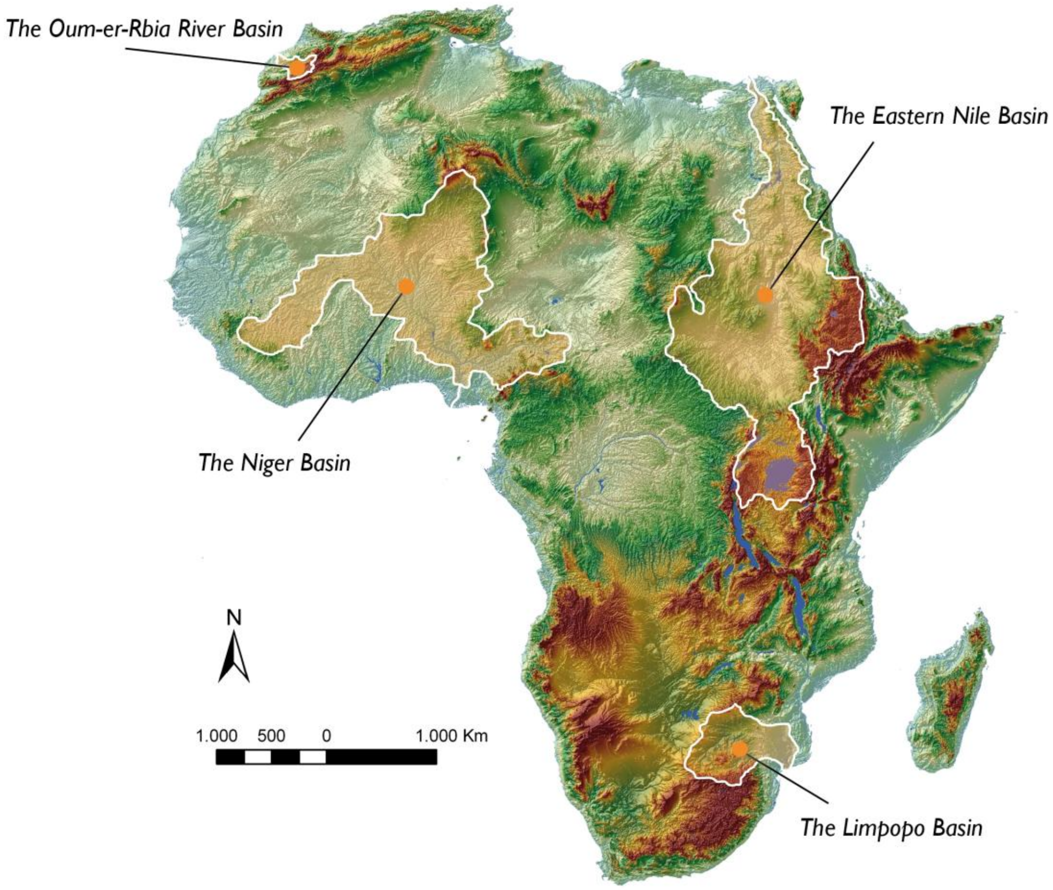


Figure 1-1 Location of the four regional case studies of the DEWFORA project.

While each of the pilot basins has a specific contribution to the aims of the project, these also share common objectives to allow comparison across environmental and climatic conditions. Four regional case studies are as well as a Pan-African system and a considered:

- The Eastern Nile Basin (North & Eastern Africa), focusing on improved tools for the forecasting of water availability, the impact of climate change and community scale adaptation.

- The Limpopo Basin (Southern Africa), focusing on improving existing drought monitoring and forecasting capabilities, as well as institutions, policies, guidelines and procedures for management of the scarce water resources in the basin.
- The Niger Basin (Western Africa), focusing on mid-term climate forecasting and strengthening preparedness to droughts to improve food security and human welfare.
- The Oum er-Rbia River Basin (Morocco, Northern Africa), focusing on improving capabilities in the forecasting of agricultural drought and establishing guidelines on adaptation in agricultural practices to reduce vulnerability.

Furthermore, a demonstrative continental pan-African system will also be developed, focusing on a pre-operational drought monitoring and forecasting system, in order to improve current drought and food security predictions at continental scale.

Finally, there will be a study focusing on the inter-comparison of approaches applied in the pilot case studies of the DEWFORA project, and those applied in other EU projects, particularly in Southern Europe.

The implementation of the case studies in the DEWFORA project will ensure that the research not only brings the state-of-the-art in drought related research to the operational domain, but also provide viable and effective solutions with direct applicability in Africa.

1.2 GOALS

The primary aim of the DEWFORA project is to develop a framework for the provision of early warning and response to mitigate the impact of droughts in Africa. The project has three key targets:

1. Improved monitoring: by improving knowledge on drought forecasting, warning and mitigation, and advancing the understanding of climate related vulnerability to drought – both in the current and in the projected future climate.

2. Prototype operational forecasting: by bringing advances made in the project to the pre-operational stage through development of prototype systems and piloting methods in operational drought monitoring and forecasting agencies. The piloting of methods in an operational context is not necessarily done during the lifetime of the project.

3. Knowledge dissemination: through a stakeholders platform that includes national and regional drought monitoring and forecasting agencies, as well as NGO’s and IGO’s, and through capacity building programmes to help embed the knowledge gained in the community of African practitioners and researchers.

DEWFORA is expected to contribute to increase the effectiveness of drought forecasting, warning and response in Africa. DEWFORA will also provide guidance on how and where drought preparedness and adaptation should be targeted to contribute to increased resilience and improved effectiveness of drought mitigation measures.

1.3 PURPOSE OF THE CASE STUDIES

The case studies are the basis for the implementation, assessment and refinement of the improved methodologies developed in work packages 3, 4, and 5. This will allow applying these methods across Africa to systems reflecting different climatic and environmental conditions. The four case studies (Tasks 6.1 to 6.4) share the core activities indicated below, although each of them has a specific focus as described in the detailed descriptions:

- Assess the existing drought monitoring and forecasting networks, practices and capacities in the region and provide this information to WP 2 (due to the time schedule of the activities most of the work was already done in D2.1).
- Synthesize the current state of the art of climate research in the basin.
- Identify key stakeholders in the region to be invited to participate in the Stakeholders Platform and provide this information to WP 7.
- Identify and maintain contact with end-users throughout the project.
- Collect case specific meteorological and ground data needed for implementation of the case study, providing this information to WP 4.
- Collect information on regional water resources use for identification of indicator thresholds in WP 3.
- Investigate the applicability of the methodologies developed in WP 3, 4 and 5.
- Link activities of the case study to other relevant initiatives in the region.
- Present the results to local stakeholders, relevant authorities and decision makers.

The pan-African continental system (Task 6.5) will test the applicability of the methodologies developed in WP 4 and adapt the indicators developed in Task 3.1 for analysis at a larger scale, providing results that will be implemented in a Pan-African web map server.

The results from the regional case studies will be compared to results from other studies in Europe dealing with drought/climate vulnerability and risk (Task 6.6), to exchange experiences, highlighting lessons learned, and identifying opportunities for improvement of drought monitoring and forecasting in Europe and Africa. This task will be closely linked to WP 7.

The close link of WP6 with the remaining work packages is illustrated in Figure 1-2 and a detailed description of interdependencies between WP and deliverables is shown in Table 1-1.

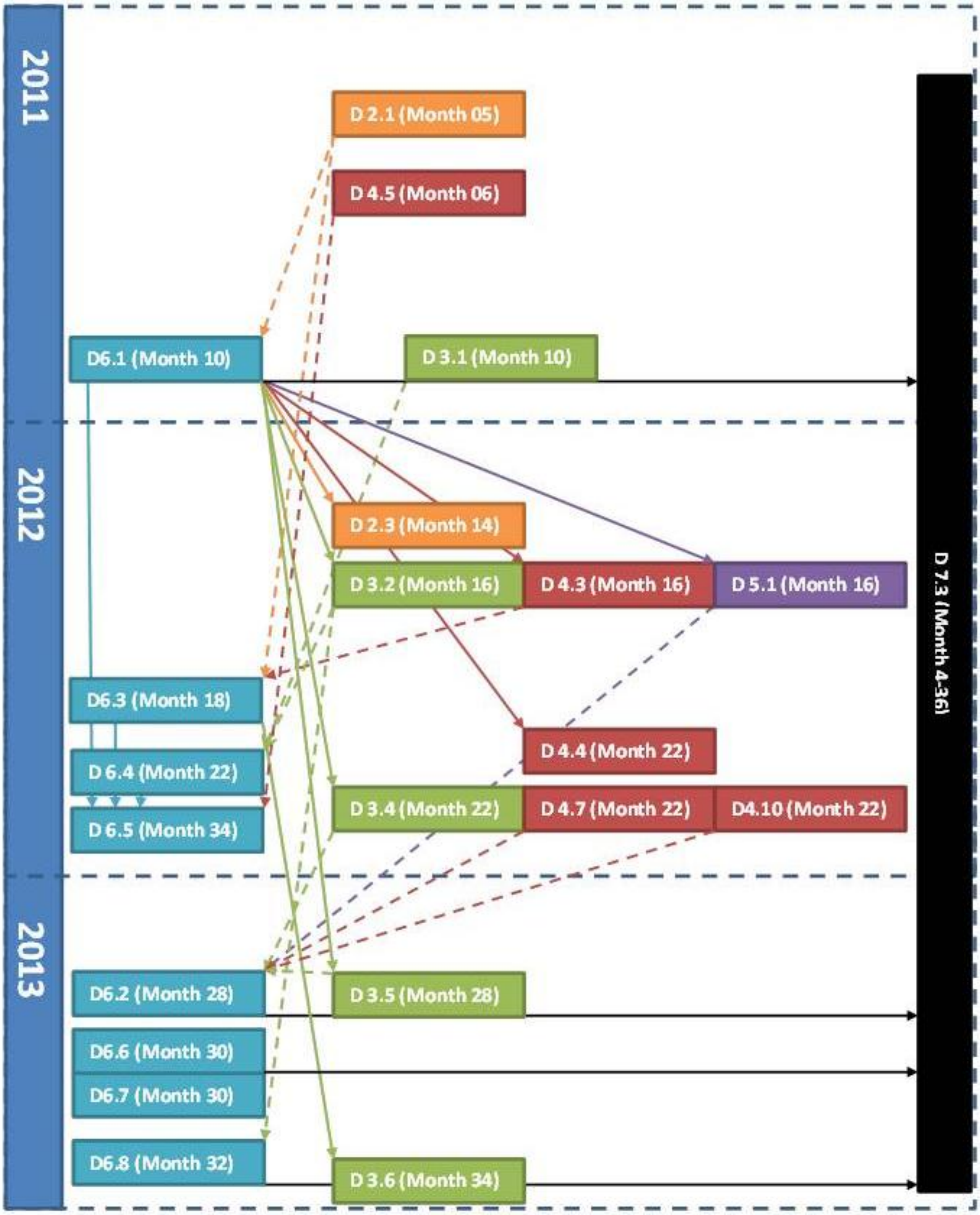


Figure 1-2 Graphical representation of the interdependencies of each deliverable of WP6 with the other WPs.

Table 1.1 Description of the WP6 deliverables and other WP deliverables connected to WP6.

WP2	**D2.1)** Inventory of drought monitoring and forecasting systems in Africa as fact sheets and institutional mapping. **[month 5]** **D2.3)** Assessment report on drought warning experiences. **[month 14]**
WP3	**D3.2)** Report presenting consolidated and generic methods for mapping drought vulnerability at different spatial scales based on piloting in the regions and selected catchments in WP 6. These maps allow drought vulnerability to be indicated at the continental level, selected regions and selected catchments. **[month 16]** **D3.4)** Meteorological climate scenarios for Africa and specific case study regions of the Nile and Niger River basins. **[month 22]** **D3.5)** Hydrological climate scenarios for Africa and specific case study regions of the Nile and Niger river basins. **[month 28]** **D3.6)** Report on impact of climate change on drought hazard across the whole of Africa and at the regional case study scale, describing the analysis of different climate change scenarios and the expected impact on drought hazard. **[month 34]**
WP4	**D4.3)** Report on the potential to supplementing drought early warning systems with new meteorological information and indices for the African continent **[month 16]** **D4.4)** Report on the potential to supplementing drought early warning systems with new meteorological information and indices for the Nile test catchment **[month 22]** **D4.5)** Overview report of available continental scale hydrological models and their suitability for African drought forecasting. **[month 6]** **D4.7)** Downscaled and tailor made hydrological models for the Limpopo and Niger case study basins, including user manuals **[month 22]** **D4.10)** Local scale agricultural models for Limpopo and Oum-er-Rbia river basins **[month 22]**
WP5	**D5.1)** Concept report describing the outline of a framework for drought warning and mitigation in Africa **[month 16]**
WP6	**D6.1)** Inception report for the regional case study (Task 6.1, 6.2, 6.3 and 6.4). This report is needed as input for WP 2, 3 and 4. **[month 10]** **D6.2)** Final report for each case study concluding on the specific case study objectives and findings **[month 28]** **D6.3)** Testing of drought indicators at Pan-African level. Report and maps. **[month 18]** **D6.4)** Integration of drought vulnerability and hazard into risk maps at the Pan-African level. Report and maps. **[month 22]** **D6.5)** Integration of drought forecasting tools for Africa into the Pan-African map server. Report and maps **[month 34]** **D6.6)** Development and implementation of Pan-African map server **[month 30]** **D6.7)** Evaluation of the performance of the proposed improved drought forecasting methods applied to selected river basins in Africa **[month 30]** **D6.8)** Comparative review of drought forecasting in Europe and Africa **[month 32]**
WP7	**D7.3)** Project Knowledge Sharing Platform (online from Month 4 onwards) **[month 4-36]**

1.4 PAN-AFRICAN SYSTEM AND STUDY ON EU/AFRICA PERSPECTIVES

PAN-AFRICAN SYSTEM

The aim of the Pan-African system is to develop and test a pre-operational system for drought monitoring and forecasting in Africa at the continental scale, using medium-range, monthly and seasonal probabilistic forecasts. For the implementation of this case study the project will capitalize on the experience gained by JRC with the development of the European Drought Observatory (EDO) and with the European Flood Alert System (EFAS), as well as with pilot studies on drought early warning in the Horn of Africa.

The specific objectives of the Pan-African system are:

- Collection of meteorological and ancillary data needed for implementation of the case study.
- Development and testing of drought indicators at Pan-African scale (D6.3). A number of drought indicators suitable for Pan-African scale will be selected and tested.
- Risk assessment by integration of vulnerability and hazard at Pan-African level (D6.4). Indicators for vulnerability and hazard estimates will be integrated in this task by using the tools and results produced in WP 3. The selected global models (ECMWF for meteorology and the selected hydrological model from WaterMIP) will be used in order to produce current Pan–African vulnerability and risk maps as well as future projections.
- Integration of meteorological, hydrological and agricultural drought forecasts at Pan-African level into an African drought map server (D6.5). The results produced in WP4 will be integrated in this task to produce Pan–African drought forecasts and integrated with the results from the case studies at different spatial scales.
- Development and implementation of the African drought map server (D6.6). This server will contain all the products created in the previous tasks. Products from different spatial scales, going from continental to regional will be integrated in the map server.

STUDY ON EU/AFRICA PERSPECTIVES

This study will address the comparative review of drought forecasting in European and African river basins. The implementation of the newly proposed methodologies on drought monitoring and early warning systems of selected African river basins will be evaluated, monitoring the increase in performance. A comparative review of these systems will result in guidelines for bilateral improvement of forecasting methods, while emphasizing differences due to regional concerns. The specific objectives of this study are:

- Trends on drought monitoring and early warning systems in Europe. This sub-task will dynamically characterize and resume current and foreseen drought monitoring and early warning systems in European river basins, capitalizing on the information from previous (e.g. MEDROPLAN, AquaStress, Watch, CIRCE, XEROCHORE, MIRAGE) and ongoing (,, CLIMB, WASSERMed) EU projects, as well as the experiences with the European Drought Observatory (EDO). Since drought affects mostly countries from Southern Europe, the work will focus on river basins from those regions, namely the ones with characteristics most similar to the African ones (e.g., from Portugal, Spain and Greece), including some trans-boundary cases.

- Performance of improved drought monitoring and early warning systems in Africa. This subtask will assess the increase in performance of the new proposed methodologies on drought monitoring and early warning systems in African river basins, continental scale, in comparison to the existing systems (D6.7). The analysis will use the output from work packages 2 and 5 and the results from the regional case studies, covering a wide spatial and climatic range of the African continent, also having in attention twinning/proximity to southern European cases.

- Comparison of drought forecasting in Europe and Africa (D6.8). Based on the results of the previous two sub-tasks a comparative assessment of the European and African perspectives of drought monitoring and forecasting will be made.

1.5 SHORT DESCRIPTION OF EACH CASE STUDY NEEDS AND PROBLEMS

EASTERN NILE BASIN

The Nile River is the longest river in the world (6650 km); its basin covers 3,400,000 km2 and encompasses ten countries in east and central Africa. From the socio-economic and political points of view, the Nile Basin can be regarded as one of the most important basins in Africa. Water management in the basin has historically been a controversial issue and cause of tensions between the countries, which often have a sole dependency on the Nile as a water resource.

The aim of this case study is to provide and test all the improved tools for droughts warning and prediction of the effect of climate change on drought risk in the region. The study will focus on the Blue Nile and Atbara River basins. The particular activities in this case study will be:

• Conduct statistical (e.g. based on ENSO) and dynamical seasonal forecasting in the Blue Nile and Atbara Basins (linked to Task 4.1)

• Pilot the methods to produce a seasonal drought warning, combining indicators, thresholds and model outputs from meteorological models and hydrological models (WP 3 and 4). NFC already has hydrological models, and these will be used as a starting point in this case study.

• Pilot the methods to identify the effects of climate change on drought risk using climate projections and vulnerability maps from WP 3.

• Recommend methods for strengthening drought preparedness and improving farming practices in response to drought in the Blue Nile basin.

Challenges:

- Respond to higher drought vulnerability due to growing population

- Account for extreme weather variability
- Address the high system losses
- Account for high upland erosion

LIMPOPO RIVER BASIN

The Limpopo River located in central-southern Africa, is about 1,750 km long and has a drainage basin of 415,000 km2, covering four countries: Botswana, Mozambique, South Africa and Zimbabwe. The basin experiences a short and intense rainy season, with highly unreliable rainfall, which leads to frequent droughts. Poverty is widespread and people are extremely vulnerable to the effects of drought on crop failure. Starvation and malnutrition are common occurrences. About one million people in the basin currently rely on food aid (Love et al., 2006).

The focus in this case study is on the flow of information during drought early warning. Information will be generated by the forecasting system developed in WP 4. This information will flow from the warning system through the institutional framework from regional to local scale. The Limpopo is therefore a pilot for the application of DEWFORA's drought early warning framework. In close collaboration with other stakeholders in the region, improvements in the institutional framework and procedures will be suggested and implemented, building on the technical developments.

The particular activities in this case study will be:

• Implement improvements to existing monitoring and forecasting systems and drought mitigation policies by coupling meteorological, hydrological and agricultural forecasting tools into a water allocation model (WP 4).

• Pilot the drought early warning framework by identification and involvement of the end-users and analyze how the issued warnings flow through the institutional structure. The piloting will reveal potential shortcomings in the institutional structure, which will result in recommendations for improvement.

Challenges:

- Understand better the drought connections with ENSO.
- Understand the high inter-annual and spatial variability of rainfall leading to dry spells that can impact significantly the crops.
- Understand the drought impact on crops (mainly maize) that have consequences for food security, and food aid.
- Understand the drought impact on livestock that have consequences in financial security of the population.
- Understand the drought impact on water supply that has consequences for cities and mines.

OUM ER RBIA RIVER BASIN

The Oum-er-Rbia Basin is a river basin of strategic importance in Morocco. It represents 7% of the total area of Morocco and contains 14% of the population. The basin has diverse economic activities, including irrigated and rain-fed agriculture, mining, and numerous large manufacturing industries. The basin also provides water transfers to large cities, including Casablanca and Marrakech.

The aim of this case study is to further agricultural drought forecasting by means of the newly developed indicators (WP 3) and model techniques (WP 4). First of all the seasonal forecasting of agricultural drought in the basin will be improved to gain lead time for effective drought mitigation. Second, recommendations will be made how to reduce vulnerability through the implementation of better adapted agricultural practices. The case study will be led by IAV and will capitalize on the results from the MEDROPLAN project (MEDA-Water).

The particular activities in this case study will be:

• Test improved agricultural drought indicators (WP 3) and forecasting of agricultural drought (WP 4).

• Transfer drought forecasts to drought warnings according to the framework developed in WP 5.

• Pilot and analyze the effectiveness of adapted agricultural practices on vulnerability

Challenges

- Improve the management of water demand;
- Improve the management and development of water offer
- Preservation and protection of water and land resources
- Reduce drought vulnerability
- Promote exchanges between decision maker and stakeholder
- Tackle the increase of drought frequency from the 80’s onward

NIGER RIVER BASIN

The Niger River is the third longest river in Africa (4180 km) and its basin (2,117,700 km2) encompasses nine countries in West and Central Africa. About 30% of the basin is located in Mali, one of the poorest countries in the world. The main economic activities in Mali are agriculture and fishing. The agricultural sector employs about 80% of the work force, even though less than two percent of the land is arable. For this reason, livelihood and welfare in Mali depends largely on the timely onset and intensity of the annual monsoon. hazard using model outputs from WP 3 and 4.

The aim of this case study is to provide a climate projection for the region to strengthen preparedness to droughts and in this way improve future food security (WP 5, Task 5.3). The implementation of this case study will be closely linked to the WETwin project (FP7) that is active in the region as well.

The particular activities in this case study will be:

- Application of a mesoscale distributed eco-hydrological model combining hydrology and agriculture (and other vegetation types).
- Pilot the drought preparedness by predicting future hydrological and agricultural drought risk through climate projections. The drought risk will be identified using the vulnerability maps and climate predictions of meteorological and hydrological drought hazard using model outputs from WP 3 and 4.

Challenges:

- Tailor the work to the need of the local people;
- Stimulate the willingness of local partners and providers to collaborate
- Communication of uncertainty in any scenario.

2. DESCRIPTION OF THE EASTERN NILE BASIN CASE STUDY

2.1 GEOGRAPHICAL AREA

2.1.1 Blue Nile

The Blue Nile (Figure 2-1) is a river originating at Lake Tana in Ethiopia. The river is one of the two major tributaries of the Nile.

Ninety percent of the water and ninety-six percent of the transported sediment carried by the Nile originates in Ethiopia, with 59% of the water from the Blue Nile (the rest being from the Tekezé, Atbara, Sobat, and small tributaries). The erosion and transportation of silt only occurs during the Ethiopian rainy season in the summer, when rainfall is especially high on the Ethiopian Plateau. For the rest of the year, the great rivers draining Ethiopia into the Nile (Sobat, Blue Nile, Tekezé, and Atbara) have a weaker flow.

The Blue Nile has a total length of 1,450 kilometres, of which 800 km are inside Ethiopia and the rest is inside Sudan. The Blue Nile flows generally south from Lake Tana and then west across Ethiopia and northwest into Sudan.

Figure 2-1 Blue Nile Map [**Source:** http://en.wikipedia.org/wiki/Blue_Nile]

Although there are several feeder streams that flow into Lake Tana, the main source of the river is generally considered to be a small spring at Gish Abbai at an altitude of approximately 2,744 metres. This stream, known as the Lesser Abay, flows north into Lake Tana. Other affluents of this lake include, in clockwise order from Gorgora, the Magech, the Northern Gumara, the Reb, the Southern Gumara and the Kilte. Lake Tana's outflow flows over 30 kilometres before plunging over the Tis Issat Falls.

The river then loops across northwest Ethiopia (Figure 2-2) through a series of deep valleys and canyons into Sudan, beyond this point it is only known as the Blue Nile.

There are numerous tributaries of the Blue Nile between Lake Tana and the Sudanese border. Those on its left bank, in downstream order, include the Wanqa River, the Bashilo River, the Walaqa River, the Wanchet River, the Jamma River, the Muger River, the Guder River, the Agwel River, the Nedi River, the Didessa River and the Dabus River. Those on the right side, also in downstream order, include the Handassa, Tul, Abaya, Sade, Tammi, Cha, Shita, Suha, Muga, Gulla River, Temcha, Bachat, Katlan, Jiba, Chamoga, Weter and the Beles. After flowing past Er-Roseires inside Sudan, and receiving the Dinder on its right bank at Dinder, the Blue Nile joins the White Nile at Khartoum and, as the River Nile, flows through Egypt to the Mediterranean Sea at Alexandria. The Blue Nile is so-called because during flood times the water current is so high, it changes colour to an almost black; and in the local Sudanese language the word for black is also used for blue. (Source: http://countrystudies.us)

Figure 2-2 Map of Ethiopia [**Source: http://countrystudies.us**]

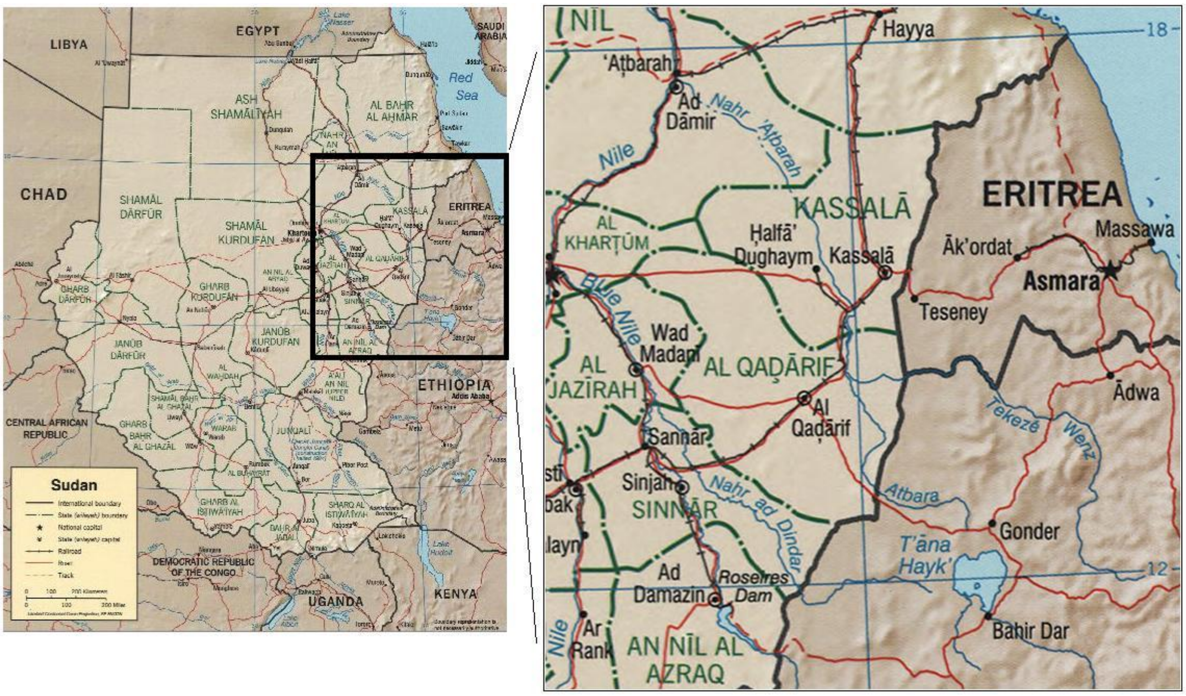


Figure 2-3 Atbara River Map [Source: http://en.wikipedia.org/wiki/Atbara_River]

2.1.2 Atbara River

The Atbara River (Figure 2-3) in northeast Africa rises in northwest Ethiopia, approximately 50 km north of Lake Tana and 30 km west of Gondar. It flows about 805 km to the Nile in north-central Sudan (Figure 2-4), joining it at the city of Atbara. Its tributary, the Tekezé River, is perhaps the true upper course of the Atbara, as the Tekezé follows the longer course prior to the confluence of the two rivers in northeastern Sudan. The Atbara is the last tributary of the Nile before it reaches the Mediterranean.

For much of the year, it is little more than a stream. However during the rainy season (generally June to October), the Atbara rises some 5 m above its normal level. At this time it forms a formidable barrier between the northern and central districts of the Amhara Region of Ethiopia. Besides the Tekezé, important tributaries of the Atbara include the Shinfa River which rises west of Lake Tana, and the Greater Angereb which has its source north of the city of Gondar.

In 1964, the river was dammed at Khashm El Girba near Kassala in Sudan to provide irrigation up to the newly built town of Halfa Dughaym.(Source: http://en.wikipedia.org/wiki/Atbara_River)

Figure 2-4 Map of Sudan [**Source: http://countrystudies.us**]

2.2 CLIMATE

To understand the climate conditions of the area of the Blue Nile basin we have to consider that this area is located in the tropical zone and is affected by the criteria of this area. The geography of the Ethiopian plateau affects the temperature and also the rain. In the next sections these characteristics affecting the Blue Nile basin as well as the whole of Nile basin area, will be explained.

Blue Nile Basin Climatology

Diverse rainfall and temperature patterns are largely the result of Ethiopia's location in Africa's tropical zone and the country's varied topography. Altitude-induced climatic conditions form the basis for three environmental zones: cool, temperate, and hot.

The cool zone consists of the central parts of the western and eastern sections of the north-western plateau and a small area around Harer. The terrain in these areas is generally above 2,400 meters in elevation; average daily highs range from near freezing to 16°C, with March, April, and May the warmest months. Throughout the year, the midday warmth diminishes quickly by afternoon, and nights are usually cold. During most months, light frost often forms at night and snow occurs at the highest elevations.

Lower areas of the plateau, between 1,500 and 2,400 meters in elevation, constitute the temperate zone. Daily highs there range from 16°C to 30°C.

The hot zone consists of areas where the elevation is lower than 1,500 meters. This area encompasses the Denakil Depression, the Eritrean lowlands, the eastern Ogaden, the deep tropical valleys of the Blue Nile and Tekezé rivers, and the peripheral areas along the Sudanese and Kenyan borders. Daytime conditions are torrid, and daily temperatures vary more widely here than in the other two regions. Although the hot zone's average annual daytime temperature is about 27°C, midyear readings in the arid and semiarid areas along the Red Sea coast often soar to 50°C and to more than 40°C in the arid Ogaden. Humidity is usually high in the tropical valleys and along the seacoast.

Variations in precipitation throughout the country are the result of differences in elevation and seasonal changes in the atmospheric pressure systems that control the prevailing winds. Because of these factors, several regions receive rainfall throughout most of the year, but in other areas precipitation is seasonal. In the more arid lowlands, rainfall is always meagre.

In January the high pressure system that produces monsoons in Asia crosses the Red Sea. Although these northeast trade winds bring rain to the coastal plains and the eastern escarpment in Eritrea, they are essentially cool and dry and provide little moisture to the country's interior. Their effect on the coastal region, however, is to create a Mediterranean-like climate. Winds that originate over the Atlantic Ocean and blow across Equatorial Africa have a marked seasonal effect on much of Ethiopia. The resulting weather pattern provides the highlands with most of its rainfall during a period that generally lasts from mid-June to mid-September.

The main rainy season is usually preceded in April and May by converging northeast and southeast winds that produce a brief period of light rains, known as balg. These rains are followed by a short period of hot dry weather, and toward the middle of June violent thunderstorms occur almost daily. In the southwest, precipitation is more evenly distributed and also more abundant. The relative humidity and rainfall decrease generally from south to north and also in the eastern lowlands. Annual precipitation is heaviest in the southwest, scant in the Great Rift Valley and the Ogaden, and negligible in the Denakil Depression.

The Climate of Tropical Africa

In tropical region (roughly 15° S to 15º N) the atmospheric circulation is driven partly by intense convective activity near the equator. This region characterized by general upward motion and relatively low surface pressure is called the equatorial trough or the Intertropical Convergence Zone (ITCZ). This rising air forms a central common branch of two meridional circulations, one in each hemisphere, known as “Hadley Cells”. The Earth’s rotation causes this upper-troposphere meridional flow originating above the ITCZ to gain westerly momentum as it moves poleward. By 30°-40° latitude, the flow becomes basically west-east, at an altitude of about 12km. This flow is concentrated in a strong meandering air currents called the *Subtropical Jet Stream*. Subsiding air in these regions forms two belts of high pressure at around 30° S and N.

The ITCZ is equivalent to a “meteorological equator”, about which the atmospheric circulation system is roughly symmetrical. However, because of land-sea asymmetries between the hemispheres and because of the more consistent and generally stronger westerly flow in southern mid latitudes, the ITCZ tends to lie, on average, a little north of the geographical equator (varying between about 5°S in the Northern Hemisphere winter to about 15°N in the Northern Hemisphere summer) (farmer, G. and Wigley, T.M.L., 1985).

The ITCZ moves north-south with the seasons, following the Sun. Because the effective heat capacity of the land is less than that of the upper layer of the ocean, the land can warm and cool more rapidly. This results in the amplitude of the seasonal north-south movement of the ITCZ being significantly greater over the landmasses than over the oceans. This differential land-sea heating is also one of the main causes of the monsoons, which are largely driven by land-sea temperature contrasts, and the seasonal movement of the ITCZ is closely linked with the seasonal monsoon cycle. The north-south movement of the ITCZ is the most important feature of the tropical climate system since it largely controls the spatial and seasonal distributions of rainfall (farmer, G. and Wigley, T.M.L., 1985).

The Annual Progression of the ITCZ

The ITCZ is bounded by northeasterly and southeasterly trade winds. However, the surface flows on either side of the ITCZ are far from being universally easterly as is clearly shown in Figure 2-5. When the ITCZ is in the Northern Hemisphere, the earth’s rotation tends to curve the southeasterly flow to the east as it crosses the equator, producing, on the southern side of the ITCZ, surface winds that are generally southwesterly. Thus, as the ITCZ moves northward over Africa, in the Northern Hemisphere summer, it is followed by southwesterly monsoon winds.

The monsoon regions are, in very simple terms, the result of seasonally varying land-sea air temperature contrasts. They tend to be located near and associated with semi-permanent areas of particularly intense convective activity. Such a region migrating from 5°S to 15°N and south of the equator with the seasons following the sun. It is readily apparent on satellite imagery, and can be identified on rainfall maps as a region of maximum precipitation. Other such intense convection regions exist in Indonesia north of Australia and over or near to equatorial South America.

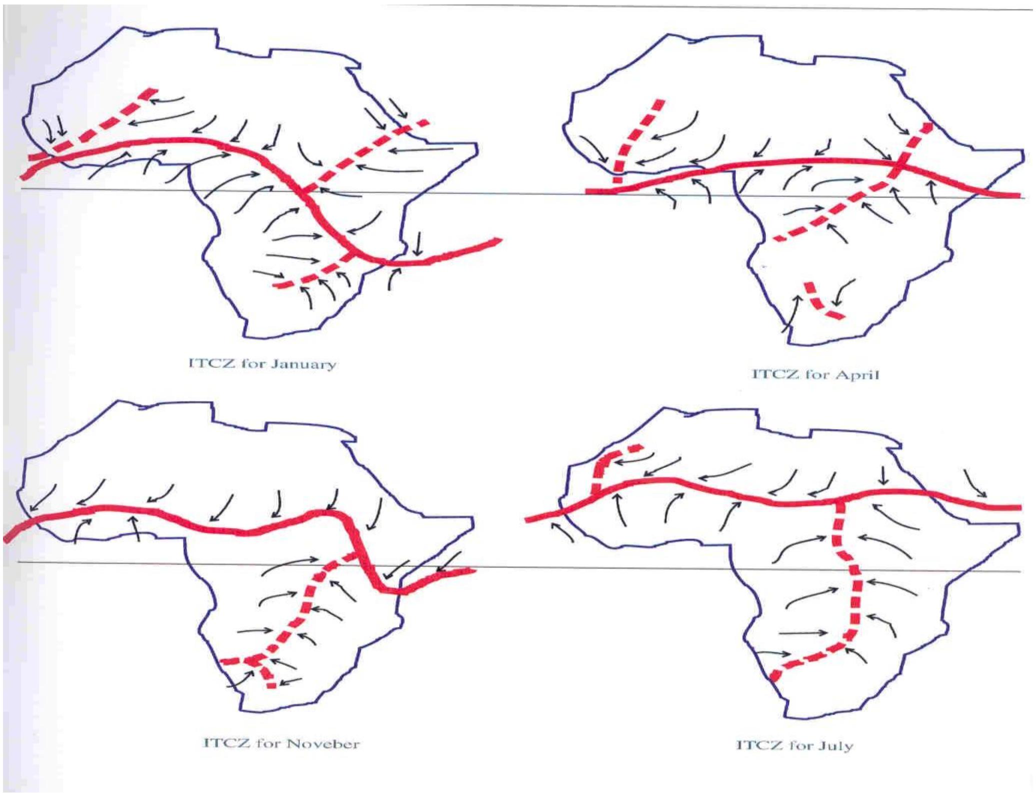


Figure 2-5 Annual progression of ITCZ and surface winds over Africa [Source: Dhonnoeur, 1974]

Tropical African Precipitation

The movements of the ITCZ largely control tropical African Precipitation. Although light rain may fall from cumulus cloud, heavy rain is restricted to the ITCZ region. Rainfall tends to be randomly distributed and spatially discontinuous with strong diurnal variations due to the daily insolation cycle. Intense convective activity may be limited to 1-10% of the total convergence area. However, although rainfall patterns may be strongly heterogeneous, the underlying differences in pressure and temperature gradients between dry and rainy zones may be very small. This makes weather analysis and forecasting in tropical regions extremely difficult.

Rainfall of the Nile River Basin

Since the Nile extents over 36 degrees of latitude the climate of the Nile basin is extremely variable. The average annual rainfall over the basin is seen to differ considerably from upstream to downstream, see Figure 2-6

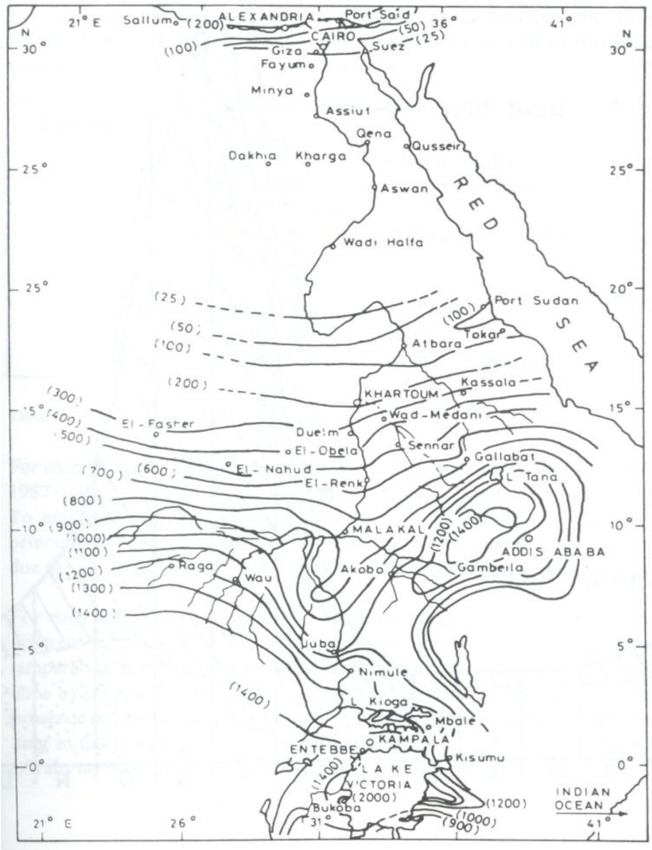


Figure 2-6 Isohyetal map of annual rainfall in the Nile basin

Rainfall pattern shows large spatial and temporal variability. The result of temporal variability is that no single time period is really representative of the long-term rainfall climate because of the strength of the long-term variations. Moreover, long-term mean values need not be representative of the climate of shorter periods. There is also marked and spatially variable seasonally in East African rainfall.

Near the equator, the seasonal distribution is basically bi-modal, having two peaks. The higher one during the spring in March and April, and lower one in autumn in November and December and becoming more uni-modal (with summer rains) as distance from the equator increases. This pattern is linked to the movement of the ITCZ, but there are regional deviations from the general pattern. For example, regional topography and the large lakes of East Africa have significant secondary influences on the seasonal cycle of rainfall.

Considering the Nile River Basin area, which extends from 4° S to 31° N, it is characterized by a belt of rainfall extending across the tropical portion of Africa with an annual oscillation northwards and southwards following the sun. Due to his effect, over most of the Equatorial Lake Plateau Basin, rain may fall at any time of the year. Meanwhile, over the southern half of Lake Victoria Basin the principal maximum of rainfall is in April and the principal minimum in August, while the secondary minimum in January.

At the north of this region, the January minimum extends and the maximum of the latter half of the year increases relatively until finally in the Sudan plains and Ethiopian Plateau the rainfall has a single maximum. Climate is definitely of the wet and dry season type. In Ethiopian plateau, November, December and January are dry but there is some rain from February onwards. The rains of February to May cause the early flushes on the Blue Nile and seem to be distinct in origin from the later rains, which cause the Nile flood.

2.3 HYDROLOGY

Blue Nile

The Blue Nile River basin covers the eastern Nile countries (Ethiopia and Sudan).The Blue Nile and its tributaries all raise on the Ethiopian Plateau at elevations of 2,000 to 3,000m a.m.s.l. The average level is 2,400 m with peaks up to 4,200 m. The Gigel Abay, the main tributary to Lake Tana, is generally considered the source of the Blue Nile. Lake Tana is a flat bottomed and relatively shallow lake formed by geologically recent volcanic activity. On 1997, the Chara Chara weir had been put in operation at the outlet of Lake Tana and since that the lake levels are controlled between 1784 and 1787 m a.m.s.l. Downstream Lake Tana, the river has cut a deep gorge through the Ethiopian Plateau, with numerous rock-outcrops in the riverbed. It enters The Sudan at Diem some 735 km upstream of its confluence with the White Nile at Khartoum. Between Lake Tana and Diem, the river flow is augmented by contributions from a number of tributaries including Beshile, Welaka, Jemma, Muger, Guder, Finchaa, Didessa, Dabus and Beles. The slope of the river changes drastically upon entering Sudan from 1.6 m/km to 0.15 m/km. In Sudan the Blue Nile is joined by the Dinder and Rahad rivers, which are seasonal streams, reduced to pools in the dry season.

The Blue Nile, including Rahad and Dinder has a basin area of 337,362 km^2, of which the greater part is located in Ethiopia. Table 2-1 shows the areas of the sub-basins of the Blue Nile. The river contribution over the last century around 57% of the total Nile flow at Aswan. Its contribution, however, has a strong seasonal variation, as shown in Figure 2-7.

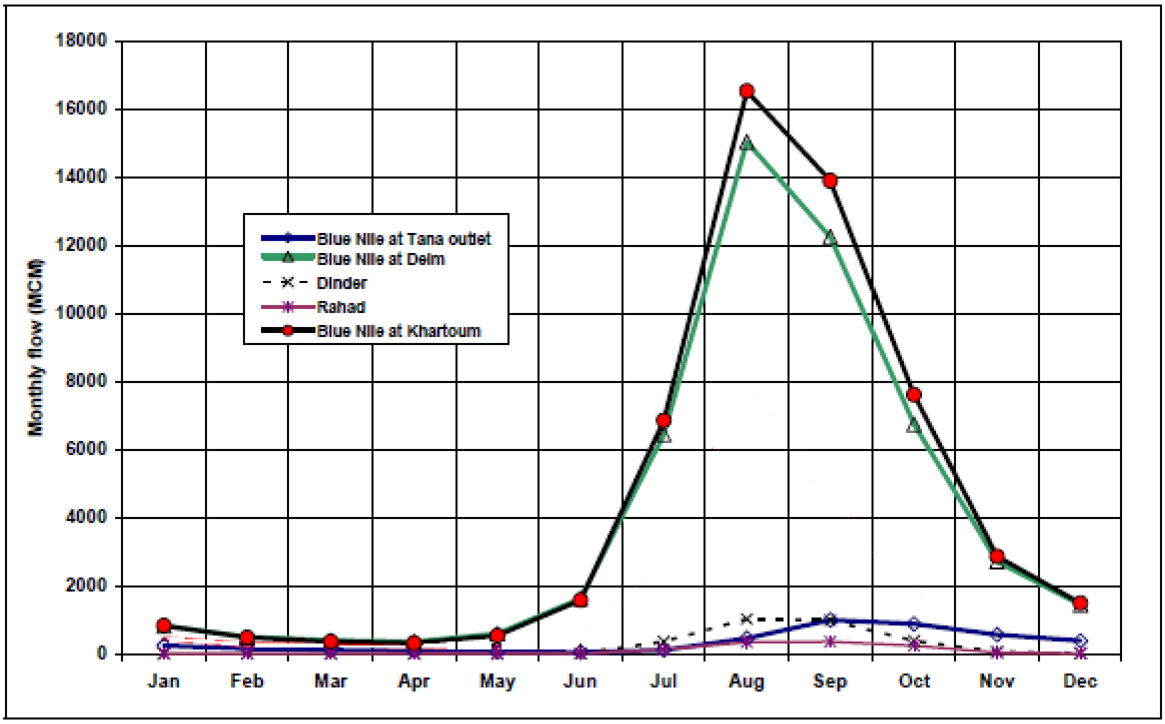


Figure 2-7 Mean natural hydrographs of the Blue Nile at Lake Tana outlet, Diem and Khartoum and for Dinder and Rahad at their mouths [Source: LNFDC/ICC Project Report, Volume I]

The inter-annual variation of the Blue Nile flow is presented in Figure 2-8. The persistent dry period of the seventies and eighties of the last century is an obvious feature. Reductions due to irrigation abstractions in the Sudan are clearly visible from the records of natural and actual flows. Flooding at Khartoum occur from Blue Nile flows and have been experienced without attenuation by major lake storage and wetland spilling as occurs for the White Nile flows.

Table 2-1 Areas of the Blue Nile sub-basins [Source: LNFDC/ICC Project report, Volume VIII]

Name		Area (km2)	
		Partial	Total
Blue Nile	Lake Tana + basin	15,320	176,623
	Tana-Karadobi	66,901	
	Finchaa dam	881	
	Karadobi-Mabil	14,289	
	Mabil-Medaia	42,639	
	Medaia-Border dam	35,384	
	Border dam-Deim	1,209	
	Deim-Roseires	18,388	337,362
	Roseires-Sennar	10,072	
	Dinder and Rahad	99,375	
	Sennar-Khartoum	32,904	

As the flows in the Blue Nile show strong seasonality, reservoirs have been built at Roseires and Sennar. The Sennar dam was completed in 1925 for the irrigation of the Gezira scheme; in the 1960s a hydropower station was added (15 MW installed capacity). The Roseires dam and reservoir, some 266 km upstream of Sennar, was put in operation in 1966 to be operated in conjunction with Sennar to satisfy irrigation requirements and to increase hydropower production (212 MW). The annual water requirement from the schemes drawing from the Blue Nile amounts to 11.4 Bm^3 per annum.

Due to its geography and strong seasonal fluctuations the Blue Nile carries significant amount of sediment. The storage in the Roseires and Sennar reservoirs is fairly limited (actual about 2.2 and 0.4 B m^3 respectively) and it is vital to minimise the sedimentation.

The live storages of both reservoirs have been reduced considerably due to siltation. Estimates of the sediment load are as high as 140 million tonnes/year at Diem. The strategy to minimize the sedimentation is to pass the flood peak and fill the reservoirs when the flow at Diem drops below 350 Mm^3/day on the falling limb of the hydrograph peak (during September). Emptying of the reservoirs takes place in the period November to April/May.

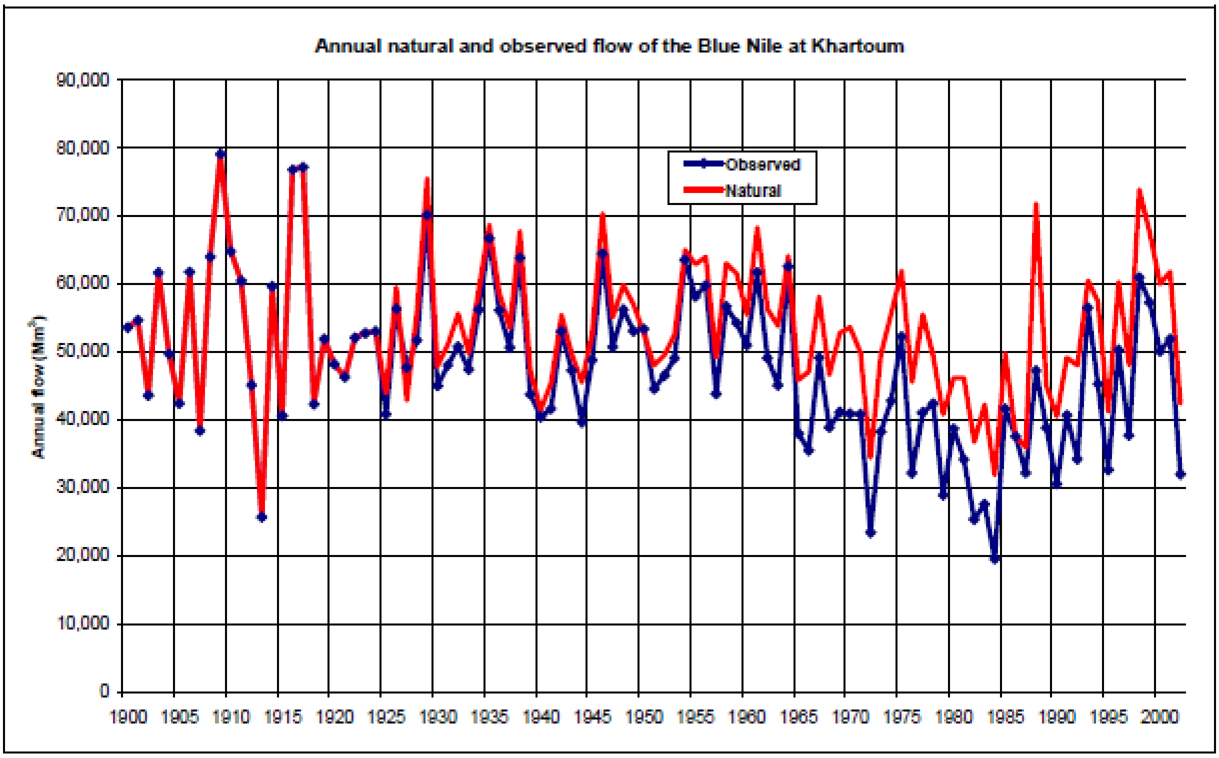


Figure 2-8 Annual natural and observed flow series of the Blue Nile at Khartoum, Period 1900-2002 [Source: LNFDC/ICC Project report, Volume I]

Atbara

The River Atbara, which is the last tributary of the Nile, joins the Main Nile at about 320 km downstream of Khartoum, approximately 880 km long. Its catchment area amounts to 112,400 km^2, the greater part of which is in Ethiopia, and it has an average annual flow of about 16 Bm^3 (see Figure 2-9). The main tributary of the Atbara is the Setit river (in Ethiopia called the Tekeyze), with a catchment area of 69,000 km^2. Over its first 300 km, the slope of the Atbara is very steep, some 5 m/km. Below the Setit junction the river runs over a distance of about 500 km at a slope of 0.25 m/km. Table 2-2 shows the areas of the sub-basins of Atbara.

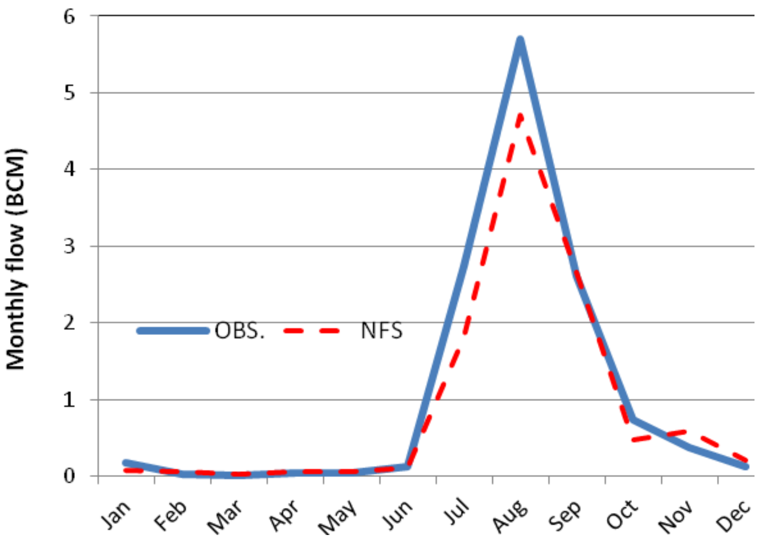


Figure 2-9 Mean natural hydrographs at Atbara River outlet,[Source: LNFDC/ICC Project Report, Volume I]

The flow in Atbara River show greater seasonality behaviour than the Blue Nile. The steep slope in its upper reaches is responsible for the excessive sediment load of the Atbara in proportion to its flow volume. At Khashm el Girba, about 440 km upstream of the Atbara mouth, a dam has been constructed with storage capacity of 1.3 billion m^3 at a peak water level of 473 m above sea level, to supply water to the irrigation canals in the New Halfa scheme and to generate hydropower. The irrigation water requirement is about 1.4 Bm^3 per annum. As a result of the large sediment load, the initial capacity of the reservoir reduced drastically from 1.3 Bm^3 to 0.6 Bm^3 in less than 30 years.

Table 2-2 Areas of Atbara sub-basins [Source: LNFDC/ICC Project report, Volume VIII]

Name		Area (km^2)	
		Partial	Total
Atbara	Setit u/s Humera	65,591	170,289
	Humera-mouth	2,747	
	Atbara u/s Metema	4,806	
	Metema-Khashm el Girba	27,749	
	Khashm el Girba-K3	69,073	
	K3-mouth Atbara	324	

2.4 GEOLOGY

The northwestern Ethiopian Plateau, with a mean elevation of 2500 m, is located on the western flank of the tectonically active Main Ethiopian Rift and the Afar Depression. The plateau was uplifted due to the combined effects of the rising Afar mantle plume and flank uplift of the Main Ethiopian Rift and the Afar Depression (Collet et al., 1999; S¸engör, 2001; Davis and Slack, 2002; Beyene and Abdelsalam, 2005). A tectono-chronostratigraphic calculation led S¸engör (2001) to conclude that the ~1000 km diameter Afar dome began to rise in the middle Eocene, reaching an elevation of about 1000 m by the early Oligocene. Extensive basaltic flows (500–2000 m thick) were erupted over a short, 1 million years, interval ca. 30 Ma (40Ar/39Ar age dating and magnetostratigraphy of Hofmann et al., 1997). This eruption, covering an area greater than 500,000 km^2, is inferred to mark the appearance of the Afar mantle plume (Mohr and Zanettin, 1988; Hofmann et al., 1997; Kieffer et al., 2004). Plume-related uplift caused deep-seated faults within the Ethiopian lithosphere, leading to the collapse that formed the Afar Depression ca. 24 Ma (Capaldi et al., 1987; Beyene and Abdelsalam, 2005). This event was followed by shield-volcano–building episodes, which gave rise to the development of Choke and Guguftu volcanoes in the northwestern Ethiopian Plateau ca. 22 Ma (40Ar/39Ar ages of Kieffer et al., 2004). After the initiation of rifting, the Danakil block started to separate from the Nubian Plate ca. 20 Ma (Manighetti et al., 2001; Beyene and Abdelsalam, 2005). Based on geochronology (Ar/Ar), Wolfenden et al. (2004) suggested that the northern Main Ethiopian Rift, which dissected the Ethiopian Plateau (Figure 2-10) into northwest and southeast sections, developed ca. 11 Ma. Meanwhile, the Guna shield volcano formed at 10.7 Ma (Ar/Ar ages of Kieffer et al., 2004). WoldeGabriel et al. (1990), based on stratigraphic relationships and geochronological (K/Ar) studies, proposed that the western boundary fault of the Main Ethiopian Rift initiated by at least 8.3 Ma. However, in a recent structural, petrological, and geochronological (K/Ar) study, Bonini et al. (2005) concluded that extension forming the Main Ethiopian Rift started between 6 and 5 Ma. Lake Tana appeared ca. 8 Ma, marked by the deposition of lignitiferous sediments (Chorowicz et al., 1998). (GSA Today, September 2007)

Figure 2-10 Gorge of the Nile where the Blue Nile deeply dissected the Mesozoic sedimentary rocks

Figure 2-11 Relatively young incision of the Blue Nile through Quaternary basalts close to its source at Lake Tana.

Mesozoic

In the Blue Nile (also called Abbai) basin Mesozoic strata show a completely developed succession, they are successively revealed where the upper Blue Nile has cut southwards more deeply beneath the overlying Trap lavas.

Thicknesses of the strata in the Blue Nile region are as follows:

Adigrat Sandstone 550 meters, Antola Limestone 500 to 570 meters, Upper Sandstone 200 meters, and Tertiary basalts less than 500 meters.

The Adigrat Sandstone consists of white, massive quartzose sandstone. Quartz invariably greatly predominates over feldspar in the clastic grains; these grains are usually angular, rarely subrounded.

The Antalo Limestone comprises many lithological types of limestone, such as the crystalline, compact and dolomitic ones. The Uppsr Sandstone is characterized by a lithology similar to that of the Adigrat Sand stone.

Although the Mesozoic rocks thus reach a considerable thickness in the Blue Nile basin, they are exposed and subject to denudation in a relatively small area only, because their outcrops are confined to the river canyon. The precise relationships of the Nubian Sandstone in eastern Sudan with the Mesozoic succession in northern and northwestern Ethiopia remain to be elucidated (Mohr, 1963).

Tertiary

The term 'Continental Terminal' is applied to the Tertiary continental deposits (Furon and Lombard, 1964).

Extruding from fissures and centres, these lavas covered the greater part of the Mesozoic rocks in Ethiopia and their flow extended onto Basement Complex rocks in the peripheral regions, as in east Sudan on the Gedaref ridge (the divide between Atbara and Blue Nile). The Trap Series chiefly consists of flood basalts (traps), but with trachytes and rhyolites occurring more especially near the top of the series, and caps the Ethiopian Plateaux except where overlain by rare patches of evidently recent lavas (Mohr, 1963).

The Trap Series has been divided by Mohr (1965) into three major units:

(1) The Shield Group, composed of basalts, alkaline silicics and under-saturated lavas, dated as late Miocene-early Pliocene, generally conformable on

(2) The Magdala Group, fissure and central-type basalts, with silicic lavas and pyroclasts becoming more abundant near the top, dated as Oligocène and early Miocene, unconformable on

(3) The Ashangi Group, fissure basalts with localized silicic lavas in N.E. Ethiopia, dated as Eocene.

The Trap lavas thicken away from some 220 m in the Abbai gorge, to an average 1000 m rising to a maximum of over 3000 m toward the west in Gojjam in west Ethiopia. Here also the more recent silicic lavas occur, including trachyte (alkali feldspar and green augite) and flow-banded or brecciated, glassy or cryptocrystalline rhyolite.

Directly south of Lake Tana large areas of the Plateau are covered by recent basalts (see Figure 2-11). According to Andrew (1948) the Ethiopian lavas extended farther north and west into the Sudan than does the present continuous outcrop. In central Sudan there are scattered occurrences of volcanicity: basaltic rocks west of Khartoum and west of Atbara. One effect of this volcanicity has been preservation by burial of the Hudi Chert. (Source: Soils of central Sudan (J. Buursink)).

2.5 SOILS

The soils of the Blue Nile water shed are the result of the decomposition of tertiary volcanic rocks such as rhyolites, trachites, rhyolitic and trachitic tuffs and basalts. The red colour of the soil in the undulating portions of the Ethiopian plateau is a highly characteristic feature of the landscape & the origin of the masses of red clay is only betrayed by the occasional presence of kernels of the undecomposed rock. The most important soils in terms of extent and quality are andosols encompassing 60% of the watershed and found mainly in the upper portion of the watershed. Regosols cover 32% and dominant the lower portion of the catchment. Cambisols (1%) and gleysols and fluvisols (1 %) are minor soil types found in the watershed (Bono and Seiler, 1984b).

Soil depth is apparently related to soil type and varies from 10 - 150 cm. Andosols, fluvisols and cambisols are generally deeper, while regosols and lithosols are shallow (Bono and Seiler 1984a). Regosols are intensively cultivated during the main rainy season on the lower portion of the watershed compared to the upper part where fallow periods of five to eight years are practiced (Bono and Seiler, 1984b; Grunder and Zeleke, 1989)

Two samples of soil gave the following mechanical analysis (Table 2-3)

Table 2-3 Results of two soil samples analysis

	Sample 1.	Sample 2.
Stones & gravel	0.4	0.8
Coarse sand	11.9	10.4
Fine sand	24.9	8.5
Silt	31.8	44.0
Clay	31.8	36.3

(Source: The Nile Basin volume IX, 1959)

2.6 LAND COVER/LAND USE

In the far north of the Blue Nile basin area, between the 75 mm and about the 250 mm isohyets “Semi-desert Scrub” is the most prevalent vegetation type, comprising a varying mixture of grass and herbs, with a variable scattering of shrubs up to 4 m high, interspersed with bare earth. Grass is mainly an annual plant in Sudan. Heavy grazing and low rainfall ensures that there is insufficient dry matter for annual fires. In years of low rainfall and heavy grazing there can be an almost complete failure of annual plant growth.

South-eastwards of the basin, from the 250 mm to the 360 mm isohyets, the vegetation type becomes “Semidesert Grassland”. Much of this vegetation is now covered by the Gezira and Managil irrigation schemes. On the heavy alkaline clay soils the natural vegetation is grassland without trees or shrubs. Between the 360 and 570 mm isohyets on the heavy clays grassland merges into A. mellifera thornland. Above 570 mm to the border with Ethiopia there is increasing dominance of A. seyal in association with Balanites aegyptiaca. A. senega is retained for gum arabic harvesting whilst A. seyal is used for charcoal production. B. aegyptiaca becomes increasingly prevalent because it is fire resistant.

Woodlands and shrublands cover some 28% and grasslands 25% of the basin. Sedentary rainfed cropping covers nearly 26% of the area mainly located in the Ethiopian Highlands. Semi-mechanized farms cover 10% and the irrigated schemes 2.6% of the basin. Much of the major Gezira and all of Managil schemes, although irrigated with water from the Blue Nile, lie in the White Nile Basin. Table 2-4 presents the land cover of the Blue Nile.

Table 2-4 Dominant land cover in the Blue Nile Basin (Source: Hydrosult Inc et al. 2006b)

Land cover type	Area (ha)	Total (%)
Rainfed crops: sedentary	8,037,337	25.8
Grassland	7,777,274	25.0
Woodland	5,225,555	16.8
Shrubland	3,671,919	11.8
Semi-mechanized farms	3,123,087	10.0
Irrigated crops	815,480	2.6
Rock	732,392	2.4
High forest	429,777	1.4
Water	420,103	1.3
Rainfed crops: shifting	340,930	1.1
Plantation	211,977	0.7
Sand	128,804	0.4
Seasonal swamp	94,518	0.3

Land cover type	Area (ha)	Total (%)
Permanent swamp	51,831	0.2
Urban	65,136	0.2
Afro-alpine	28,680	0.1
Sub-basin	31,154,800	

2.7 DEMOGRAPHY

The demographics of the Blue Nile and Atbara Region divided into two regions the first region located in Ethiopia, and the second region located in Sudan in two states; the Blue Nile State and Sennar State.

Blue Nile at Ethiopia

80% of the country's population inhabits only 37% of the total land area, mostly in the highlands. Table 2-5 shows the population of 2008 in the main Ethiopian cities. The factors responsible for this include climate, soil and history. First of all the altitude plays a major role in population distribution so about 10% of the population lives at an altitude of over 2,600 meters above sea level, 39.2% lives between 2,200 meters and 2,600 meters above sea level, 28% between 1,800 meters and 2,200 meters above sea level, and the lowlands are very sparsely populated mainly because of malaria and other vector borne diseases as the insects are more existing in the lowlands. There has been an ongoing resettlement of highland populations in the lower elevations of western and south-western Ethiopia to provide better services and to start developing new areas of the land.

Table 2-5 population of the main regions in Ethiopia- 2008

Population size of the Blue Nile & Atbara Regions (July 2008)

Tigray 4,565,000 **Amhara** 20,136,000

Oromiya 28,067,000 **Addis Ababa** 3,147,000

Benishang G. 656,000

Oromiya has the largest population size, and Amhara is second. For the primarily urban regions, Addis Ababa has the largest population (4% of the country's total).

Ethiopia has a very young age structure with more than two in five (40 %) of its citizens below age 15 (Table 2-6) which points to a huge growth potential down the road, or even an explosive growth if unchecked, due to the built-in momentum. The momentum is evidenced by the very high percentages of women in the various reproductive age groups, or soon to be in the reproductive age groups. Less than three percent of the population is in the 65+ age category reflecting the very young age structure as well as high fertility and mortality in the past, which now is keeping the age pyramid very wide at the bottom and tapering quickly toward higher ages.

Table 2-6 population age distribution- 2008

Age Distribution (2008)			
Age	**% of tot. population**	**Age**	**% of tot. population**
0-4	15.9	35-39	5.4
5-9	14.4	40-44	4.3
10-14	12.4	45-49	3.4
15-19	10.3	50-55	2.8
20-24	*9.4*	*55-59*	*2.2*
25-29	8.1	60-64	1.7
30-34	6.7	65+	2.8
Percent below Age 15 = 42.7			

Blue Nile at Sudan

Blue Nile State is one of the 15 states of Sudan. It was established by Presidential Decree Nº3 in 1992 and is named after the Blue Nile River. It has an area of 45,844 km². The Central Bureau of Statistics quoted the population at 832,112 in the 2006 Census. Ad-Damazin is the capital of the state. Blue Nile State is home to the Roseires Dam, the main source of hydroelectric power in Sudan before the completion of the Merowe Dam in 2010. The region is host to around forty different ethnic groups. Its economic activity is based upon agriculture and livestock and increasing mineral exploitation.

Sennar is one of the 15 states of Sudan. It has an area of 37,844 km² and an estimated population of approximately 1,100,000 inhabitants (2000). Sinja is the capital of Sennar State. Another significant town is Sennar, largest city in the state. The main economic activity is agriculture with the irrigated scheme of Suki, the Sugar factory of Sennar and a number of fruit growers (including bananas and mangos) located on the banks of the Blue Nile.

2.8 INFRASTRUCTURES

2.8.1 Blue Nile

To describe the hydraulic infrastructure a distinction is made between Lake Tana and its feeder rivers, & Blue Nile with tributaries downstream of Lake Tana.

Lake Tana Basin

Lake Tana is fed by the following rivers:

1) Gigel Abay in the south.
2) Megech in the north.
3) Rib in the west.
4) Gumara in the south west.

In 1997 the Chara Chara weir at the outlet of Lake Tana was put in operation. The weir controls a volume of 9.1 BCM in the lake, which is equivalent to almost two and half times of the average annual outflow of the lake, between the levels 1784 and 1787 m + MSL.

Blue Nile tributaries downstream Lake Tana

Downstream of Lake Tana the following tributaries discharge to the Blue Nile (Figure 2-12):

1) Small streams discharging to the right bank of the Blue Nile, south-west of Lake Tana in the Debre Markos sub-basin (area = 28,040 km2).
2) Beshile River (area = 15,680 km2), entering the Blue Nile from the left.
3) Welaka River (area = 8,320 km2), entering the Blue Nile further downstream of Beshilo from the left.
4) Jemma River (area = 15,720 km2) entering the Blue Nile from the left south of Welaka.
5) Muger River (area = 7,640 km2), draining a basin just north of Addis Ababa and enters the Blue Nile from the left.
6) Guder River (area = 7,480 km2), a left bank tributary draining an area north-west of Addis Ababa. Just downstream of its mouth the Karadobi Dam is proposed.
7) Finchaa River (area = 4,720 km2), a left bank tributary and draining an area in the south central portion of the Blue Nile, about 150 km northwest of Addis Ababa. The upper part comprises the Chomen Swamp.
8) Diddessa River (area = 32,440 km2), a left bank tributary; the Didessa is the largest tributary of the Blue Nile in Ethiopia and it delivers about 25% of the flow at Deim. Major tributaries are:
    - Wama River, entering from the east.
    - Dabana River entering from the west.
    - Angar River entering from the east.
9) Dabus River (area = 27,480 km2); the Dabus River drains about 14,400 km^2 mountainous areas in the southern part of the basin, then crosses the Dabus swamps and continues northward to enter the Blue Nile from the left.

10) Beles River (area = 19,960 km2): the river basin is located south-west of Lake Tana and has a large area of land suitable for irrigation but limited water resources.
11) Dinder River is a right bank tributary draining between Sennar dam and Wad Medani. The Galegu River is a tributary of Dinder entering the river in Sudan.
12) Rahad River is a right bank tributary of the Blue Nile, which joins in Sudan downstream of Wad Medani.

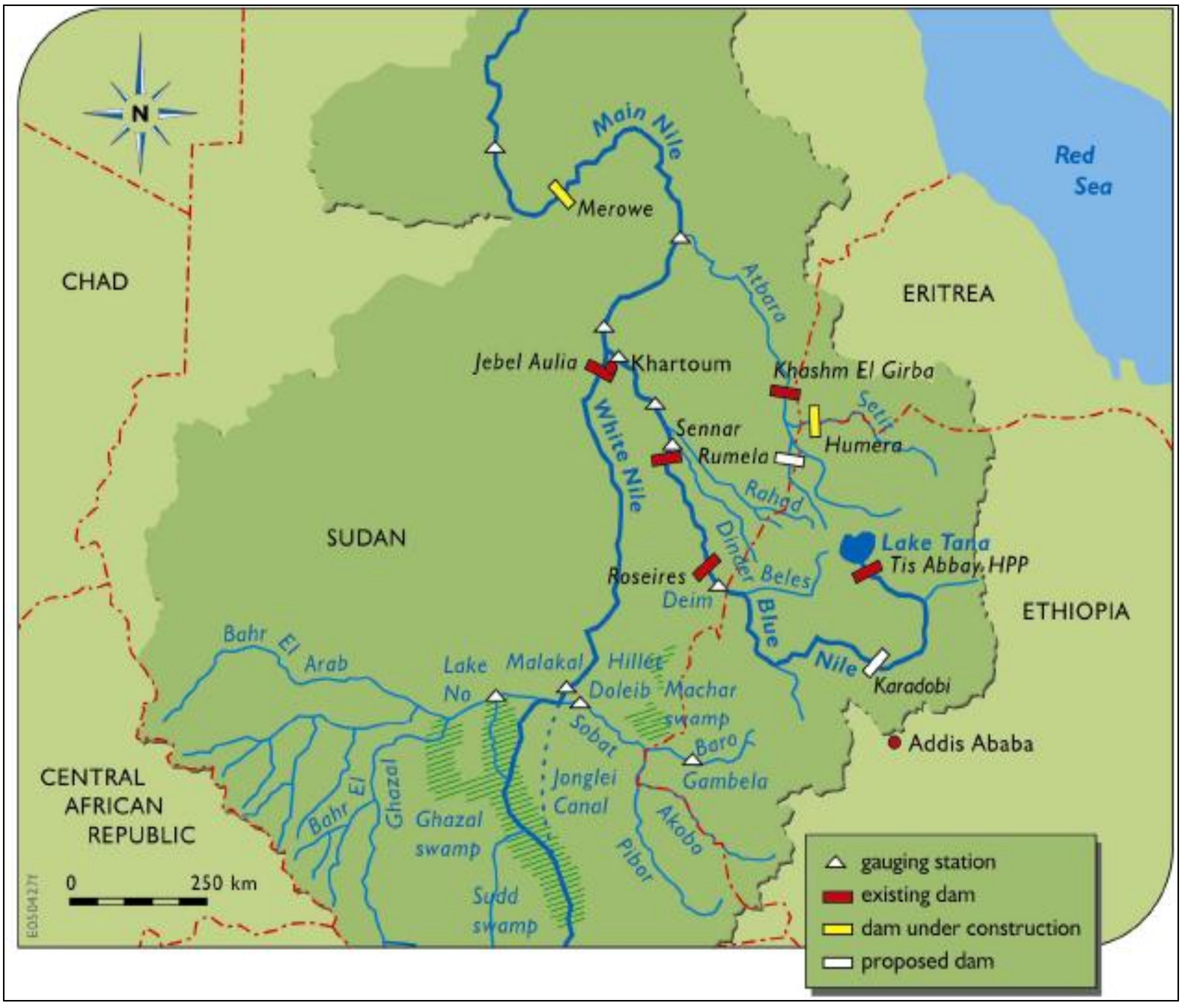


Figure 2-12 Nile basin from the Sudd to Dongola

On the Blue Nile the Roseires (1966) and Sennar (1924) reservoirs supply water for irrigation and for the generation of hydropower. Their storage capacity at present is less than 3 Bm3. Their main fillings take place in September and October as soon as the river flow at Deim has dropped to 350 Mm3/day. Their emptying starts in November till April-May. To increase the capacity of Roseires reservoir to allow development of new irrigation schemes the maximum level of the dam has been raised on 2010.

Major gauging stations on the Blue Nile and tributaries are:

-Bahir Dar at the outlet at Lake Tana, Kessie, Guder DS, Shogole and at the Sudan-Ethiopian Border in Ethiopia.

-Deim, Roseires/Wad el Aies, Sennar DS, and Soba/Khartoum in the Sudan.

-Gwasi and Hawata on Dinder and Rahad in Sudan.

2.8.2 Atbara

The El Girba Dam on the Atbara River (design capacity 1.3 km3, present capacity 0.6 km3) is for flood control, irrigation of New Halfa Scheme for the benefit of the people displaced by the High Aswan Dam, and hydropower.
(http://www.fao.org/nr/water/aquastat/countries/sudan/index.stm)
The Tekezé River is a major tributary of Atbara River, and forms a section the westernmost border of Ethiopia and Eritrea for part of its course. The river is also known as the Setit in Eritrea, western Ethiopia, and eastern Sudan. According to materials published by the Ethiopian Central Statistical Agency, the Tekezé River is 608 km long.http://en.wikipedia.org/wiki/Tekez%C3%A9_River - cite_note-1 The canyon which it has created is the deepest in Africa and one of the deepest in the world, at some points having a depth of over 2000 meters
Tekezé Dam is a double-curvature arch dam in the Tigray region of northern Ethiopia on theTekezé River, a Nile tributary that flows through one of the deepest canyons in the world. At the time of completion, the 188 metres high dam is said to be Africa's largest arch dam. The dam consists of four turbines, generating 300 MW of electricity together. The dam helped to reduce power shortages as Ethiopia's power demand continues to increase.
The Tekeze hydroelectric in Ethiopia was first proposed seven years ago and was scheduled to be completed in 2008; the end cost of the dam was $360 million which was $136 million over budget.

2.9 REGIONAL WATER RESOURSES USE

2.9.1 Ethiopia

Though the country possesses a substantial amount of water resources little has been developed for drinking water supply, hydropower, agriculture and other purposes. The water supply coverage was estimated to be 30.9 percent, thus the rural water supply coverage being 23.1 percent and that of urban being 74.4 percent (UNESCO 2004). PASDEP envisages that the unserved population will be reduced and more people being served than planned by MDG (Millennium Development Goals) by year 2015. The goal during PASDEP is also to reduce the share of malfunctioning rural systems from 30 percent in 2005/06 to 10 percent by 2010 (MOFED 2006). The great majority of the rural Ethiopian population community water supply relies on groundwater. The safe supply of water in rural areas is usually derived from shallow wells, spring development and deep wells. People who have no access to improved supply usually obtain water from rivers, unprotected springs, hand-dug wells and rainwater harvesting. Despite its immense relevance and importance, the groundwater sector has been given less attention until recently.
In order to utilize the ground water resource properly, understanding of the groundwater occurrence and distribution in space and time, proper management and efficient exploitation is necessary. The available studies on the groundwater resources of the country are very limited, in that, the delineation of aquifer systems; the water balance and determination of the aquifer characteristics have not been conducted. Any sustainable utilization of groundwater

resources demands systematic study and raising the technical and manpower capability. In this regard the country has a long way to go, yet.

The conditions of sanitation are even worse in Ethiopia. The sanitation coverage in the capital Addis Ababa, which is believed to have better service, was estimated at 12.5% (MoH and World Development Report 1997). The welfare monitoring survey (CSA 1998) pointed out that, out of this, 11% of the households have flush toilet, 73.3% of the households have pit latrine, 3.1% of the households use household containers,10.5 percent of households use open defecation (field and forest) and 2.2% of the households use other means. Re-use of treated waste water could provide an additional potential of water for irrigation.

Based on the present indicative information sources, the potential irrigable land is about 3.7 million hectares. This figure is believed to be on a lower side, and could change as more reliable data emerge particularly on small-scale irrigation potential. The area under irrigation development to-date, obtained from different sources is estimated to range between 160,000 - 200,000 hectares. At present some 197,000 hectares of land is under irrigation (Solomon 2006). Estimates of the irrigated area presently vary, but range between 150,000 and 250,000 hectares less than five percent of potentially irrigable land (Werfring 2004; Awulachew et al. 2005). Estimates of the irrigated area, according to the data reported by the MoWR, is 107,265.65 hectares, which is less than 5% of the potential.

2.9.2 Sudan

Water used in Sudan derives almost exclusively from surface water resources, as groundwater is used in only very limited areas, and mainly for domestic water supply. There are large areas in Sudan where the exploitation of groundwater has been hampered by cost, as the water table is very deep. Internally produced water resources are estimated at 35 BCM/year. Incoming water resources are estimated at 119 BCM/year, resulting in total natural water resources of 154 BCM/year.

Surface water is provided mainly by the Nile River. The main part of Nile is formed by the confluence of the Blue Nile (65%) and the White Nile (23%) in the capital Khartoum and receives, before flowing into Egypt, one more tributary, the Atbara River (12%). Both the Atbara and the Blue Nile rivers originate in the Ethiopian plateau. The rivers of the Ethiopian catchment are marked by the extreme range in discharge between the peak and low periods. At its peak the former provides nearly 90% of all water reaching Egypt, the latter only 5%. During the months with low flow the contributions are 30% and 70% respectively. The available average annual flow of the Nile is about 84 BCM at Aswan at the Sudano-Egyptian border, of which more than 80% between August and October. According to the Nile water agreement between Sudan and Egypt, Sudan's share is 18.5 km/year, measured at Aswan, at the border with Egypt. The agreement does not consider possible future reduction in water flowing from upstream countries.

Apart from the Nile system, there are also the seasonal rivers of Gash and Baraka in eastern Sudan. During the rainy period of July-September, the water flow, which is very violent, is drawn off into canals and spread over the land forming a very fertile delta area (spate irrigation). Furthermore, from year to year variations in water resources greatly reduce the amount of water actually available for use.

Agriculture, and especially crop production, is the most significant element in Sudan's economy. Most of the cash crops are produced by irrigation, and irrigated agriculture represents about 50% of total crop production. Sudan has an irrigation potential of about 4.8 million ha considering land resources. Taking into account water resources, the irrigation potential has been estimated at almost 2.8 million ha (without considering possible large scale developments at in the enormous wetland in southern Sudan).

The total water managed area is around 1.95 million ha, or 26% of the cultivated area. Some 46 200 ha is under spate irrigation in the Gash and Tohar deltas; the rest are full or partial control irrigation schemes. All irrigation water comes from surface water. Most schemes are large-scale schemes, which are managed by quasi-public Agricultural Corporations (AC), while small-scale schemes are owned and operated by individuals or cooperatives. The combined GeziraManagil scheme, located between the Blue and the White Nile, constitutes one of the largest irrigation complexes in the world under single management (about 760 000 ha). It receives its water from the Sennar dam on the Blue Nile and more than 100 000 tenant farmers and their families operate the scheme in partnership with the government and the Sudan Gezira Board, which provides administration, credit and marketing services. Originally planned for the cultivation of cotton, more and more areas are coming under food crop production. Other large schemes are the Rahad Scheme, which receives its water from the Roseires dam on the Blue Nile, and the New Halfa Project (also known as Khashm AlGirba), located on the Atbara river in the east of the country. The latter project was partly financed by Egypt after the newly constructed High Aswan dam created Lake Nasser, which flooded the Sudanese town of Wadi Halfa in 1964. The inhabitants were moved to the new irrigated agricultural lands where they have been growing a variety of crops for over 30 years.

Although irrigated agriculture has been Sudan's greatest economic investment, returns have been far below potential. A study by the World Bank showed that, during the period 1976-1989, yields were low and extremely variable and cultivated areas suffered gradual decline. Cropping intensity in the Gezira Scheme, dropped from 75% to 57%, as 126 000 ha were taken out of production due to siltation and mismanagement of the canals, leading to reduced availability of water. Because of bad water management, water supply is about 12% below crop requirements at crucial points in the growth cycle, while at the same time as much as 30% of the water delivered is not used by crops. The new government in Sudan reports that since 1990 there has been considerable improvement in agricultural crop production and returns. Major irrigated crops are cash crops (cotton, groundnut, and sugar), wheat and sorghum.

2.10 HISTORICAL INFORMATION ON DROUGHTS

Ethiopia faces a heightened vulnerability to extreme weather events such as droughts and floods. According to EM-DAT, the International Disasters Database, in the last 30 years there have been ten periods of drought (see Table 2-7) and 43 floods. One of the most serious drought events, which occurred in 2003, affected approximately 12.6 million people. In addition to the direct impact on human lives, natural disasters have been also detrimental to

Ethiopia's economy. Total economic damage costs due to the three major droughts since 1969 are estimated at US$ 92.6 million (EM-DAT 2010).

In 2008, two successive seasons of minimal rain events left Ethiopia in drought, and millions of people across the country hungry as crops failed and food prices soared (NASA Earth Observatory 2008). With close to half of Ethiopia's GDP attributable to the agricultural sector, managing food and economic security in the face of an uncertain climate continues to be an issue.

Table 2-7 List of the main droughts in the Blue Nile in Ethiopia and the total number of affected people

Disaster	Date	Total affected (Millions)
Drought	2003	12.6
Drought	May-83	7.8
Drought	Jun-87	7.0
Drought	Oct-89	6.5
Drought	May-08	6.4
Drought	Sep-99	4.9
Drought	Dec-73	3.0
Drought	Nov-05	2.6
Drought	Sep-69	1.7
Drought	Jul-65	1.5

[Source: Africa Water Atlas]

During the last 100 years, the Sahel Zone in Sudan had witnessed drought and famine years of crisis which claimed millions of animal and human lives. British records refer to several periods of serious drought (Table 2-8).

Table 2-8 List of the main droughts in Blue Nile in Sudan

Disaster	Date	Comment
Drought	1888-89	no rain for a year
Drought	1904	
Drought	1910-1911	
Drought	1925-1927	

Drought	1941-1942	
Drought	1948-1949	
Drought	1955- 1958	
Drought	1984	no rain
Drought	1990	no rain

[Source: http://adroub.net/default.aspx?page=Climate.%20Drought%20A]

2.11 PURPOSE OF THE CASE STUDY

The Nile River is the longest river in the world (6695 km); its basin covers about 3 million km2 and encompasses eleven countries in east and central Africa. The two major tributaries of the Nile are the White Nile, originating in the Great Lakes region in Eastern Africa, and the Blue Nile, originating in Lake Tana in Ethiopia, and draining the Ethiopian Highlands. These two tributaries meet near the city of Khartoum in Sudan and are joined 300 km downstream by the Atbara River, which originates in Ethiopia north of Lake Tana and flows only while there is rain in Ethiopia. From the socio-economic and politic points of view, the Nile Basin can be regarded as the most important basins in Africa. Water management in the basin has historically been a controversial issue and cause of conflicts between the countries depending on the water of the Nile.

The aim of this case study is to provide improved tools for forecasting droughts and hence water availability in the region. The study will focus in the Blue Nile and Atbara River basins, and will pay particular attention to the expected effects of climate change. The case study will be lead by the Nile Forecast Center (NFC) in collaboration with other partners already active in the region.

2.12 DESCRIPTION OF NEEDS AND PROBLEMS TO BE ADRESSED BY THE CASE STUDY

The main aim of this case study is to provide and test all the available or improved tools, for drought warning and prediction of the effect of climate change on drought risk in the Blue Nile and Atbara basin. In the study area, there are models which could be useful in studying the droughts from the hydrological and meteorological prospective. On the other hand, there is no model available to assess he impacts of droughts on agriculture. It will be useful if such a model is developed and tested within this workpackage.

3. DROUGHT MANAGEMENT PRACTICES IN THE EASTERN NILE BASIN

3.1 CURRENT DROUGHT MANAGEMENT SYSTEM

There are some organizations in the Eastern Nile countries (Ethiopia, Sudan and Egypt) which are responsible for drought management whether in drought prediction or in adaptation to the consequences of a drought event. Some of these organizations are important to this study in one or more of the main three prospective: Agriculture, water resources and human health. Some of them generally work in the drought monitoring and early warning. In the next section, the main organization and their main aim or target will be explained. Then the activities related to every prospective will be mentioned under its specific section.

- **Productive Safety Net Program, Ethiopia**

The PSNP was established as a government led program where government systems and personnel implement the activities with coordinated donor support. The objective of the PSNP is to span the mandates of two Ministries and multiple departments within each Ministry.

- **Contingency planning and financing, Somali Region, Ethiopia**

Also known as Disaster Prevention and Preparedness committee (DPPC), which currently has two contingency planning that would involve food and non-food sectors, consider the effects of food crises like increased incidence of diseases, and that would consider mitigation and recovery interventions to ensure the continued development of a more robust emergency response system is in process. Some agencies working in Ethiopia have contingency plans for their own operations. For example Oxfam international has a drafted contingency plan for humanitarian operation in Ethiopia. There are also contingency plans of agencies for specific areas like the contingency plan for Somali Region that was initiated by a multi-agency team working in the Region and supported by UNDP in 1997.

- **Relief and rehabilitation commission, Ethiopia**

The relief and rehabilitation commission (RRC) was established in 1974 (RRC, 1984). It was set up to organize and coordinate government's relief and rehabilitation measures for the millions of people affected by the 1973/74 famine. The awkward manner in which RRC was created, the magnitude of tasks (reaching out millions of victims, inexperienced and unprepared staff, archaic government bureaucracy with little skills in sheltering victims, warehousing, stockpiling and emergency operations), the rampant corruption inherent in the administrative system and absence of a clear policy and/or legal framework had all operated to undermine disaster management efforts. A tumultuous social and political milieu coupled with a series of disaster situations never allowed sufficient breathing space to look towards a coherent, integrated and comprehensive DM system. The arrival of another famine in 1983/84 made the work of the agency (RRC) all the more intractable.

- **Sudan Meteorological Authority, Sudan**

The SMA is governmental body work in monitoring, Forecasting the weather parameters and it is consider as an advisor for policy makers in all issues about climate and weather. The SMA also provides data and information for Public uses and for scientific researches and also work as consultants for some organizations and companies.

- **Institute of Environmental Studies, Sudan**

The institute of Environmental Studies (IES) has special interest and experience in educational and research in monitoring, environmental awareness and how the community's response to drought.

- **Nile Forecasting Centre, Egypt**

The general aim of the centre is to provide tools and information for water planning and management. To this end the Nile Forecast Centre and its NFS system will provide to planners and decision-makers in Egypt with:

- Timely forecasts of the Nile River inflows into the High Aswan Dam reservoir;
- Real-time information about hydrological and meteorological processes occurring in the whole Nile Basin; and
- Rules to simulate the flow regime of the Nile and assess the possible consequences of changes, man-induced or natural, in the Basin.

3.1.1 Agriculture

- **The Ministry of Agriculture and Rural Development (MOARD)**:

Through the PSNP in Ethiopia, the MOARD is responsible for the management of the PSNP, with the Disaster Risk Management and Food Security Sector (DRMFSS) responsible for overall program coordination. Within the DRMFSS, the Food Security Coordination Directorate ((FSCD) previously called the Food Security Coordination Bureau) facilitates the day-to-day management and coordination of the PSNP. It is directly responsible for the timely delivery of transfers to beneficiaries and supports the implementation of public works.

- **Agricultural Sector Support, including Livestock**

For drought affected farmers in the central highlands of Ethiopia assistance is needed in the form of seeds. In some areas small-scale irrigation can be supported through the provision of pumps. Lowland farmers in the Somali region, especially those living along the permanent rivers (in Gode, Liben and Afder zones) also need help with seeds, farm tools and irrigation pumps. Livestock and pastoralists in the drought-affected lowlands of Somali region, the Borena zone of Oromiya and South Omo Zone of the SNNP region are also being targeted for special emergency assistance. The provision of feed for animals, the provision of adequate veterinary services in the drought affected areas, and the establishment of slaughter facilities for the preparation of dried meat are all elements of the planned programme.

3.1.2 Water Resources

- **Activities of the Contingency Planning and Financing in Water Supplies Sector**

Under the umbrella of the Contingency planning and financing, Somali Region in Ethiopia, in many seriously drought affected areas of the country, especially in the lowlands of Somali region and Borena Zone of Oromiya region, there is little alternative to the emergency tankering of water from permanent sources of water to where people have congregated. Tankering operations need to be supported with the provision of storage and delivery systems. The repair and rehabilitation of boreholes is feasible in some areas and also needs support.

- **Information available from the NFC**

The information available from the NFC is only internally published by the Nile Forecast Center (NFC) for different departments in the Ministry of Water Resources and Irrigation (MWRI) in Egypt. The Nile Water Sector also makes estimates of inflows to Lake Nasser for short-term operational decisions using simple regression techniques. The lead time from the monitored river station at Eddeim on the Blue Nile is of the order of 17 days. A Standing Committee with representatives from the Nile Water Sector, the Nile Forecasting Center, HADA, the Irrigation Sector and other sectors and research institutions of MWRI meets two-weekly, or more frequently as circumstances demand, to review the flood forecasts and adjudicate on operational decisions.

3.1.3 Human health

- **The role of Relief and Rehabilitation commission (Ethiopia)**

Absence of coordinated and integrated prevention, preparedness and response effort between central government and local government institutions on the one hand, and RRC and line ministries on the other were the major predicaments facing the EDM system (PDRE, 1989). Lack of organized information system and planned logistical support undermined the post-disaster response and recovery efforts of the agency (ibid), let alone thinking strategically towards mitigation and preparedness measures. This trend during the period from 1974 to 1989, therefore, the disaster management machinery in Ethiopia heavily invested in response and recovery rather than in preparedness and prevention.

- **The Role of Contingency planning and financing, Somali Region (Ethiopia)**

The DPPC has a lot of activities in related to human health protection and quality; some of these activities are as follows:

Migration and Population Tracking
A mechanism for tracking and monitoring migratory movements in order to understand the determinants to displacement is urgently needed. The data and findings thus generated can be applied to design interventions and to optimize the allocation of resources to areas with urgent needs.

Emergency Education
Three years of poor rains have placed a serious economic burden on many poor rural families. In drought-affected areas, school attendance has been low and drop-out rates have been accelerating. The aim is to assist children whose parents might not otherwise be able to afford to send their children to school.

Special Protection Needs of Women and Children
The severe drought in the Somali region, in particular, has led to the migration of at least 10,000 people in the Gode area. The most vulnerable segments of the displaced population, especially women and children, have a greater need for special help under such circumstances.

Shelter and Logistics Requirements
The migration of communities in search of water and food significantly increases the risks associated with exposure to wind, sun and rain. The aim is to mitigate the effects of exposure, and to provide some basic household requirements to the most vulnerable families.

3.1.4 Other management systems

- **The Natural Resource Management Directorate (NRMD) within MOARD**

Through the PSNP in Ethiopia, NRMD is responsible for coordination and oversight of the public works. This includes capacity building and technical support, supervision of environmental guidelines, liaising with FSCD and other PSNP partner institutions on coordination and management of public works, and participation in PSNP design and management forums, including policy issues and the roll out of the pastoral PSNP.

- **The Ministry of Finance and Economic Development (MOFED)**

Oversees financial management of the program and disburses cash resources to implementing federal ministries and to the regions based on the annual plan submitted by MOARD.

3.1.5 Current drought early warning and adaptation

- **The Early warning System at DPPC**

One of the main components of the National Disaster prevention and preparedness commission (DPPC) in Ethiopia is an early warning system (EWS) which has been in place since 1976 to monitor and warn against the threat of disasters ahead of time, and to trigger timely, appropriate, and preventative measures. It monitors closely factors which affect food security at household, regional and national levels.

The system is an inter-agency activity involving different relevant government institutions. It is led at the national level by a committee with the DPPC acting as its secretariat. Since 1993, The EWS has been decentralized in line with the regionalization policy and bottom-up planning approach. Training in data collection for early warning and analysis has been given to functionaries at regional and lower levels.

As part of the regular activity of the program, all relevant indicators of food security are monitored on a monthly basis culminating in an annual nation-wide pre and post harvest crop assessments. Pastoral assessments are also carried out in the livestock dependent regions, while disaster assessments are conducted in an emergency situation.

Early warning reports are regularly issued to Government, donors and the international community. Efforts are now underway to improve the system through the introduction of enhanced methodologies, and tools for data analysis. The system enhancement work which is in progress focuses on six major components: The monitoring of national food security, and crop, livestock, market and agro-metrology assessments.

- **Weather Forecast and Early Warning Team in the Ethiopian National Meteorological Services Agency**

The agency has started as a small Meteorological unit which was established in 1951 within the Civil Aviation department (now Civil Aviation Authority) to deliver only the needed data for aeronautical purposes. Thirteen years later and due to more requests for meteorological information the unit was promoted to Meteorological Department under the auspices of civil Aviation Authority.

The National Meteorological Services Agency responsible for the control and operations of short-medium-and long-range forecasts and early warnings. This agency also develops ways and means for adopting new systems, better techniques and simplified procedures so as to render an efficient and effective weather forecast services.

For more information about the different management agencies or institutes please check: deliverable 2.1- Inventory and Capability Assessment of Drought Monitoring and Forecasting Systems in Africa.

- **The Early Warning and Response Directorate (EWRD)**

Previously called the Disaster Prevention and Preparedness Agency, which is also through PSNP and under DRMFSS, provides accurate and timely early warning information for the PSNP Risk Financing (RF) (see PSNP Risk Financing Mechanisms) and ensures adequate linkages between PSNP RF and other humanitarian response activities. The EWRD is responsible for the timely delivery of food resources.

3.2 EXISTING DROUGHT MONITOR PRODUCTS

- **National Meteorological Services Agency (NMSA)** is preparing and disseminating Agro Meteorological Advisory Bulletins at real time basis, which can assist planners, decision makers and farmers at large. The agency disseminates agro meteorological reports on ten daily, monthly and seasonal in which all the necessary current information relevant to agriculture is compiled. NMSA also issues agro-meteorological bulletins through World Agro Meteorological Information Service Web site. The government decision-makers are using their recommendations to alter agricultural practices on relatively short notices in order to maximize the value of the forecasted rains and minimize the impacts of forecasted droughts (Nicholls & Katz, 1991).
- **Sudan Meteorological Authority (SMA)** is governmental body work in monitoring, Forecasting the weather parameters and it is consider as an advisor for policy makers in all issues about climate and weather. The SMA also provides data and information for Public uses and for scientific researches and also work as consultants for some organizations and companies.
- **Desertification Research Institute, Sudan (DRI).** The research is focused on two axis: Socio-economic and Basic and Applied research to achieve the institute objectives which are: Formulation and execution of basic and applied research in dry and desertified lands putting livelihood in top agenda; Applied research to develop drought and disease resistant crops and improve productivity and dissemination of research results and developed techniques.
- **The Nile Forecasting Centre (NFC),** the centre activities and products were previously described in section 3.1.

3.2.1 Meteorological drought indices

- Early warning Agro Meteorological Advisory reports, *by NMSA*
- Estimates of rainfall in Blue Nile basin from CCD data, *by NFC*
- Long-term Regional Climate Change studies on the Nile Basin Area, *by NFC*

3.2.2 Agricultural drought indices

- Early warning reports, *by NMSA*
- Short-term advisory plans for lake Nasser operation based on the predicted flows to lake Nasser, *by NFC*

- Long-term studies on the lack of water distribution (including the water for the agriculture areas) in case of the decreased inflows (droughts), *by NFC*

3.2.3 Hydrological drought indices

- Streamflow estimates of inflows to Lake Nasser, *by NFC*
- Short-term and medium term streamflow forecasting at the main stations, *by NFC.*

3.3 CURRENT DROUGHT FORECASTING TOOL

3.3.1 Existing gaps in management systems, organization and information

Though there are more than one valuable research centre available in the eastern Nile area, they mainly exists in the downstream countries (Sudan and Egypt). On the other hand the main responsible management agencies are in Ethiopia. There seem to be a great lack of communication between the two components of good management. The result of this is that the main budget of management is going to response and recovery of the event of drought rather than going to early warning and preparedness and prevention of the crisis.

3.4 STAKEHOLDERS

3.4.1 Producers of available monitoring and forecast products

- National Meteorological Services Agency (**NMSA**), Ethiopia
- Sudan Meteorological Authority (**SMA**), Sudan
- The Nile Forecasting Centre (**NFC**), Egypt
- Egyptian Meteorological Authority (**EMA**), Egypt

4. DETAILED CASE STUDY APPROACH AND METHODOLOGY IN THE EASTERN NILE BASIN

4.1 APPROACH TO BE FOLLOWED

The first model that is going to be applied on this case study is the NFS (described in sec. 4.3.3). Through which some of the climate change scenarios- which are expected to result in a drought situation in the Blue Nile area- are going to be examined to see their effect on the meteorological and hydrological parameters in Blue Nile and Atbara.

4.2 COLLATION AND REVIEW OF EXISTING DATA

4.2.1 Hydrological Data

The hydrological data available in NFC is divided into two main databases; the first one called "Nile Basin Hydro-meteorological Information System – NBHIS" which is built in Nile Forecasting System and holds several types of time series data of water levels and discharges. The second is from the "Nile Decision Support Tools – Nile-DST data base".

- **Discharge**

Data in NBHIS

The NBHIS holds daily and monthly records of levels and discharges at several key locations (Figure 4-1). The database is updated frequently as records are communicated from other departments of the MWRI to the NFC. Table 4-1 lists the different hydrological datasets stored within the NBHIS (Table 4-1). The time span and record completeness differ for each station and dataset. The given dates relate to the earliest and latest records of the whole set. Monthly volumes were mainly collected from available records in "The Nile Basin" series but recent years are calculated from observed daily discharges and therefore can be updated as required.

Table 4-1 NBHIS Hydrological Blue Nile Time Series

Dataset	***Time Span***	***#Gauges with data****
Observed Monthly Volume	Jan 1871 – Dec 1994	52 of 58
Historical Flow (Daily)	1 Jan 1970 - 30 Nov 1990	57 of 64
Observed Discharge (Daily)	1 Jan 1940 – date	6 of 32
Observed Daily Volumes	1 Jan 1940 – date	6 of 20
Observed Reservoir Releases (Daily)	1 Jan 1945 – date	3 of 6

* More gauges are included in the files but with empty records for the whole period or outside the Blue Nile & Atbara

Figure 4-1 Location Map of Key Sites and Tributaries of the Blue Nile & Atbara Basins Triangles indicate locations of river gauges, Squares indicate dam sites

The "Observed Daily Volumes" dataset contains accumulations of daily discharges from 1st of May (the beginning of the monsoon rains over Ethiopia) till 30th of April of the following year so that the last day gives the annual total. Table 4-2 and Table 4-3 show the data sets of the observed daily flow, and the reservoir daily releases for the key location on the Blue Nile and Atbara.

Table 4-2 Discharge Stations over the Blue Nile & Atbara in NBHIS

Station	***Start Date***	***End Date***	***%of complete***
Diem	01-May-65	02-Sep-11	98
KharBlue*	01-May-45	Up to Date	97
Roseires	01-Jan-75	Up to Date	92
Sennar	03-May-75	Up to Date	67
Atbara	01-Jan-56	Up to Data	77
Khashm el Girba	01-May-87	Up to Data	95

Table 4-3 Available Reservoirs Releases over the Blue Nile & Atbara in NBHIS

Station	***Start Date***	***End Date***	***%of complete***

Roseires	01-Jan-75	Up to Date	92
Sennar	03-May-75	Up to Date	67
Khashn	01-May-87	Up to Date	95

- **Gauge Height**

Data in NBHIS

Stages are converted into flows using rating curves coded within the NFS but for some gauges, the discharge data are received directly by the NFC in log books. The validity of the rating curves is questionable as they have not been updated for several years due to the unavailability of concurrent flow and stage measurements. Table 4-4 shows the available Gauge Height Station over the Blue Nile and Atbara.

Table 4-4 Available Gauge Height Station over the Blue Nile & Atbara in NBHIS

Station	***Start Date***	***End Date***	***%of complete***
Diem	01-May-65	02-Sep-11	98
KharBlue*	01-May-45	Up to Date	90
Roseires	01-Jan-75	Up to Date	47
Atbara	01-Jan- 56	Up to Date	50

*KharBlue , is the name of the gauge station in Khartoum located on the Blue Nile

4.2.2 Data in Nile-DST

The Nile-DST was built through an NBI project with cooperation between FAO, Georgia Institute of Technology, and the Georgia Water Resources Institute (GWRI). The main applications included in the Nile-DST are: Remote Sensing, Hydrology, River Basin Management, and Agricultural Planning.

The Nile-DST Database, which has been developed to support the Nile-DST tool, is designed to visualize and analyze a large and dynamic database. This database holds data recorded at stations throughout the Nile Basin. Since the database holds large number of parameters, the parameters are classified according to their type. The parameter types are Agricultural, Ecological, Economic, Geographic, Hydrologic, Meteorological, and River Basin Management. Some of these categories have no parameters as yet, but are in place because as the interface grows they are likely to be needed.

For Ethiopia and Sudan, the database includes hydrological stations with datasets of levels and discharge. Table 4-5 shows the number of hydrological stations per country and the available period of record in the Nile-DST data sets. Table 4-6 shows the details of the available data stations in the two countries. The data period and completeness varies per station. Worth noting that some countries do have substantial number of additional stations while others have very few or not in the list at all. Figure 4-2 shows the geographical distribution of these stations for hydrology.

Table 4-5 Number of hydrological stations per country and period of record for NileDST Datasets

Country	Type of Data	Number of Stations	Period of data
Ethiopia	Daily Level	2	41/1/1982-4/31/1990
Sudan	Daily Level	13	1/1/1968-1/30/2000

Table 4-6 NileDST Hydrological Stations

Country	Station name	Lat.	Long.	Type	Time Step	Period	
						From	To
Ethiopia	nr baco	9.05	36.992	Level	Daily	3/6/1979	3/23/1996
	nr sheboka	9.397	36.934			1/1/1981	2/1/1997
Sudan	eddiem	11.593	34.853	Level	Daily	1/2/1964	12/31/1996
	Roseries U/S	12.692	34.102			7/6/1966	12/31/2000
	Roseries D/S	12.692	34.102			7/6/1966	12/31/2000
	wad elias	13.328	33.928			1/1/1965	12/31/2000
	sennar U/S	14.253	33.697			1/1/1965	12/31/2000
	sennar D/S	14.021	34.697			1/1/1965	12/31/2000
	w.hadad	14.426	33.408			1/1/1965	12/5/1997
	h Abdalla	14.185	33.523			1/1/1965	12/31/1998
	wad el nau	14.6	33.523			6/1/1965	12/31/1993
	giwasi	13.732	34.044			7/3/1972	11/25/2000
	medani	14.715	33.35			1/1/1965	12/31/1999
	hawati	13.675	34.391			7/9/1972	12/27/1999
	khartoum	15.756	32.714			1/1/1965	1/1/2000

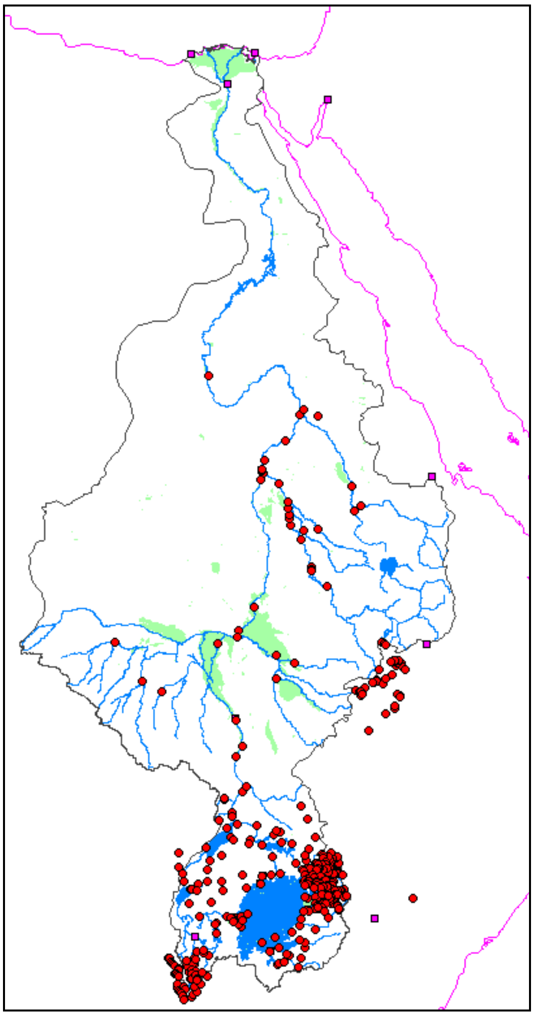


Figure 4-2 Locations of hydrological level stations within Nile-DST

4.2.3 Rainfall

Rainfall data for the Blue Nile and Atbara basin are sparse compared to discharge data. The large extent of the basin and the lack of a data exchange protocol between riparian countries limit the quantity, quality, and availability of rainfall data. All of the riparian countries are still developing and cannot bear the costs of dense rain gauge networks to provide enough coverage over the basin. Therefore, the NFS relies on estimating rainfall from satellite images as well as gauges.

- **NBHIS Rainfall Gauge Data**

Gauge data have been collected from a variety of sources to form a historical database (Lin et al., 1996). Historical gauge data include daily data, monthly data, and average statistics and refer to data prior to the start of the MFS project while operational data (in the observed daily database) refer to data collected since May 1992 till present. Currently, observed data for about 290 raingauges in and around the Nile basin (some in Egypt) are downloaded daily from the Florida State University website. These data come in WMO synoptic format and contain several meteorological variables; however, only precipitation data are saved to the NBHIS in NFS after decoding. Decoding involves some initial quality control on the data. It is worth mentioning only that not all stations data are sent continuously and, on any particular day, usually data from about 40 stations are available, not necessarily the same ones received on another day. Out of the 290 received stations only 236 have entries in the observed daily database and only 142 of these lie within or close to the Nile Basin and 20 from them lie in the Blue Nile and Atbara basins (Figure 4-3). Other real-time rainfall data are downloaded regularly from NOAA via FTP. The real-time gauge data from NOAA and WMO are used in the daily operation of the NFS.

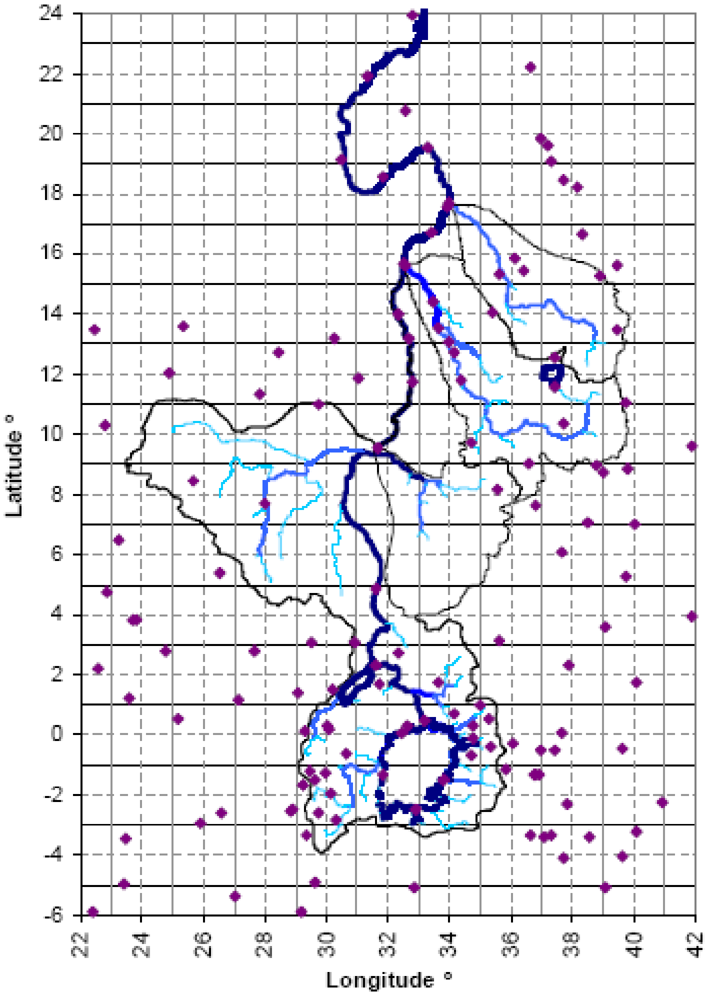


Figure 4-3 Locations of WMO synoptic Daily Rain gauges within the Nile Window

The raw historical and operational gauge data have been organized in the Nile Basin Hydrometeorological Database (NBHIS) in three time series files (Table 4-7). There is an overlap period (1992-1995 inclusive) between the so-called historical and observed time series, but deviations are minimal for most gauges. The monthly totals are developed by accumulating daily data since 1992 and from the respective collected records before that. The time span varies for each station from the time span of the whole file. Few stations have complete (or near complete) records and a few have no record at all, but for many stations the record is only complete over a very short period. The overall completeness of the time series shown in Table 4-7 is defined as the percentage of days with records relative to the total time span of the whole time series.

Table 4-7 Precipitation Time Series available within NBHIS

	Precipitation		
STATION_NAME	start	end	Data %
ABU_NA'AMA	19-Jun-92	14-Sep-11	53%
ADDIS_ABABA	1-Jan-92	8-Jul-11	60%

	Precipitation		
ARBA_MINCH	2 Jul 1992	8-Jul-11	52%
AROMA			0%
ATBARA	19-Jun-92	14-Sep-11	57%
AWASSA	19-Jun-92	8-Jul-11	56%
BAHAR_DAR	1-Jan-92	8-Jul-11	62%
BAMBESI			0%
COMBOLCHA	9-Jan-92	8-Jul-11	61%
DAMAZINE	19-Jun-92	14-Sep-11	54%
DEBREMARCOS	1-Jan-92	8-Jul-11	57%
DIRE_DAWA	19-Jun-92	8-Jul-11	59%
ED_DUEIM	19-Jun-92	14-Sep-11	49%
GEDAREF	21-Jun-92	13-Sep-11	56%
ROBE	19-Jun-92	8-Jul-11	57%
GODE	24-Jul-93	8-Jul-11	54%
GONDAR	1-Jan-92	8-Jul-11	58%
GORE	22-Jun-92	8-Jul-11	41%
HALFA_EL_GEDIDA	2-Oct-93	14-Sep-11	50%
HARAR_MEDA	19-Jun-92	7-Jul-11	56%
HUDEIBA			0%
JIGGIGA			0%
JIMMA	19-Jun-92	8-Jul-11	49%
KASSALA	19-Jun-92	14-Sep-11	47%
KHARTOUM	19-Jun-92	14-Sep-11	61%
KOSTI	19-Jun-92	14-Sep-11	49%
LEKEMTI	1-Jan-92	8-Jul-11	52%
MAKALE	6-Aug-92	8-Jul-11	54%
METEHARA	19-Jun-92	7-Jul-11	57%
MOYALE	1-Apr-94	3-Sep-11	40%
NEGHELLI	19-Oct-92	7-Jul-11	53%
RENK	9-Sep-92	4-Sep-11	47%
SENNAR	19-Jun-92	14-Sep-11	51%
SHAMBAT_OBSERVATORY			0%
SHENDI	23-Jul-92	13-Sep-11	2%
UMM_BENIN	31-Oct-97	4-Sep-11	3%
WAD_MEDANI	21-Jun-92	14-Sep-11	53%

- **NBHIS Gridded Data**

The NFC receives satellite images from the European METEOSAT second generation geostationary satellite stationed at 0º Latitude, 0º Longitude which has Europe and Africa within its field of view. The view scanned by METEOSAT is essentially a square divided into

2500 × 2500 pixels giving a resolution of approximately 5.5 × 5.5 km^2. The satellite has 12 channels and only 6 channels are stored where infra-red; 9.7 μm, 10.8 μm, 12.0 μm, and 13.4 μm, visible 0.8 μm and water vapour 6.2 μm. Images are received every 15 minutes. The receiving software is configured so that a window covering the Nile basin is only saved from the whole image. These images have been archived on tapes (currently on CDs) since the beginning of reception in the NFC in mid-May 1992. Until 1997, Gridded data are data defined on the METEOSAT grid. These datasets (Table 4-8) include a historical monthly time series interpolated from monthly gauge data and a daily time series derived in a similar way, but only for periods with sufficient gauge data (as listed in last row of Table 4-8). The later part of the series (15/5/1992 – present) is the merged gauge and satellite precipitation estimate. The daily gridded time series is not homogeneous because of changes in the derivation methods of the daily time series (first as gauge only then as merged estimates).

Table 4-8 Gridded Precipitation Datasets within NBHIS

Dataset	Time Span
Average Annual Precipitation	Time Invariant
Average Annual Precipitation	Time Invariant
Average Monthly Historical Precipitation	Jan – Dec
CV of Monthly Historical Precipitation	Jan – Dec
Std. Dev. of Monthly Historical Precipitation	Jan – Dec
Monthly Precipitation	Jan 1940 - Dec 1995
Daily Precipitation	1 Jan 1970 - date Years 1977 – 1983 and 1985 – 1987 missing

4.3 COLLATION AND REVIEW OF EXISTING MODELS

The next mentioned models are the available models within the Nile Forecasting Centre (NFC). All these models have been evaluated through the Climate Change Risk Management Program (CCRMP) except the Regional Climate Model (the PRECIS model).

4.3.1 Numerical Weather Prediction- Forecast models

Numerical Weather Prediction (NWP) uses the power of computers to make a forecast. Complex computer programs, also known as forecast models, run on supercomputers and provide predictions on many atmospheric variables such as temperature, pressure, wind, and rainfall. A forecaster examines how the features predicted by the computer will interact to produce the day's weather.

The NWP method is flawed in that the equations used by the models to simulate the atmosphere are not precise. This leads to some error in the predictions. In addition, there are many gaps in the initial data since we- in NFC- do not receive many weather observations from areas in the mountains or over the ocean. If the initial state is not completely known, the computer's prediction of how that initial state will evolve will not be entirely accurate.

- **Eta Model**

The Eta Model is a state-of-the-art atmospheric model used for research and operational purposes. The model is a descendent of the earlier HIBU (Hydrometeorological Institute and Belgrade University) model, developed in the seventies in the former Yugoslavia (the earliest reference being Mesinger and Janjic, 1974). In the eighties, the code has been upgraded to the Arakawa-style horizontal advection scheme of Janjic (1984), then rewritten to use the eta vertical coordinate (Mesinger et al. 1988), and subsequently, at NCEP, supplied with an advanced physics package (Janjic 1990, Mesinger and Lobocki 1991). It became officially operational at NCEP on 8 June 1993 (Black 1994). In its various versions, the model has been and/or is widely used in numerous countries, including Algeria, Argentina, Belgium, Brazil, Cameroon, China, Costa Rica, Cyprus, Czech Republic, Denmark, Egypt, Finland, Germany, Greece, Iceland, India, Israel, Italy, Malta, Tunisia, Turkey, Peru, Philippines, Serbia and Montenegro, South Africa, Spain, Sweden, and the United States.

The last version of the code is available for downloading at the NCEP site. It is a very efficient code which can run on small personal computers in UNIX or LINUX systems.

The name of the model derives from the Greek letter η (eta) which denotes the vertical coordinate (Mesinger 1984), one of the model features, defined as

The model prognostic variables are: surface pressure, horizontal wind components, temperature, specific humidity, turbulent kinetic energy, and cloud hydrometeors. Model variables are distributed on the Arakawa E-grid.

Major features of the Eta dynamical core are:

- The eta vertical coordinate (Mesinger 1984), resulting in quasi-horizontal coordinate surfaces, and thus prevention of pressure-gradient force errors due to steep topography;
- Forward-backward scheme for time differencing of the gravity-wave terms, modified so as to suppress separation of solutions on two C-subgrids of the model's E-grid (Mesinger 1974, Janjic, 1979);
- The Arakawa approach in space differencing, with conservation of enstrophy and energy, as defined on the C-grid, in horizontal advection within the nondivergent barotropic part of the flow (Janjic 1984), thereby enforcing a strong constraint on the false systematic cascade of energy toward smaller scales;
- Energy conservation in transformations between the potential and the kinetic energy in space differencing (Mesinger et al. 1988);

- Option to run the model in a non-hydrostatic mode (Janjic et al. 2001);
- Lateral boundary conditions are prescribed along a single outer line of grid points. All variables are prescribed at the inflow points; at the outflow points tangential velocity components are extrapolated from inside of the model domain, while other variables are prescribed. There is no boundary relaxation (Mesinger 1977).

Model physics package comprises:

- Convection schemes: Betts-Miller (Betts and Miller (1986), Betts-Miller-Janjic (Janjic 1994), or Kain-Fritsch (Kain 2004);

- Cloud mycrophysics: Ferrier scheme (Ferrier et al. 2002);

- Radiation scheme: SW − Lacis and Hansen (1974); LW − Fels and Schwarzkopf (1975);

- Land surface scheme: Noah (Chen et al. 1997) with 12 types of vegetation and 7 types of soil texture, 4 soil layers;

- Turbulence and PBL: Mellor-Yamada 2.5, and Monin-Obukhov similarity theory in the surface layer, with Paulson stability functions.

Upgrades included in the CPTEC ("ICTP 2005") Eta code downloadable here, compared to the NCEP Workstation Eta code that is downloadable at the NCEP site, are listed on page 40 of the lecture Mesinger (2005).

While the primary use of the model has been for regional weather prediction and NWP type applications (for a review, see Mesinger 2000), the model has been very successful also in regional climate and seasonal prediction applications (e.g., Altshuler et al. 2002, Chou et al. 2005, Katsafados et al. 2005).

A more complete list of references can be found here. Users and to-be-users are all invited to take part in the Eta Model Forum.

- **MM5 Model**

The PSU/NCAR mesoscale model (known as MM5) is a limited-area, nonhydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation. The model is supported by several pre- and post-processing programs, which are referred to collectively as the MM5 modeling system. The MM5 modeling system software is mostly written in Fortran, and has been developed at Penn State and NCAR as a community mesoscale model with contributions from users worldwide.
The MM5 modeling system software is freely provided and supported by the Mesoscale Prediction Group in the Mesoscale and Microscale Meteorology Division, NCAR

The PSU/NCAR mesoscale model is a limited-area, nonhydrostatic or hydrostatic (Version 2 only), terrain-following sigma-coordinate model designed to simulate or predict mesoscale and regional-scale atmospheric circulation. It has been developed at Penn State and NCAR as a community mesoscale model and is continuously being improved by contributions from users at several universities and government laboratories.

4.3.2 PRECIS- Regional Climate Model

A Regional Climate model (RCM) is a downscaling tool that adds fine scale (high resolution) information to the large-scale projections of a Global Circulation Model (GCM). GCMs are typically run with horizontal scales (resolution) of 300km; regional models can resolve features down to 50km or less. This makes for a more accurate representation of many surface features, such as complex mountain topographies and coastlines.

There are three types of technique for obtaining regional climate change projections: statistical, dynamical and hybrid (statistical-dynamical) techniques. RCMs fall into the dynamical category.

The regional modelling system, PRECIS (Providing Regional Climates for Impacts Studies, pronounced pray-sea, i.e. as in French), has been developed at the Hadley Centre and is sponsored by the UK Department for Environment, Food and Rural Affairs (DEFRA), the UK Department for International Development (DFID) and the United Nations Development Programme (UNDP).

PRECIS runs on a personal computer (PC) and comprises:

- An RCM that can be applied easily to any area of the globe to generate detailed climate change projections.
- A simple user interface to allow the user to set up and run the RCM
- A visualisation and data-processing package to allow display and manipulation of RCM outputs.

A comprehensive set of variables has been chosen for PRECIS's default output. Variables are automatically output as "climate" means (monthly, seasonal, annual, decadal etc.). Daily and hourly means can be selected if required. If a particular variable is not included in the standard list or an existing variable on a different timescale is require, it is possible to reconfigure PRECIS so as to include it.

PRECIS has three possible output data formats: PP, GRIB and NetCDF. It is up to the user to decide which is most appropriate to their data analysis and visualization software. PP format is a Met Office format, and various tools are supplied with PRECIS to process it. It can easily be converted into both GRIB and NetCDF formats, but not vice versa. Therefore PP format is the recommended output data format.

4.3.3 The Nile Forecast System (NFS)

The NFS is a near real-time distributed hydro-meteorological forecast system designed for forecasting Nile flows at designated key points along the Nile; of major interest is the inflow of the Nile into the High Aswan Dam, Egypt. The core of the NFS is a conceptual distributed hydrological model of the Nile system including soil moisture accounting, hillslope and river routing, lakes, wetlands, and man-made reservoirs within the basin. The main inputs to this model are the rainfall and potential evapotranspiration. The current version of the NFS is 6.08, which is still under testing. The latest stable release of the system is 5.1.

From the outset of NFS development, it was decided to utilize satellite remote sensing technology in estimating rainfall over the basin. This was motivated by the scarcity and discontinuity of rainfall records within the basin in addition to the lack of direct monitoring control over rain gauges, as all basin rainfall occurs outside the borders of Egypt where the system is hosted. Therefore, the system grid was designed to match that of the satellite rainfall. In addition, the system includes a large database of rain gauge data, as part of the Nile Basin Hydrometeorlogical Information System (NBHIS) which also holds flow records at all key river gauges.

Geostationary satellite imagery is received using a dish antenna on the roof of the ministry building. This imagery is used to generate daily high resolution (20km) gridded estimates of rainfall over the basin, that is then blended with gauge-only rainfall analyses. The combined daily rainfall product is used to drive a gridded distributed hydrological model of the basin.

When used for forecasting as intended, a short NFS simulation (a few weeks) is performed using observed rainfall (merged satellite and gauge estimates) to define the model status (soil moisture storage, reach storage) on the current date. Subsequently, an ensemble of historical rainfall (for as many years as available) for the 3 months following the current date is applied to the model to simulate possible inflow series to Lake Nasser, called Extended (and more recently Ensemble) Streamflow Predictions (ESP). Once a week observed flows at some key points (e.g. Diem) are assimilated to update the model states. It implies that the rainfall estimates are adjusted for the last 4 weeks to minimise the difference between the simulated and the observed flows. When input data are missing or felt unreliable the deterministic model can be replaced by a first order Markov model for three locations (Malakal, Roseires and Khartoum). This model produces possible monthly runoff traces, which are subsequently disaggregated to daily data. The stochastic model is often applied to replace the deterministic forecast for the White Nile at Malakal, as the quality of the latter is considered less reliable. The system relies on a GIS database to represent the connectivity of the different pixels as well the different streams, rivers, and sub-basins associated with the designated forecast points. In summary the NFS (Figure **4-4**) is composed of 6 main components that perform the following functions:

1. Rainfall Estimation
2. Hydrological Simulation
3. River Flow Forecasting
4. Assimilation
5. Data Collection and Management (NBHIS)
6. GIS Functions

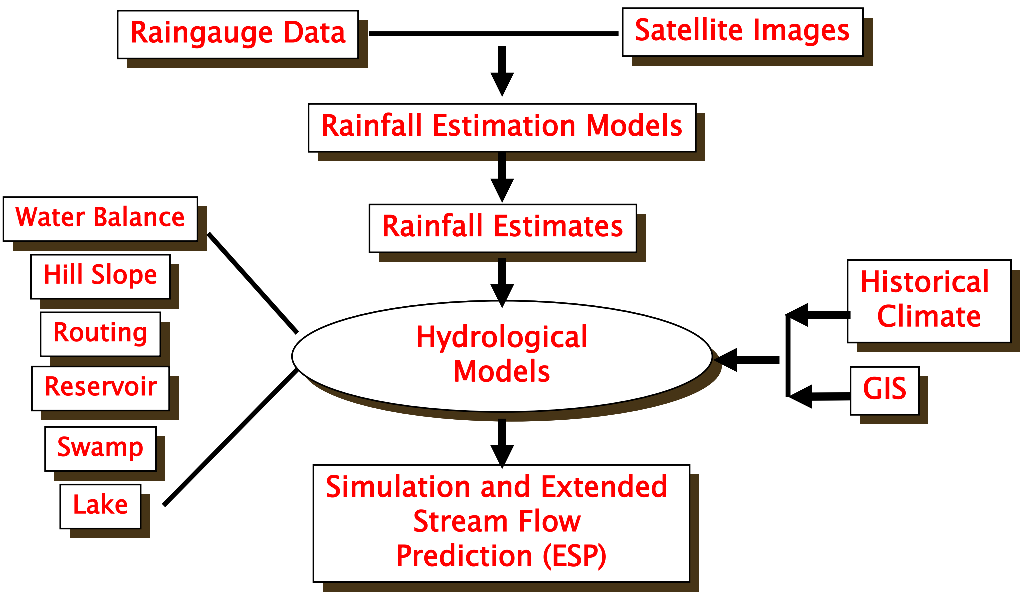


Figure 4-4 Schematic of the Nile Forecast System

As mentioned above, the NFS requires rainfall and potential evapotranspiration data for the whole Nile basin as inputs. These are required as gridded rainfall and potential evapotranspiration data (i.e. maps) with a daily time step although monthly data can be also used as the system contains routines for disaggregating these to the daily time step. NFS also requires discharge data at key stations for assimilation, calibration, and performance evaluation. Discharge is usually obtained from stage measurements using rating curves that are updated annually based on concurrent stage and discharge measurements.

Since its development started in 1992, the NFS has been enhanced several times. The latest enhancement of the NFS was undertaken in 2009 by the Hull University under the remit of the Nile Basin Initiative Flood Preparedness and Early Warning (FPEW) project. The enhancement focused, amongst other things, on the rainfall estimation methodology through developing a multi-spectral technique that takes advantage of the new generation of the European METEOSAT satellite (METEOSAT Second Generation – MSG). The NFC obtained a new reception system from VCS Engineering, Germany in 2007 to replace the old Primary Data User System (PDUS) unit that was in operation since 1992. The MSG spacecraft provide considerably enhanced datasets over their predecessors, both in the spatial and temporal resolutions of available imagery and in the number of separate wavebands for which images are available.

4.3.4 The River Basin Simulation Model of the Nile Basin upstream the High Aswan Dam (RIBASIM-NILE)

RIBASIM is a river basin simulation model developed by WL| Delft Hydraulics (changed in 2008 to Deltares). For the simulation of the water distribution in the Nile Basin up to Lake Nasser, RIBASIM has been setup as shown in Figure 4-5 within the Lake Nasser Flood and Drought Control (LNFDC) project. The developed model can be used to assess the impacts of potential developments or measures to improve, for example, the water supply and distribution. It makes use of a schematization in the form of a network, consisting of nodes connected by links to represent the flow of water between the different nodes. The main groups of schematization elements are natural and man-made infrastructure (i.e. reservoirs, rivers and lakes) and water users (i.e. agriculture, municipal and hydropower).

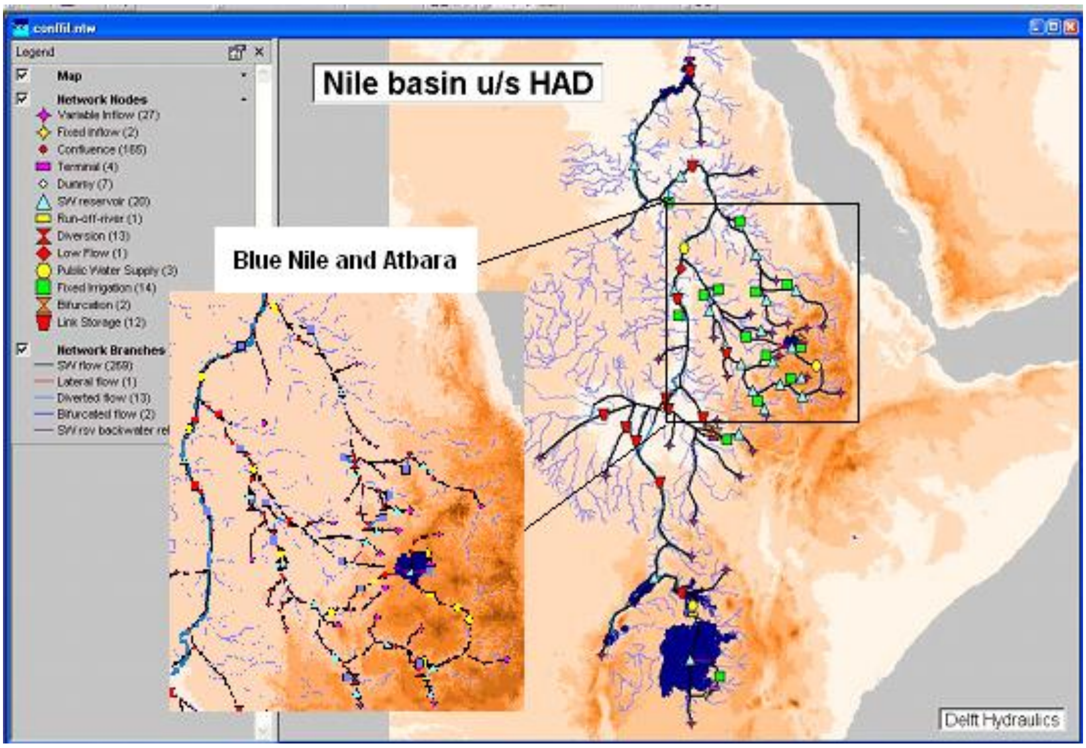


Figure 4-5 RIBASIM schematization for the entire basin upstream Lake Nasser- with the case study area shown

After schematizing the river network of nodes and links, the main input to the model are inflows at the different nodes. These can be input to the model as a direct inflow data series or as rainfall data series, and in this case, data for the catchment areas must be input to the model as well. The evaporation rates are usually entered as data series similar to those for rainfall (values for different locations plus the areas for this locations or the represented catchment by the node).

One of the main parts of the RIBASIM schematization is the demand identification. The demand can be represented by different types of nodes for different types of demands. Each one of these nodes requires different input data series. For example agricultural areas can be represented by either a fixed, a variable or an advanced irrigation node depending on the case. For the advanced irrigation node, the area is defined, as well as the planted percentage of the area, the cropping pattern, the evaporation rate and the irrigation coefficient (i.e. efficiency). A public water supply node can be defined as a fixed node or by population and a per capita rate.

To combine the routing of the inflow and to control how to satisfy the demand, the allocation priorities of water must be provided to the system. In case these are not defined, the model distributes water by location (first come, first served). The operation rules for all the structures should also be included to control the water management through the water network.

The model allocates water to different demands. Then, the shortage, if any, can be exported directly as an output of the model. The model compares the total demand of a node with the satisfied demand, and then defines the shortage. By knowing the allocated water and the operation rules of the energy generating structures, the energy production can be one of the direct outputs of the model. The discharge at any link in the network or at the end points can be determined from the model. It can also be used to compare two or more cases with respect to any of the outputs.

4.3.5 The High Aswan Dam Decision Support System (HAD-DSS)

The High Aswan Dam Decision Support System (HAD-DSS) is a comprehensive decision support software including a database, several utility tools, and a suite of control models to support the long range planning and short range operation of the High Aswan Dam (HAD) and Old Aswan Dam (OAD) reservoirs. HAD-DSS is used by the NFC staff to simulate the behavior of Lake Nasser. Through this simulation the application of different lake management strategies can be assessed for current conditions as well as for other conditions. These other conditions can be a reconstruction of the past but also a prediction of the future conditions (i.e. impacts of Climate Change).

The HAD-DSS covers the High Aswan Dam and Old Aswan Dam, with their hydropower plants. All turbine characteristic curves and reservoir data are incorporated in the HAD-DSS database and can be viewed using the software.

The assessment framework is shown in Figure 4-6 and consists of hierarchical models according to their temporal resolution. In operational mode, one would start with running the forecasts and then the long range control model followed by the short range model and finally the hourly dispatching models. In the current set-up, HAD-DSS also includes a planning module, a scenario/strategy simulation and assessment component to quantify the system response under various scenarios of reservoir inflows, irrigation requirements, and release strategies.

The applications in HAD-DSS provide the following models to assist the management of the hydro system from long range planning to short range operation:

1. 24 Hour Optimal Load Allocation Model to find the optimal unit load schedule for each hour. It can be used to support real time operation.
2. Short Range Control Model to implement the long range control model results for the first week/10day/month and find the best hourly control sequences that maximize hydro energy value.
3. Long Range Inflow Forecasts to generate inflow traces over a selected horizon for Lake Nasser. The results can be used in the control models.

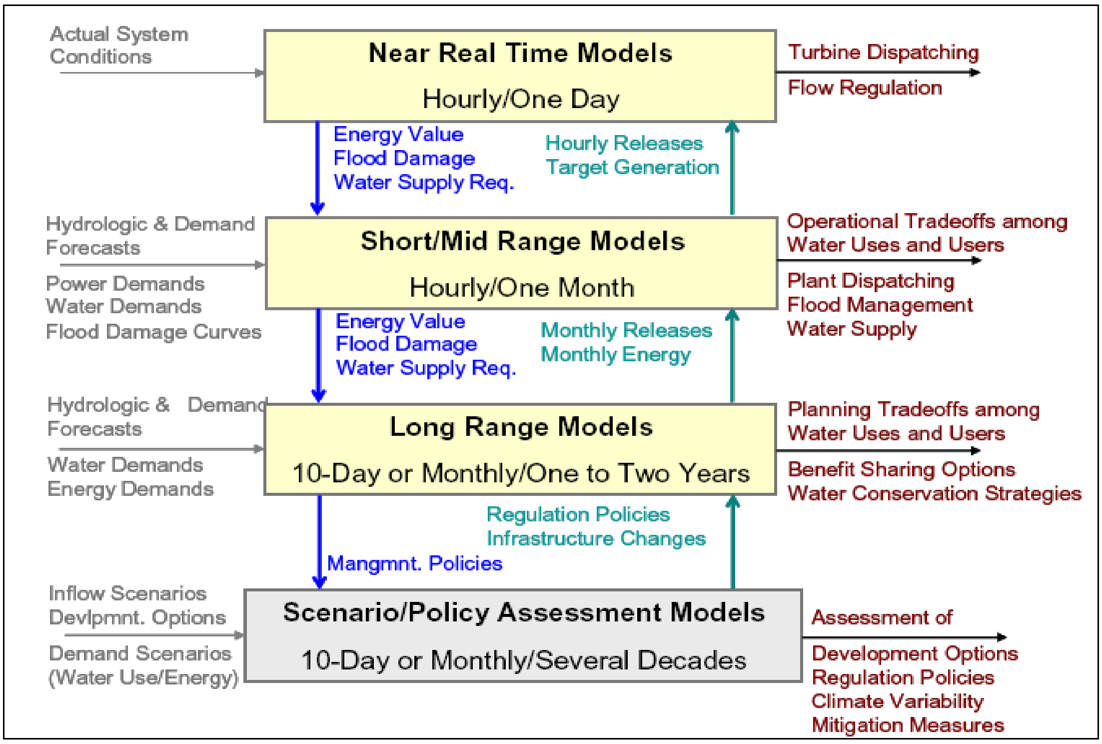


Figure 4-6 Assessment framework in the HAD-DSS

Long Range Control Model to find the best weekly/10 day/monthly release schedule for all reservoirs over a control horizon up to a year, subject to all hydrological constraints, water withdrawal requirements and forecasted inflow sequences. The optimization approach implemented for this model is the Extended Linear Quadratic Gaussian (ELQG) method.

Long Range Assessment Model to allow the user to simulate the operation of High Aswan Dam over a horizon of several decades. With this tool, the effect of different conditions and operations strategies can be assessed allowing for long term planning. After a policy is chosen, the rest of the models can be used for operations planning.

The HAD-DSS uses the inflow to Lake Nasser as an input in the following two forms:

The Natural flow (neglecting the effect of storage and losses of all the man-made structures as well as abstractions) and in this case the Sudanese abstractions should be provided explicitly.

The discharge at Dongola, which is usually an output from the NFS system (or any other source) and in this case all the upstream abstracts and reservoir effects are included.

The input data need to be in a monthly time step, though the output can be decadal, monthly, or annually. The model processes the inflow data combined with the operation rules of the dam to provide output time series for release, energy production, reservoir level and storage at Lake Nasser as well as any spillage.

4.4 METHODS AND TOOLS TO BE APPLIED

The Nile forecasting System in the NFC includes a hydrological forecasting capability to generate medium term hydrological forecasts using an Extended Streamflow Prediction (ESP) system (implementation described in Bellerby, 2005). Historical precipitation data for a given span of days within a year are taken from all available historical years in the hydro-meteorological database. These data are used to run the hydrological models forward, with each historical year rainfall being treated as an equally likely scenario for future rainfall. This procedure yields a Monte Carlo evaluation of the possible range of future streamflow, conditional upon current hydrological model states.

These capabilities can be used to predict of the low flows for both Blue Nile and Atbara River, however the forecasted flow can be compared with the average annual inflow for the Blue Nile and Atbara River. These capabilities can be modified or improvement to deal with the hydrological drought indicators to give alarm of dry season coming and how long the drought may be continue.

4.5 EXPECTED OUTCOMES AND PRODUCTS

The main expected outcome is to have a hydrological model that is able to forecast droughts in the study area with suitable lead time (about 3 month). This is expected to be established by using the models available in the NFC (mentioned in section 4.3)

4.6 HOW RESULTS AND IMPACT WILL BE MEASURED OR DETERMINED

The determined indicators (by NFC) shall be used to evaluate the results of the hydrological model (mentioned in the previous section).through that a good evaluation of the droughts and its expected meteorological and hydrological impacts can be provided. This can also reflect on the agricultural indices, but this will depend on the final form of these indicators and its requirements.

5. PROPOSED ACTIVITIES AND WORKPLAN FOR THE EASTERN NILE BASIN

5.1 PROPOSED ACTIVITIES

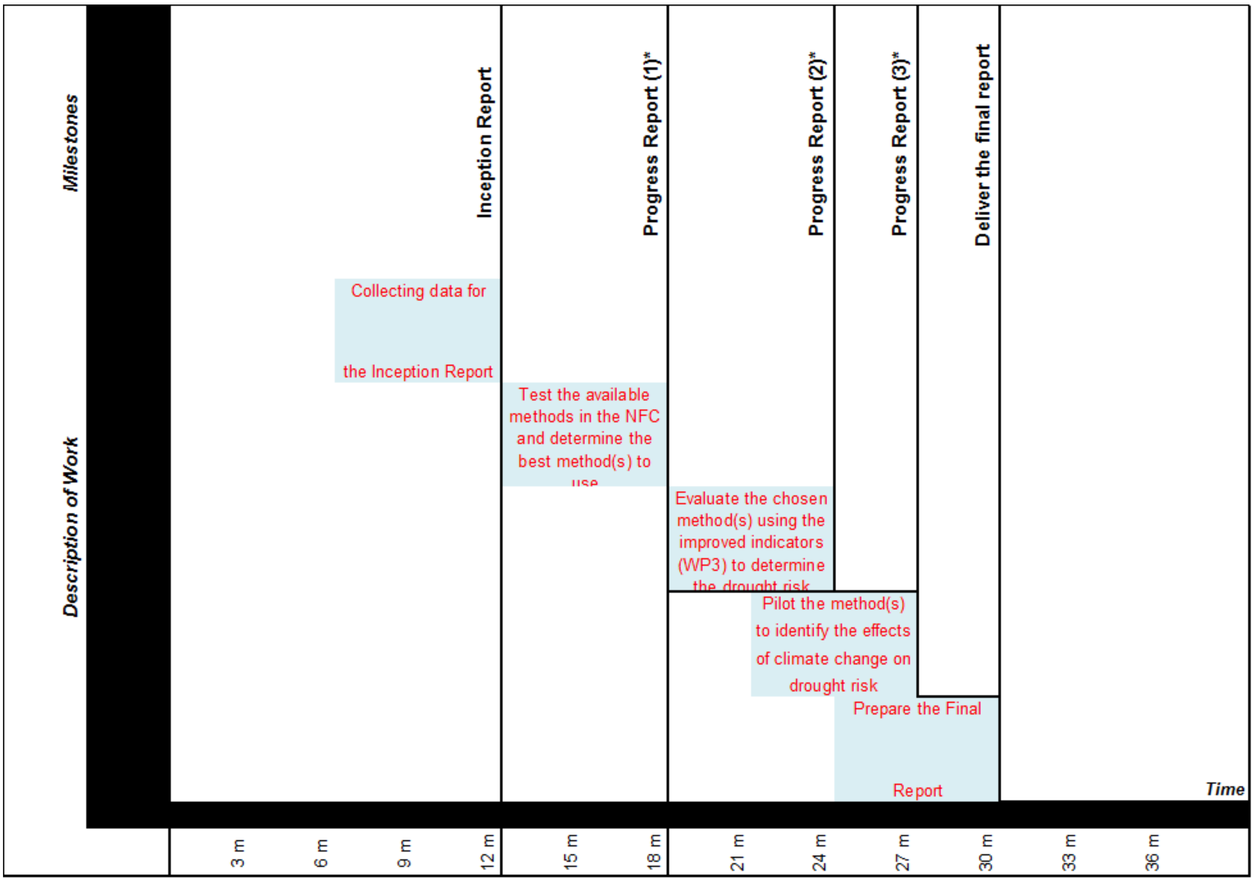
The four main activities as listed in the Description of Work (DOW) report are:

- To conduct statistical and dynamical seasonal forecasting in the Blue Nile and Atbara Basins (linked to Task 4.1).
- Pilot the methods to produce a seasonal drought warning, combining indicators, thresholds and model outputs from meteorological models and hydrological models (WP 3 and 4). NFC already has hydrological models, and these will be used as a starting point in this case study.
- Pilot the methods to identify the effects of climate change on drought risk using climate projections and vulnerability maps from WP 3.

Recommend methods for strengthening drought preparedness and improving farming practices in response to drought in the Blue Nile basin.

5.2 PROPOSED WORKPLAN, MILESTONES AND TIME SCHEDULE

Table 5-1 Proposed workplan and milestone for the Blue Nile case Study



6. DESCRIPTION OF THE LIMPOPO BASIN CASE STUDY

The Limpopo River located in eastern southern Africa, is about 1,750 km long and has a drainage basin of 415,000 km2, covering four countries: Botswana, Mozambique, South Africa and Zimbabwe. It is a semi-arid basin, with a mean annual rainfall of 530 mm and range of 200 -1200 mm (Ncube et al., 2010). The basin experiences a short and intense rainy season, with high spatial and temporal variability (Love et al., 2010b, 2011; Mupangwa et al., 2011b). The basin experiences frequent dry spells during the peak rainfall months and regular droughts, related to the occurrence of El Niño (Love et al., 2010a; Mupangwa et al., 2011a). Poverty is widespread and people are extremely vulnerable to the effects of drought on crop failure on both household food security and household income. (Love et al., 2006; Magombeyi et al., 2008).This has led to considerable reliance on food aid (FewsNet, 2011). More generally, the poor reliability of water resources can be related to the competition for water among countries and communities within the region (Ncube et al., 2009). The basin serves some of the continent’s largest urban areas, while it also supports several critical natural resource conservation initiatives, including the Greater Limpopo Transfrontier Park.

The SADC region, within which the basin falls, includes countries where vulnerability to food and water insecurity recur in most seasons as alluded to earlier. As a result, a number of organizations have long been involved, in partnership with SADC governments, in improving the ability of the region to have early warning of food and water insecurity; as well as improved response capacity. In fact, the process of producing a consensus seasonal forecast for the region had its genesis in the SADC region almost 20 years ago, in part in response to growing concern and awareness of the El Niño phenomenon.

Significant challenges remain, however, in terms of vulnerability assessment, early warning and support for response. This section of the inception report provides some baseline information for the Limpopo Basin, as well as gaps in order to inform the development of a consolidated plan of action, in partnership with other collaborators in the SADC region.

6.1 GEOGRAPHICAL AREA

The Limpopo River Basin is situated in the east of southern Africa between about 20 and 26 °S and 25 and 35 °E. The basin covers almost 14% of the four riparian states, Botswana, Mozambique, South Africa and Zimbabwe. The percentage coverage of the different countries is 45% for South Africa; 20% for Botswana and Mozambique and 15% for Zimbabwe (LBPTC, 2010). The Limpopo River flows north from the confluence of the Marico and Crocodile Rivers, where it creates the border between South Africa and Botswana, then the border between South Africa and Zimbabwe, before crossing into Mozambique, where it runs across a broad floodplain and into the Indian Ocean (Figure 6.1).

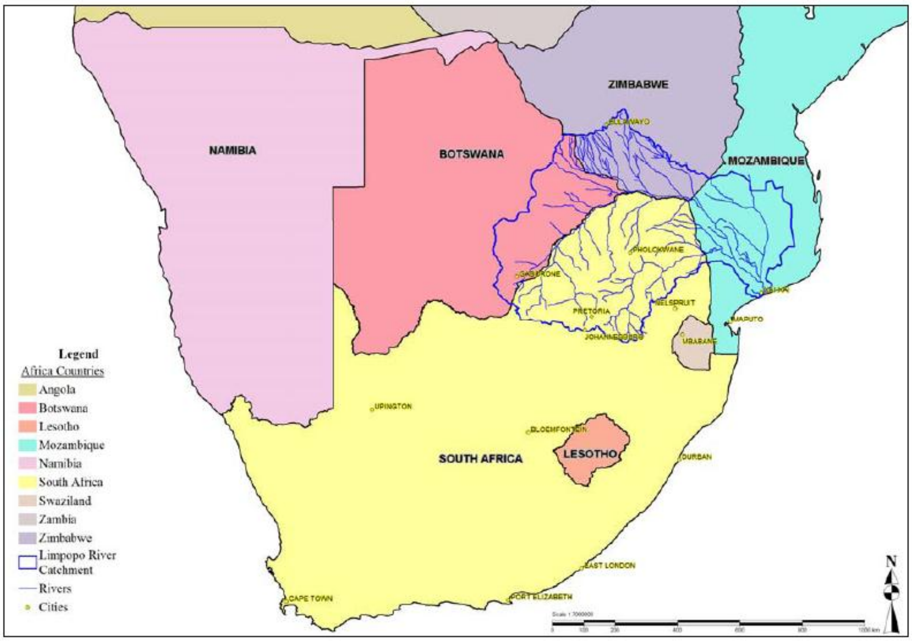


Figure 6-1 Regional map showing the Limpopo River Basin (LBPTC, 2010)

The Limpopo River basin consists of 24 individual tributaries - 13 on the north bank and 11 on the south bank. These 24 tributaries differ in size from the small Shabili River in Zimbabwe to the large Olifants River, which is shared by South Africa and Mozambique. The layout of the Limpopo River basin and its tributaries are presented in Figure 6-2:

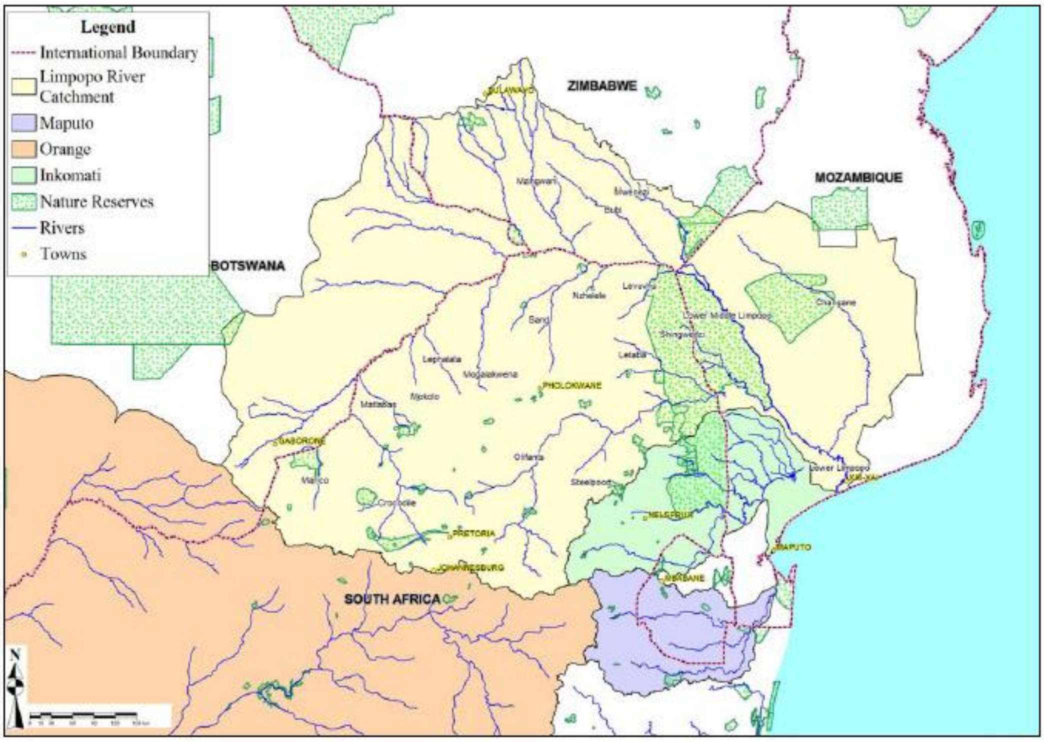


Figure 6-2 Limpopo River Basin Layout (LBPTC, 2010)

The topography varies from above 2,000 m.a.s.l in the mountain regions of South Africa to the vast flood plains in the Mozambican part of the catchments (Figure 6-3). The last 175 km of river stretch has elevations below 7 m.a.s.l. The river basin is mainly characterised by flat or undulating plains with grass and bushland. The exceptions to the generally flat landscape are the mountainous regions in South Africa, such as the Waterberg, Strypoort Mountains and the Drakensberg range that comprises the divide to the Incomati River in the south-eastern part of the catchment.

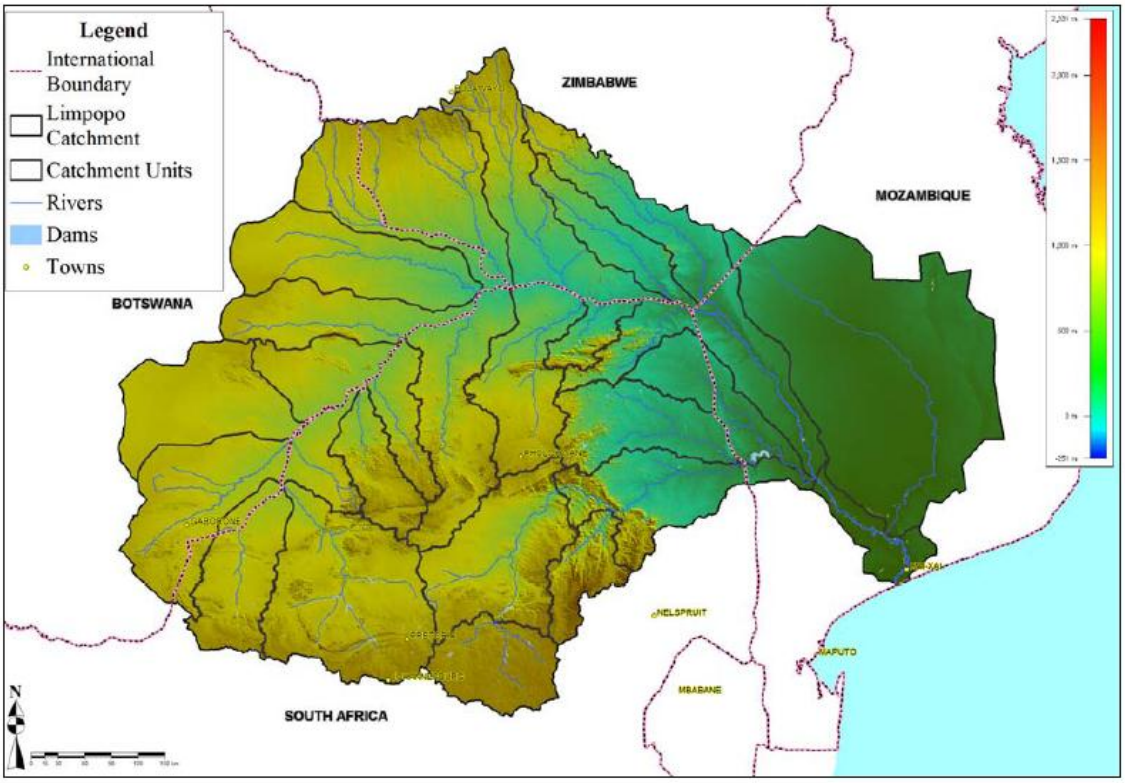


Figure 6-3 Topography of the Limpopo River Basin (LBPTC, 2010)

6.2 CLIMATE

According to climate classification by Köppen (1918), seven types are found within the Limpopo basin (Figure 6-4).

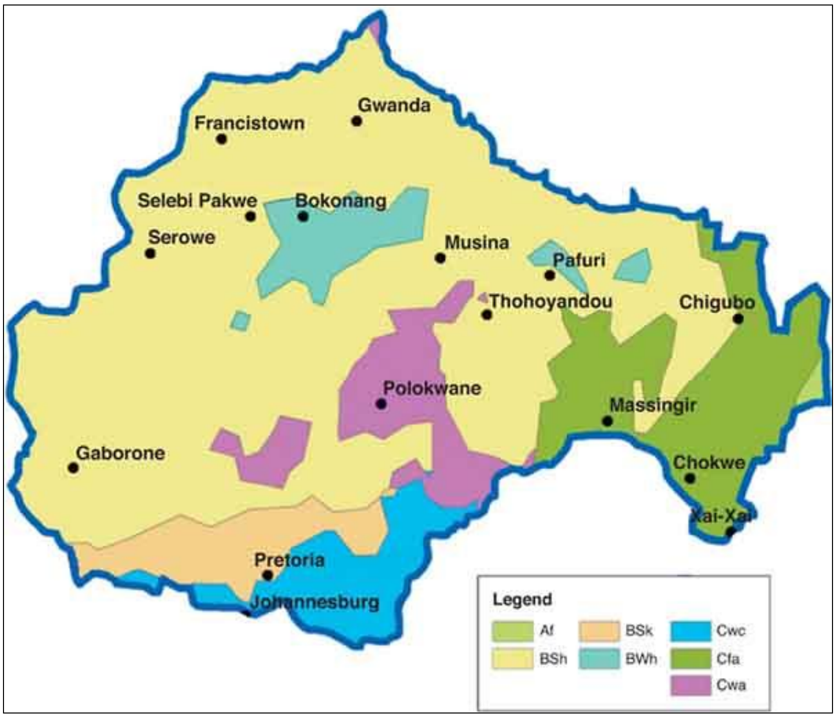


Figure 6-4 Map of the Limpopo showing the climate classification according to Köppen (1918)

Rainfall

Annual rainfall varies between 200 mm in the hot, dry western and central areas to 1,200 mm in the high-rainfall eastern escarpment areas. Rainfall is highly seasonal and unevenly distributed spatially, with about 95 % occurring in the summer season between October and April, typically concentrated in a number of isolated rain days and in isolated locations (CPWF, 2003). The areas that receive the highest rainfall are the mountainous areas in South Africa while the lowest rainfall is found along the Limpopo River between Zimbabwe and South Africa. Figure 6-5 illustrates the distribution of average rainfall across the Limpopo Basin.

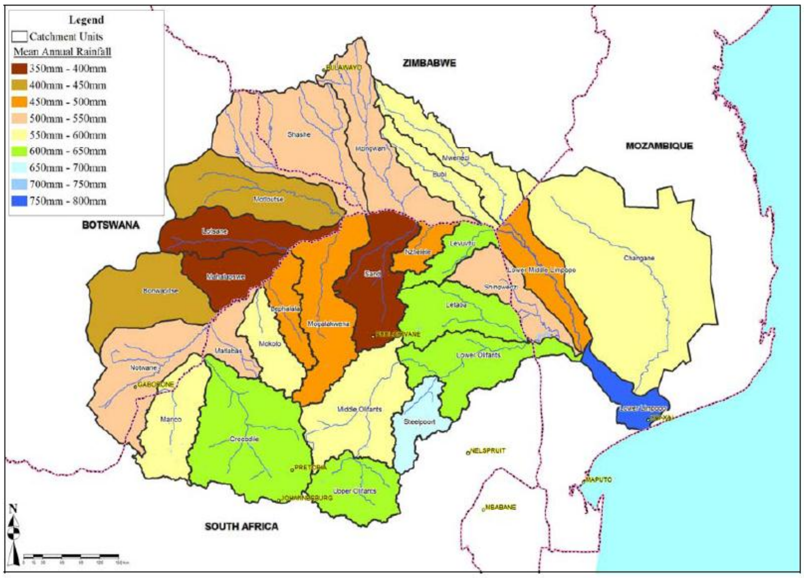


Figure 6-5 Average rainfall in the Limpopo Basin

An overview of the annual rainfall per country in the basin is given in Table 6-1 below:

Table 6-1 Annual rainfall per country in the basin area

Country	Annual rainfall in the basin area (mm)		
	Min.	Max.	Mean
Botswana	250	555	425
Mozambique	355	865	535
South Africa	290	1050	590
Zimbabwe	300	635	465
Basin	250	1050	530

Source: CPWF (2003)

Evaporation

Evaporation within the Limpopo River Basin varies from 1 600 mm/year to more than 2 600 mm/year. The highest evaporation occurs in the hot Limpopo River Valley. High levels of evaporation mean that the soil dries up quickly and this reduces the amount of water available for plant uptake. This results in crops being more prone to drought. Evaporation is highest during the rainfall season, and it significantly reduces effective rainfall, runoff, soil infiltration and groundwater recharge. Evaporation loss from dams is significant owing to the high storage-yield relationship and flat dam basins.

Table 6-2 below shows the mean annual precipitation and the mean annual evaporation for major sub catchments in the Limpopo River basin

Table 6-2 Rainfall and evaporation figures for major sub catchments

Catchment	Area [km^2]	MAP [mm]	MAE [mm]
Mohalapwe	3385	454	2000
Lephalala	4868	513	2328
Lotsane	9748	430	2000
Mogalakwena	20248	386	1902
Motloutse	19053	430	2000
Shashe	18991	485	2154
Umzingwani	15695	475	2065
Sand River	15630	384	1690
Nzhelele	2436	422	2160
Bubi	8140	315	2427
Luvuvhu	4826	715	1635
Mwenezi	14759	465	1810
Olifants	68450	500	1700

Source: CPWF Limpopo (2003)

Temperature

Similarly to the rainfall, surface air temperatures in the Limpopo River basin show a marked seasonal cycle, with highest temperatures during the summer months and lowest temperatures during the cool and dry winter months. In summer, the daily temperatures may soar above 40°C, while in winter temperatures may fall to zero. The mean maximum daily temperature in most of the Limpopo River Basin, notably South Africa, Botswana and Zimbabwe, varies from about 30-34 °C in the summer to 22-26 °C in winter. The mean minimum daily temperature in most areas lies between 18-22 °C in summer and 5-10 °C in winter.

Humidity

Relative humidity is generally higher on the eastern side of the Limpopo River Basin, and decreases inland. The relative humidity varies from less than 50 percent in September and October in the hot western parts of the basin in South Africa, to about 65 percent in January and February. Humidity in the Lowveld in South Africa varies only slightly (65-70 percent) in the same period.

Relative humidity in Botswana is comparatively low, with daytime averages of about 30 percent in winter and 40 percent in summer. However, much higher values are reached in the morning, nearing 60 percent in winter and more than 70 percent in summer. Humidity also increases before rainstorms, and is therefore highest between January and March. The dry western parts of Botswana record the lowest humidity (FAO, 2004).

6.3 HYDROLOGY

The Limpopo River basin is located in a region classified as arid to semi-arid, where water resources are under huge pressure from the environment alone, even before human development demands are factored in (CGIAR 2003). Therefore, water is a limiting factor in development in the region (CGIAR 2003).

The water resources of the Limpopo River basin support a large population and significant economic activities, including mining and agriculture, all of which depend on water for survival and growth.

Surface Water Resources

The Limpopo River can be divided into the following logical reaches (FAO, 1997):

- Upper Limpopo River, down to the Shashe confluence at the South Africa-Botswana-Zimbabwe border; runoff from South Africa and Botswana.
- Middle Limpopo River, between the Shashe confluence and the Luvuvhu confluence at the South Africa-Zimbabwe-Mozambique border (at Pafuri); runoff from Botswana (Shashe), Zimbabwe and South Africa.
- Lower Limpopo River, downstream of Pafuri to the rivermouth in the Indian Ocean; runoff from Zimbabwe (Mwenezi), South Africa and Mozambique.

Several tributaries originate in Botswana, the most important being the Shashe River, which forms the border between Botswana and Zimbabwe before flowing into the Limpopo River. Other major tributaries, ranked according to decreasing mean annual runoff (MAR), are the Motloutse, Lotsane, Notwane, Bonwapitse and Mahalapswe Rivers.

The main tributaries within Zimbabwe are the Shashe and Umzingwane Rivers, with the Mwenezi and Bubi Rivers as other major tributaries. The Mwenezi River originates in Zimbabwe, but joins the Limpopo River in Mozambique.

The most important tributary within South Africa is the Elephants River, which originates between Johannesburg and Witbank and flows into the Limpopo River in Mozambique. Important tributaries of the Elephants River are the Shingwedzi and Letaba Rivers. Major tributaries of the Crocodile-Limpopo part of the Limpopo River Basin, ranked according to decreasing MAR, are: Luvuvhu (which joins the Limpopo River at Pafuri), Mokolo, Mogalakwena, Marico, Lephalala, Nzhelele, Sand and Matlabas Rivers.

The part of the Limpopo River Basin in Mozambique is estimated to contribute 10 percent of the total MAR of the river. The Limpopo River, which was initially a perennial river in

Mozambique, can actually fall dry for up to a period of eight months per year, mainly as a consequence of abstractions in the upper catchment area (GOM-DNA, 1995). Downstream of Chokwé, the Changane River (an intermittent tributary) joins the Limpopo River. Although it drains 43 000 km^2, it has a very low runoff coefficient and periods with no discharge at all. The Lumane River, the last of the most important tributaries, originates in Lake Pave and receives water from the sandy hillsides and, therefore, flows permanently. Table 6-3 below indicates some estimated contribution of major tributaries in terms of MAR.

Table 6-3 Limpopo River tributaries (ranked by current MAR)

Country	Tributary	Catchment Area (km²)	Naturalised Runoff (million m³)	Denaturalised Runoff (million m³)	Unit Runoff (denat. MAR) (mm)
South Africa	Marico	13 208	172	50	3.8
South Africa	Crocodile	29 572	391	205	6.9
Botswana	Notwane	1 853	55	24	1.4
South Africa	Matlabas	3 448	382	21	6
South Africa	Mokolo	7 616		117	15.4
Botswana	Bonwapitse	9 904	15	15	1.5
Botswana	Mahalapswe	3 385	13	13	3.9
South Africa	Lephalala	4 868	150	99	20.3
Botswana	Lotsane	9 748	62	62	6.4
South Africa	Mogalakwena	20 248	269	79	3.9
Botswana*	Motloutse	1 953	111	111	5.8
Total for upper reach		**139 103**	**1 620**	**796**	5.7
Botswana	Shashe	12 070	250	250	20.7
Botswana	Other	7 905			
Zimbabwe**	Shashe	18 991	462	462	24.3
Zimbabwe**	Umzingwane	15 695	350	350	22.3
South Africa	Sand	15 630	72	38	2.4
South Africa	Nzhelele	3 436	113	89	26
Zimbabwe**	Bubi	8 140	53	53	6.5
Total for middle reach		**81 867**	**1 300**	**1242**	15.2
South Africa	Luvuvhu	4 826	520	492	102
Zimbabwe**	Mwenezi	14 759	256	256	17.4
Zimbabwe**	Other	4 956	36	36	7.3
South Africa	Elephants	68 450	1 644	1233	18
South Africa	Other	13 996	2 352		
Mozambique	Changane	43 000			

Mozambique	Elephants	1 550			
Mozambique	Other (e.g. Lumane)	40 431	315		
Total for lower reach		**151 537**	**5 123**	**2017**	**21.7**
Total		**412 938**	**8 043**	**4055**	**9.8**

Source: Limpopo River Awareness Kit 2010

Groundwater resources

Groundwater is a critical source of water for people living in the SADC region, with approximately 37% of the population of the region relying on formal or improved groundwater sources, 23% from formal surface water supplies and 40% relying on unimproved groundwater and surface water sources. This level of dependence is combined with the fact that approximately one third of the population of the region live in drought-prone conditions, making groundwater an even more precious resource (SADC 2011).

Groundwater is used extensively throughout the southern African region, including the Limpopo River basin, supplying a large percentage of water for irrigation and rural water supply schemes (FAO 2004). This is especially true in rural areas, located away from surface water resources. Groundwater is also used extensively by the mining industry in the basin (CGIAR 2003).

Country cases:

Due to limited surface water resources, particularly in the south of the country, **Botswana's** rural population is highly dependent on groundwater (FAO 2004). Approximately 65% of water resources supplied in Botswana comes from groundwater. Rural groundwater supplies are now augmented by surface water inputs from the North-South Water Carrier, which is due to be linked to Serowe in the Limpopo River basin during 2010.

While groundwater potential in **Mozambique** is generally quite high, potential in the Mozambique portion of the Limpopo River basin is poor, with high mineralisation in many of the aquifers. The Dune area along the coast of Mozambique is thought to have good groundwater potential, with approximately 5 to 10 m^3/h per km^2 (Kundell 2007).

Groundwater plays an important role in water supply in rural areas of the **South African** portion of the Limpopo River basin, providing domestic and irrigation water in the order of approximately 850 Mm^3/year. Many of the rural communities of this region are located on or near marginal aquifers with potential yields of 2 l/s (FAO 2004). Groundwater quality is relatively poor due to high salinity. Groundwater resources in the Dendron area of the Limpopo Province of South Africa have been severely overexploited.

Groundwater Resources in southern **Zimbabwe** are not very productive, with many of the domestic wells and boreholes supplying individual households and small communities drying up before the end of the dry season (FAO 2004). Land degradation resulting from poor land use management have meant that the remaining *dambo* wetlands of the Matabeleland south province have long dried up.

In addition to the local aquifer systems, the Limpopo River basin includes a series of transboundary aquifers. These aquifers are particularly important as they are shared by two or more countries, requiring cooperative management of water use/abstraction and sources of pollution that may affect them.

Groundwater is primarily abstracted through boreholes (groundwater wells), drilled from the surface by a groundwater drilling rig. The estimated distribution of boreholes across the Limpopo River basin. The actual number of boreholes may vary significantly as many boreholes are not registered when drilled or were drilled prior to the creation of national inventories.

Overall the potential yields of boreholes in the Limpopo River basin is relatively low, limiting the extent to which groundwater can be used for large scale water supply. The exceptions to this are areas accessing the alluvial aquifers along the Limpopo River.

Although potential yield is low, groundwater forms an essential resource in times of low stream/river flow (CGIAR 2003).

6.4 GEOLOGY

The geology of the Limpopo Basin (Figure 6-6) spans the stratigraphic record for the African continent. Igneous and metamorphic rocks found in the upper Basin date back 3,400 million years to the Precambrian Era and are some of the oldest in Africa. These rocks are part of the vast crystalline basement complex underlying the continent. Thin veneers of younger terrestrial deposits from the Permian (290 million years) and Triassic (240 million years) are present as well.

Eras overlay the basement complex in several places in the upper Basin, and younger-still Mesozoic igneous rocks intruded beneath these sediments have become exposed through erosion. Cretaceous marine deposits from 138 million years ago extend across a narrow north-south strip along the western edge of the Limpopo Basin in Mozambique. Further east, Tertiary Era sediments (66 million years) straddle the Limpopo and Elefantes rivers. Relatively recent Quarternary rocks (1.6 million years) comprise the rivers' floodplains and the Basin's western borders. Pleistocene deposits form Mozambique´s coastal plain. Minerals and salts eroded from the upper reaches of the Basin contribute to poor water quality in Mozambique (FAO,2004).

Major tectonic features in the region are associated with the East African Rift system extending from northern Uganda to southern Mozambique. Several widely distributed and inactive faults occur in the Precambrian rocks. Relatively strong earthquake activity occurs near Johannesburg and Pretoria, and may pose some risk to the built environment and dams.

There is a close, fundamental relationship between soils and the geology of the rocks that lie beneath them. Most soils are weathered and modified sediments from underlying bedrock, or have been transported to their present location by some form of mass transit.

Another relationship that it is important to recognise is the close link between geology and geohydrology/groundwater. The lithology and geological structure of a region has a direct result on the storage, quality, availability and recharge potential of groundwater resources. While the majority of aquifers in southern Africa are associated with secondary porosity - secondary aquifers - the Limpopo River basin features some of the few alluvial aquifers in the region, with subsurface flow of the Limpopo River and some of the tributaries providing groundwater to towns and mines along the main stem river during periods of low flow (FAO, 2004).

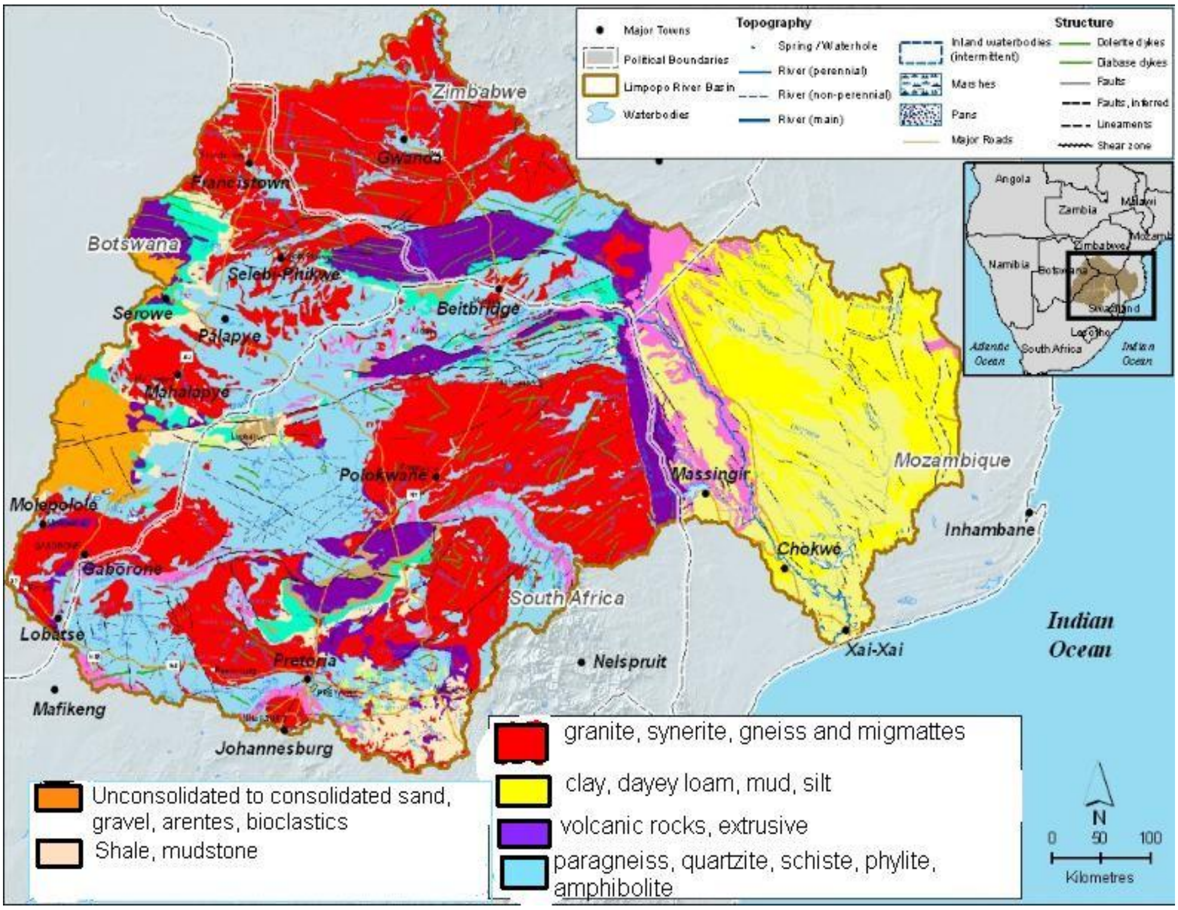


Figure 6-6 Map of the generalised geology of the Limpopo River basin. Source: SADC 2010

Landforms and soil development are linked to geological and tectonic development at a subcontinental scale. Much of the present landscape of the Limpopo River Basin reflects recent geological events - in geological terms - following the break-up of Gondwanaland (Moon and Dardis, 1988). Tankard *et al.* (1982) and McCourt and Armstrong (2001) recognized the sequence of crustal evolutionary stages in southern Africa.

6.5 SOILS

The dominant soil types in the Limpopo River basin (Figure 6-7) are generally broken down into two main groups:

- Older soils that have formed from deep weathering of parent material - examples of such deeply weathered, old sediments are the soils occurring on the Highveld plateaus of South Africa and Zimbabwe; and
- Considerably younger, shallower sediments from more recent erosional activities or deposited alluvium - the lowveld and coastal plains of Mozambique are good examples of younger, less weathered soils.

These two periods of soil formation are a result of erosional activities in different climates at different times. The older soils were created during a time of higher temperatures and higher rainfall, whereas the shallower younger soils have developed in drier climates, less conducive to soil development.

Table 6-4 presents a description of major soils found in the Limpopo basin.

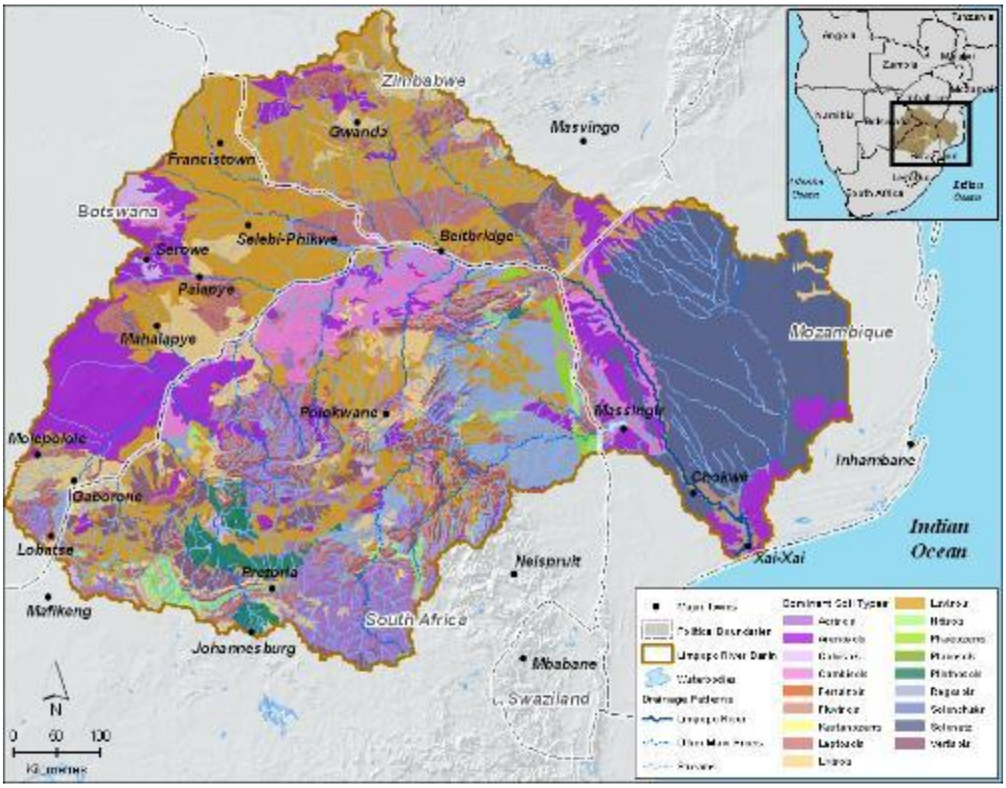


Figure 6-7 The dominant soil types in the Limpopo River basin. Source: FAO ISRIC, (2003)

Table 6-4 Dominant soil types of the Limpopo River basin.

Name	Description	Distribution
Arenosols	Sandy soils, developed from weathering of quartz-rich material or rock. Loamy sandy consistency up	The Mozambique coast, in a zone adjacent to the

	to approximately 100 cm depth. Less than 35 % rock fragment. Parent material unconsolidated calcareous or sandstone rocks. Code: AR	Lebombo range, and in the southern half of the Botswana part of the basin
Solonetz	Soils with a densely structured, clay subsurface layer, with a high proportion of absorbed Sodium and Magnesium and are generally alkaline. Parent materials are generally unconsolidated, fine-textured sediments. These soils generally occur in flatter lands in warmer climates that experience hot, dry summers. Code: SN	The Mozambique coastal plain
Luvisols	Soils with a higher clay content in the lower horizons, that the upper horizons. Wide variety of different parent material types, including glacial, aeolian (wind-blown), alluvial (water-borne) or colluvial (gravity) deposits. Code: LV	Zimbabwean and northern Botswanan parts of the basin.
Leptosols	Shallow soils found over continuous stony/gravelly rock and soils. Parent materials are various, with fine earth volumes of less than 20 %. Code: LP	Zimbabwean and northern Botswanan parts of the basin.
Regosols	A group of Weakly developed mineral soils originating from unconsolidated material that do not conform to other classes. Code: RG	Dominate the Lowveld between the eastern escarpment and the Lebombo range in the South African part of the basin
Leptosols	Very shallow soils developed over hard rock or calcareous material. Common in mountainous regions. Less than 10 % fine earth content. Code: LT	Wherever the terrain is hilly in the South African part of the basin
Vertisols	Heavy, churning (internally moving) clay soils that include clay minerals that swell with water, resulting in large cracks when dry. Code: VR	Found overlying mafic rocks

Nitisols	Deep, well-drained red tropical soils with diffuse horizons and >30 % clay content in the subsurface. Parent materials include intermediate basic parent rock products. Code: NT	Found overlying mafic rocks
Acrisols	Soils with higher clay content in the subsurface than upper portions. Parent materials include strongly weathered acid rocks and weathered clays that are degrading. Found mostly in older landscapes of undulating topography in sub-tropical or former sub-tropical environments. Code: AC	Dominate the Highveld of the southern basin

Adapted from FAO 2004; IUSS 2006

6.6 LAND COVER/LAND USE

The land cover of the Limpopo River basin is relatively heterogeneous (using the USGS/IGBP Global Land Cover Characteristics dataset), with four main classes dominating the landscape (Loveland et al., 2000):

- Cultivated agriculture
- Savanna
- Grassland
- Shrubland

This information agrees with several other regional and global estimates of land cover, including the Global Land Cover Facility data (2005) and World Resources Institute (2003). The distribution of the main land cover classes across the Limpopo River basin are shown in the figures 6-8 and table 6-5 below.

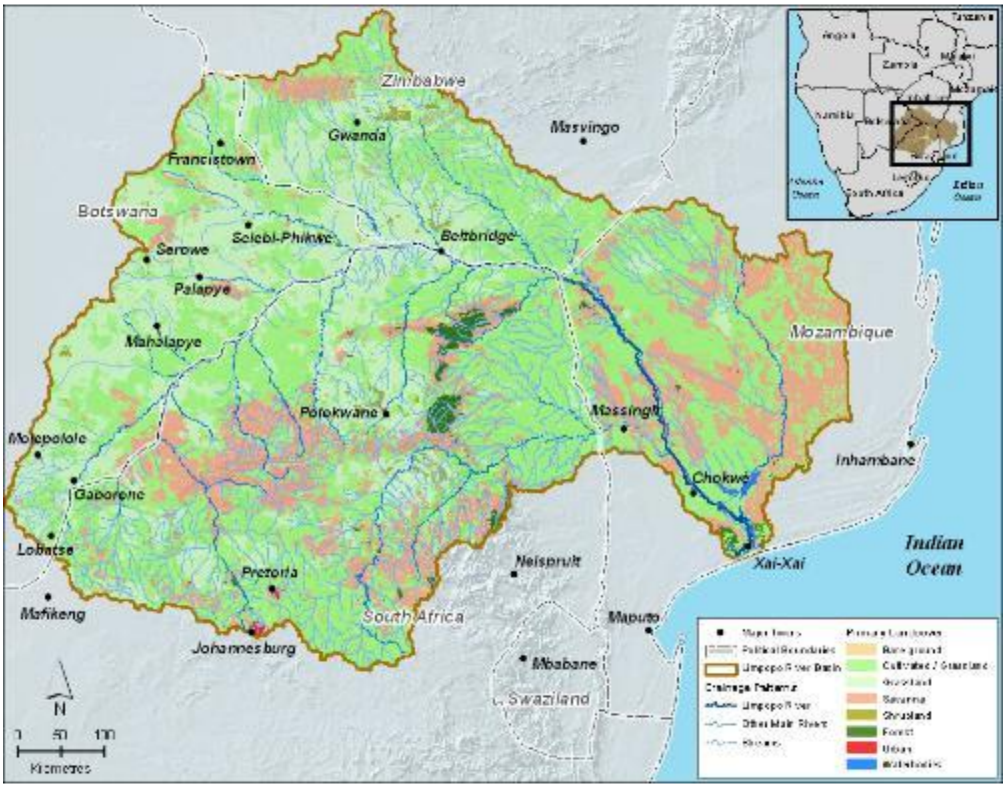


Figure 6-8 Primary land cover classes of the Limpopo River basin. Source USGS/IGBP, (2010)

Table 6-5 Summary of the main generalised land cover for the Limpopo River basin.

Land cover type	**Area (Ha)**	**Percentage of total**
Bareground	112,154	<1
Cultivated land/grassland	21,678,104	53
Grassland	10,306,742	25
Savanna	8,067,132	20
Shrubland	192,269	<1
Forest	481,043	1
Urban	48,014	<1
Waterbodies	228,714	<1
Total	**41,114,172**	

Source: Limpopo River Awareness Kit 2010/ USGS 2010.

6.7 DEMOGRAPHY

The Limpopo River Basin is home to around 14 million people in four riparian states, Botswana, Mozambique, South Africa and Zimbabwe.

Population characteristics of countries in the Limpopo River Basin is presented in table 6-6

Table 6-6 population in the Limpopo Basin

Country	Total 2007 population (million) estimated	Total population in Limpopo basin 2007 (million) estimated	% living in the Limpopo river basin
Botswana	1,756651	1,205580	69
South Africa	47,900000	10,720838	22
Zimbabwe	11,392629	1,140833	10
Mozambique	20,366795	1,389703	7
Total	81,416075	14,456954	18

Source LBPTC, (2010)

There is a strong diversity of rural versus urban population in the Limpopo Basin. In Botswana and South Africa, the capital cities and some of the largest populations reside within the basin boundaries, such as Gaborone, Francistown, Pretoria, Witbank and Polokwane. Aside from these urban centres, the population is predominantly rural. On average at the national level, the population in the Limpopo Basin countries is just over 50% rural-ranging from 31% in Botswana to 66% in Zimbabwe.

6.8 INFRASTRUCTURES

Water infrastructure consists of man-made structures and facilities used to abstract, retain, treat, convey and deliver water to users, and to collect, transport, treat and dispose of wastewater. Typical infrastructure includes: groundwater well-fields, water supply schemes, sewage treatment facilities, dams, river water abstraction works, inter-basin transfers (bulk transfers), and canals.

Although surface water delivered through large transfer schemes and dams is an important source of fresh water in the Limpopo River basin, the arid regions of the basin are highly dependent on groundwater and the small-scale supply of surface water. The majority of users are informal small-scale users in rural areas with use governed by informal local arrangements (van Köppen *et al*. 2008).

Storage dams are quite prevalent in the Limpopo River basin as they are necessary to make use of its water resources (LBPTC 2010). There are many small dams within each country in the basin under 5 Mm^3 with most under 1 Mm^3 which have not been listed here as they have a negligible effect on the basin hydrology (LBPTC 2010).

Figure 6-9 below illustrates the percentage of MAR stored within the dams in each sub-catchment in the Limpopo River basin (LBPTC 2010). The catchments of Notwane (Botswana), Marico and Upper Olifants (South Africa), and Msingwani and Mwenezi (Zimbabwe) store greater than 100 % of MAR in dam developments. Conversely, the sub-catchments in Botswana (Lotsane, Bonwapitse, and Mahalapswe), South Africa (Lephalala, Steelpoort, Lower Olifants, Levuvhu, Shingwedzi), all catchments in Mozambique, and Bubye in Zimbabwe store 25 % or less of MAR within dams.

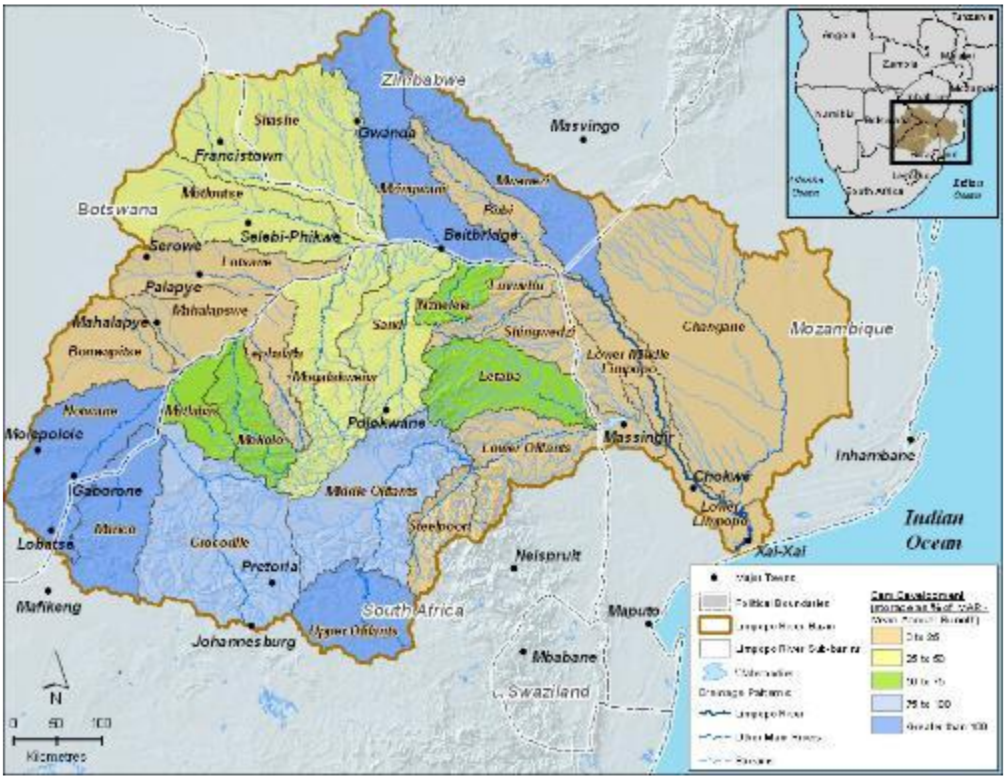


Figure 6-9 Dam Development (Storage as % of Mean Annual Runoff). Source: LBPTC 2010

Groundwater is mainly used in the Limpopo basin for irrigation and rural supplies (Barros 2009). It is noted that over 1 000 boreholes have been drilled in the Limpopo basin, however, very few of these have had continuous water levels measured and there is limited information on depth, geological characteristics, and location (LBPTC 2010). The existing aquifer in the medium lower Limpopo Valley has depths ranging from 80 to 200 m.

Very little monitoring of groundwater conditions has been conducted throughout the basin and has only been completed where resources have been overexploited. The main need for groundwater data is due to the interconnected nature of groundwater and surface water interactions.

Within the Limpopo River basin there are three transboundary aquifers along the northern border of South Africa with Botswana, Mozambique, and Zimbabwe (Cobbing et al. 2008):

- Ramotswa Dolomite

- Tuli Karoo
- Limpopo

The Limpopo aquifer underlies the Limpopo River which is a well-known sand river in southern Africa. It is also a transboundary aquifer with unconsolidated alluvial deposits which fill the river channel and build up the irregular adjoining floodplain. Sustainable utilisation of the aquifer is dependent up the management of surface water in the river. A mean saturated thickness is noted at 3.5 m with a hydraulic conductivity of 120 m/day. The aquifer is the broadest east of the Limpopo/ Shashe confluence increasing from 500 to 700 m as it enters Mozambique, but narrows to 50 m near the Limpopo/Crocodile confluence.

6.9 REGIONAL WATER RESOURSES USE

In all the four countries represented in the basin, agricultural water use clearly dominates when compared to the domestic and industrial water use sectors (Table 6-7). The high proportion of water used for agriculture suggests that each Limpopo riparian country heavily relies on grown food within its borders to meet national goals of food security.

Table 6-7 Water use by sector for Limpopo riparian states

Country	Agriculture (%)	Industry (%)	Domestic (%)
Botswana	48	20	32
Mozambique	89	2	9
South Africa	62	21	17
Zimbabwe	79	7	14

Source: SADC 1999

Table 6-8 presents the estimated annual groundwater abstractions in the Limpopo River basin (Environmentek, CSIR 2003).

Table 6-8 Annual groundwater abstractions in the Limpopo River basin (estimated).

Country	Estimated Annual Groundwater abstraction (Mm^3/year)	Sector use
Botswana	Approx. 23,1	Domestic, irrigation
Mozambique	Approx. 15	Domestic
South Africa	462	Domestic, irrigation, mining
Zimbabwe	Approx. 5,9	Irrigation,

Source: Environmentek, CSIR 2003

In 1997, the Food and Agriculture organisation of the United Nations estimated the irrigation potential of the Limpopo basin at 295 400 ha based on land and water resources and appropriate cropping patterns (FAO 1997). Table 6-9 summarised the irrigated land as reported by FAO.

Table 6-9 Irrigation Potential of the Limpopo basin.

Country	**Irrigation Potential (ha)**	**Irrigation water requirements (Mm^3/year)**	**Irrigated Area (ha)**
Botswana[1]	5 000	53	1 381
Mozambique	148 000	1 702	40 000
South Africa	131 500	1 578	198 000
Zimbabwe[1]	10 900	120	4 000
TOTAL	**295 400**	**3 453**	**243 381**

[1] Other literature has given Botswana and Zimbabwe higher irrigation water requirements thereby reducing the irrigation potential estimates herein. Source: FAO 1997

6.10 HISTORICAL INFORMATION ON DROUGHTS

According to the International Fund for Agricultural Development (IFAD), as cited by Benson, Thomson and Clay (1997), at least 60 % of sub-Saharan Africa (SSA) is vulnerable to drought and probably 30 % is highly vulnerable.

Drought is the most common and devastating of all environmental affecting the Limpopo basin, with impacts felt in economic, social and environmental terms (Leira et al 2002; FAO 2004). Variable and erratic rainfall means that the rainy season often does not start when expected and can be episodic, with an entire season's rainfall occurring within a few days.

In the period 1980-2000, the SADC region was struck by four major droughts, notably in the seasons 1982/83, 1987/88, 1991/92 and 1994/95. This corresponds to an average frequency of once every four or five years, although the periodicity of droughts is not necessarily so predictable. FAO (1994) identified three drought cycles during the years 1960 to 1993 with lengths of 3.4, 7.1 and 5.8 years, respectively. Amplitudes were 0.38, 0.35 and 0.28 standard deviations, respectively. Leira et al 2002 suggests that droughts in the region occur every 7 to 11 years. FAO (2004) states that extreme droughts occur in the basin every 10 to 20 years. The northern bank of the Limpopo River in Botswana, Zimbabwe and Mozambique, appears to be more susceptible than the northern bank in the South African portion as indicated in figure 6-10 below.

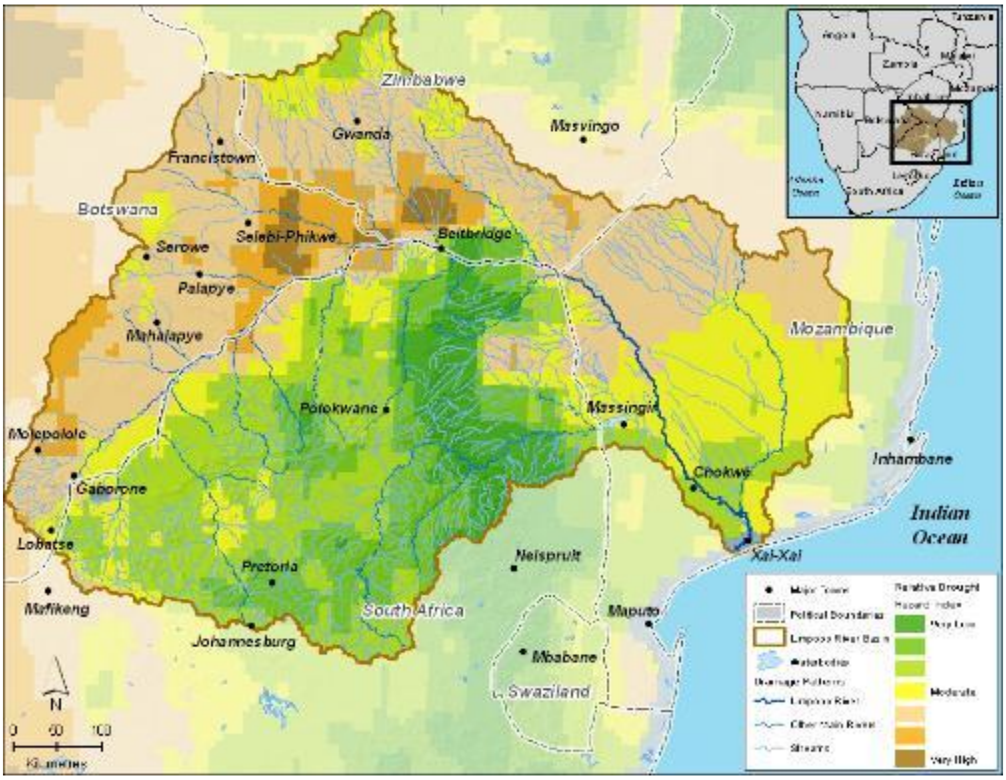


Figure 6-10 Relative Drought Hazard Index for the Limpopo River basin. **Source: Leira et al. 2002**

The drought of 1991–92 was the most severe in recent history, affecting the entire southern Africa region including the Limpopo River basin. Although there are strong indications that drought occurs cyclically in southern Africa, it is not yet possible to predict these events with a high degree of certainty. Scientists have discovered a relationship between the El Niño Southern Oscillation (ENSO) and drought in southern Africa, but the correlation is not strong. In terms of hydrological drought, a mixed positive and negative correlation between the warm ENSO events and the quarterly seasonal river runoff in southern African Rivers has been reported (Alemaw and Chaoka 2006).

6.11 PURPOSE OF THE CASE STUDY

The focus in this case study is on the flow of information during drought early warning. Information will be generated by the forecasting system developed in WP 4. This information will flow from the warning system through the institutional framework from regional to local scale. The Limpopo is therefore a pilot for the application of DEWFORA's drought early warning framework. In close collaboration with other stakeholders in the region, improvements in the institutional framework and procedures will be suggested and implemented, building on the technical developments.

6.12 DESCRIPTION OF NEEDS AND PROBLEMS TO BE ADRESSED BY THE CASE STUDY

The Limpopo Basin comprises one of the most water stressed basins on the African continent, shared by South Africa, Botswana, Zimbabwe and Mozambique. Supporting approximately 14 million people (Direcção Nacional de Águas 2010); the basin serves some of the continent's largest urban areas, while it also supports several critical natural resource conservation initiatives, including the Greater Limpopo Transfrontier Park. As alluded to in the introduction, The SADC region, within which the Limpopo basin falls, includes countries where vulnerability to food and water insecurity recur in most seasons. As a result, a number of organizations have long been involved, in partnership with SADC governments, in improving the ability of the region to have early warning of food and water insecurity; as well as improved response capacity. In fact, the process of producing a consensus seasonal forecast for the region had its genesis in the SADC region almost 20 years ago, in part in response to growing concern and awareness of the El Niño phenomenon.

Significant challenges remain, however, in terms of vulnerability assessment, early warning and support for response. This section of the inception report provides some baseline information for the Limpopo Basin, as well as gaps in order to inform the development of a consolidated plan of action, in partnership with other collaborators in the SADC region.

The goals of this case study will be therefore to:

- To enhance methods characterising drought through **improved** drought **indicators,** that integrate drought **hazard** and **vulnerability** in a risk based approach.

- To increase knowledge in the **link between climate (change) and drought**, and understand how **sector specific vulnerability to drought** will change in the (near) future.

- To **advance methods used for forecasting droughts in Africa** through operationalising the state-of-the-art in (seasonal) meteorological, hydrological and agricultural prediction, and by adopting methods used in Europe, Australia and the US, and tailoring these for use in Africa.

- To **advance early warning for droughts** through identification of **thresholds** for decision making that are for initiation of mitigation activities, and establishing mitigation and adaptation strategies to increase resilience to drought at seasonal and longer time scales.

- To practically **integrate knowledge developed with operational drought warning** and **build capacity** in Africa to ensure that the knowledge developed is sustainable.

7. DROUGHT MANAGEMENT PRACTICES IN THE LIMPOPO BASIN

7.1 CURRENT DROUGHT MANAGEMENT SYSTEM

Components of drought management have been established in regional, national, and local policies of countries covered by the Limpopo basin. The components concern areas such as agriculture, livestock, land, natural resources, rural development, and poverty alleviation (FAO, 2004). While at the regional level the Southern African Development Community (SADC) has shown concern on drought, its four countries drained by the Limpopo river have developed specific approaches at national and local levels.

7.1.1 Agriculture

At the regional level, the SADC established the Food Agriculture and Natural Resources (FANR) Directorate. The main focus of FANR is to ensure food availability, access, safety and nutritional value; disaster preparedness for food security; equitable and sustainable use of the environment and natural resources; and strengthening institutional framework and capacity building (http://www.sadc.int/fanr/).

Agriculture is particularly important for livelihoods in the Limpopo basin. To illustrate, while the agricultural sector only contributes 4 % to the national GDP in Botswana, 65 of the Tswana population within the Limpopo basin area live on agricultural activities, mostly located in the Central and the Kweneng Districts (FAO, 2004).

Agro-based drought management practices vary from a place to another in the Limpopo basin. In Mozambique, practices to cope with drought include the intensification of fishing and hunting and the diversification of farming systems (FAO, 2004). Farming systems were indeed established on the basis of main zones characterised by the Food Security and Nutrition Survey (FSNS), which was developed in order to monitor, to gather, and to infer information about the food security in entities under the district level (FAO, 2004). In the case of Gaza district, two main zones were characterised by the FSNS – namely the productive coastal zone and the arid zone – and drought management practices were implemented accordingly. On one side, in the productive coastal zone, agriculture is favoured by fertile soils and climate, local markets are well developed, and poor families can meet 50 to 60 % of their primary needs (FAO, 2004). Principal crops are water intensive, such as rice, maize, manioc, and cash crops such as fruits (oranges, mango, and cashew), sugar cane, tobacco, and cotton. On the other side, in the arid zone, agriculture is mainly practiced along the rivers, because of low and irregular rainfall. Before the war, livestock was a key drought management approach in this zone (FAO, 2004).

In Botswana, drought management practices can be subdivided into indigenous and current approaches (Babugura, 2005). In the 'indigenous' category are included practices such as use of wild foods, flexibility of local production, dietary diversity, food preservation, dietary change, agricultural innovation, social organization and supernatural means like 'rainmaking' (Babugura, 2005). The current approaches are mostly cash reliant perspectives and included purchasing of food, selling of assets, remittances and reliance on government for assistance (Babugura, 2005). The government assistance has allowed the establishment of an Inter-Ministerial Drought Committee and a drought relief programme, which implemented initiatives such as (Babugura, 2005):

- Supplementary feeding to those identified as vulnerable to droughts;
- Labour Based Relief Programme which empowered rural people with unskilled labour through provision of employment in activities such as road construction, construction of dams and wells, or brick making;
- Agriculture, Livestock and Water: which included the provision of vaccines, subsidies, drilling emergency boreholes, etc;

7.1.2 Water Resources

Water resources suffer from recurrent droughts in Southern Africa in general and this significantly affects smallholder farming and food security in the area (Love *et al.*, 2006). A challenge to ensure water security is the impracticability to build more dams either in some of the overcommitted catchments or where no suitable soils could be found (Love *et al.*, 2006).

7.1.3 Human health

There is some data on the human population in the Limpopo basin. However, the databases are not generally in comparable or usable formats, which is partly due to administratively-based rather than catchment-based data (Centre for Applied Social Sciences, 2008). As far as human health is concerned, the basin faces challenges of high rates of HIV/AIDS that mostly affects women, as illustrated by adult prevalence of 36% in Botswana with 51% of adult females being concerned (FAO, 2004). This has significantly affected the agricultural production (FAO, 2004).

7.1.4 Current drought early warning and adaptation

At the regional level, there is the SADC Regional Early Warning System (REWS). The SADC REWS works under the auspices of the SADC FANR. The focus of the REWS is thus on provision of information that ensures food security (SADC REWS, 2011). Under the FANR directorate, other units were established to provide information that enhances food security. A typical example that is relevant to early warning is the SADC Regional Vulnerability Assessment & Analysis Programme (RVAA). The RVAA was established in 2006 and its focus is expected to establish information systems that are interlinked with early warning, monitoring, assessment and analysis (SADC RVAA, 2011). The RVAA has decentralised units at sub-national levels, established under the label of National Vulnerability Assessment Committees (NVACs). These SADC units benefit from the data support provided by its Agriculture Management Information System (AIMS) programme and its Regional Remote Sensing Project (RRSP). The CGIAR Challenge Program on Water & Food also is set up to improve early warning capabilities of natural hazards as well. (http://www.arc.agric.za/, 19.12.2011).

7.2 EXISTING DROUGHT MONITOR PRODUCTS

In the Limpopo basin, a hydrological monitoring programme was established by the SADC HYCOS. Approximately 9 of these stations lay in the Limpopo basin (http://www.limpoporak.org, 19.12.2011). The major limitation of these stations was their very low density and poor spatial representation of catchment heterogeneity.

Characterisation of drought mainly involves analysis of rainfall data which is by far the readily monitored data for monitoring drought. Quantitatively, a drought is characterised with an index computed as a measure of the extent of negative departures of the rainfall from a pre-determined normal or average. The larger the departure in the negative direction, the severe the drought is taken to be. A combination of the severity and the duration gives an idea of the drought intensity.

There are so many methods available for computing drought index that making a choice has now become a daunting task. One consideration that influences the choice of a method is the availability of suitable data and the simplicity of the interpretation of the indices obtained.

As a result, the Standardised Precipitation Index (SPI) is a commonly used index in most drought characterization, even though its useful for drought forecasting, it depends on rainfall forecasts that is still less reliable. The understanding that a deficit of precipitation has different impacts on groundwater, reservoir storage, soil moisture, snowpack, and streamflow led McKee, Doesken, and Kleist to develop the SPI in 1993. The SPI was designed to quantify the precipitation deficit for multiple time scales. These time scales reflect the impact of drought on the availability of the different water resources. Soil moisture conditions respond to precipitation anomalies on a relatively short scale. Groundwater, streamflow, and reservoir storage reflect the longer-term precipitation anomalies. For these reasons, McKee et al. (1993) originally calculated the SPI for 3–, 6–,12–, 24–, and 48–month time scales.

7.2.1 Meteorological drought indices

The scientific community has developed several drought indices that are able to indicate onsets of droughts and are easy to communicate. Amongst these indices the standardized precipitation index (SPI) is one of the most popular for its applicability to different timescales. (Rouault, 2005) has proved that the SPI is capable of monitoring the intensity and the extent of droughts in southern Africa. Drought indices are substantial elements of the US National Drought Mitigation Center (http://www.drought.unl.edu, 19.12.2011) or the European Drought Observatory (http://edo.jrc.ec.europa.eu, 19.12.2011) but similar operational monitoring systems are not established for Southern Africa, to date. In the Limpopo basin, hydrological drought is monitored by the following commonly used indicators:

- SPI
- Dry spells (Consecutive dry days)

A typical SPI index in the Limpopo basin is presented in Figure 7-1. These SPI indices are based on monthly time scale, and their use is limited to pinpoint periods and severity of droughts that occurred. Real time forecasting applicability of these tools need further refinement of the model to incorporate lead time forecasts and simulated rainfall amounts.

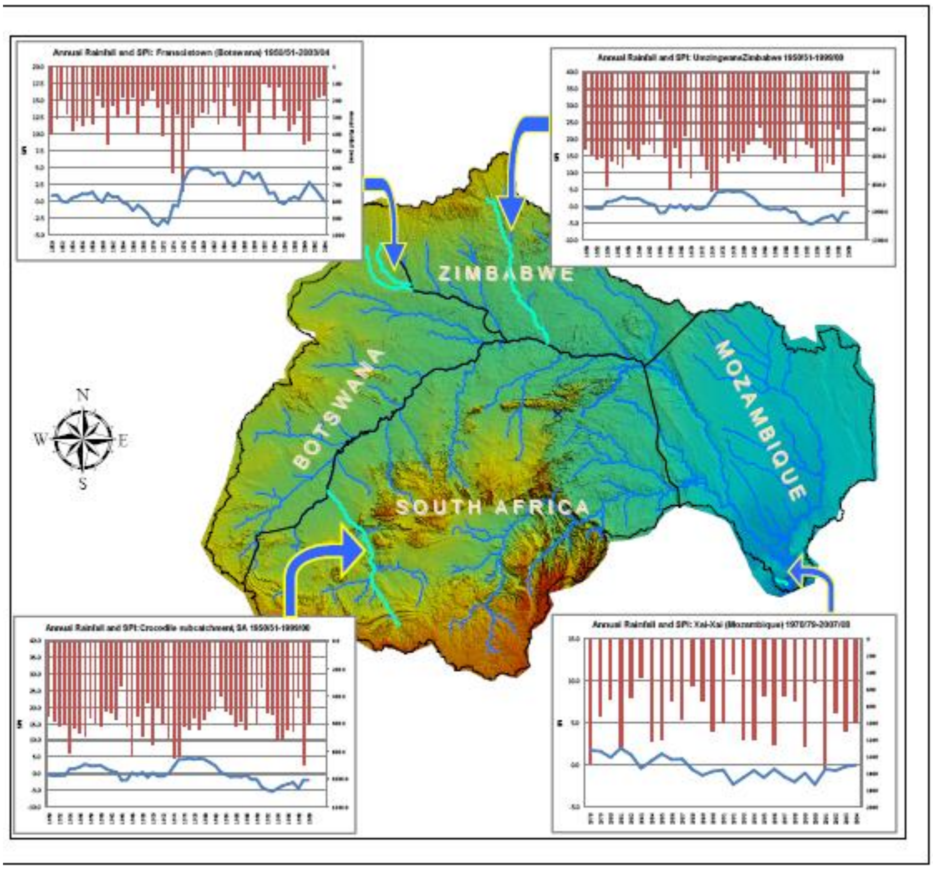


Figure 7-1 SPI at selected stations in the Limpopo basin. (Source: LBFP/ Alemaw et al 2009)

7.2.2 Agricultural drought indices

The following indices are commonly used indices:

- Crop production systems:
  - Cereal growth and phenology development
  - Cereal yields especially in rainfed systems
- Livestock production systems:
  - State of cattle feed supply
  - Grazing land availability
  - Animal feeding balance,
  - Imports of animals and animal products such as milk
- Remote sensing indicator: NDVI
  - Deviation from historical monthly mean NDVI
  - Deviation from historical seasonal mean NDVI

7.2.3 Hydrological drought indices

In the Limpopo basin, hydrological drought is monitored by the following indicators:

  - Reservoir storage
  - Reservoir inflows and outflows
  - Reservoir levels (state of reservoir stage)
  - Ground-water table (level)
  - Stream flows
  - Domestic water demand
  - Supply ability of dam storages to meet agricultural, domestic and other demands

7.3 CURRENT DROUGHT FORECASTING TOOL

General note is needed here on availability of drought forecasting tools – merely weather forecasting tools do exist. The indicators are usually confused with forecasting tools.

7.3.1 Existing gaps in management systems, organization and information

A problem analysis was made on the causal factors of vulnerability to droughts in the Limpopo basin (UN-HABITAT, 2007), which could inform the effectiveness of early warning systems in the basin. The analysis noted gaps like:

- Low level of preparedness for drought events;
- Limited communication between centralised disaster management agencies and local communities;
- Limited planning of land use that do not consider vulnerability to droughts;
- Unrelated models and limited information flow among basin countries;
- Low institutional and human capacity in drought forecasting

- Disjointed effort and low coordination among several institutions that deal with meteorological, hydrological and hydrological droughts

Therefore, to improve early warning in the Limpopo basin, it is recommended to address the above gaps.

7.4 STAKEHOLDERS

In the Limpopo basin various research projects and networks tackle the challenge of water resource management and food security. As in DEWFORA, stakeholder participation is major aim of these projects. Important networks and projects in the Limpopo basin:
CGIAR Challenge Program on Water and Food – Limpopo River Benchmark Basin (http://www.arc.agric.za/limpopo/index.htm),Limpopo Watercourse Commission (LIMCOM), http://www.limcom.org/

7.4.1 Producers of available monitoring and forecast products

The National Meteorological Services (NMSs) of the region are required to do weather and climate monitoring. However, the availability of data is problematic when NMSs start charging handling fees for data. There are also a good amount of gridded data products, some of which are updated in near-real-time, for example the CAMS OPI (Climate Anomaly Monitoring System and OLR Precipitation Index) estimated precipitation set based on observations from rain gauges and satellite data.
Apart from the large international centres such as ECMWF, UK Met Office and IRI among others, institutions in SADC currently producing seasonal forecasts based on locally-run global models include the CSIR, SAWS and UCT-CSAG. The global forecasts from these centres are displayed on the website of the Global Forecasting Centre for Southern Africa (www.GFCSA.net).

7.4.2 Regional Climate outlook forums

Currently three fora are active on the continent: the Southern African Regional Climate Outlook Forum (SARCOF), the Greater Horn of Africa Climate Outlook Forum (GHACOF), and the Climate Outlook Forum for West Africa (PRESAO: PRÉvisions Saisonnières en Afrique de l'Ouest).

7.4.3 Users requirements for a drought forecast system

General Approach:

The study will establish the exact level of existing capacity and competence of drought management in the basin and each of the riparian states. Multi-level (**Technical staff, Experts, Commissioners, and Stakeholders.** assessment will be conducted among various sector organizations/ministries in each country and cross-country synthesis report of requirements and capacities will be established.

Existing capacities and gaps in the individual's capacity are related to the nature of the enabling environment and the organizations' set up for capacity development. This is reflected in the competence that exists and level of staff attraction and retention, which is a challenge to almost all the riparian countries, where dwindling technical personnel is evident in the public water services organisations as a result of absorption by or defection to the private sector in and outside the national boundaries. Motivation and the incentive systems in place might have a bearing in this regard.

Using a structured format, the project will study the capacity needs and gaps at different levels within the set-up of LIMCOM including **Technical staff, Experts, Commissioners, and Stakeholders. At national level, sector organizations that deal with drought will also be subject to similar analysis. The enabling environment of staff attraction and retention and the challenge of staff turnover will be investigated.** Individual capacities may include but not be restricted to job skills and needs, values, attitude and motivation, performance incentives, relationships, communication skills and team spirit. Benchmarks that define the level of capacity on the job will be developed based on existing job descriptions and needs.

An important step in capacity needs assessment is the determination of what capacity is needed most in order to meet the desired purpose, and in line with the current LIMCOM vision and strategies. A set of criteria will be developed which are suitable for identifying priority capacity needs, and which allow estimates of possible impact on the sector performance –i.e. drought management. The assessment follows a typical gaps-analysis model presented in Figure 7-2.

Figure 7-2 indicates how in a capacity building initiative, a gap-analysis can evolve from top organisational setup and its objectives (LIMCOM strategy, action plans or country level in each riparian states) down to individual level (including experts, technical staff stakeholders and the population at large that contributes to drought management).

This top-down needs analysis process is used to identify capacity gaps and problem areas in a sequential manner:

- Business Needs –how the training initiative supports goals of LIMCOM or riparian sector ministries as an organization?
- Job Performance Needs – what capacities exist now to support LIMCOM?
- Training Needs – what performance interventions are needed?

- Individual Needs – who for what capacity building interventions should be targeted?

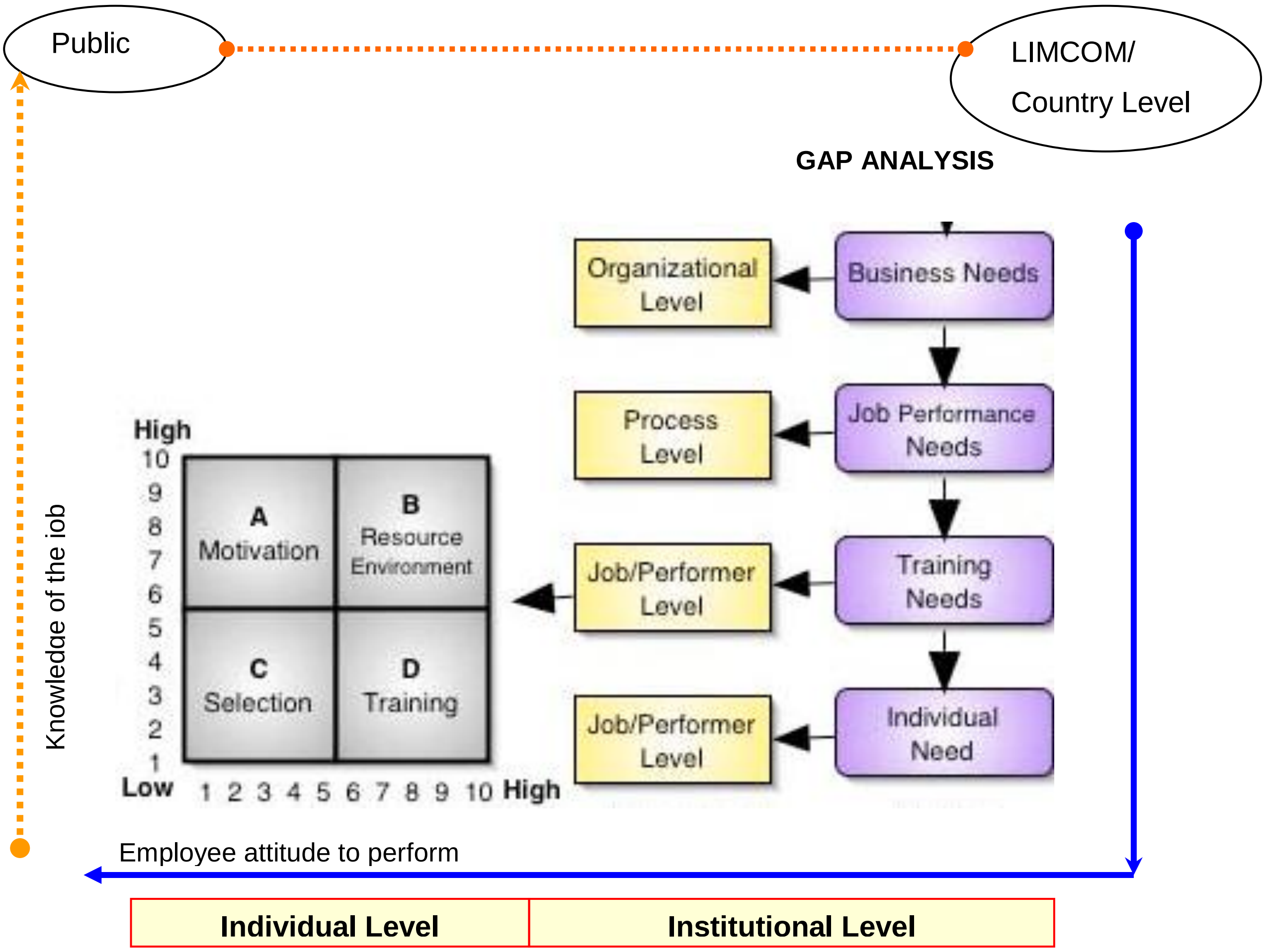


Figure 7-2 gaps-analysis model demonstrating hierarchical analysis of capacity needs and performance at different levels, Institutional to individual, as well as LIMCOM (riparian national level) to public as a feed-back to influence politics and politicians towards drought.

Detailed capacity building programs, short courses, etc., will be identified with resources and potential stakeholder personnel that will be involved in those efforts, and plan of action will be drawn for final implementation of the same during the project's life cycle.

The main TOR that will be used for needs assessment and capacity building plan in drought forecast will involve:

- Description of the perceived importance of drought management capacity building from capacity plans and activities.
- Identifying and prioritising the immediate and long term new knowledge requirements, institutional changes, enabling environment and linkages required for improved drought management.

- Developing opportunities for capacity building and recommending different types of activities based on results from drought indicators, forecasting and management tools and analysis and prioritisation of capacity needs.

Capacity building implementation plan:

The capacity building component will be executed in the following three separate stages. To ensure high quality of delivery and as a measure of impacts of the component, the accompanying reports are to be delivered.

Stage 1: Capacity Needs Assessment Report.

In Stage 2, the detailed capacity needs and gaps are in detail worked out which culminate with a draft Needs Assessment Report. This report is anticipated to be finished and report submitted at the end of 3 months since commencement and delivery of inception report. Following a presentation of the report and comments incorporated Final needs assessment report will be presented approximately by the end of the 4th month.

Stage 2: Definition and Planning of Capacity Building Programme

Stage 2 will bring about the completion of the capacity building component with the submission of the draft final capacity building report at the end of month 6. Some important interactions are required during this stage, notably to agree on the prioritisation and listing of the various Capacity Building Programmes – those that will be delivered during the life cycle of the DEWFORA Project.

The final report will be submitted by incorporating stakeholders comments and to the satisfaction of the DEWFORA task leaders.

Stage 3: Capacity building management and reporting

Apart from the close liaison and project management, this stage involves production of project report that will guide the future of capacity development programme and subsequent implementation by LIMCOM or SADC. In Stage 3 the following outputs will be produced and submitted to the major stakeholders (LIMCOM, SADC, etc):

- Draft Capacity Building Programme Report
- Final Capacity Building Programme Report
- Project database of reports and needs assessment survey reports

Other WaterNet's long-term capacity building programme:

It should be noted that the capacity building plans mentioned refer to the short term training which are meant to target direct stakeholders of the DEWFORA project. WaterNet through the network universities in the Limpopo basin will also ensure when possible graduate level student involvement especially on final research dissertations, which shall be based on drought monitoring, forecasting and management.

8. DETAILED CASE STUDY APPROACH AND METHODOLOGY IN THE LIMPOPO BASIN

8.1 APPROACH TO BE FOLLOWED

Statistical seasonal forecasting

A statistical seasonal forecasting model will be developed as an alternative to the dynamical models. Hereby, the quality of alternative methods could be compared. Detailed methods suggested for the Limpopo case study are reported under section 8.4

8.2 COLLATION AND REVIEW OF EXISTING DATA

A first assessment of data availability showed that the meteorological and hydrological data will have to be collated from several institutions per country. The local project partners per country will provide the available meteorological and hydrological with a detailed description of precedent quality procedures. Waternet will then collate the data to one data set and perform a general quality control (support by GFZ, if necessary), following the procedure proposed by the JRC. The dataset will then be distributed to all Limpopo case study partners for analysis and modelling activities.

8.3 COLLATION AND REVIEW OF EXISTING MODELS

Statistical methods have been proven to be successful in seasonal forecasting of precipitation in Ethiopia (Diro et al. 2011). This approach to employ forcing by sea surface teleconnections for seasonal forecast predictors can serve as a framework. Alemaw & Chaoka 2006, have shown that teleconnections can also serve as forecasting means for hydrological conditions in southern Africa.

8.4 METHODS AND TOOLS TO BE APPLIED

Following the approach of (Diro et al. 2011), in a first step climatically homogeneous regions in the Limpopo basin will be determined with special regard to drought conditions. Sea surface temperature teleconnections will be identified and a forecasting model built for each region.

Hydrological drought forecasting using process-based hydrological model:

A process-based hydrological model for the Limpopo basin will be available from WP4. The forecasting from the hydrological model will be based on the meteorological forcing inputs (in particular precipitation and temperature) available from ECMWF (also a part of WP4). The development of the hydrological model (calibration and validation) requires time series of observed runoff (preferably daily time-series from 1979 to current) at key interest locations of the basin as well as relevant information about the reservoirs of interest and large irrigation areas in the basin. The reservoir location and capacity, water depth verses surface area or volume relationship and typical operation rule (e.g. monthly target level) are the key data requirements about the reservoirs. These data will be provided to UNESCO-IHE for calibration/validation of the model based on the specified interest area for the case study and availability. The results of the hydrological model forecasts are mainly provided in terms of expected deviation from the long term mean of evaporation, soil moisture (in limited cases) and runoff (for selected locations of interest) for the forecasted period. The hydrological model outputs may also be used to compute hydrology related drought indices (indicators) specified in WP3.

Detailed analysis and synthesis of existing data:

a) Collection of all raw primary and secondary data
b) Develop minimum quality control protocols for all case study areas in Limpopo
c) Quality control and report on data quality
d) Detail archival of time series and spatial data to support WP4 and other WPs

Drought indicators refinement, forecasting and modelling:

a) Meteorological droughts
    - SPI– modelling for various case sites
    - Dry spells analysis and modelling for various case sites
    - Sustainability, soil moisture modelling and risk analysis of various crops rainfed systems: risk, resilience, vulnerability indices
    - Risk of failures of irrigated systems under different agro-ecological and crop systems

b) Agricultural droughts details investigations

- Crop production systems – based on agricultural statistical data analysis
    - Cereal growth and phenology development
    - Cereal yields especially in rainfed systems
- Livestock production systems– based on agricultural statistical data analysis
    - State of cattle feed supply
    - Grazing land availability
    - Animal feeding balance,
    - Imports of animals and animal products such as milk
- Remote sensing analysis: NDVI analysis and modelling
    - Deviation from historical monthly mean NDVI

  - Deviation from historical seasonal mean NDVI
  - Modelling and analysis of seasonal NDVI and rainfall drought indices

c) Hydrological droughts

- Reservoir risk analysis to meet domestic, agricultural demands needs and under different societal, operational as climate change scenarios
- The actual and potential local level dam storages and their risk of failure

Drought management:

a) Inventory of agricultural dams from remote sensing
b) Detailed analysis of dam development stages in the different basins
c) Preliminary inventory of scientific and ingenuous knowledge systems on drought management

8.5 EXPECTED OUTCOMES AND PRODUCTS

Apart from the inception and the final report, generate interim reports were agreed to be produced during the WP6 team members first project inception meeting. The interim report will be vital to generate and share useful reports for the project. The following therefore are expected outcomes to be generated.

Report on detailed analysis and synthesis of existing data:

This will involve a report on:

- All raw primary and secondary data collected for the project in the case study basin
- Developed minimum quality control protocols for all case study areas in Limpopo
- Quality control and report on data quality
- Archival and database of time series and spatial data to support WP4 and other WPs

Report on drought indicators refinement, forecasting and modelling:

a) The sub-report on meteorological droughts will involve report on:
  - SPI – modelling for various case sites as well as operationalization of SPI for lead-time forecasting of droughts
  - Dry spells analysis and modelling for various case sites
  - Sustainability, soil moisture modelling and risk analysis of various crops rainfed systems
  - Risk of failures of irrigated systems under different agro-ecological zone crop systems

b) The sub-report on agricultural droughts will include:

    - Crop production(Cereal growth, phenology development, cereal yields data)
    - Livestock production systems (State of cattle feed supply, Grazing land availability, Animal feeding balance, Imports of animals and animal products such as milk)

c) The sub-report on remote sensing analysis results will include:

- Deviation from historical monthly and seasonal mean NDVI
- Modelling and analysis of seasonal NDVI and rainfall drought indices

d) The sub-report on hydrological droughts will include report on:

- Reservoir risk analysis to meet domestic, agricultural demands needs and under different societal, operational as climate change scenarios (at selected agricultural dams)
- The actual and potential local level dam storages and their risk of failure

Report on drought management:

- Inventory of agricultural dams from remote sensing
- Report on detailed analysis of dam development stages in the different basins
- Preliminary inventory of scientific and ingenuous knowledge systems on drought management

8.6 HOW RESULTS AND IMPACT WILL BE MEASURED OR DETERMINED

The various results will be delivered as per the reports that will be communicated with WP6 lead institution between the inception and final reporting periods.

Impact will be measured by the quality and timely delivery of the reports which shall pass internal team member review scrutiny and use of the reports to feed to the various WPs and project outputs. The delivery of reports measured from date of inception report submission is given as follows:

(1) Report on detailed analysis and synthesis of existing data: Apprx. in 3 months

(2) Report on drought indicators refinement, forecasting and modelling: Apprx.in 6 months

(3) Report on drought management: Apprx. in 18 months

(4) Report on capacity building reports:

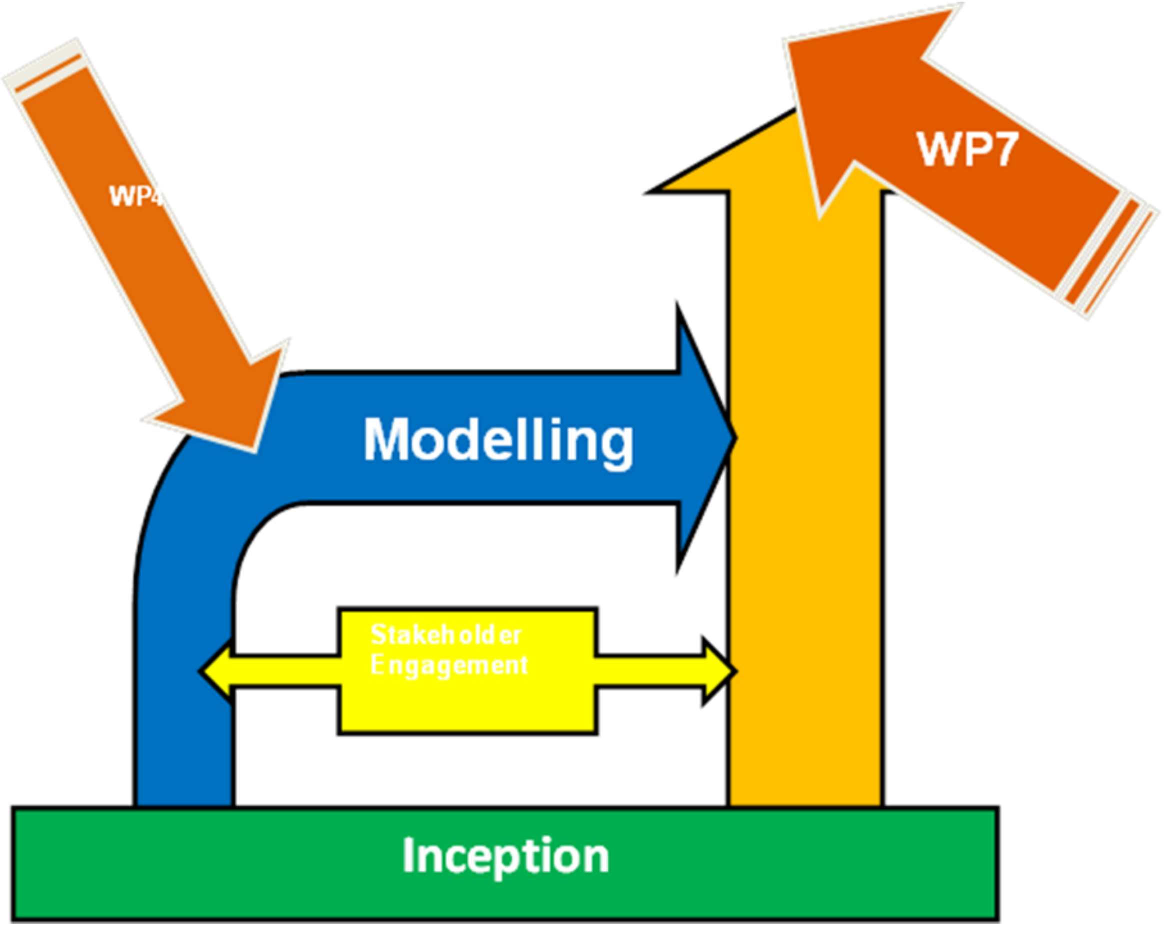
- Draft Capacity Building Programme Report:Apprx. in 6 months
- Final Capacity Building Programme Report:Apprx. in 8 months
- Project database of reports and needs assessment survey reports:Apprx. in 10 months

9. PROPOSED ACTIVITIES AND WORKPLAN FOR THE LIMPOPO BASIN

9.1 PROPOSED ACTIVITIES

The focus in this case study is on the strategy of flow of information during drought early warning. Information will be generated by the forecasting system developed in WP 4. This information, designed for a variety of end users will flow from the warning system through the institutional framework from regional to local scale. The Limpopo is therefore a pilot for the application of DEWFORA's drought early warning framework. In close collaboration with other stakeholders in the region, improvements in the institutional framework and procedures will be suggested and implemented, building on the technical developments. The particular activities in this case study will be divided into three sub-packages:

- Sub-package A "Inception": Produce baselines on the Basin(A1) and its early warning systems (A2) and collate and review existing data (A3) and existing models (A4), which are used by
- Sub-package B "Modelling": Select suitable models developed under WP4. Implement improvements to existing monitoring and forecasting systems and drought mitigation policies by coupling meteorological, hydrological and agricultural forecasting tools into a water allocation model (WP 4), which is then incorporated into
- Sub-package C "Early Warning Systems": Establish a direct partnership with the early warning implementation agency. Incorporate the new modelling system (B). Pilot the drought early warning framework by identification and involvement of the end-users and analyze how the issued warnings flow through the institutional structure and how the coupled model can be used to support this. The piloting will reveal potential shortcomings in the institutional structure, which will result in recommendations for improvement.



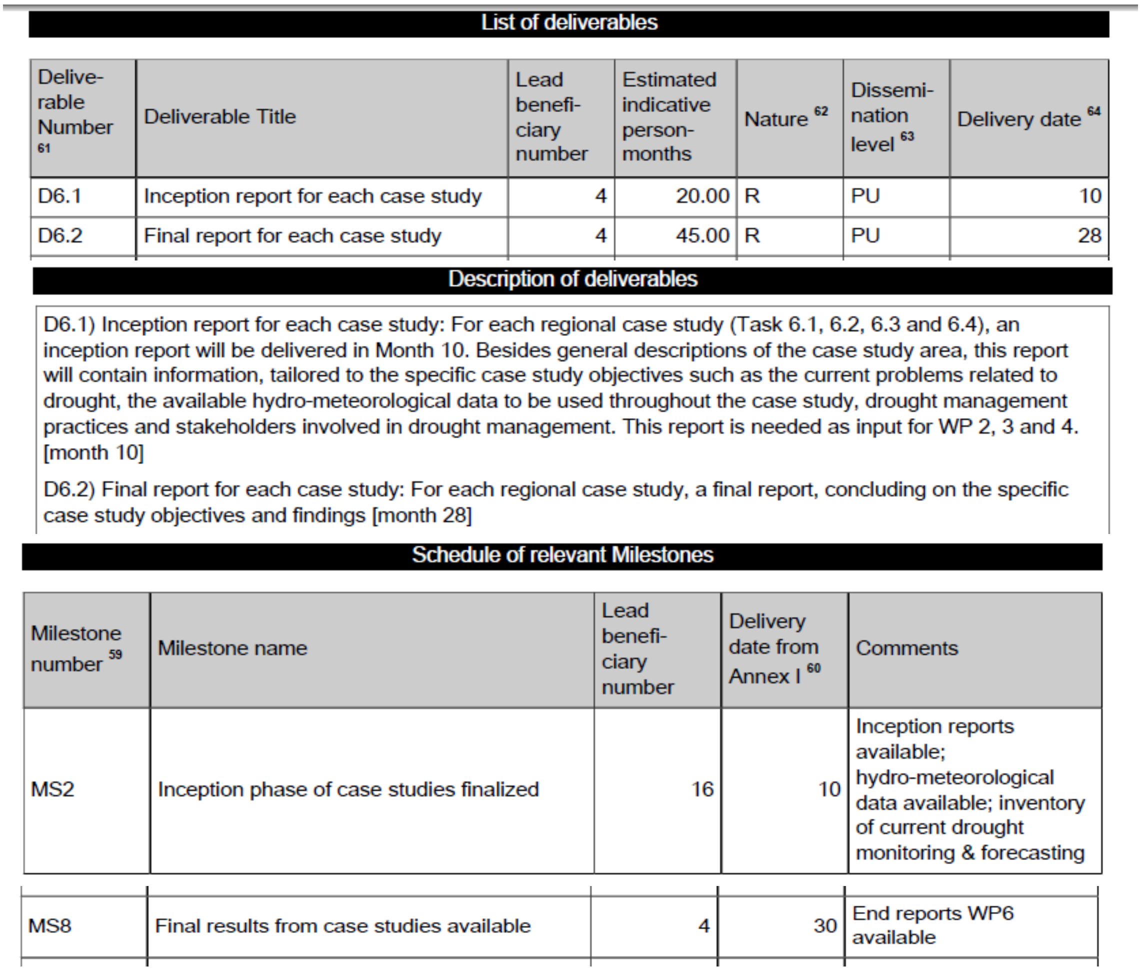
9.2 PROPOSED WORKPLAN, MILESTONES AND TIME SCHEDULE

Proposed activities and staff deployment:

Person	Activity	Deliverable	Time
WaterNet			9 pm total
Tatenda Tsiko, Jean-Marie Kileshye-Onema	Sub-package A1 (lead)	Inception Report 6	
Tatenda Tsiko, Jean-Marie Kileshye-Onema	Sub-package C (lead)	Contribute to Inception Report 8 Final Report component on early warning systems (lead)	
Manuel Magombeyi	Sub-package A3 (lead) Sub-package A4 (lead)	Inception Report 8 (lead)	

Person	**Activity**	**Deliverable**	**Time**
Berhanu Alemaw			
Berhanu Alemaw	Sub-package B (lead)	Final Report component on modelling (lead)	
David Love, Jean-Marie Kileshye Onema	Inception report: final drafting Final report: final drafting	Inception Report Final Report	
WRNA	Sub-Package A2 (lead) [use del 2.1] Input to Sub-Package B	Inception Report 7 Contribute to Final Report component on modelling	6 pm*
UEM	Contribute to Sub-Packages A and C	Contribute to Inception Report 7 Contribute to Final Report component on early warning systems	12 pm
CSIR	Work with Manuel on Sub-Package B	Contribute to Final Report component on modelling	5 pm*
IHE	Input to Sub-Package B		7 pm*
GFZ	Input to Sub-Package B		10 pm*

* includes time committed to other components of WP6



List of deliverables

Deliverable Number [61]	Deliverable Title	Lead beneficiary number	Estimated indicative person-months	Nature [62]	Dissemination level [63]	Delivery date [64]
D6.1	Inception report for each case study	4	20.00	R	PU	10
D6.2	Final report for each case study	4	45.00	R	PU	28

Description of deliverables

D6.1) Inception report for each case study: For each regional case study (Task 6.1, 6.2, 6.3 and 6.4), an inception report will be delivered in Month 10. Besides general descriptions of the case study area, this report will contain information, tailored to the specific case study objectives such as the current problems related to drought, the available hydro-meteorological data to be used throughout the case study, drought management practices and stakeholders involved in drought management. This report is needed as input for WP 2, 3 and 4. [month 10]

D6.2) Final report for each case study: For each regional case study, a final report, concluding on the specific case study objectives and findings [month 28]

Schedule of relevant Milestones

Milestone number [59]	Milestone name	Lead beneficiary number	Delivery date from Annex I [60]	Comments
MS2	Inception phase of case studies finalized	16	10	Inception reports available; hydro-meteorological data available; inventory of current drought monitoring & forecasting
MS8	Final results from case studies available	4	30	End reports WP6 available

10. DESCRIPTION OF THE OUM-ER-RBIA BASIN CASE STUDY

10.1 GEOGRAPHICAL AREA

Oum Er-Rbia (*the mother of spring*), is a river in central Morocco. The river is 550 km long. With an average water debit of 105 m^3/s, Oum Er-Rbia is the second largest river in Morocco after the Sebou River. It takes source in the Middle Atlas, to 1800 m altitude, passes through the chain of the Middle Atlas, the Tadla plain and the coastal plateau and comes in the Atlantic ocean in Azemmour city, at 17 km in the south of Casablanca, and 16 km north of El Jadida city.(Figure 10-1).

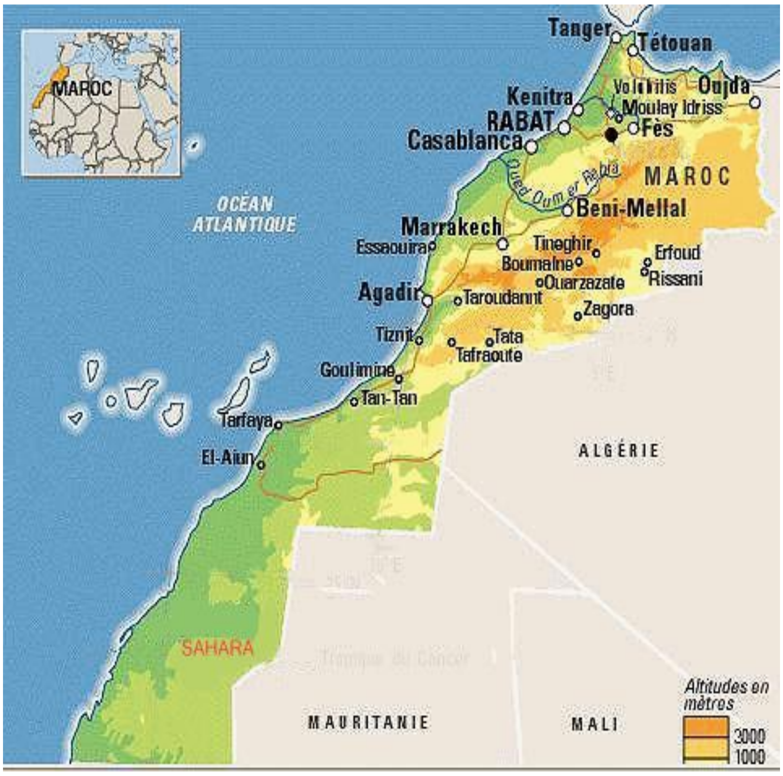


Figure 10-1 Location of Oum Er-Rbia river in Morocco

The action area of Hydraulic basin Agency of Oum Er-Rbia (*ABHOER*) covers an area of 48070 km2, which represents 7% of the Morocco land area (Figure 10-2)

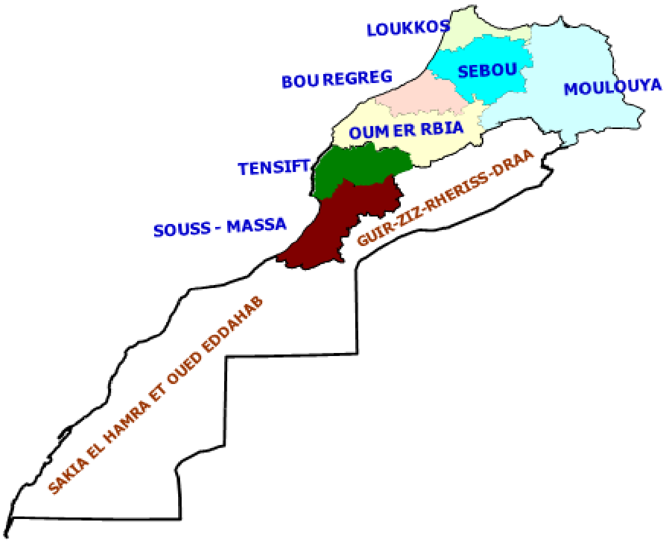


Figure 10-2 The location of the Oum Er- Rbia Basin

The ABHOER covers the basin of Oum Er Rbia (35000 km^2) and the Atlantic coastal basins situated between El Jadida and Safi (13070 km^2). This area covers all or part of the administrative provinces (perimeters) from Beni Mellal, Azilal, Khenifra, Settat, Khouribga, Kelaa des Sraghna, El Jadida and Safi (Figure 10-3).

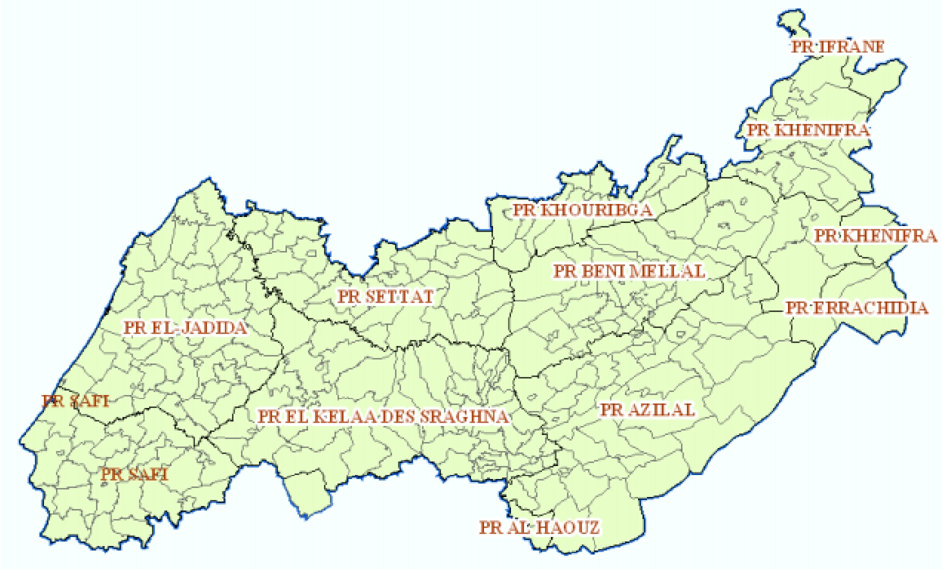


Figure 10-3 Administrative divisions covered by the Oum Er-Rbia basin

According to the administrative divisions of Morocco, two major regions as shown by figure 10-4 include these various provinces: These are the region of Tadla-Azilal (Region 12) and the region of Doukkala-Abda (Region 11).

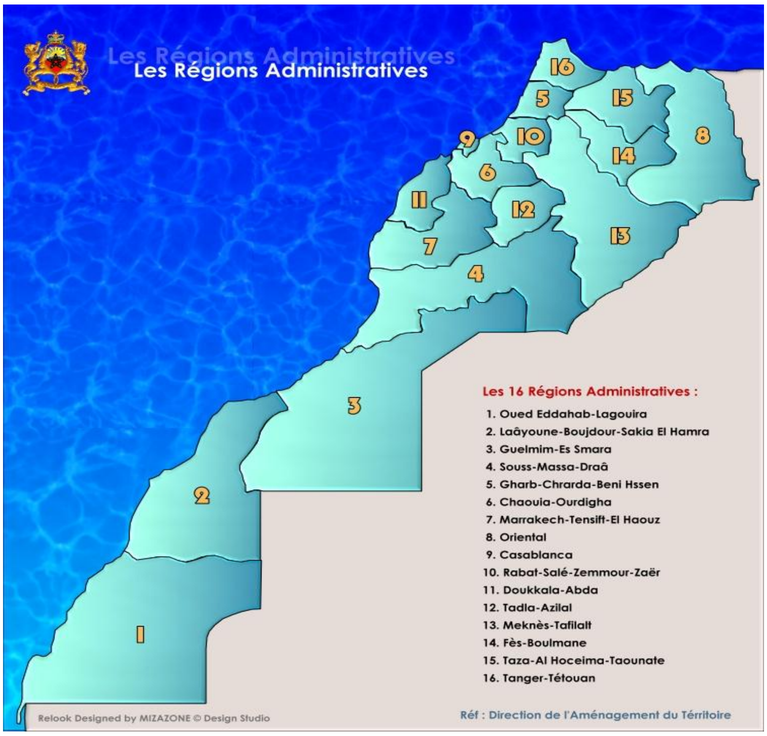


Figure 10-4 Moroccan Administrative regions

In this report, we will develop the points distinguishing, whenever warranted, between the two main regions: Tadla-Azilal and Doukkala-Abda

Tadla-Azilal perimeter (*AquaStress, 2005*) Tadla is located on the left and right banks of the Oum Er Rbia river, some 200 km northeast of Marrakech and 170 km southeast of Casablanca. The perimeter, which irrigates about 100000 hectares, is composed of two sub-perimeters which are hydraulically distinct. The Beni Amir sub-perimeter, irrigating 30500 hectares on the right bank of the Oum Er Rbia river, and the Beni Moussa sub-perimeter, irrigating 69500 hectares (Figure 10-5).

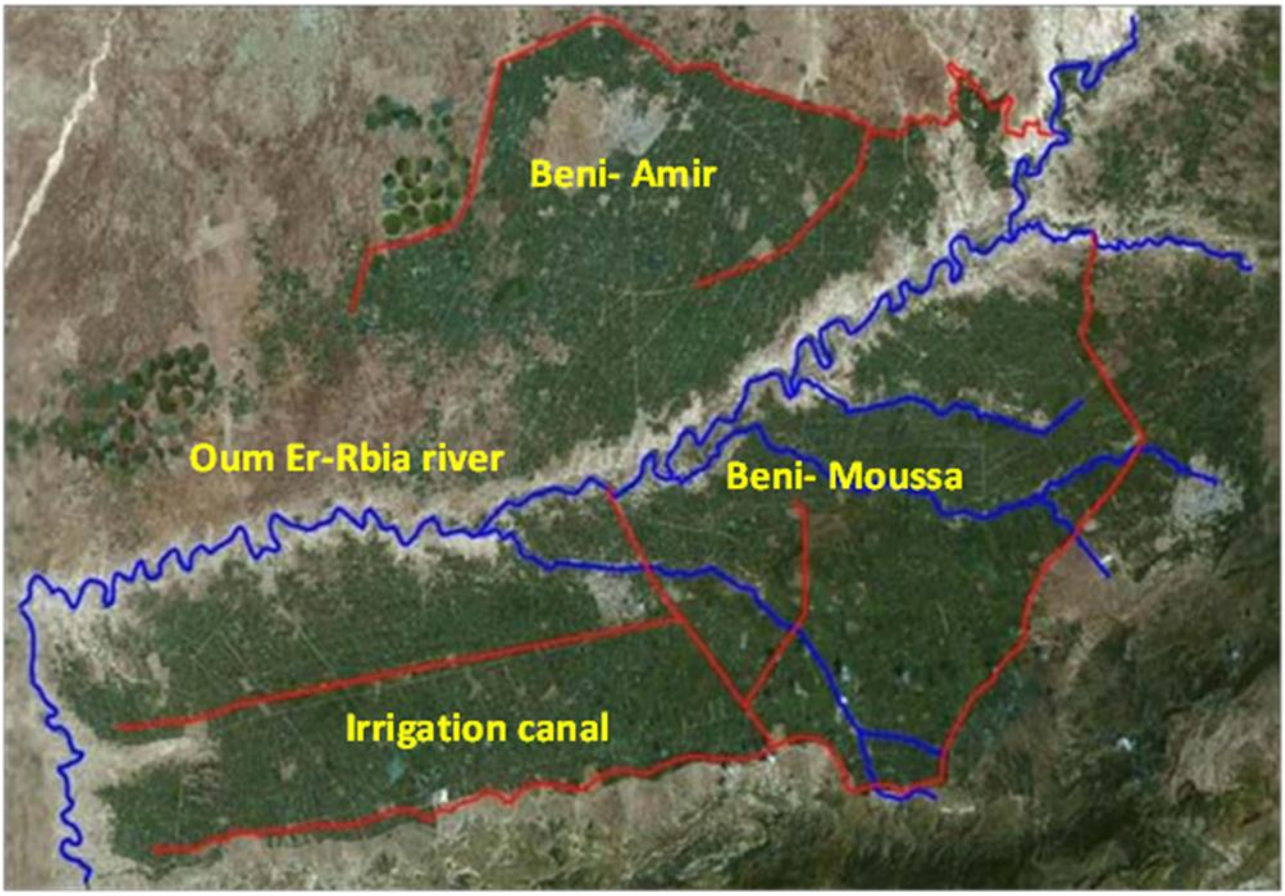


Figure 10-5 Satellite view of the Beni-Amir and Beni-Moussa perimeters (*ABHOER, 2007*)

Doukkala-Abda perimeter

The region is located in the central Atlantic area between Oum Er-Rbia and Tensift rivers. Doukkala-Abda is bounded, in the north by the province of Settat, in the east by the province of Kalaa des Sraghna, in the south and the south-east by the province of Marrakech and in the south-west by the province of Essaouira. The region occupies a privileged geographical position; it has a coastline of 350 Km over the Atlantic Ocean. Doukala-Abda region covers an area of 12344 km², distributed between the two provinces that constitute the region that are Safi (51.4%) and ElJadida (48.6 %) (Figure 10-6).

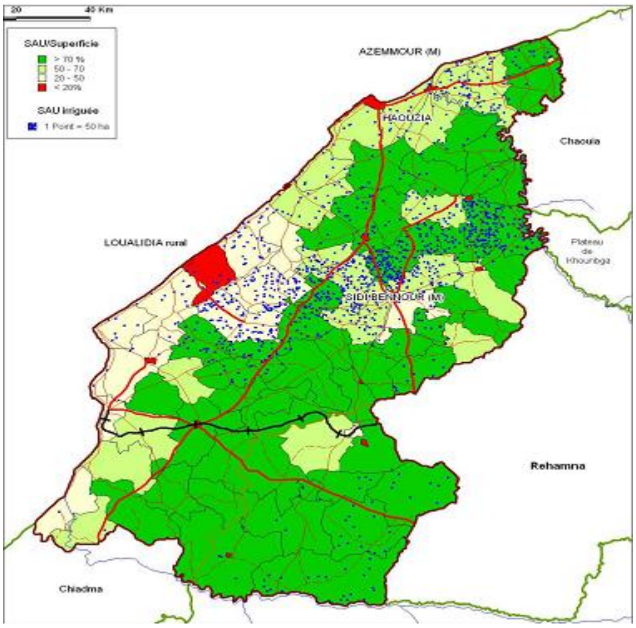


Figure 10-6 the Doukkala-Abda region

The Oum Er-Rbia basin in a few words:

Oum Er-Rbia Basin :

7% of the national land area

10 provinces

17% of the population

19% of water resources

36% of storage capacity

33% of the irrigated area

70% of the average production

Economy based on:

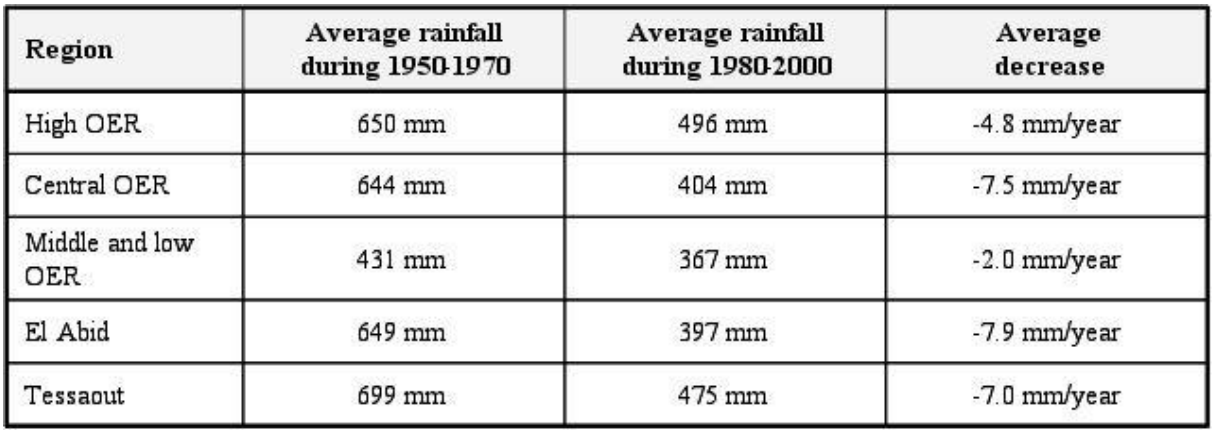
- ❖ **Agriculture and livestock**
- ❖ **Food Industry**
- ❖ **Phosphate**
- ❖ **Craft**

10.2 CLIMATE

The climate in the Oum Er-Rbia Region is temperate in coastal areas and mountains, arid to semi-arid in the plain.

The yearly middle rainfall on the Oum Er Rbia basin is 550 mm: it varies between 1100 mm on the Middle Atlas and 300 mm in the downstream zone of the river. The precipitation decreases from east to west and from the Atlas chain towards the plain (*INECO, 2009*).
On average, it snows 20 days/year on the above 800 meters.
The temperature varies between 10 and 50°C and the evaporation is 1600 mm per year in average on coasts and 2000 mm inside of the country with a monthly maximum of 300 mms in July and August.
As shown by Table 10-1, Levels of rainfall in the basin have declined by an average of 2 to about 8 mm/year during the two decades of 1980-2000 compared to the previous two decades.

Table 10-1 Rainfall decrease in the basin of the Oum Er-Rbia (OER) (*INECO, 2009*)

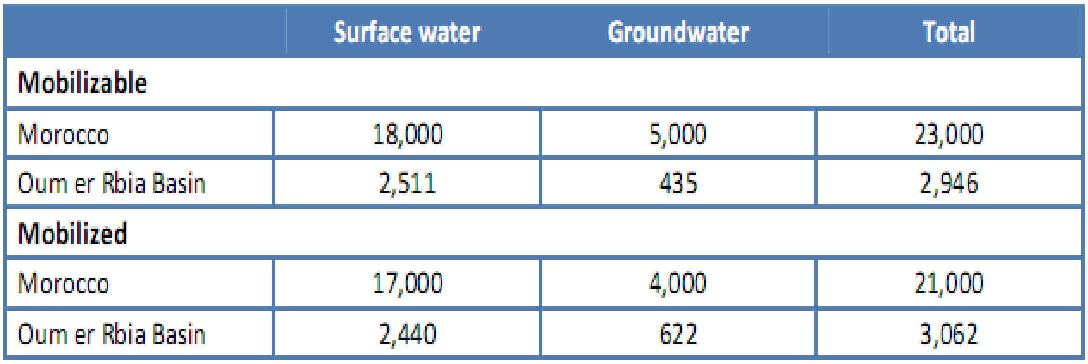


Region	Average rainfall during 1950-1970	Average rainfall during 1980-2000	Average decrease
High OER	650 mm	496 mm	-4.8 mm/year
Central OER	644 mm	404 mm	-7.5 mm/year
Middle and low OER	431 mm	367 mm	-2.0 mm/year
El Abid	649 mm	397 mm	-7.9 mm/year
Tessaout	699 mm	475 mm	-7.0 mm/year

10.3 HYDROLOGY

The water resources of the basin are extremely important, as they are used in the strategic economic zone of Morocco (Tadla, Doukkala and the inshore zone Casablanca-Safi). There is also a concentration of economic activities (industry and irrigated agriculture), and a significant part of the population. Table 10-2 summarizes the mobilizable and the mobilized water in the basin in reference of the national levels:

Table 10-2 Oum Er-Rbia basin water resources (Million m3) (*INECO, 2009*)



	Surface water	Groundwater	Total
Mobilizable			
Morocco	18,000	5,000	23,000
Oum er Rbia Basin	2,511	435	2,946
Mobilized			
Morocco	17,000	4,000	21,000
Oum er Rbia Basin	2,440	622	3,062

Surface water

The main basin streams are represented by the Oum-Er-Rbia oued and its main tributaries: Tessaout, Lakhdar and El Abid (Figure 10-7). Contributions of water of the Oum Er-Rbia basin are valued to 3680 Mm³/year, varying between a maximum of 8300 Mm³ and a minimum of 1300 Mm³. Numerous sources contribute to those of the snow melting and guarantee a very sustained level for the Oum-Er-Rbia.

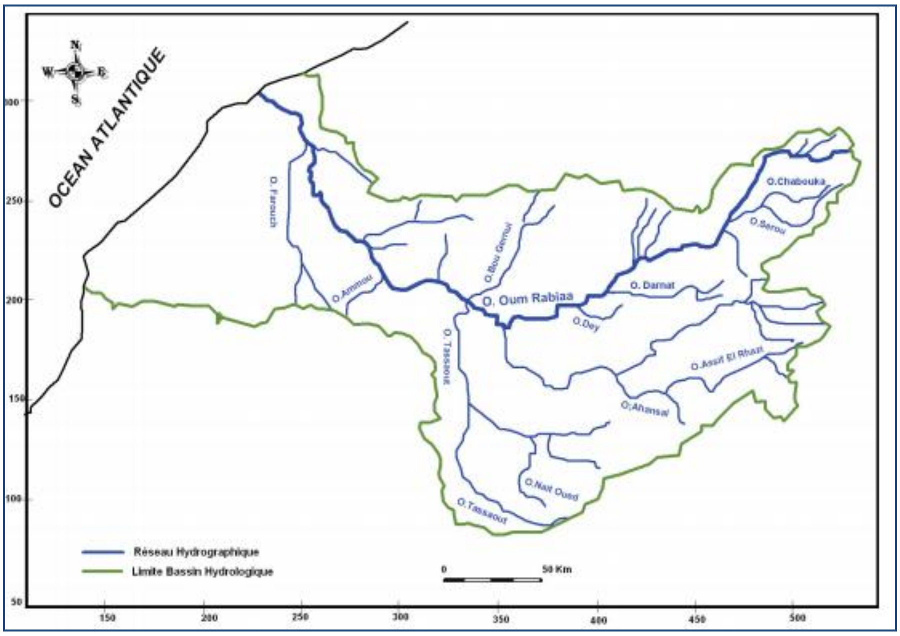


Figure 10-7 Oum Er-Rbia river and its tributaries

Groundwater resources

The groundwater resources of the Oum Er-Rbia basin are relatively important, distributed between several aquiferous units (Figure 10-8).

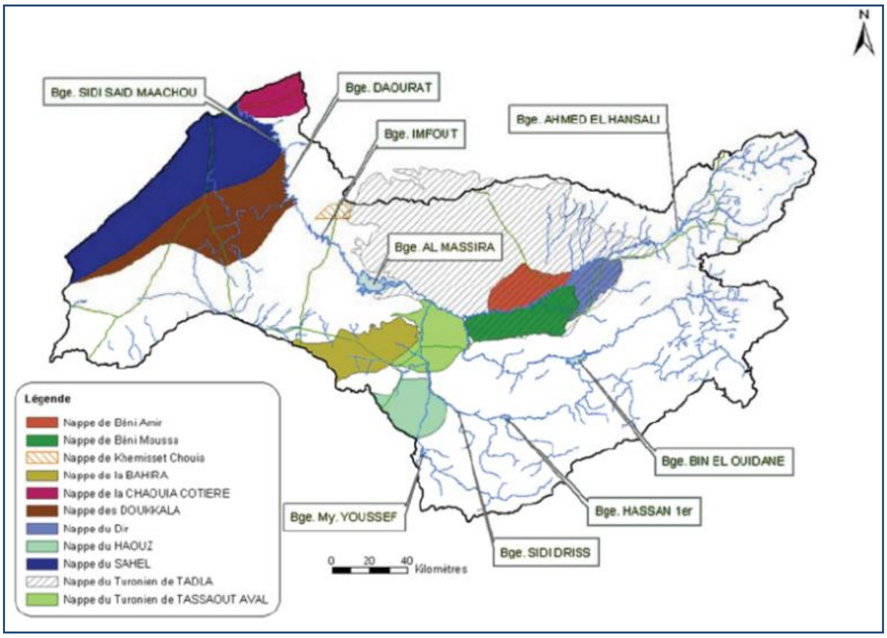


Figure 10-8. Groundwater resourses of the Oum Er-Rbia basin

The aquiferous of the Tadla form a multicouche system composed of 4 aquiferous superimposed separated by impervious or semi impervious levels.

The size of the aquiferous is highly variable across the plain of Tadla, inducing heterogeneity in the groundwater resources availability (Figure 10-9). The thickness of the water table exceeds

80 m over the entire perimeter of Tadla with a value up to 300 m near the Oum Er-Rbia river. The thickness of the Eocene aquifer is relatively homogeneous, but its depth is the lowest in the north-east perimeter of Beni Amir where drilling exceeding 100 m depth can easily reach it. The Eocene disappears at the west perimeter of Beni Moussa. The Turonian has high depths relatively of the entire area which puts it theoretically far from pumping. (*Hammani and Kuper, 2007*)

The four aquiferous of the system are from the stocking toward the top:

- The carbonated Turonien aquiferous: Contributions to the water measured at 92Mm^3/year consist of 40mm^3 from infiltration of rainwater and 52 mm^3 in the runoff and ground water inputs.
- The Senonien aquiferous: The entries int his ply consist of infiltration of rainwater rand runoff under
- The calcaréo-sandy Eocène aquiferous: The entries int his ply estimated at 77Mm^3/year consist of 75mm^3 from infiltration of rainwater and runoff sub 2mm^3.
- The quaternary alluvionnaire aquiferous of the Tadla and the Tessaout downstream: aquiferous of Beni Amir, aquiferous of Beni Moussa, aquiferous of the Tessaout
  - Groundwater of the Beni-Amir: The entries in this sheet are made up largely of water seepage irrigation is estimated at 114 Mm^3/year. Infiltration from rainwater are only 2 mm^3.

  - Groundwater of the Beni-Moussa: The entries in this sheet are made up largely of water seepage irrigation is estimated at 24 Mm^3/year. Infiltration from rainwater is only 2 mm^3, while the underground flows are estimated at 22 mm^3.

  - Groundwater of Beni Moussa-Dir: The entries in this sheet valued at 67 Mm^3/year consist of 8 million m^3 of water infiltration from rain, 11 mm^3 of infiltration from the wadis and springs, and of 48 mm^3 from infiltration of irrigation water. tablecloth Tessaout downstream: Contributions to the water measured at 77 Mm^3/year, consist of 5 million m^3 of infiltration from streams and springs, 70 mm^3 of water seepage irrigation and 2 mm^3 inputs underground.

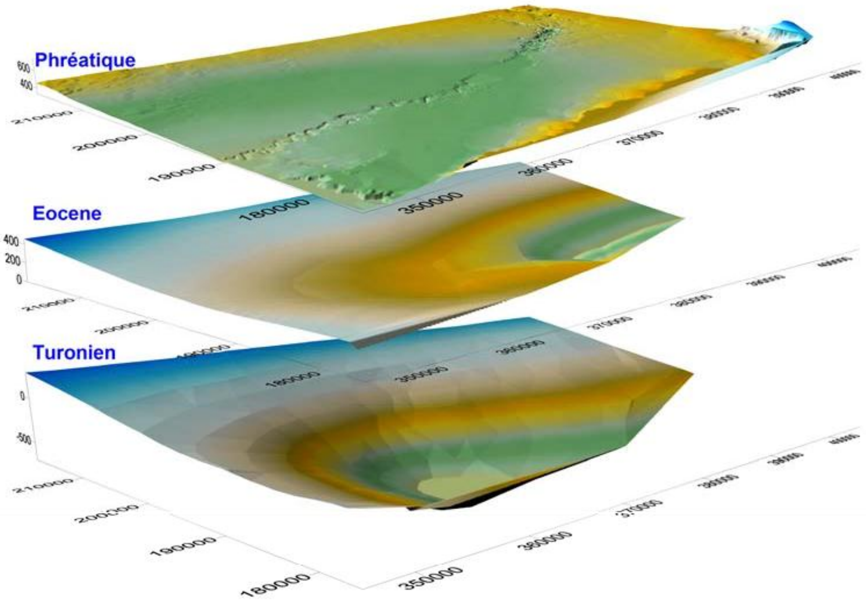


Figure 10-9 Groundwarter resources of the Tadla plain (Hammani and Kuper, 2007)

10.4 GEOLOGY

The hydro-geological formations of the Oum Er-Rbia basin are illustrated by figures 10-10 and 10-11.

The basin area is part of the Atlantic area. It covers six geographical units (Plan Maroc Vert):

- Rhamna Massif: It consists of strongly folded Paleozoic sedimentary formations with a blanket of secondary age on the edges.
- Plateau of phosphates: It consists of a set of platforms, each corresponding nested at most resistant limestone of the sedimentary series. It is characterized by the existence of the deposit of phosphates of Ouled Abdoun.
- Doukkala Abda, which is part ofthe Moroccan Meseta: This regime is characterized by a tabular deposits secondary and tertiary land-based primary pleated friction.
- Coastal Zone Azemmour Safi; It has a morphology with a series of dune ridges separated by depressions filled with very sandy loam.
- Tadla Plain consists of a vast depression covered with asymmetric heterogeneous deposits. This plain is characterized by the existence of two major agricultural areas, located on either side of the Oued Oum Er Rbia (Beni Amir and Beni Moussa).
- The Gantour plateau and the plains of Bahira Tessaout downstream: The base is covered by primary coverage Triassic formations, Cretaceous and Eocene, prior to the Atlas first movements. These formations outcrop in the north and sink in the plain to the south. They are covered by continental formations filling and recent Quaternary deposits.

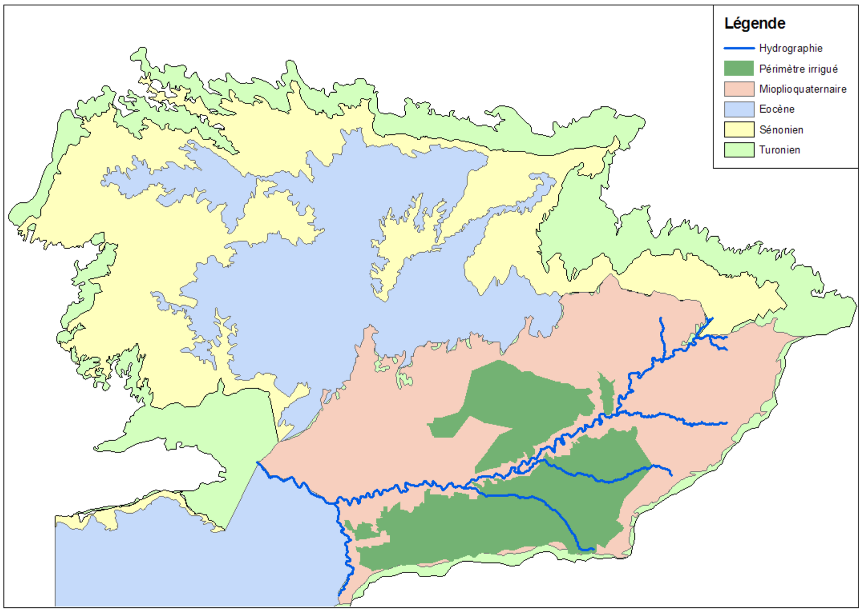


Figure 10-10 Hydro geological formations of the Oum Er-Rbia basin (*ABHOER, 2007 ; Hammani et al., 2005*)

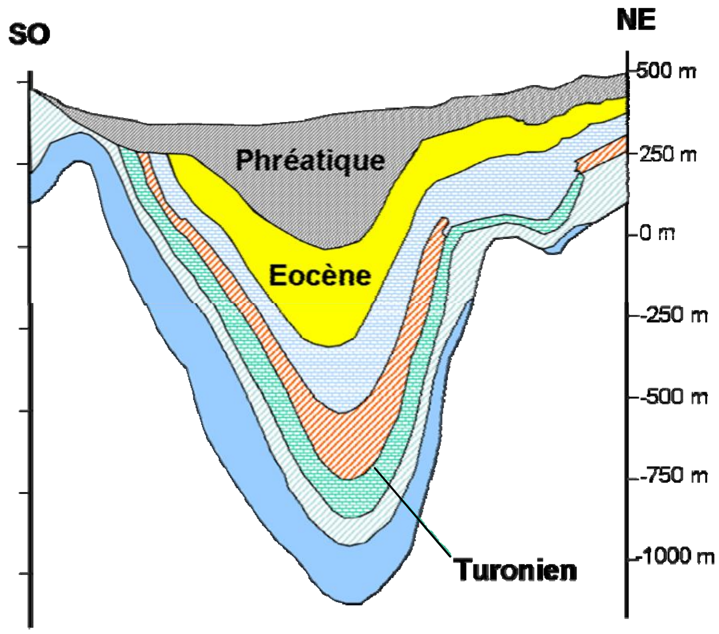


Figure 10-11 Superposition of Aquifers in the Tadla (*Hammani and Kuper, 2007*)

The grouping of geologic units into classes representing the desired parameters has been based on the following table 10-3:

Table 10-3 Geologic units of the oum Er-Rbia basin

Code	Description	Resistance to erosion	permeability
1	Resistant sedimentary rocks metamorphic rocks volcanic rocks	High	Low permeability in general -but variable with respect to lithology (limestone –Permeable sandstone) and the degree of fracturing of the rock
2	Sedimentary rocks of resistance average (flysch - marl) Metamorphic schist	average	Low permeability in general -but variable with respect to lithology and degree of fracturing of the rock
3	Paleogene sedimentary rocks and Neogene	average-low	Relatively high permeability (predominantly sand stone, limestone and conglomerates)
4	quaternary deposits	low	Average permeability and variable Depending on the lithology (clay-sand-silt)

10.5 SOILS

Tadla-Azilal: The soils of the region are diverse due to the nature of the rocks: Deep in the plain and the foothills and rocky in mountains zones (*Plan Maroc Vert*).

The soils of Beni Amir perimeter

The perimeter of Beni Amir (36,000 ha) is located on the right bank of the Oum Er-Rbia. It is irrigated from Kasba Tadla dam. Its development was initiated in 1930. There are several types of soil in the Beni Amir; there are in order of importance:

- The brown soils: They cover a large area; their structure is unstable in water. These soils formed on limestone are themselves limestone.
- The red-auburn soil: They are quite porous and have a high retention capacity.
- Rendzime Soils: Their physical properties are better than brown soils but they are still too thick. In general, they are more adapted for arboriculture and forests.
- The auburn-red soils: These soils have a limestone slab and have physical properties favourable to crops.
- Complex soils: They are only adapted to arboriculture or rangelands.

In conclusion, on the plain of the Beni Amir, the auburn-red and red-auburn soils are the most fertile; they allow the development of varied crops.

The soils of Beni Moussa perimeter

The perimeter of Beni Moussa on the left has an area of nearly 70,000 ha; it is irrigated by the regularized water of Oum Er-Rbia dam, there are several types of soils:

- The red soils are formed primarily in the eastern part of the perimeter and are also localized in the down of Afourer mountain. Their texture is clay or sandy clay , the upper horizons are non-calcareous.
- The auburn soils occupy large areas in the center of the perimeter, in the vast plains. These soils receive spreading waters that flow from the Atlas. They are formed on calcareous loam.
- The brown soils: are the most important, they are localized at the periphery of the plain.
- The brown auburn soils. : They are often formed on calcareous red loam soils.
- Rendzime soils: They cover two areas in eastern and central perimeter and are formed either on the limestone slab, or on calcareous red loam.

Abda-Doukkala

Three units characterize the regional territory soils: (*Plan Maroc Vert*)

- **The coast** : The soils of the littoral are sandy in the north and sandy limestone in the south.
- **The plain**: these soils are generally heavy and deep they allow a good agricultural potential.
- **The plateau of Ahmar zone** : The soils are more or less barren in the south and the west, and are gypsy-limestone and marly-limestone on the plateau.

10.6 LAND COVER/LAND USE

The Tadla is a vast agricultural plain of about 320 000 ha (Figure 10-12), drained by the Oum Er-Rbia river and its main tributaries, the El Abid wadi. It is divided into two parts (*Kobri and Elamani, 2004*):

- The Bour (Rainfed) area (137,500 ha):It consists of cultivated bour, forests, rangeland and uncultivated land. There are also irrigated lands in small and medium Hydraulic scale.
- The area of large hydraulic scale (97,000 ha): It has two distinct parts separated by the the Oum Er-Rbia river. On the left bank, the area of Beni-Moussa covering an area of 69,500 ha, entirely irrigated by the Bin al Ouidane dam built on El Abid oued, and on the right bank, the area of Beni Amir, an area of 27,500 hectares, irrigated by the Ahmed El Hansali dam built on the Oum Er- Rbia river.

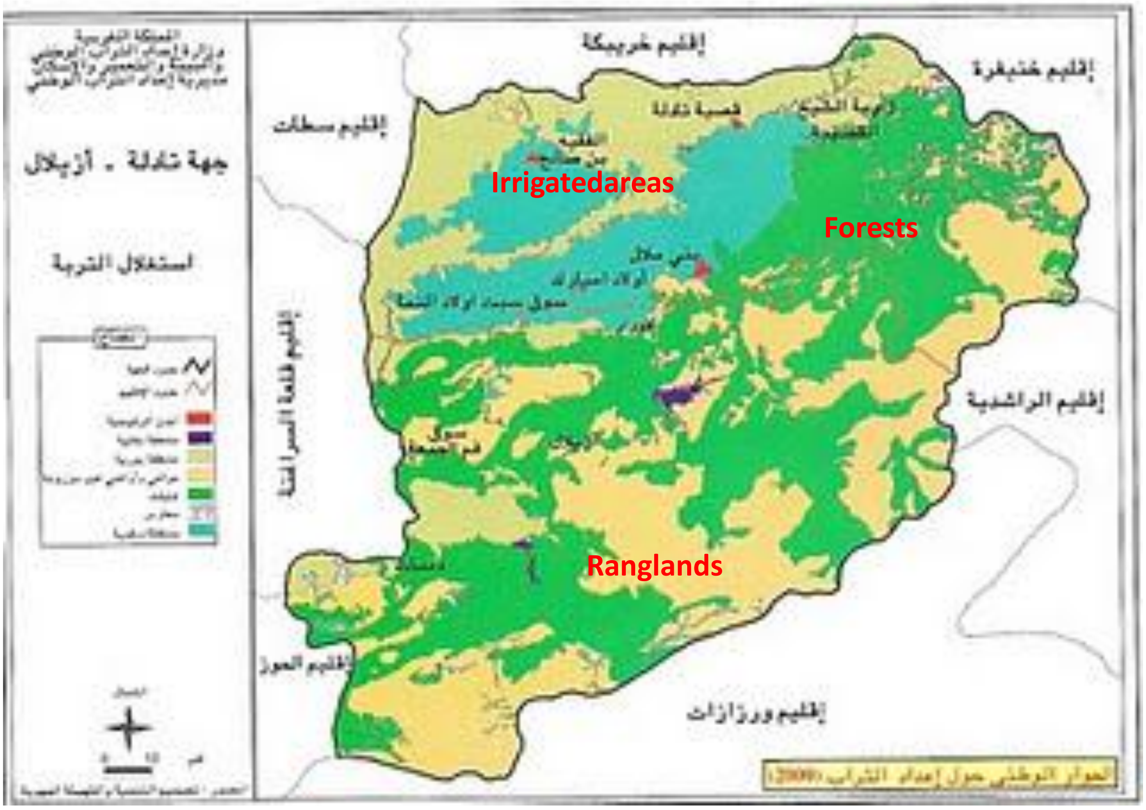


Figure 10-12 Land cover in the Tadla plain

Ref:
http://www.google.co.ma/imgres?q=tadla+azilal&um=1&hl=fr&sa=N&rlz=1C2DVCL_enMA395&biw=1013&bih=660&tbm=isch&tbnid=Mz

The agricultural production in the Oum Er-Rbia basin is presented in the following table:

Table 10-4 Agricultural production in the Oum Er-Rbia basin (*Plan Maroc Vert*)

Vegetal production		Surface		Production	
		(1000 Ha)	% of national hectarage	(1000 qx)	% of national production
Cereals		1702.2	31	20151.3	28
legumes		55.55	16	328.553	15
Sugar beet		38.794	59	21269.541	64
Livestock production					
	1000 head	%			
Cattles	660.672	25			
Sheeps	3877.606	24			
Goats	711385	13			

✓ Tadla-Azilal

The following tables present agricultural production in the Tadla-Azilal region (*Plan Maroc Vert*)

Table 10-5 Crop production in Tadla-azilal region:

Crops	**Hectarage (Ha)**	**Production (Tonnes)**
Cereals	81 500	301 380
Citrus	12 000	210 000
Olives	49 580	101 200
pomegranate	1410	28 800
Carob	15 000	4 000
Almond	11 200	804
Walnut	700	154
apple	1087	15 218
Sugar beet	11 520	599 000

Table 10-6 Animal production in Tadla-azilal region:

Type	**head**	**Production**
Cows of milk production	95 000	210 Millions of Litres
Cattles, sheeps, goats, for meat production	2 131 Millions	42 000 Tonnes
Aviculture	164 Units	15 200 Tonnes
Beekeeping	47 00 beehives	300 Tonnes

✓ Doukkala Abda

In the Doukkala-abda region, crop production (Table 10-7) remains dominated by cereals and legumes (81% of the SAU vs 74% at national level) essentially cultivated in the rainfed area. Orchards represent only 2.5% of the SAU (national average 9.3%). With 12% of the SAU, the fallow remains similar to the national average.

Table 10-7 Crop production in the Doukkala-abda region

Crops	Hectarage (Ha)	% Of the SAU
Cereals	839 433	79
legumes	20 562	2
Gardening crops	34 174	3
Industrial crops	16 998	2
Fodder crops	17 046	2
Orchards	26 020	2
Fallow	129 331	12
Total	**1 083 564**	**102**

Cereals, legumes and fallows represent about 94% of the SAU vs 7% for industrial crops and 2% for the orchards, thus showing the weak diversification of the cropping system in the region. This is mainly due to the dominance of rainfed agriculture (88% of the SAU) in a semi-arid climate.

Next to the crop production system, there is the livestock production system with aherd consisting of 3720938 head of cattle, 1 517 768 head of sheep, 43 515 head of goats, 5633 head of camel and 236 849 head of horses. Converted into livestock units (LU), this number represents 781 930 LU, corresponding to 11% of the national value. This stock is dominated by cattle (46%) and by small ruminants (sheepsand goats) with 35%.
The average number of livestock units per farm is 5, which is similar to national average. (table 10-8).

Table 10-8 Livestock units in the Doukkala-Abda region

Zones	Total LU	LU per farm	% LU cattle	% LU small ruminants	% LU horses
Doukkala-Abda	781 930	5	45	36	19
National	7 353 591	5,91	29	54	17

10.7 DEMOGRAPHY

According to the 1994 census, the population of the area was estimated at 4,420,000 inhabitants, corresponding to about 17.0% of the national population. This population is divided between 1,422,200 (36%) in urban areas and 2998 000 (64%) in rural areas. Indeed, the concentration is higher in centres and adjacent areas of streams and springs *(INECO, 2009*).
In 2004, the population of the area has increased to nearly 4,855,090 inhabitants, representing 16.2% of the population of the kingdom, divided among 1,879,900 in urban areas representing the 39% of the total population of the area (over 65 urban centers see list in Table 10-9 below) and 2,975,194 in rural areas (61%) with a list of all the municipalities is

attached. The average density of the population has increased to nearly 91 in 1994 to 100 inhabitants per km^2 in 2004 (*INECO, 2009*).

Table 10-9 Distribution of Population in Oum Er-Rbia Bassin

	Population 1994			Population 2004		
	Total	includingrural	Includingurban(*)	total	includingrural	Includingurban(*)
AL HAOUZ	6113	6113	0	6967	6967	0
AZILAL	454914	419052	35862	504501	422802	81699
BENI MELLAL	869748	523711	346037	946018	498688	447330
EL JADIDA	929870	733513	196357	1054948	771542	283406
EL KELAA DES SRAGHNA	559051	449348	109703	631438	468485	162953
ERRACHIDIA	7253	7253	0	8222	8222	0
IFRANE	9882	9882	0	11028	11028	0
KHENIFRA	207593	146758	60835	230908	99653	131255
KHOURIBGA	398471	113525	284946	423204	96530	326674
SAFI	676577	311929	364648	733724	318401	415323
SETTAT	288668	264851	23817	292377	261121	31256
Marrakech	11685	11685	0	11755	11755	0
	4419825	2997620	1422205	4855090	2975194	1879896
(*)This is thepopulationofmunicipalities in the zone of action of the Oum Er-Rbia						
(**)See list of urban centers of the agency of the Oum Er-Rbia						

As for the urban population of the Oum Er-Rbia, the three categories of cities and centres identified are those of the Department of Statistics, namely:

- Cities: Population over 100 000 inhabitants;
- Centers means: Population between 20,000 and 100,000 inhabitants;
- Small centers: Population less than 20,000 inhabitants.

10.8 INFRASTRUCTURES

10.8.1 Road Network

The zone of action of ABHOER has a fairly large road network (Figure 10-13):

- 145 km of highways, especially those linking Casablanca to El Jadida and Casablanca to Marrakech;
- 193 km of railway, mainly roads linking Casablanca to El Jadida and Casablanca to Marrakech;
- 730 km of national roads: RN1, RN 7, 8 RN, RN RN 9 and 11;
- More than 2000 km of regional roads.

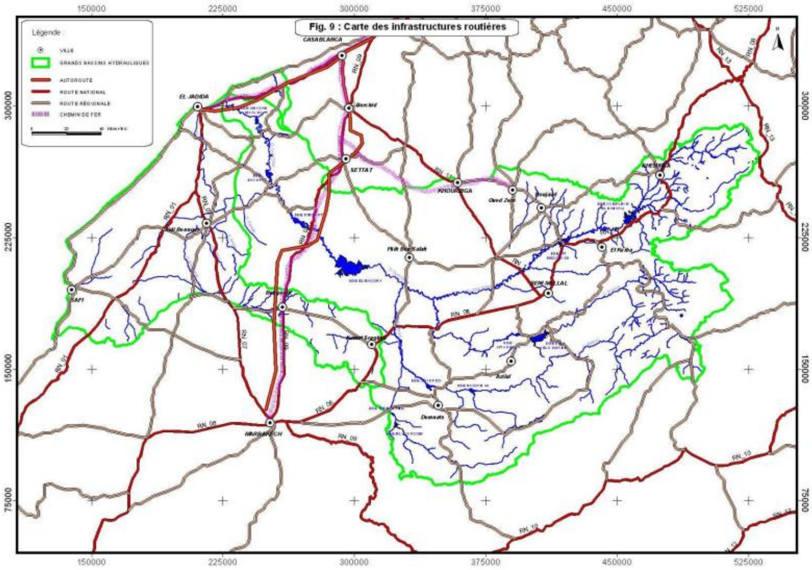


Figure 10-13 Roads map of the Oum Er-Rbia basin

10.8.2 Hydraulic infrastructure

The OER basin has already been the subject of important investments on hydraulic infrastructure. The basin has the largest number of dams among the Morocco Basins.

Indeed, the basin of the Oum-Er-Rbia includes 15 dams, of which 5 can be considered important (Figure 10-14).The current storage capacity is around 5.09 billion cubic meters, while the total volume of water is regulated 3.604 billion cubic meters / year, or 33% of the total in the country.

Table 10-10 Oum Er-Rbia basin dam infrastructure

Dam	Operation year	Storage capacity (million m³)	Height (m)	Purpose[1]	Regulated volume (million m³)[2]
Ahmed EL HANSALI	2001	740	101	E, I	473
A.MESSOUD	2003	14	34	E, I, U	-
Kasba TADLA	1935	0.1	11	E, I	-
BIN EL OUIDANE	1954	1243	132	E, I	945
AIT OUARDA	1954	4	46	E, I	-
HASSAN 1st	1986	245	145	E, I U	346
SIDI DRISS	1980	1.3	42	I, U	-
MY YOUSSEF	1969	150	100	E, I	250
TIMINOUTINE	1979	5.3	45	I	-
AL MASSIRA	1979	2657	82	E, I, U	1590
IMFOUT	1940	17.3	50	E, I, U	-
DAOURATE	1950	7.7	40	E, U	-
Sidi Said MAACHOU	1929	1.5	28	E, U	-
Dam of Safi	2001	2	18	U	
Dam Sidi Daoui	2003	5	8.5	U	
TOTAL		5086.6			3604

Overall, the regulation of surface water is favorable in the region, mainly due to the existence of Al Massira large dam, located in the downstream part of the basin.Water is mainly used to supply drinking water, irrigation and hydropower generation.

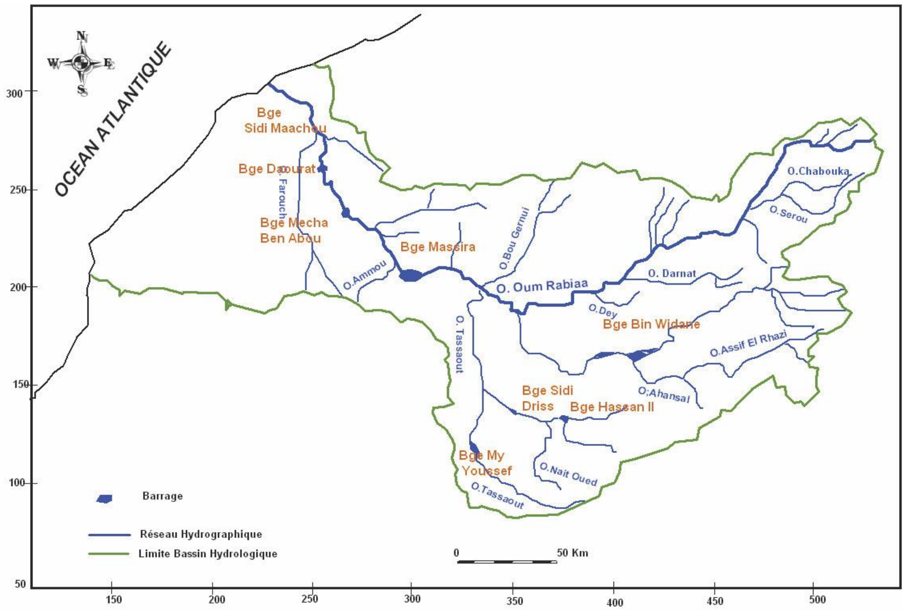


Figure 10-14 Localisation of main dams in the Oum Er-Rbia basin

Hassan I dam My Youssef dam

Bin A Ouidane dam Al massira dam

Figure 10-15 Main Oum Er-Rbia dams

The Oum Er-rbia basin in a few words

Total irrigated area: 446,000 ha

Mean intakes of water surface: 3250 Mm^3/year

Groundwater potential fund of approximately: 350 Mm^3/year

Water projects: 15 dams, (Total capacity: 5100 m^3)

Current water needs: 337 Mm^3/year and Irrigation: 3891 Mm^3/year

Average production of hydroelectric power: 1 680 million kWh / year

10.8.3 Food industry

- **Doukkala-Abda**

Due to its vocation and hydro-agricultural equipments that are made, Doukkala-Abda region has seen the installation of a relatively important agro-industrial infrastructure

especially for key sectors:
- Storage of cereal grains: 17 units, 3.6 million quintals per year;
- Transformation of cereal grains: 13 units, 450 000 tonnes / year;
- Treatment of beet production: 1 unit, 15 000 tonnes / day;
- Machining of milk: 3 units; 1430 tonnes / day;
- Production of animal feed and poultry: 3 units; 140 000 tonnes / year;
- Crushing of olives: 8 units, 400 tonnes / year;
- Conservation of olives: 3 units; 2000 tonnes / year;
- Conservation of capers: 2 units 5 000 tonnes / year.

10.9 REGIONAL WATER RESOURSES USE

The volume of water used in the Basin rises to about 3.861 Mm³ of which 91% comes from the mobilization of the surface waters. This volume allows for the irrigation of more than 345.000 ha, the production of 1630 1866 GW/h of energy in average year, the provision of drinking water supply for 5 million inhabitants and a minimum flow to guarantee the healthiness of water courses.

Table 10-11 Oum Er-Rbia basin water resources use:

Water use (million m³)			
Use	Surface water	Groundwater	Total
Irrigation	3250	257	3507
Water supply and industry	100	89	189
AEPI* transfer	165		165
Total	3515	346	3861

*: AEPI (Alimentation of (Drinkable (potable) and Industrial water)

Surface water is used for irrigation, domestic, industrial use and hydropower generation, with agriculture being the main consumer (using more than 90% of the water resources at the Oum Er-Rbia watershed scale). Surface water is used to irrigate four large and some small and middle scale perimeters which are:
- The Tadla irrigated perimeter (100,000 ha);
- The Doukkala irrigated perimeter (104,600 ha);
- The Tassouat Aval irrigated perimeter (49,000 ha);
- The Tassouat Amont irrigated perimeter (51,700 ha);
- The small and medium scale perimeters (64,000 ha involving downstream and upstream basin, Dir de Beni Mellal [Tadla], downstream of Oued El abid, downstream basin).

The Tadla Irrigated Perimeter (PIT) is one of the nine large-scale agricultural irrigation districts developed by the government of Morocco as part of its so-called “one-million irrigated hectares” program. The Oum Er-Rbia river divides PIT into two independent hydraulic regions: the Beni Moussa (the larger of the two) on the south bank and the Beni-Amir on the north (Figure 10-5).The Beni Moussa gets its surface water from the Bin el

Ouidane reservoir and Beni Amir from Ahmed el Hansali reservoir.

Water flows from these reservoirs by gravity through approximately 3,000 km of open canals. The total gravity-fed irrigated area is 117,500 ha. Additional lands (a least 8,500 ha are irrigated exclusively with well water. Surface water is allocated to farmers by ORMVAT (Office Régional de Mise en Valeur Agricole de Tadla) based on available applies and the crops grown, priority is usually given to fruit trees, sugar beets, and forage crops. However, farmers are free to manage the water as they wish, within their property. Water is supplied on apriority-based system called “Tour d’eau” every 2 to 4 weeks. (Berrada, 2009).

Concerning groundwate user, farmers give priority to forage crops irrigation then to cereals. Indeed, farmer’s main priority is to secure livestock feeding and then their household alimentation (Hammani and Kuper, 2007)

Drinking and Industrial water supply

The global demand in drinking and industrial water from water resources of the basin is about 354 Mm³ of which 20 Mm³ for the rural area and 30 Mm³ for the isolated industry.

This demand is satisfied thanks to 265 Mm³ from the superficial waters and 89 Mm³ from the underground waters.

The great centers supplied from water resources of the basin are Beni Mellal, Khouribga, Oued Zem, El Jadida Casablanca, Settat, Berchid Safi and Marrakech

Irrigation

Needs in irrigation water from resources of the Oum Er Rbia are 3507 Mm3/year (2533 Mm³/year for the great hydraulic works and 974 Mm³/year for the small or middle hydraulic works - SMH).

The hydraulic equipment established in the basin allowed a remarkable irrigation development: the irrigated surface in great hydraulic from the Oum-Er-Rbia waters is 308.500 ha (including 35.400 ha currently equipped in the Central Haouz). As for the SMH, irrigated surface is 36.000 ha.

Water transfers

The cities of Casablanca (close to 4 millions of inhabitants) and of Marrakech (close to a million of inhabitants), which are cities situated out of the Oum Er Rbia Basin, depend for drinking water supply on waters transferred from this basin.

The water volume currently transferred, for cities situated out of action zone (Casablanca, Settat, Berchid and Marrakech) is about 165 Mm³/year distributed as follows :

- 120 Mm³/year for Casablanca, Settat and Berchid from the Al massira complex;
- 45 Mm³/year for the Marrakech city from the Hassan 1er-Sidi-Driss complex.

Energy

The hydroelectric power stations of the Oum Er-Rbia, associated to dams, occupy the first place in the national hydroelectric production. The currently installed power in the hydroelectric factories of the Oum-Er-Rbia basin not including the STEP of Afourer, is 623 MW (50% of the national hydroelectric park). These factories produce in average 1866 GW/h (60 to 72% of the national hydroelectric production).

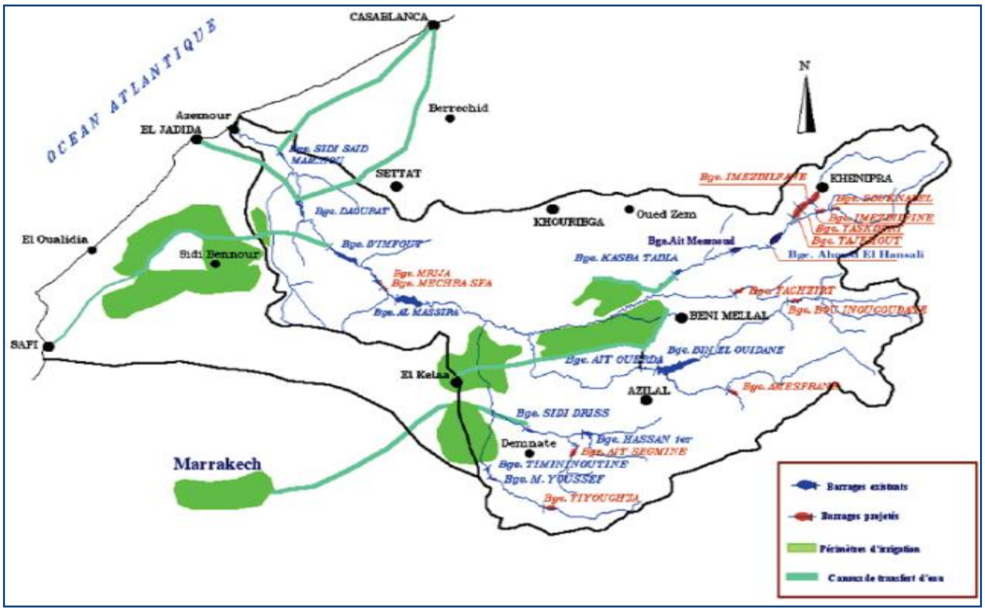


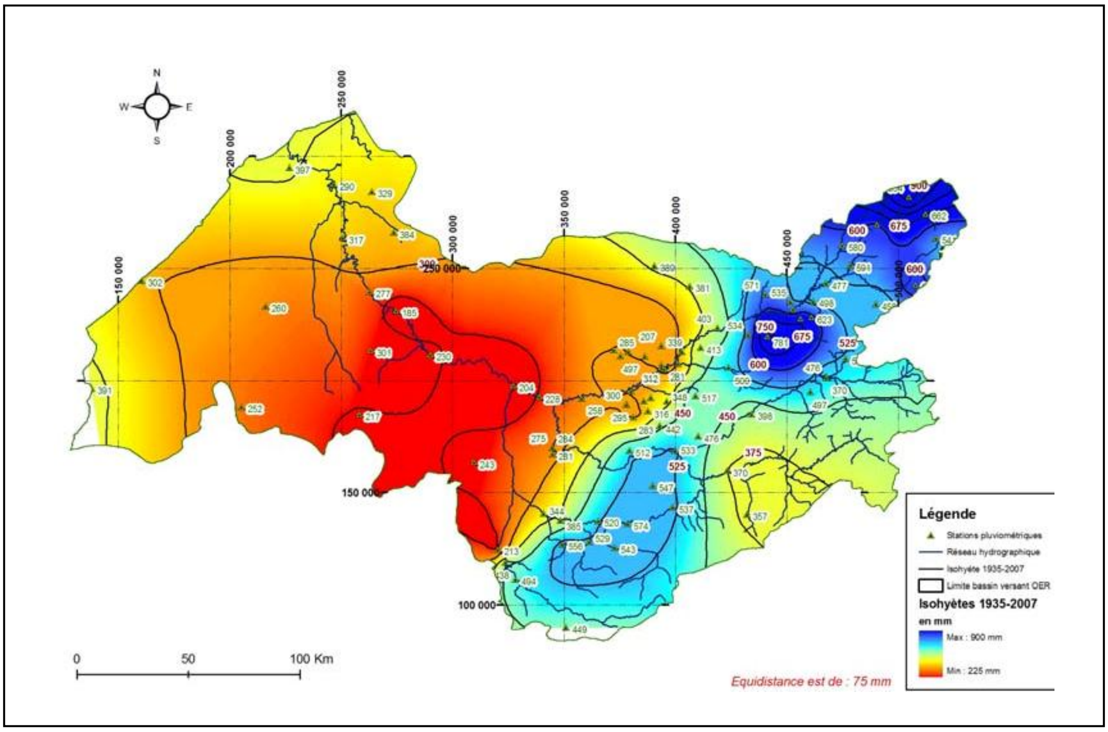
Figure 10-16 Location of storage tanks, channels for inter-basin transfers and irrigation

10.10 HISTORICAL INFORMATION ON DROUGHTS

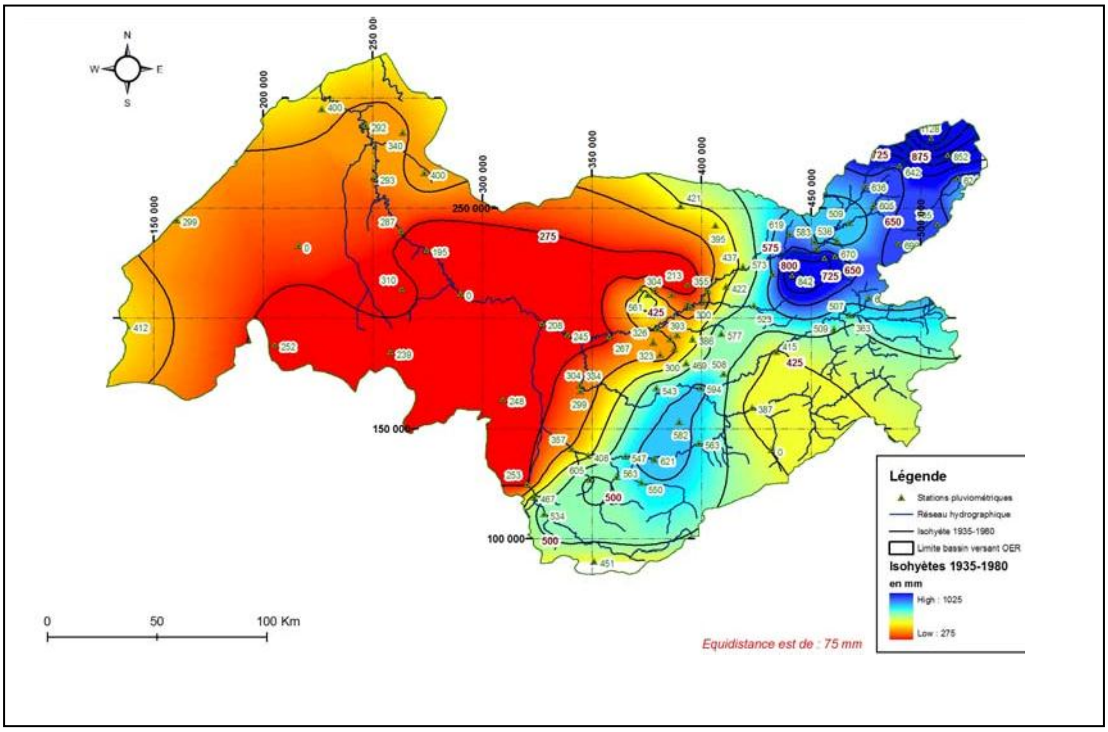
✓ Rainfall trends between 1935 and 2007

Three isohyets maps were established during this period (PDAIRE, 2008):

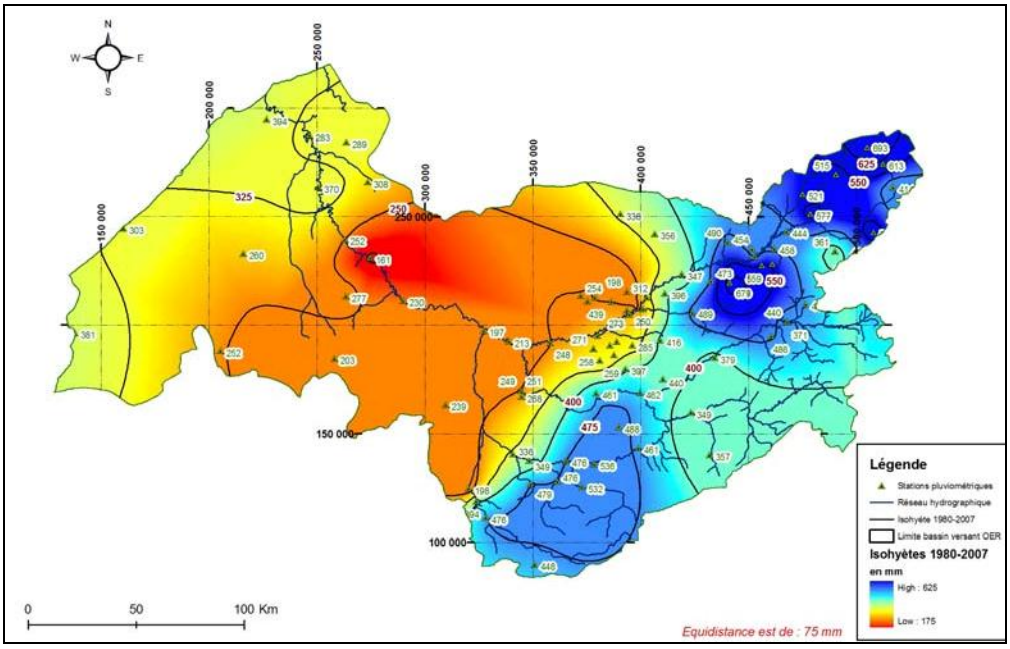
Map1: Isohyets of Oum er_Rbia area: Annual means (1935-2007);
Map2: Isohyets of Oum er_Rbia area: Annual means (1935-1980);
Map3: Isohyets of Oum er_Rbia area: Annual means (1980-2007);



Map1: Isohyets of Oum er_Rbia area : Annual means (1935-2007)



Map 2: Isohyets of Oum er_Rbia area : Annual means (1935-1980)



Map 3: Isohyets of Oum er_Rbia area : Annual means (1980-2007)

The first map gives a global idea on the inter-annual spatial distribution of rainfall from 1935 to 2007. It shows that annual rainfall is very important in the mountainous part of the river basin where it can reach 900 mm. In coastal areas, rainfall is mean whereas in central areas the average annual rainfall is very weak. The comparison between maps 2 and 3 reveals a significant rainfall decrease over the last 3 decades. Thus, the average annual rainfall moves from an interval of [275-1025] mm from 1935 to 1980 to an interval of [175-625] mm from 1980 to 2007 corresponding to a 15% loss of annual rainfall.

Table 10-12 presents drought periodicity for a given year. For example, the probability of having on a given year, an average annual rainfall inferior or equal to 317 mm in the AB sub-basin is of 1/10. In other words, this table shows the period of returns of droughts. In the example, we have taken and which is marked in green in the table a total annual rainfall of 317 mm represents 70% of the average rainfall and consequently a rainfall deficit of 30%. Thus, the such a deficit has a periodicity of 10 years. Similarly a rainfall deficit of 40% (marked in blue) has a periodicity of 50 years.

Table 10-12 Drought periodicity in Oum er-Rbia sub-basins (PDAIRE, 2008)

(AB=El Abid sub-basin, BO=Low Oum er-Rbia sub-basin, CO=Central Oum er-Rbia sub-basin, HO=High Oum er_Rbia sub-basin, LT=Oum Er-Rbia Tensift boarders, MO= Middle Oum er-Rbia sub-basin and TS= Oued Tassaout sub_basin)

Drought periodicity (D)	AB	BO	CO	HO	LT	MO	TS
100years	255	171	249	303	130	113	243
50years	270	184	262	324	142	123	261
20years	294	206	281	360	162	140	290
10years	317	228	301	394	181	157	320
5years	349	258	327	442	207	180	359
2years	424	327	390	553	269	234	452
90% of average rainfall	398,5	306,9	364,7	531,3	258,5	222,8	427,7

Values in mm/ year

✓ Surface water flows

Table 10-13 presents the interannual average inflows expressed as surface water flows in m^3/s and the corresponding total water volume in Mm^3,in the main sub-basins (fig. 10-17)for the two periods of 1941 to 1980 and 1981 to 2006. These data show that in all the sub-basins, average inflows computed over the last 3 decades are very inferior to those computed between 1941 and 1980. All the sub-basins have been affected, although at various degrees, by this decrease. On the whole Oum er-Rbia basin, annual average inflows of 3245 Mm^3 and 2313 Mm^3 were recorded respectively between 1940 and 2006 and between 1981 and 2006 whereas an annual average inflow of 3850 Mm^3 has been recorded between 1940 and 1980. Thus, the inflow decrease between these two periods represents 1536 Mm3/year, corresponding to a 40% loss.

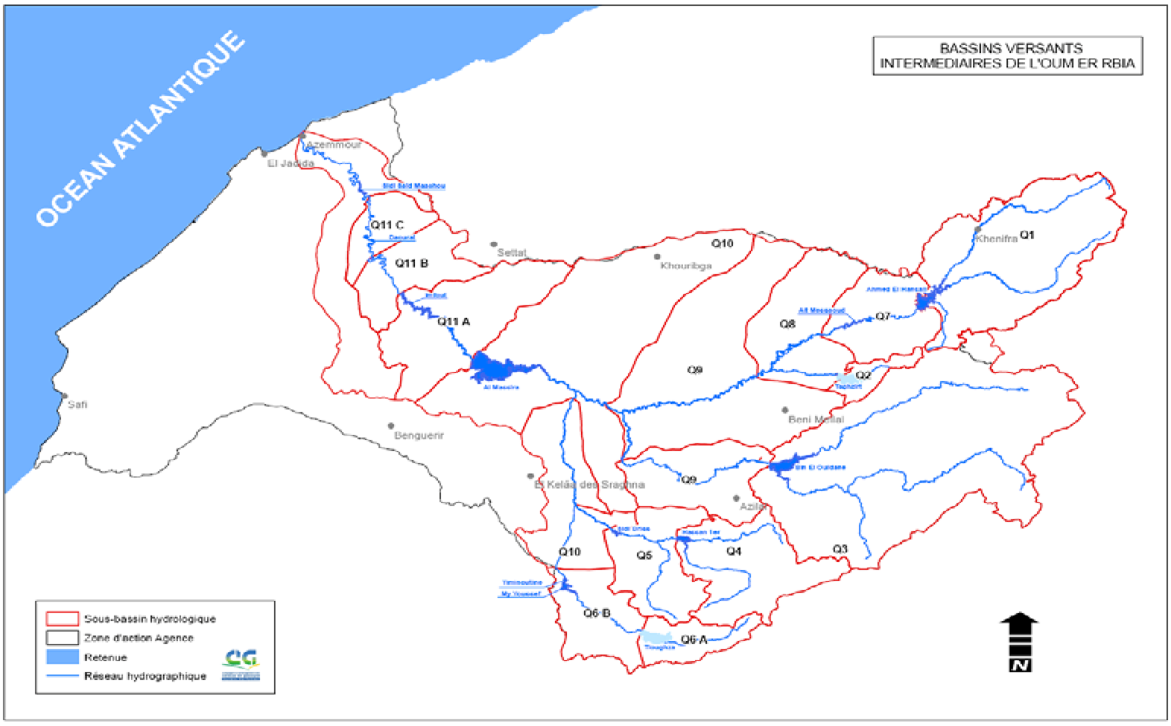


Figure 10-17 Hydrological sub-basins in the Oum er-rbia basin

Table 10-13 Intermediate inflows in Oum er-rbia sub-basins

Sub-basin	Average inflows				
	Volume (Mm3)		Flow (m3/s)		Relative decrease
	1941 - 1980	1981- 2006	1941 - 1980	1981- 2006	
Hassan 1er damQ4	314.28	168.18	9.99	5.33	46%
My Youssef dam Q6	311.30	205.51	9.88	6.53	34%
Bin El Ouidane dam Q3	1228.68	631.95	39.09	20.11	49%
Ahmed El Hansali dam Q1	996.10	543.66	31.66	17.22	45%
Station Taghzirt 2 Q2	75.63	52.24	2.41	1.67	31%
Kasbat Tadla dam Q5	258.53	204.92	8.24	6.51	21%
Sidi Driss dam Q7	138.15	111.51	4.39	3.54	19%
Basin between Kasba Tadla and Mechra Eddahk Q8	115.23	61.98	3.67	1.97	29%
Basin between Mechra Eddahk and t Ouaouirhint) Q9	300.34	119.48	9.56	3.80	
Basin between Ouaouirhint and El Massira Q10	50.84	151.11	1.62	4.80	
Basin aval El Massira Q11	61.63	63.42	1.96	2.01	-3%
Q12	3850.71	2313.97	122.46	73.57	40%
Q13	938.72	701.24	29.88	22.30	25%

- ✓ **Drought characterization in the Oum er-Rbia basin**

Meteorological, hydrological and agricultural droughts were characterized in the Oum er-Rbia basin in the framework of Medroplan Project.

Meteorological droughts in the Oum er Rbia basin

The meteorological drought in Tadla region (Oum er Rbia basin) was characterized using the 6-month Standardized Precipitations Index (SPI) over the period 1934-2003 (see Fig.10-18).

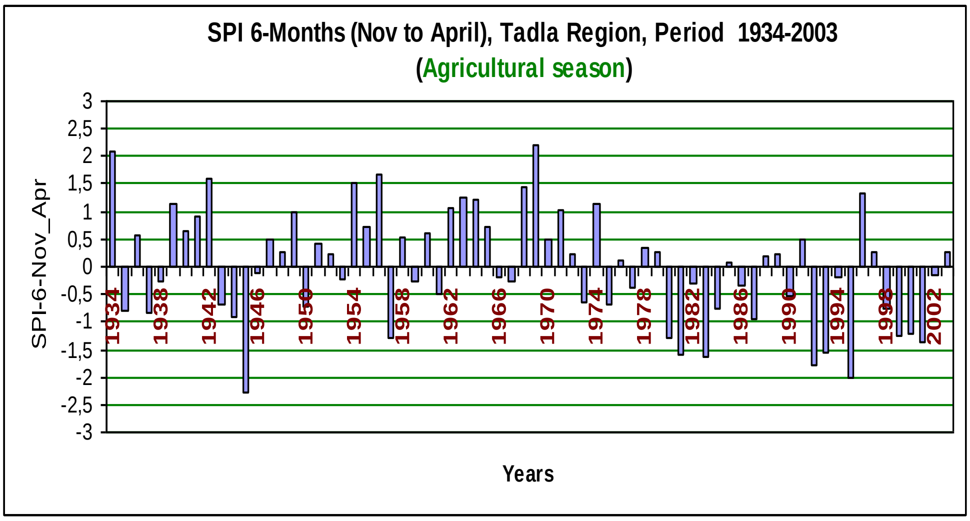


Figure 10-18 Determination of SPI values for Tadla region (Oum Er Rbia basin).

These data show that the most severe drought episodes for the Tadla region (Oum Er Rbia basin) over the last seventy years are the 1940-45, 1957-1958, 1980-85,1992-93, 1994-95 and 1998-2002 periods (Ouassou *et al*. 2007).

Hydrological drought in the Oum er Rbia basin

The Oum er Rbia basin has 15 multi-purpose dams. They supply various uses such as drinking water, irrigation and hydro-electricity power. Bin Al Ouidane, Al Massira and Ahmad al Hansali dams (Fig. 10-19) are the most important in terms of capacity. Figure 10-20 presents the variability of water reserves in inflows (million m^3) for Bin El Ouidane dam from 1971 to 2003. It shows three main periods of severe hydrological droughts as follows: 1980-81 to 1986-87, 1990-91 to 1994-1995 and 1998-1999 to 2002-2003.

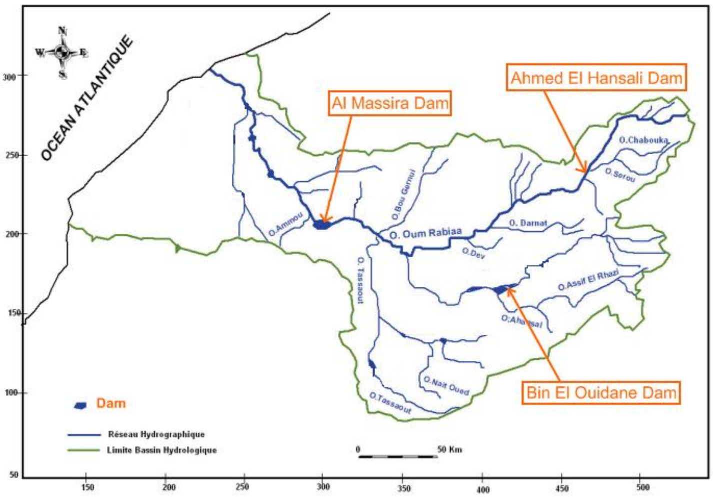


Figure 10-19 Location of Bin Al Ouidane, Al Massira and Ahmad al Hansali dams in the Oum Er rbia basin

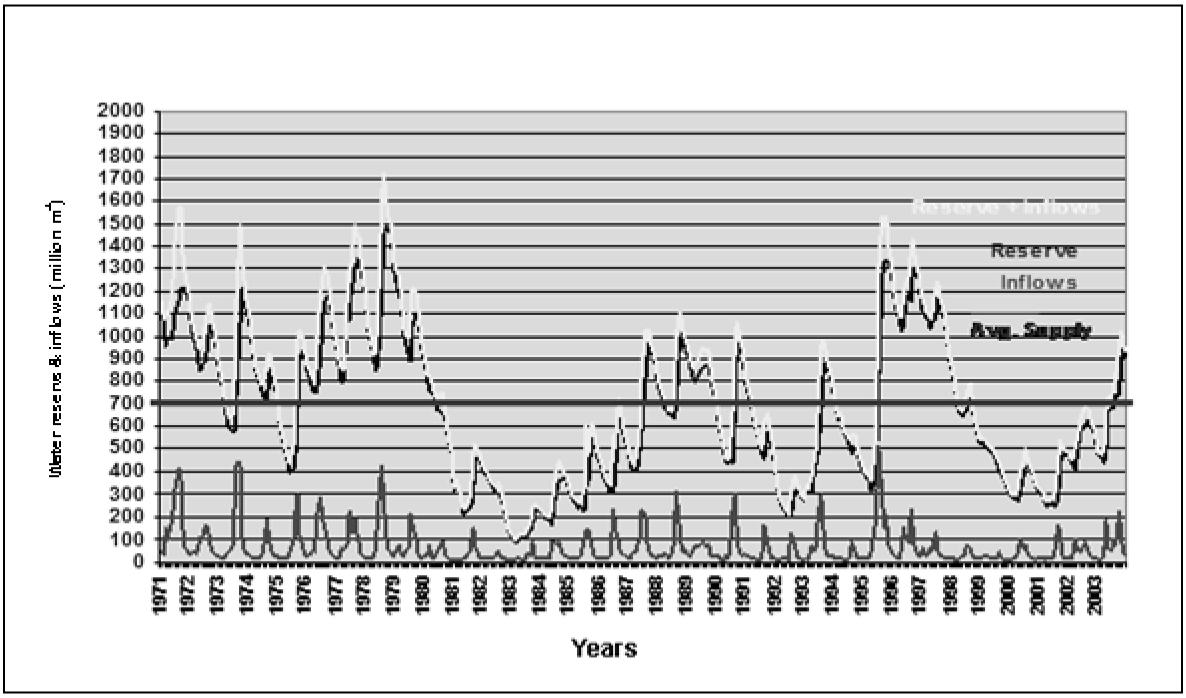


Figure 10-20 Variability of water Reserves and Inflows (Mm^3) (Bin El Ouidane dam in Oum Er Rbia Basin; 1971-2003)

The hydrological droughts for Bine El Ouidane dam were also characterized by the 9-months SPI and by a modified Surface Water Supply Index (SWSI) (Svoboda, 2004) (Fig. 10-21 and 10-22)

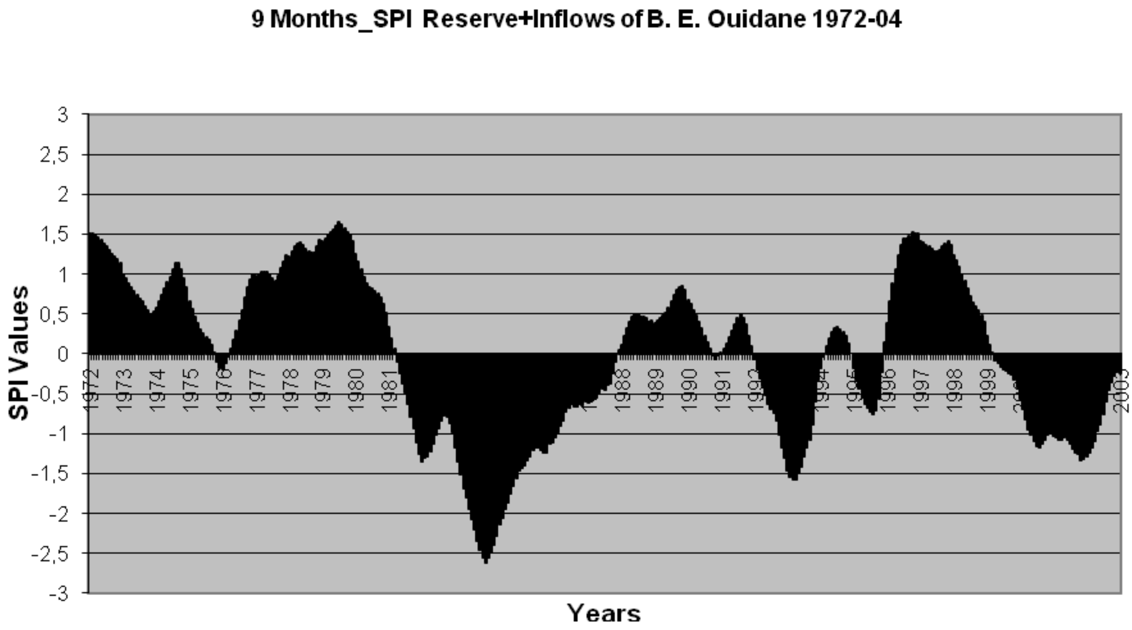


Figure 10-21 Use of SPI to monitor reserve and inflows for the Bine El Ouidane Dam (Oum Er Rbia basin)

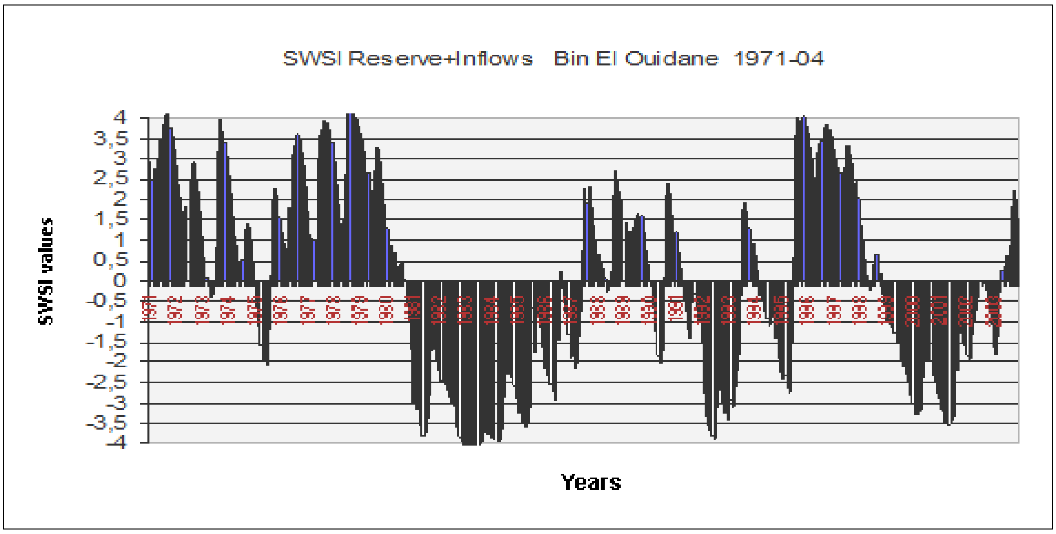


Figure 10-22 SWSI values in the Oum Er Rbia river basin over the period 1971 – 2004 for the Bin El Ouidane Dam

Agricultural drought in the Oum er- Rbia basin

The characterization of drought years based on the yield threshold profitability over the cropping seasons from 1980 to 2000 is illustrated in Figure 10-23. Based on results of field surveys, the yield threshold for profitability was calculated to be 11 Quintals per hectare (or 1.1 ton per ha). On average, there were 9 severe drought years during 1980 – 2000 of which 6 dry years in the decade 1990 – 2000.

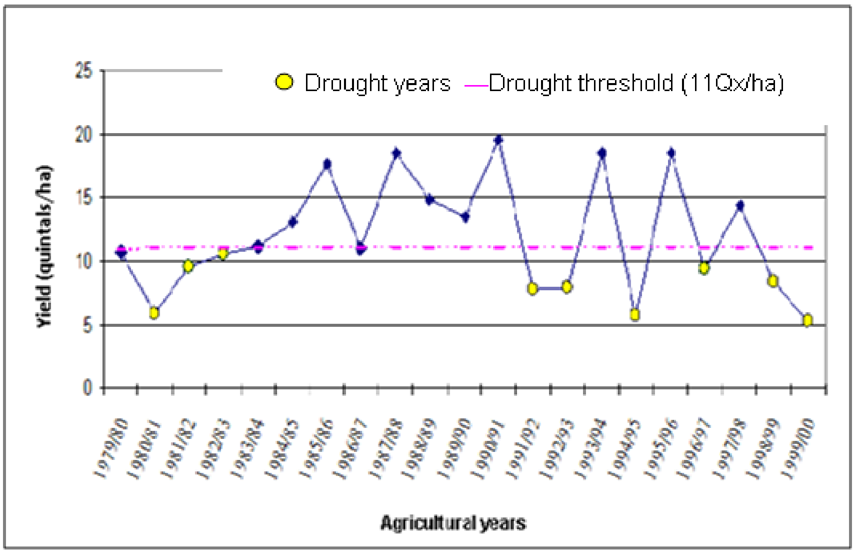


Figure 10-23 Characterization of drought years based on cereal yield threshold in Oum Er Rbia basin from 1979-80 to 1999-2000

10.11 PURPOSE OF THE CASE STUDY

The aim of this case study is to further agricultural drought forecasting by means of the newly developed indicators (WP 3) and model techniques (WP 4). First of all the seasonal forecasting of agricultural drought in the basin will be improved to gain lead time for effective drought mitigation. Second, recommendations will be made on how to reduce vulnerability through the implementation of better adapted agricultural practices.

The particular activities in this case study will be:

- Test improved agricultural drought indicators (WP 3) and forecasting of agricultural drought (WP 4)
- Transfer drought forecasts to drought warnings according to the framework developed in WP 5.
- Pilot and analyze the effectiveness of adapted agricultural practices on drought vulnerability

10.12 DESCRIPTION OF NEEDS AND PROBLEMS TO BE ADRESSED BY THE CASE STUDY

The Hydraulic Basin of the Oum Er-Rbia river faces various natural and technical constraints, mostly concerning the sustainability and availability of water in terms of both quantity and quality but related also to its geographical situation:

Water availability is subject to the large variation of precipitation in both space and time. This is due to several factors, and most importantly to the overall climatic conditions. Thus, drought frequencies, severity and lengths increased during the last three decades and It should be noted that in the drought episodes experienced from 1980 and onwards, **the reduction in the volume of water available was about 15 to 20% (**see point 10.11).Consequently, a number of problems associated with these recurring and extended droughts and increasing water scarcity have been noticed in the Oum er-Rbia basin and Tadla area, particularly in the past few decades (Debbarh and Badraoui,2002; Hammani *et al*.,2004; Knippertz *et al,*.2003; Petitguyot and Rieu, 2004). Manifestations of water scarcity include, among others:

- **Groundwater overpumping**

As a consequence to the increase frequency and severity of droughts episodes, the number of wells increased in the regions. The subsequent groundwater overexploitation has resulted in an alarming decrease in water table levels, especially in the plains of Abda and Doukkala. In certain areas, extracted volumes are almost doubling every 15years, as a result of well construction and borehole drilling for irrigation purposes. The situation is further aggravated by the current practice of pumping from deep water tables, which are considered strategic reserves, to be used only under exceptional circumstances. At present, the decrease of watertable levels is observed throughout the Basin, and reaches alarming values, which often exceed 2m/yr. Furthermore, the coastal aquifer, located between Azemour and Safi, and used for the irrigation of high-valued crops, faces the risk of sea intrusion (INECO, 2009).

- **Alarming water quality deterioration**

Approximately half of water resources of the Oum Er-Rbia Basin are being polluted by the discharge of industrial and domestic wastewater, agrochemicals and sea-water intrusion. In the area under the authority of the Oum Er-Rbia Hydraulic Basin Agency, domestic pollution originates from 70cities and agglomerations. The quality of surface waters is generally good in the upstream parts of the basin (i.e. upstream of Khénifra) and becomes degraded downstream, as a result of urban and industrial discharges. The section between the downstream Kasba-Tadla and the downstream discharge point of Dar Ouled Zidouh on the Oum Er-Rbia River is significantly polluted by the combined discharge of industrial and domestic effluents. Agriculture contributes to groundwater pollution due to the application, at times excessive, of manure, fertilizers and pesticides. In the area controlled by the Oum Er-Rbia Agency, the quantity of nitrogen leaching towards aquifers or streamed towards water courses is estimated at 10% of the quantities applied. Therefore, approximately 3,500 tons of nitrates, originating from manure application reach the Tadla aquifer as a result of leaching. Furthermore, the pollution originating from pesticides is estimated at 2.2 tons/yr. Groundwater quality experiences a continuous degradation. Over the past 15 years, the measured concentrations of nitrates have escalated to alarming levels, reaching values higher than 50mg /l in the majority of points sampled. Since the 1980s, the problem of nitrates has become particularly acute in the Tadla plain, where concentrations exceed the acceptable norm of 50 mg/l in the largest part of the area (Figure 10-24). At present, more than 60% of the watertable surface area (80,000ha) is polluted, and if no action is taken, the entire aquifer will shortly become contaminated (INECO, 2009).

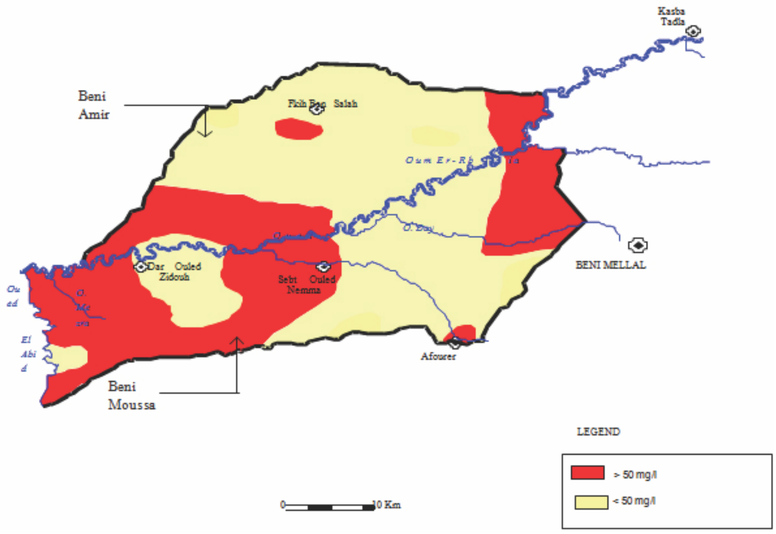


Figure 10-24 Nitrate pollution in groundwaters in the Tadla perimeter (from INECO, 2009)

- **The reduction of water supply for the irrigated sector**

As a consequence of water shortage, the amount of water allocated to the different irrigated perimeters of the Oum er-Ria basin during the last 30 years faced an average deficit ranging from 33 to 67 % (Zerouali et Chtioui, 2007).

In addition to the increase of water scarcity due to the increase of drought frequency and severity, the Oum er-Rbia basin is confronted to other important constraints namely water losses and water transfers to other basins.

- **Water losses and low efficiency in water use**

In the Oum er-rbia basin, about 90% of water resources go to the agricultural sector.

Waterlosses in the agricultural sector are extremely important. Losses in irrigation distribution networks are estimated at 20%, whereas losses within the fields (in crop irrigation) are estimated at 50%.The situation is aggravated by the small share of agricultural land (10%) equipped with advanced irrigation systems. In the domestic sector, distribution losses are approximate 35%.

Figure 10-25 Water losses in the Agricultural sector in the oum er-Rbia basin

With regard to dam siltation, measures taken are aimed at addressing the transportation of sediments in the corresponding watersheds (Table 10-14). In total, the volume lost in regulation dams (Al Massira, Bin El Ouidane, Moulay Youssef, Hassan the first), is currently estimated at 350 million m^3. Dam siltation has direct impacts on the regulated volumes, dam performance, dam security, required supplementary works, downstream infrastructure and water quality.

Table 10-14 Siltation in major dams

Dams	**Operation startyear**	**Initial capacity (million m^3)**	**Presentcapacity(millionm^3)**	**Lossofcapacity (millionm^3)**	**Yearlysiltation (million m^3)**
BinElouidane	1954	1500	1243	257	5.14 0.34
M.Youssef	1970	197	150	47	1.38 0.70
Hassan1er	1987	272	245	27	1.59 0.58
AlMassira	1979	2785	2657	128	5.12 0.18
A.ElHansali	2001	740	740		
Total		**5494**	**5035**	**459**	**13.23 0.24**

- **Water transferts from the basin**

The Oum Er-Rbia Basin is located between two other Basins of high socio-economic importance, which face significant water management issues: More specifically:

- TheTensift Basin, where Marrakech is located, experiences a widening gap between supply and demand; A volume of 300 million m³/yr is transferred from the Oum Er-Rbia Basin to the region of Marrakech. Of this amount, 260 million m³ are used for irrigation purposes and 40 million m³ for meeting urban water needs.
- The Bouregreg Basin, where Casablanca and Rabat are located, cannot depend on its own water resources, and inter-basin transfers had to be implemented. The annual supply provided by the Basin for meeting water needs in the Casablanca metropolitan area is equal to120 million m³.

Financial, administrative and institutional issues represent other constraints in the basin. Thus, the overall administrative and institutional setting suffers from the delay in the implementation of the Water Law. This delay is actually preventing more rational water management, and the application of the “polluter-pays” principle. Delays in implementation mostly concern the water charges that will constitute the financial resources of the Basin Agencies, which permit them to provide financial assistance for the development and protection of water resources.

As a conclusion, the biggest equation to resolve is the widening gap between supply and demand. Indeed, due to urban growth, to the development of the industrial and agricultural sectors, and the development of tourism, water demand is growing whereas, due to the decrease of precipitation levels, water supply is decreasing. Thus, a 30% reduction in rainfall has already been observed during the 1980-2002 period and this decrease may reach 60% by 2020 if these phenomena keep the same trend. In addition, there is no possibility for further hydraulic infrastructure development, as more than 90% of available water resources have already been exploited. Consequently, there is a need for a more integrated water resources management oriented towards:

- Water saving and valuation
- Preservation of underground water resources both in quantity and quality
- The mitigation and adaptation to extreme situations such as droughts and floods

11. DROUGHT MANAGEMENT PRACTICES IN THE OUM-ER-RBIA BASIN

11.1 CURRENT DROUGHT MANAGEMENT SYSTEM

There is no specific drought management system for the Oum er-Rbia basin. Indeed, since it is one among the 7 Moroccan hydrological basins, the overall drought management system is developed and adopted at the national level and applied in all river basins although some specific actions and practices may be considered according to each river basin or province characteristics and constraints.

The overall model for drought management in terms of decision making, coordination and implementation processes is represented in Figure 11-1. Most ministerial departments dealing with water management including agriculture, water and environment, forestry, interior, health, energy and mines, and finance are concerned with drought management.

Overall coordination of drought management issues is the responsibility of the Permanent Interministerial Council for Rural Development (PICRD), which is headed by the Prime Minister and has ability to officially declare the onset of drought. The technical secretariat of this Council is under Ministry of Agriculture and Rural Development which heads the weekly meetings of the Interministerial Technical Commission once a drought episode is declared.

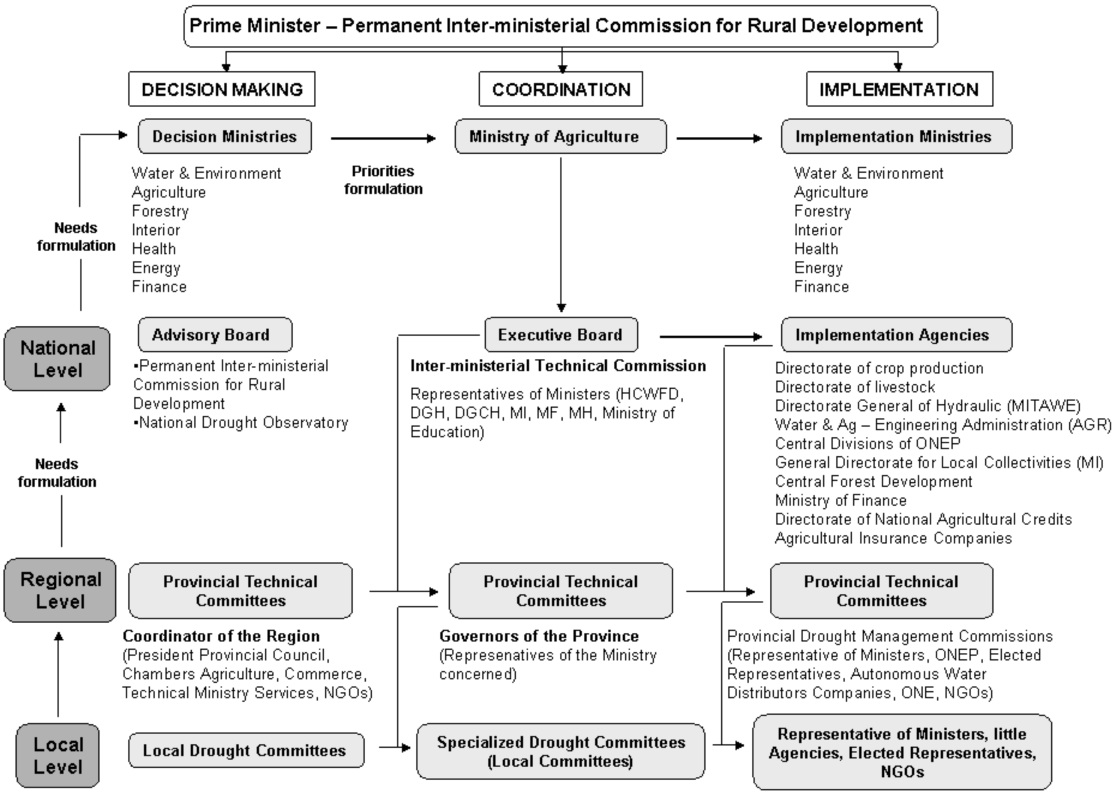


Figure 11-1 Drought management in Morocco (Ouassou *et al*, 2007)

- **National advisory board**

In addition to the political board represented by the Permanent Interministerial Council for Rural Development the other members of the national advisory board on drought are the National Drought Observatory, the National Meteorology Office, the Superior Council for Water and Climate and the National Environment Council. The first two structures have advisory role to their respective ministry on a continuous basis while the last two have much less frequent consultative role on drought issues.

- **National executive board**

The Interministerial Technical Commission (ITC) is the basis of the executive board at the national level. It includes ministry representatives of Agriculture (MAPM), Forestry (HCFWFD), Water (DGH, ONEP), Energy (ONE), Interior (MI), Health (MH), Finance and Credits (MF, CNCA). The ITC meets weekly to report to the Permanent Inter-Ministerial Council for Rural Development which, based on the Commission report and the information provided by the advisory bodies, may or may not declare drought and drought affected regions. If drought is declared nationwide, then the National Drought Mitigation Plan is set for execution. This is basically the reactive relief dimension of the plan that has to be implemented and supervised at the national, regional / provincial and local levels.

- **Regional and local setting of drought management**

Due to its important geographical area, the Oum er-Rbia basin covers several economic regions. The main ones are Tadla-Asilal and Doukkala-Abda. The river basin covers also a part of the Meknès-Tafilelt region.

Within these regions, Regional Drought Committees are headed by the Wali of the Economic Region, who normally supervises more than one province in the Region while the Province is headed by a Governor. The Regional drought committee is responsible for all decisions pertaining to the national drought mitigation plan related measures and actions to be implemented in the region. This committee includes representatives of key ministries (ONEP, ORMVA, DPA; ABH) and elected members of the rural and urban collectivities of the region, in addition to active NGO's operating in the region. The coordinating role and the composition of the Provincial Technical Committee at the province level are similar to those of the regional drought committee at the region level. At the local level, a number of Local Drought Committees/Specialized Drought Committees representing ministry line agencies and NGO's are responsible for detailed examination of the content of the proposed measures in order to match the needs of the local drought affected population, livestock and environment. At the different levels of implementation of the national drought mitigation plan, political pressure groups and elected members of the local communities become actively involved. (Ouassou *et al*., 2007)

11.1.1 Agriculture

This section documents farmers' coping strategies as well as institutional, technological and policy interventions adopted at national as well as Oum er- Rbia basin levels.

Farmers and Herder's Coping Strategies

Historically, households have adapted to irregular rainfall quantity and timing by stockpiling grain and fodder from good years, scattering fields, moving herds in search of better forage, planting late crops such as lentils (after late rains), and liquidating animals to a minimum reproductive herd that requires less fodder (Swearingen and Bencherifa, 2000).

Herders on their side developed the following strategies:
- an extension of the cultivation of rangelands
- a significant reduction in the numbers of ewes
- an increase in the numbers of the livestock by retention and purchase of lambs in the great herders
- a reduction of the size of the herds in the small herders
- increase of herd mobility to search zones not affected by drought
- an abandonment of the breeding in the small herders
- the practice of the supplementary feeding to compensate the rangelands production
- the storage of the forage in particular in the great herders to avoid the variations of the price
- improvement of animal health for better resisting

- improvement of the marketing chains for Livestock valorization

As traditional measures lose their effectiveness, many farmers have developed new ones. Swearingen and Bencherifa (2000) report that farmers increasingly use mechanization, nitrogen fertilizer, and irrigation to deal with drought. Arguably, the single most important drought-coping mechanism is mechanized plowing. Mechanized plowing affords greater flexibility in both the area planted and the timing of planting, because it can be done far faster than animal plowing and does not require that the first rains first soften the soil. Farmers can therefore get a better sense of the season to come before breaking the soil. Nitrogen fertilizer is also used to increase production during good years so that it may be stockpiled in preparation for drought years. And to a lesser extent, households have attempted to develop irrigation systems, by digging new wells, diverting surface water onto fields, and using motorized pumps. At the same time, however, households are relying less on the farm for income (Swearingen and Bencherifa, 2000).

At the state level, drought management practices in agriculture include mitigation and adaptation practices:

11.1.1.1 Drought relief actions:

Because of the severe droughts which dominated much of the country during the 1980's, the Government adopted in 1985 a reactive action plan to mitigate the drought effects in the form of relief operations which focused on:

Livestock Protection

The program of livestock protection focused on:

- Providing supplementary feeds to safeguard livestock, with the predominant expenditure going for subsidies toward the costs and distribution of concentrates and other feeds. Barley is the most commonly subsidized feed, and the extent of the subsidy extends to as much as 50 percent in Morocco. Feed imports are also relaxed in drought years, while imports of livestock and livestock products are constrained to maintain domestic prices.
- The transport and distribution of livestock food across the drought prone areas.
- The improvement of animal health: the drought relief program have embodied veterinary prophylaxis measures, as a means of reducing losses of stock rendered more vulnerable to diseases and parasites by drought. Vaccine availability has been expanded with 8 million doses provided during the 1995 drought.
- The plantation of forage shrubs and cactus.
- The development of water points and water equipment (fixed or mobile cisterns) for livestock.

These kinds of programs have been very successful in protecting livestock numbers and production during droughts. Although the 1995 Moroccan drought was devastating with total cereal production falling to only 17 percent of that in the good 1994 season, the ruminant livestock sector was barely affected (Laamari and El-Mourid 1998).

Drinking Water

The drinking water programs aimed to enable a continuous supply of water to all the urban centers and rural areas in the country. In 1994-1995, a water supply component brought clean drinking water to 196,000 rural people, and significantly improved the health of children and elderly people in particular. During the same period, special measures were taken for the city of Tanger in order to compensate for a 50% shortfall. This included the transportation of water using barges which cost nearly 300 million Dirhams (45 Dirhams per m^3)

Jobs Creation

In order to maintain populations in rural zones, the Government has included in the national drought relief program job creation activities such as organization and construction of country roads, operations of land improvement like land stone clearing, and irrigation management operations of small and average hydraulic structures. This component of the national drought relief program plays a key role to ensure minimum levels of revenues for the farmers and herders who lost their harvests and/or part of their animals and also to fight rural migration.

Agricultural Credit Debt Relief

In Morocco, the evolution of the financial farm situation remains characterized by low and unstable incomes with progressively increasing debts. Data available on loan recovery rates from farmers, by the CNCA (Caisse Nationale du Crédit Agricole), between 1968 and 2000 indicate an alarming fall, going from 75% to 100% during 1968-1981, 50% to 65% during 1982-1989, and 33% to 46% during 1990-1999. Within the framework of the campaign against the effects of the drought, the treatment of farmers' debts was carried out in two forms as follows:

- Decrease of the interest rates by 1 to 5 points
- Cancellation of part of current unpaid loan and redistribution of outstanding credit over a long period of 15 to 20 years at lower interest rates or even debt forgiveness.

This is typically **a crisis-management** oriented approach whose cost is tremendous in terms of public money investment, time and human resource needs.

11.1.2 Adaptation to agricultural droughts

The more dramatic subsequent development of the droughts that occurred more frequently during the 1990's and the growing awareness from the scientific community and civil society led the policy makers to adopt a more pro-active adaptation approach to this recurrent problem after the severe droughts of 1999-2000.Indeed, The complexity of climatic change and drought phenomena in agriculture imposes the development of an integrated approach of drought mitigation (Karrou, 2002) based on the choice of varieties and species, and agronomic packages adapted to these situations.

- ✓ **Development of new crop varieties**

The recently released Moroccan varieties are characterized by large adaptation, due to their optimal earliness, their tolerance to drought and their fair resistance to certain parasites.

- In the case of cereals, more than 75 varieties have been released by the National Institute of Agronomic Research (INRA) with 80 % of them after 1983. The adoption of the new varieties by the farmers allowed 35 % and 50 % increase of grain yield of bread wheat and barley, respectively. For this last 20 years, the yield improvement of cereals corresponds to an increase of 2 to 4 quintals per hectare at the national level, although this period was characterized by many dry years. The shift from the old

varieties to the newest ones increased also water use efficiency that jumped from8 to 17 Kg of grains/mm of water used.
- For food legume crops, the most important research achievement is the shift of the period of sowing chick pea from spring to fall by developing adapted varieties (Rizki, Douyet, Farihane). The advantage of this type of crop (called winter chick pea) is that it takes advantage from fall and winter rains. For faba bean and lentil, two adapted varieties per species to drought prone areas were recently released.
- In the case of forages, in addition to the development of nine varieties of Medics and three of *trifolium subterraneum*, Acacia and more importantly *Atriplex* and the alley-cropping system (annual forage grown between strips or bands of *Atriplex*) were appreciated by farmers in the arid and semi-arid areas (Karrou, 2002).

✓ **Introduction of new species:** Species consuming too much water are replaced by species with less water needs.

✓ **Development of dry land agriculture techniques**

In addition to the use of adapted species and varieties, researchers showed in on- station and on-farm trials that the adoption of dry land agriculture techniques in rainfed agriculture areas of Morocco can also substantially contribute to drought mitigation:

- **Minimum tillage**, **no-till** and **mulching** technologies: These conservation techniques reduce evaporation, increase the interception of rain and its infiltration and insure the saving of water, energy and time, guaranty a long term productivity increase and increase the sequestration of carbon (reduction of greenhouse gases emission).
- **Early planting** can help the plant to use more water (rains received early in Fall) and to avoid terminal drought stress and high temperatures. If this technique is used, cereals can produce 40 % more than when the late sowing is practiced (Bouchoutroch, 1993).
- **Chemical fallow** (weeds are controlled chemically by herbicides) allow the conservation of an amount of 75 to 100 mm of water in the soil (Bouzza, 1990) which is available to the following crop (usually wheat).
- When limited quantities of irrigation water are available, the application of 60 to 70 mm at critical growth stages as **supplemental irrigation** (tillering, heading and during grain filling in the case of wheat) can increase yields by 70 to more than 100 % (Boutfirass, Karrou et El Mourid, 1994). In order to increase yield and water use efficiency, a good crop-management is needed in order to take advantage from water saved due to conservation techniques, supplemental irrigation **Early weed control** (at 3 to 4 leaf-stage) reduces the competition between the crop and weeds for water and hence thi**s water is better used** to produce the crop yield (Tanji and Karrou, 1992).

Examples of investigated alternatives that reduce water demand in the area are to:
• Replace a part of the alfalfa with maize;
• Increase the area cultivated with wheat;
• Change the planting dates (e.g. of sugar beet) to earlier sowing in order to avoid growing periods with peak temperatures (Hammani, 2002).

11.1.3 Water Resources

The previous actions are more related to dryland agriculture management whereas in irrigated perimeters such as tadla and Doukkala, drought management practices are more related to water resources management.

During the severe drought of 1991-93, Morocco has experienced a severe water shortage. Departments in charge of water resources management adopted several strategies to address this crisis. These measures concerned reservoirs management and also the management of irrigation. Thus restrictive management programs were implemented and the priority was to ensure drinking water needs. This obviously led to the strengthening of actions to mobilize water, to the rehabilitation of distribution networks and awareness among water users. Furthermore, it was decided that the energy production in the dams were to be restricted to water release for agriculture use. Restrictions on water supply for irrigation had reached an average of 50% in large perimeters. If measures taken to address this situation have varied during the first dry year from one perimeter to another; they were generalized in the second year due to the worsening of water scarcity.
Measures adopted by the ORMVAs can be summarized as follows:

- The reduction of wheat areas.
- During the second dry year, spring and summer crops, very consuming in water, were forbidden and restricted to farmers using underground water.
- The reduction of irrigation: Priority was given to perennial crops (alfalfa, orchards) but safeguards volumes were applied to other crops.
- The promotion of underground water irrigation.
- The constitution of vigilance committees whose tasks were to conduct awareness campaigns for users of irrigation water, to monitor water distribution and the proper functioning of irrigation networks.

In addition, most ORMVA's has one or two experimental stations where they conduct tests and experiments in the field. These stations are equipped with meteorological devices and with lysimeters or evapotranspirometers to estimate maximum crop consumption and conduct reduced water tests on main crops. These tests allowed to determine the optimum volume and number of irrigation necessary to the satisfaction of crop water needs
In the Tadla perimeter, the ORMVA reduced the amount of irrigation water allowed to certain crops (sugar beets, cereals, alfala) according to the experimental results obtained at the Ouled Gnawa station. This allowed respecting the program of sugar crops planting regarding its importance for the agro-industry and the workforce it employs both in the field and factories (Chati, 1995).

Water allocation at regional level and within the Tadla irrigated perimeter

The amount that can be delivered to farmers depends on the water allocated to the scheme; this is decided each year at the level of the River Basin Agency. The amount to be released is calculated according to the projected inflows and available reserves in the two upstream dams; the amount released may be adjusted during the year depending on the actual rainfall. This release is shared between Tadla and other downstream irrigation schemes. As a result of the chronic droughts, irrigation expansion and the demand from other schemes, the allocation to Tadla is substantially less than the amount initially designed. In 2001–2002, only 27% of the initially designed (710 Mm^3) was delivered to the scheme. As a result, irrigation in Tadla faces a severe shortage of water and the distribution rules have been adapted to deal with a shortage situation. Now that demand largely exceeds supply, no demand-oriented management can be carried out, and water allocation among farmers is based on a rationing system (Hellegers *et al*., 2007).

Groundwater use

In the 1980s, the severe and repeated droughts led many farmers of the Tadla irrigated perimeter to invest in pumping devices; they were encouraged to do so by the state, which provided subsidies and technical support. Nowadays, about 10,000 wells are used in the schemes and approximately 40% of the farms have wells engines. Most of the pumps are powered by diesel engines, with an average discharge of 10–15 l/s. Farmers generally use groundwater to supplement surface water. As groundwater is generally more saline than surface water, conjunctive use at plot level may be necessary to avoid soil degradation and yield losses. However, farmers are much more concerned with quantity issues, and these medium-term risks are outweighed by the demand to increase the present supply (Petitguyot, 2003).There has been a regular decline in the level of the shallow aquifer for 20 years now, and there is no regulation to control withdrawals of groundwater. As a result, many wells have dried up. Farmers who can afford new investments now deepen their wells or sink deeper tube wells (wells still represent 89% of the total but 25% are non-functional). Whereas shallow resources are of bad quality and may only be used for agriculture, deep aquifers are exploited by urban and industrial users, which will result in competition.

To stabilize groundwater extraction, the sustainable aquifer yield and the demand for groundwater need to be balanced. However, there are currently no defined entitlements for the use of groundwater. There is a restriction on the pumping of groundwater (i.e.no deeper than 40 m below the soil surface), although in practice this is rarely enforced and is therefore no effective policy instrument. The majority of farmers install wells without obtaining the required authorization. An alternative policy instrument aiming at limiting groundwater extraction is currently being drawn up. Under the 1995 Water Law, the River Basin Agency is empowered to impose a tax on each volume of water extracted from individual wells (‘consumer pays’ principle). The administrative costs and technical complexity of charging for extraction on the basis of the number of pumping hours – as currently proposed by the government – would be high, and will not guarantee a reduction in usage (although the implied increase in the unit price of water will provide some incentive to reduce usage there is no assurance that sustainable supply and demand will be properly balanced).Given the problems with the enforcement of existing regulations on the installation and operation of pumps, it is not certain whether hours pumped will be easy to measure and used as an instrument for demand management. It is likely that bribery would increase and meters would be tampered with.

Water resources management in the Tadla perimeter

For Tadla irrigation perimeter (with an irrigated area of 100 000 hectares), the average surface water deficit recorded during the last ten years was 20%. This increasing water shortage and the imperative need for crop production intensification required the establishment of a rationalization program for water use in irrigation in this perimeter.

Irrigation techniques and technological tools to save water while increasing crop productivity and protecting environment from various chemical impacts exist. This challenge is made possible today by the introduction of modern management tools and a new environmental design. These are precisely the shutters of the program of improvement of water management in the Tadla perimeter which are articulated around:

1. **improving the irrigation programming and water distribution:** a greater efficiency, flexibility, reliability, and delivery in a convenient time of water to farmers by means of instruments and management models of the irrigation system;
2. **improving the management of water at the farm level:** a better management of water resources at the farm level by the introduction of water saving irrigation techniques;
3. **Sustainable management of the environment:** long-term preservation of the Tadla perimeter and its environment by seeking sustainable solutions to problems such as deterioration of the quality of water and soil using a better management practices and use of chemicals in agriculture as well as prevention against agro-industrial pollution.

To measure the results of these activities, the following performance indicators are used:

- The efficiency of transport and distribution of the irrigation network;
- The efficiency of water application to the farmer's plot and the percentage of area adopting water saving irrigation techniques;
- The quantity of potentially leachable nitrate.

1. Improvement of irrigation programming and water distribution

In order to allow a better distribution of irrigation water and in order to improve the hydraulic efficiency of irrigation network from 80 to 85%, the management tools developed in the Tadla perimeter are:
- The implementation of a network of agro-climatic stations that deliver data for the determination of crops water needs
- The development of the "CROPREQ" model to determine monthly and weekly crop water needs as well as water flows in the canal for the satisfaction of these needs.
- The measurement of water flow in the main irrigation canals

2. Improvement of water furniture and water use efficiency at the plot level

✓ *surface irrigation*

Among the surface irrigation improvement techniques that allow high performance in water savings and yield increase figure the laser leveling of irrigation pools. Four years of demonstration of this technique in 50 farms and all the main crops grown in the Tadla perimeter showed:

- a 30% saving of irrigation water
- a 30% yield improvement
- a diminution of inputs and labor by respectively 10 and 50%
- the retention of nutrients in the crops root zones.

✓ *Development of drip irrigation (see PNEEI)*

3. Sustainable management of the environment

In the Tadla perimeter, the agricultural intensification, accompanied by an excessive use of irrigation coupled with a non appropriate drainage system led to a deterioration of the quality of groundwater and soil through salinization, sodification, nitric pollution and deterioration of soil structure. In order to preserve water and soil resources, the ORMVAT implemented the following actions:

- soil and water quality monitoring
- rational management of nitrogen fertilization

These strategies, allowed in the case of Tadla perimeter to save an average of 40 Mm^3 water per year through the improvement of irrigation system management as well as a reduction of almost 45% of the excess of nitrogen applied to sugar beet and wheat (Laaroussi, 2005).

Water resources management in the Doukkala perimeter

Confronted to the necessity of implementing a rigorous management of water resources in order to guarantee the efficient use of water for irrigation and its economy and better valuation, the ORMVAD implemented an action plan whose main objectives are to:

- Increase the performance of irrigation systems and ensure the perenity of hydraulic equipments
- Promote the rational use of water and optimize electric energy consumption;
- Improve the quality of water distribution service
- Improve the efficiency of water supply to the plots;
- Improve the efficiency irrigation water use and its valuation;
- Increase farmers' incomes and the rate of recovery of irrigation water charges

The action plan focuses on three areas:

- The improvement of the performance of irrigation infrastructures by strengthening the maintenance and the rehabilitation of irrigation equipments
- The optimization of water supply to the plot and the promotion of more efficient and consuming less water irrigation techniques
- The strengthening of users association and their awareness to the necessity of a more efficient irrigation

1- The improvement of irrigation infrastructures performance.

To improve the performance of irrigation infrastructures and reduce water losses, several actions were implemented:

- The equipment of the main canal of the lower service with a remote control management system in order to ensure a better control and instantaneous monitoring of water flow;
- The entire rehabilitation of the “Faregh” locker on a total area of 8900 ha. This locker, who was the first implemented in the Doukkala perimeter was in very bad shape causing water losses and affecting the quality of water service. The operation of rehabilitation consisted in setting up a new irrigation network on a total length of 420 km and tracks rehabilitation over a total length of 16 km. The Sidi Smail irrigation network was also rehabilitated over an area of 2000 ha;
- The renewal of pumping stations components and their equipment with water counters;
- The strengthening of maintenance actions

2- The improvement of water supply at the plot level.

The improvement of water supply and use at the level plot represents the second action of the ORMVAD in order to save water.

- Surface irrigation areas:

Several actions were undertaken in order to improve irrigations in the areas of surface water irrigation. These actions include:

- The setting on disposition of certain water users associations of equipments for grading maintenance. Indeed, in the case of surface irrigation, a good leveling allows better flow of irrigation water on the surface and time gain
- The introduction of the irrigation by tubular siphons among farmers of the “High service”. For this purpose, 480 000 units have been distributed to farmers.
- The implementation of field trials in order to present the advantages of coating irrigation canals with plastic films or concrete. This coating allows reducing the time of water flow along the canal as well as the decrease of water losses by seepage (15%)

- Sprinkle irrigation areas:

In areas irrigated by sprinklers, the ORMVAD renewed the bounds of irrigation and equipped them with regulation components and water counters. This operation that concerned in 2004, 2352 irrigation bounds covering 21 760 ha gave very satisfying results since it allowed to come back to an ‘on demand’ irrigation system. In addition, the implementation of water counters ensures more transparency to water billing and promotes water savings. The objective of this rehabilitation project was to cover a total of 29 000 ha, representing 89% of the total area irrigated by sprinklers.

The actions then focused on the introduction and the promotion of drip irrigation (see chapter 11.1.2.5) (Guemimi, 2004).

3- Capacity building and participatory irrigation management

Several campaigns were organized by the ORMVAD in order to educate farmers on the necessity to rationalize water use, to adopt more efficient techniques and preserve soils. Thus, the Officehas set upa decision support system for irrigation management based on soilwater deficit monitoring. In addition, several water users associations were created (39 WUA).

The National strategy for irrigation water conservation (Plan national d’ Economie d’ Eau d’Irrigation, PNEEI)

In 2007, the Moroccan government issued an ambitious plan (“Plan National de l’Economie d’Eau d’Irrigation” or PNEEI) to conserve in excess of 510 million cubic meters (Mm^3) of irrigation water per year (MADRPM, 2007). The main premise of PNEEI is that past and current measures to conserve water in agriculture such as the revamping of existing irrigation infrastructure and the introduction of improved irrigation methods (e.g., sprinkler irrigation) are not sufficient to address water shortages. The goal of PNEEI is to equip about 555,000 ha of irrigated land with drip irrigation from 2008 through 2022. This would bring the total hectarage equipped with drip irrigation to 700,000 ha or 50% of the total irrigated land in Morocco. Most of this hectarage would be achieved by converting from flood to drip irrigation. According to PNEEI, some of the benefits of drip irrigation would be:

- Water savings of 20 to 50% compared to existing irrigation practices

- Crop yield gains of 10 to 100%
- Increased farm revenue
- Reduced labor,
- Protection of the soil and water resources e.g., by reducing leaching of salts, nitrates, and other pollutants into the groundwater.

PNEEI targets for the Oum er-Rbia basin:

Table 11-1 Land to be converted to drip irrigation from 2008 to 2022 :

1- Irrigation perimeter or type	**2- Total irrigated land (ha)**	**Land (ha) to be converted**			
		3- Collectively	**4- Individually**	**5- Total**	**5./2. (%)**
Doukkala	96000	39500	37100	76600	80
Haouz	146000	57100	23500	80600	55
Tadla (PIT)	109000	49040	39700	88740	81
Subtotal	351000	145640	100300	245940	70
Total “Grande Hydraulique”	670430	217940	177150	395090	59
Private irrigation	441400	0	160000	160000	36
Grand total	1111830	217940	337150	555090	50

Source : (MADRPM, 2007)

The target for Doukkala, Haouz, and Tadla which are located within the Oum er-Rbia watershed is 245,940ha or 70% of the total irrigated land (Table 11-1). The total for Tadla is almost 89,000 ha or 81% of the irrigated land, of which 49,000ha would be converted to drip irrigation collectively, meaning that whole irrigation sectors would be converted at once. Preliminary studies put the number of hectares that can potentially be converted to drip irrigation collectively in Tadla at about 53,000ha, at a cost of 393 million dollars (Table 11-2). Collective projects are defined here as groups or clusters of fields or whole farms that share some components of the drip irrigation infrastructure such as common storage basins or water delivery systems.

Table 11-2 Irrigated land in PIT that can potentially be converted to drip irrigation collectively and investment cost.

Irrigation district*	**Hectarage (ha)**	**Investment Cost (millions of $)**
Beni Moussa West	15,421	116
Beni Moussa East (Zones1 & 2)	32,045	240
Beni Moussa East (zone3)	1,589	5
Beni Amir	4,244	32
Total	**53,299**	**393**

Source:ORMVAT(2008)

*The total irrigable land is 69,500ha for Beni Moussa and 28,500ha for Beni Amir.

Approximately 10,700 ha were equipped with drip irrigation in Tadla irrigated perimeter from 1991 through 2008. The amount of land fitted with drip irrigation increased between 2003 and 2007 due to greater availability of government subsidies. It is worth noting that these figures do not include lands equipped with drip irrigation outside the zone of action of ORMVAT, which amounted to 3,800 ha in the Province of Beni-Mellal at the end of 2007 (Messaadi,2008). For ORMVA-Haouz, 10,794ha were fitted with drip irrigation from 2002 through 2008 and 6,720 ha prior to 2002, which is well within reach of the target set by PNEEI for individual projects(Table 11.1). Not as many hectares (approximately 2,500 ha by the end of 2008) were equipped with drip irrigation in the plain of Doukkala, which has far fewer fruit tree orchards than the Haouz or Tadla. Doukkala also suffered greatly from recent droughts and the depletion of its groundwater whose quality is unsuitable for irrigation in some areas.

11.1.4 Other management systems: Artificial rainfall program

Morocco’s **Al Ghait artificial precipitation program** represents a part of the proactive response to the problems posed by drought. The operation was a joint effort between the Government of Morocco and the United States Agency for International Development (USAID) and aimed to use weather modification techniques to augment rainfall. The program uses silver iodide as a seeding agent to increase the precipitation efficiency of cold clouds in the Central High Atlas Mountains in the upper Oum er-Rbia basin. This causes snowfall, augmenting the snowpack in the mountains which, in turn, increases snow melt run-off in summer. During the first phase of field operations conducted from 1984-1989 an average of 15-25 storm events were seeded during each season, totaling 144 seeded days during the five-year period. This resulted in a 14 to 17 per cent increase in winter precipitation. These results were viewed as ‘encouraging’, but it was recognized that further research would be required. Since 2002 the Moroccan Al Ghait program has benefited from the involvement of the US company Weather Modification Inc (WMI) of Fargo, North Dakota . WMI has been assisting in the development of the Al Ghait national cloud seeding program and provided training. A number of African countries have now benefited from Moroccan experience and expertise in the field of weather modification.

11.1.5 Current drought early warning and adaptation

In its contribution to D2.3 that aimed at assessing drought warning experiences in Africa, IAV focused its work on agricultural drought warnings in the Oum er-Rbia basin. The assessment of drought warnings from the institutional side was achieved both by literature search and a first survey (central and regional departments) while a second survey was conducted in the Oum er-Rbia basin to get farmers perceptions

Results showed that regarding drought early warning, the main governemental actions being developed in Morocco are few:

- The weekly and seasonal weather forecasts, based on the use of global and regional dynamical models and statistical models and elaborated by DMN;

- The agro-meteorological data which are the basis of the simulation models of crop growth, the irrigation models and the phyto-pathological models that are developed by research institutions;

- The monthly monitoring crop report, produced by the CRTS with the goal of providing information at national level on the qualitative state of vegetation (NDVI).

- The SMAS project (Système maghrébin d'alerte précoce à la sécheresse) aiming to establish a Maghreb-wide system for early warning to drought was coordinated by OSS and implemented in Algeria, Morocco and Tunisia from 2006 to 2009 in the framework of the LIFE-Pays-Tiers Program, financed by the European Union. At the Moroccan level, the DMN, the CRTS, the MAPM and the HCEFLCD were involved in the project. Each institution contributed by the production of drought indicators that were compiled in drought early warning bulletins produced on a monthly basis from November to April in 2008 and 2009 and available on the CRTS website (http://www.crts.gov.ma/modules.php?name=Sections&op=viewarticle&artid=73). Unfortunately, the production of these bulletins ended with the end of the SMAS project in 2009.

The survey conducted at the farmers level revealed that rainfed farmers generally characterize and recognize droughts periods and are thus warned of their emergence by the following indicators:

- The Lack of rainfall: From the farmers point view, the lack of rainfall is the major indicator of drought. Moreover, they do only not consider the total amount of rainfall but do also pay a special attention to its repartition through the agricultural season. Indeed, results from our survey show two main periods of concern for the farmers which are first October, November and December and then the month of March. Since rainfed farmers are mainly cereal growers, the first one corresponds to the ploughing, sowing period while the second one is the grain filling period.
- The increase of the price of intrants and of goods of primary necessity
- The decrease of livestock prices

The situation is different for irrigated farmers who do not rely as much and as directly on rainfall like rainfed farmers. Indeed, each year, the river basin agencies and the basin's stakeholders agree on a programme for water allocation and although farmers are represented on the agency board which sets up the annual programme, their influence is negligible (2 members out of 35 on the board) and only the ORMVA may interact with a significant power to negotiate agricultural allocation. This provisional allocation is established at the beginning of the irrigation season (September) and farmers are informed about it.
The ORMVA also issues "guidance"' on feasible cropping plans prior to each season, based on the anticipated water availability per hectare, and the demand of individual crops. Thus, in case of water shortage, priority is generally given to industrial and perennial fodder crops and orchards. In addition, summer crops and spring crops are dismissed from the irrigation provisional irrigation plan in case of initial severe water shortage.

Our main objective through this survey was to assess either there was any early or late drought warning action addressed to farmers and undertaken by state services prior to the implementation of these relief actions. Thus, according to the large majority of farmers they do not get any drought warning from agricultural services. Irrigated farmers added that since the ORMVA informs them at the beginning of the agricultural campaign about the provisional water allocation, they somehow consider it as a drought warning in case of a reduced allocation.

11.2 EXISTING DROUGHT MONITOR PRODUCTS

11.2.1 Meteorological drought indices

The meteorological drought indices mostly used in Morocco and in the Oum er-Rbia basin for monitoring and prediction purposes are:

- Deviation from normal precipitation
- Precipitation deciles analysis
- Standardized Precipitations Index (SPI)
- A modification of SWSI (Svoboda, 2004)

11.2.2 Agricultural drought indices

In the Oum er-Rbia basin, agricultural drought is monitored by the following indicators:

- Vegetal production:

- Cereal growth and phenology development
- Monitoring of dysfunction of market prices for basic commodities and agricultural inputs

In rainfed systems, cereals are the dominant crop and cereal yields are appropriate drought indicators

- Livestock production

- State of cattle feed supply
- Prices for animals and for feed,
- State of watering points for livestock,
- Grazing land availability
- Herd sanitary states.
- Animal feeding balance,
- Imports of animals and animal products

- Remote sensing indicator: Normalized Difference Vegetation Index (NDVI)

11.2.3 Hydrological drought indices

In the Oum er-Rbia basin, hydrological drought is monitored by the following indicators:

- Reservoir Inflows and outflows
- Reservoir levels
- Ground-water table
- Stream flows
- Drinkable water demand

11.3 CURRENT DROUGHT FORECASTING TOOL

The National Directorate of Meteorology (DMN) uses long term weather forecast simulation models for a proactive approach to meteorological drought management:

- **Al Masifa** project is implemented in partnership with Météo-France, ONM (Algeria) and INM (Tunisia) with financial support from the European Community. It aims at the prediction of the “rainfall state” (dry, normal, wet) using the relationship between SST anomalies and regional precipitation.
- **Al Moubarak** project is developed with Oklahoma University and aims at Climate modeling using the statistical correlation between the precipitation and the global climate patterns (NAO)

11.3.1 Existing gaps in management systems, organization and information

Despite many progresses made in terms of drought management, there are still many gaps related to:

- The availaibility and reliability, of data and especially the access free of charge to meteorological and satellite data
- A lack of coordination and information exchange between institutions/ministerial departments in charge of drought monitoring. Indeed, though there are several national and regional institutions involved in drought monitoring in Morocco, there seems to be a great lack of communication and cooperation between these institutions. Thus, for example the DMN monitors the meteorological drought, the DGH and ABH monitor hydrological drought, the CRTS, provide remote sensing data on vegetation health, the Ministry of agriculture provide information on agricultural drought while the HCEFLCD follow indicators related to forests but none of these institutions share these data with the others and there is no institution in charge of gathering and analysing all these data and indicators.
- The perenity of drought monitoring products that are generally produced in the frame of specific projects.
- Consequently to the two previous points, the lack of existance of an operational early drought warning system
- Drought prediction capabilities as to set up ***onset, persistence, and end of a drought*** are still at a modest level and a lot of research-action is still needed to proceed forward with drought forecasting, particularly in the agricultural sector
- The Drought management system remain dominated by relief actions

11.4 STAKEHOLDERS

Stakeholders involved in drought and water management in the Oum er-Rbia basins include actors at both national and local levels:

11.4.1 National level

- Stakeholders identified at the national level are:
- The Directorate General of Hydraulics, DGH (Direction Générale de l'Hydraulique)
- The National Office for Drinking Water (Office National de l'Eau Potable, ONEP)
- The Water and Ag-Engineering Administration (Administration du Génie Rural, AGR)
- Ministries of Interior, Health and Energy and Mines

- The High Commissariat for Water, Forest and Fight against Desertification (Haut Commissariat aux Eaux et Forêts et à la Lutte contre la Désertification)
- The National Directory of Meteorology (DMN)
- The Moroccan Confederation for Agriculture and Rural Development (COMADER)

11.4.2 Regional and Local levels

Stakeholders identified at regional level are:

- The Oum er-Rbia Hydraulic Basin Agency (ABHOER)
- The Local Regional Offices for Agriculture Development of Tadla and Doukkala (ORMVAT and ORMVAD)
- The Regional Directorate of Agriculture (DPA) of Beni-Mellal, El Jadida, Safi, El kelaa, Khenifra, Settat and Khouribga
- Regional Councils for Environment (CRE)
- Water Users Associations (AUEA) of Tadla and Doukkala
- Farmers associations of Tadla-Azilal and Doukkala-Abda
- Regional Offices of the National Office for drinking water and Regional régies for drinking water
- Sucreries de Tadla (main industrial in the Tadla) ;
- Caisse Régionale du Crédit Agricole, Beni Mellal ;

11.4.3 Producers of available monitoring and forecast products

The Oum er-Rbia Hydraulic basin Agency

According to the Water Law, **River Basin Agencies** are in charge of developing and allocating water resources. The **Hydraulic Basin Agencies** are the key actors in regional water management. The first (pilot) agency, established in 1999, was the one of the Oum Er-Rbia Basin. Six more were established in 2002: Moulouyas, Sebou, Loukoss, BouRegreg, Tensift and Souss–Massa.

The mandates of the Hydraulic Basin Agencies are to:

- Maintain the public hydraulic infrastructure and regulate its use and exploitation;
- Enhance the economic value of water;
- Provide financial and technical assistance for water management;
- Develop the local Integrated Water Resources Management Plan and pursue its implementation;
- Issue permits and authorize the use of the public hydraulic infrastructure;
- Provide the necessary support for water pollution prevention;
- Perform studies and assessments on water quantity and quality issues;
- Propose and implement regulatory measures, as appropriate;
- Maintain the inventory of water use rights, concessions and permits for water abstraction.

In the above context, the main responsibilities of the Basin Agencies are to:(a) develop water resources through water resource planning and management, assessment, exploitation, monitoring of quantity and quality, control of water use; (b) protect water resources and the national heritage by safeguarding the public hydraulic domain, preventing and managing exceptional situations, and operating, maintaining and exploiting hydraulic works; and(c) provide services towards third parties by offering technical assistance and receiving benefits for services delivered, develop partnerships and offer financial support.

Each year, the agencies and the basin's stakeholders agree on a program for water allocation. Urban and industrial needs have priority over the agriculture sector. In the Tadla area, water use for electricity production has the lowest priority, and water for irrigation is released according to agricultural needs only. Although farmers are represented on the agency board which sets up the annual program, their influence is negligible (2 members out of 35 on the board) and only the ORMVA may interact with a significant power to negotiate agricultural allocation.

The hydro-climatologic network managed by the Oum er-Rbia Hydraulic Basin Agency is composed of:

- 25 rainfall measurement stations
- 22 hydrometric stations (figure 11-2)
- 149 points of daily flow measures
- 13 climatologic stations (rainfall, temperature, evaporation, albedo, …)
- 22 stations of flood warnings
- 219 piezometers (figure 11-3)

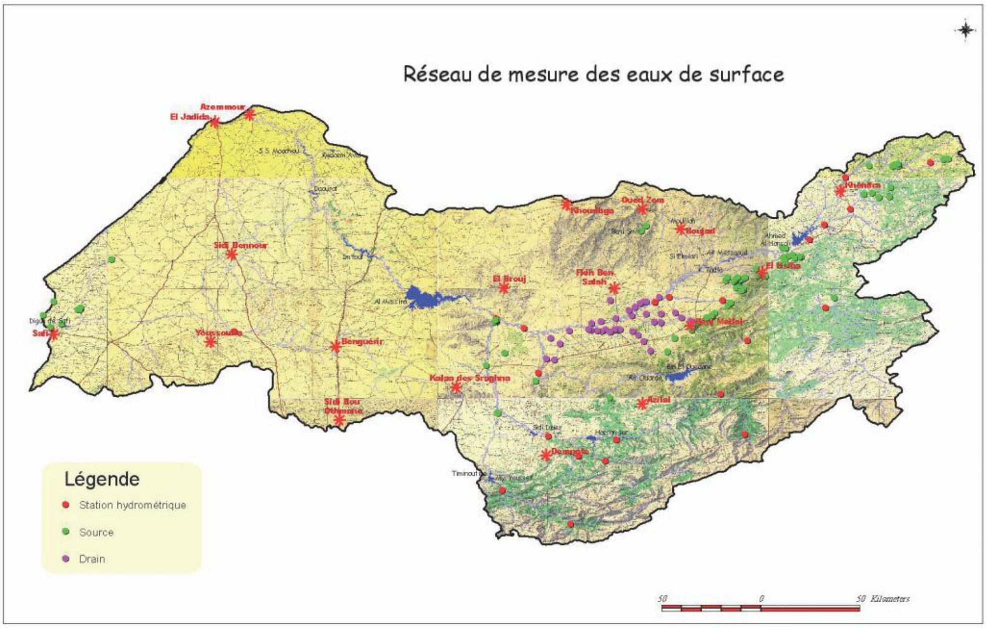


Figure 11-2 Surface water monitoring in the Oum er-Rbia basin (from ABHOER)

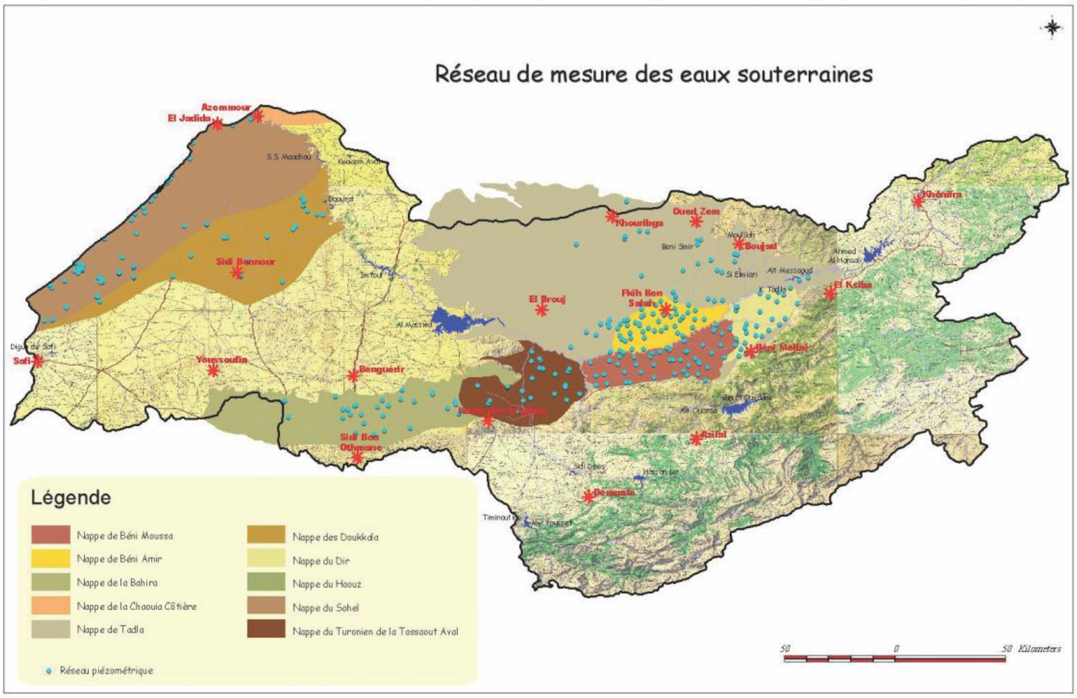


Figure 11-3 Groundwater monitoring in the Oum er rbia basin (from, ABHOER)

The ORMVAs

The **ORMVAs** (Offices Régionaux de Mise en Valeur Agricole- Regional offices for agricultural development) were first established in the 1960s with the aim of decentralizing irrigation water management. At present, the 9 ORMVAs have the mandate of promoting agricultural activities in the large irrigated perimeters of the country. In this regard, several laws and decrees have been implemented for specifying their status as financially autonomous public institutions, under the control of the Ministry of Agriculture and Maritime Fisheries.

Their main responsibilities are to:

- Assess agricultural development schemes in irrigated perimeters, within the framework of the large hydraulic infrastructure management.
- Monitor and provide assistance for the exploitation of irrigated perimeters, through irrigation scheduling, experiments in agricultural production, monitoring of irrigation and soil and drainage water quality, maintenance of irrigation networks and collection of the corresponding water charges.
- Organize agricultural production.

At the Oum er-rbia basin level, three ORMVAs are operational:

- The ORMVA of Tadla: It was created in 1966. About 1000 people work at the ORMVA in Beni Mellal, which is responsible of Tadla irrigated perimeter (400 on water management, 300 on extension and agricultural development, 300 on administrative tasks).
- The ORMVA of Doukkala: It was established by government ordinance in October 1966 as a development corporation that includes participation by the Ministry of Agriculture and maritime Fisheries. The headquarters of ORMVAD are located in El Jadida, which is southwest of the capital city of Rabat. The staff of ORMVAD consists

of irrigation engineers and technicians. Experienced engineers are given field assignments to operate and manage facilities, so there are no technical problems. ORMVAD has been promoting outsourcing for the past several years and is in the midst of a large-scale staff reduction. While it had 1,168 employees at the time of the appraisal, the number has been reduced to the current 780. A prompt restructuring of the organization and operations is required to prevent hindering the operation and maintenance of the irrigation facilities accompanying this staff reduction plan.

- The ORMVA of Haouz

Water Users associations

A law passed in 1990 provided a legal basis for establishing water user associations (WUAs), with responsibility for managing irrigation at the tertiary level.

Tadla has 29 registered WUAs (11 in Beni Amir and 18 in Beni Moussa), representing 41% of farmers in an area covering 44,540 ha. However, most of these associations are not operational. A study carried out in 2001 (ENGREF, IAV Hassan II and CNEARC, Tadla, 2001, unpublished data) reported that only one WUA was active in Beni Moussa. This could be explained by a diversification of its activities to other sectors (road construction, basic education). The WUAs did not prove to be successful, and many farmers refused to pay the charges to finance a WUA. This could be seen as a compliment to the operation of the irrigation schemes by the ORMVA the farmers found this satisfactory and did not see the need to add an additional layer of management.

In the Doukkala perimeter, there are 39 water associations, and although 24 of them conduct activities to exchange information, they rely technically and financially on ORMVAD for the operation of the irrigation facilities, and they do not operate or maintain irrigation facilities or collect water fees. The water usage association committee members and chairperson are elected. ORMVAD dispatches staff to serve as association committee members and participate in committee activities (Sakairi, 2006).

The Provincial Directions of Agriculture (DPA)

At the regional level, the Regional Directions of Agriculture, are in charge of the development of the agricultural sector in rainfed areas and areas of small and medium Hydraulics. The Oum er-Rbia basin covers several different DRAs.

11.4.4 National Climate outlook forum

Regional Climate Outlook Forums (RCOFs) are in operation in many parts of the world, mainly serving developing countries. Morocco do not figure in any of these regional forums but on their basis, the National Directorate of Meteorology (DMN) is moving towards the establishment of a National Climate Outlook Forum (NCOF):

Thus, the DMN has established a periodic evaluation and guidance council in order to validate and listen to end-users. This event helps DMN to understand the needs of the end-users and provides a platform for the users to learn how to use the information that DMN provides. The council is attended by users from all sectors including agriculture, water, energy, air and marine navigation, and scientific research.In addition to this, as recommended by the council, an annual sector council is organized. The main objective of this council is to stimulate the use of sector-specific information in an ongoing, iterative process of dialogue between the producers of climatic information and the multitude of users in Morocco.

The Collaboration with end-users focuses on the following objectives:

- Evaluate user needs
- Develop and demonstrate applications which address practical user needs
- Establish interactive dialogue with primary users
- Develop data/information delivery systems.
- Consensus forecast

The recommendations that result from the council are translated to budgetary actions for developing application tools based on monthly and seasonal products, as well as hydrological and environment tools for delivering useful products and services.

The dissemination to users should be adapted to user reception capacities:

- internet, fax, tph, sms, mms
- Verbal face to face
- Radio in local langage

As a direct result of establishing a dialogue with users, DMN has created two agro-meteorological centers in Beni Mellal (Oum er-rbia basin) and Taroudant, and developed a tool to aid decision-making in the agriculture domain**.** The purpose of this application is to make users aware of the potential benefits that farmers can gain from improving efficiency and ensuring the sustainability of farm management (health of crops, livestock, and the environment to increase their yield and the market value of their crops, as well as to solve operational problems).

Examples of products:

- Drought Monitoring bulletin:

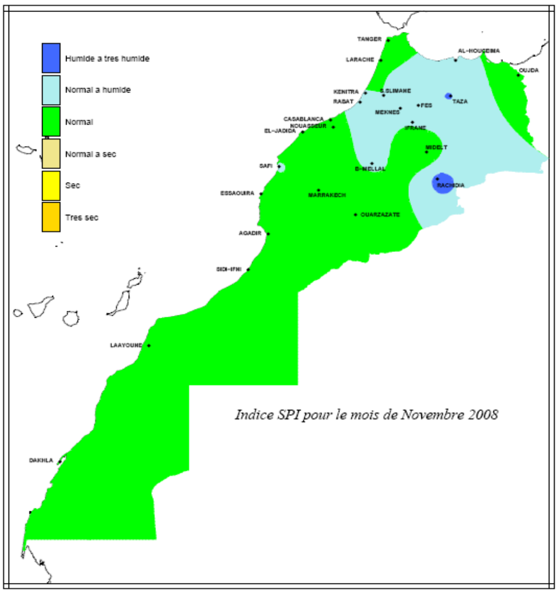


Figure 11-4 SPI index for the month of November 2008

- Comfort indices:

The humidex index is helpful for human health and informs about excessive air humidity.

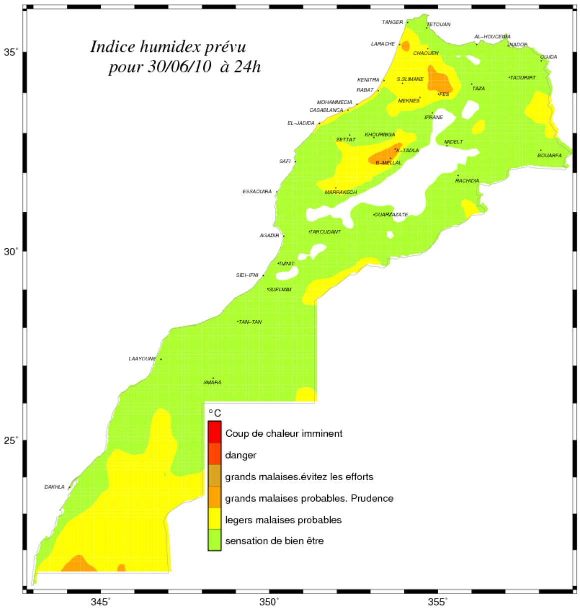


Figure 11-5 Humidex index for the 30/06/2010

12. DETAILED CASE STUDY APPROACH AND METHODOLOGY IN THE OUM-ER-RBIA BASIN

12.1 APPROACH TO BE FOLLOWED

The approach followed in the Oum er-rbia case study, will focus on in the improvement of agricultural and hydrological drought management, tailored to the needs and specificities of each of the two agricultural types: rainfed and irrigated. Medium range and seasonal weather forecasts; indicators, and ouputs from hydrological and agricultural models will be combined and transferred to drought warnings.

12.2 COLLATION AND REVIEW OF EXISTING DATA

12.2.1 Hydrological data

Surface water:

- Dams inflows: monthly data in Mm^3 and Reservoir levels (stocks) :

- Bin el ouidane: 1977- 2007
- Hassan I: 1987- 2007
- My Youssef: 1974 - 2007
- Ahmed El Hançali : 2001-2007
- Sidi Driss: 1985 - 2007
- Kasba Tadla: 1978 - 2007

- Stream flows:

Daily, monthly and annual stream flows in m^3/s

Station	Oued (stream)	Record period
Ait Tamlit	Tassaout	1980-81 to 2006-2007
Tamasmat	Tassaout	1980-81 to 2006-2007
Bissi-Bissa	Tassaout	1980-81 to 2006-2007
Zawiyat Ahançal	Ahançal	1980-81 to 2006-2007
Ait chouartit	Lakhdar	1980-1981/1985-1986
Assaka	Lakhdar	1985-4986/2000-2007
Ait ouchen Sid dri	El Asid (lakhdar)	1980-1981/1987-1988
Sgatt	Bernat (lakhdar)	2001-2002/2006-2007
Addamaghene	Lakhdar	1980-1981/2006-2007
Khenifra	Oum Rbia	1980-1981/1993-1994
Tarhat	Oum Rbia	1980-1981/2006-2007
Dchar El Oued	Oum Rbia	1980-1981/1998-1999
Mechraa Eddahb	Oum Rbia	1980-1981/2006-2007
Tillouguite	Assif Melloul	
Ghazef	Ait sigmine	1980-1981/2006-2007
El Heri	Chbouka	1980-1981/2006-2007
N'Amellal	Srou-Chacha	1980-1981/2006-2007
Taghzirt	derna	1980-1981/2006-2007
My Bouzekri	derna	2001-2002/2006-2007
Ouled sid D	OER	1980-1981/2006-2007
Taghzout	Aoumana	2001-2002/2006-2007
Tizi n'Isly	Ouirine	2001-2002/2006-2007
Tamachchate	Amangous	1980-1981/2006-2007

Groundwater: data from ABHOER

- Ground water table, water quality
- Groundwater balance

The Hydrologic situation of the following periods: September 2007-August 2008; September 2008-February 2009 and the rainfall situation of the period September 2009 to march 2010 are available on line at the Oum er-Rbia hydraulic agency web site:http://www.abhoer.ma

12.2.2 Meteorological data

- Rainfall

The Oum er-Rbia basin is covered by a large number of rainfall stations relevant from different administration: the national Directorate of meteorology (DMN), The Hydraulic basin Agency of Oum er-Rbia (ABHOER) and the General Direction of Hydraulics (DGH) and the regional directions of Agriculture (DRA).

ABHOER network:

Station	Record period	Number of years	Missing data

Addemaghene	1983/2010	27	-
Barrage My Youssef	1968/2010	42	2002/2005
Barrage Hassan 1	1973/2010	37	2002/2004
AIT OUCHENE	1975/2010	35	2003/2005
Ait Segmine	1970/2010	40	2003/2005
Ait Tamlilt	1973/2010	37	
Assaka	1963/1970 , 1988/2010	49	1970/1987
Beni Mellal	1935/2010	75	-
Bissi Bissa	1980/2010	30	-
Bouchane	1993/2007	14	
Chacha N'amellah	1974/2010	36	1987/1988
Aval El Heri	1970/2010	40	-
Dechra El Oued	1969/2007	38	2001/2002
Tarhat	1969/2010	41	-
My Bouzekri	1969/2007	38	-
Ouaouirinth	1968/2010	42	-
Ouled Sidi Driss	1969/2010	41	1971/1972
Mechra Eddahk	1968/2010	42	-
Digue de Safi	1965/2010	45	1976/1979
Sgatt	1958/2010	52	-
Barrage El Massira	1984/2010	26	-
Barrage Sidi Driss	1966/2010	44	-
Souk Essebt UP 3010	1975/2007	32	-
Taghzoute CT-11-01	1971/2010	39	1996/1997 , 1999/2002
Tamchachate	1975/2010	35	-
Tamesmat	1976/2010	34	1986/1988 , 2003/2005
Tizi N'Sli	1975/2007	32	-
Zaouia Ahensal	1985/2010	25	2003/2005

DGH network:

Station	Record period	Number of years	Missing data
AGHBALA	1965/2002	37	1968/1970 ,1999/2000
AIT M'HAMMED	1935/1998	63	1956/1957 ,1987/88 , 1995/1997
ALBA	1965/2007	42	1972/1974 , 2003/2004
ARHBAL	1973/1984 , 2000/2002	13	-
ARHBALA	1962/1986 , 1996/2000	28	
BENNI AYATT	1958/1960 , 1974/2007	35	VM
BISSA	1968/2003	35	1974/1975
BOUTFERDA	1961/2001	40	VM
DAR OULED ZIDOUH	1974/2007	33	1999/2000
EL ARICH N'GAR	1938/1942 ,1965/2007	46	1986/1987 , 1998/1999 + VM
EL JADIDA L'ADIR	-		-
KELAA SERAGHNA	-		-
ELKSIBA	1961/1999	38	1971/1973

FKIH BEN SALAH	1945/1954 , 1973/1996	32	-
HAD DU BRADIA	1965/2007	42	2001/2003
Kasba Tadla	1935/2007	72	1963/1971 , 2001/2002
kasba Zidania	1960/2007	47	1965/1967
Knizza	1969/2007	38	1971/1972 , 1994/1995 , 1999/2004
KOUMCH	1953/1999	46	1972/1973
KRAZZA	1965/2006	41	1971/1973 , 1997/2001
Taghzoute	1971/2007	36	1984/1985
OULED GNAOU SEMVA	1960/2007	47	-
Oulad Ziane	1964/2007	43	1985/1986
SIDI AHMED BEN Brahim	1962/2007	45	1997/1998
SIDI SAID MAACHOU	1941/1984	43	1975/1977 + VM
SOUK ES SEBT	1935/1982	47	1956/1957
TAGZIRT	1967/2010	43	-
TAKBALT	1970/1999	29	-
TILLOUGUIT	1979/2010	31	1988/1989
TIZI N'ISLY	1979/2010	31	VM
ZAOUIA ES CHEIKH	1965/2007	42	1990/1992 , 1999/2003
ZAOUIA CERCLE	1952/1995	43	1972/1973 + VM

DMN network

Station	Record period	Number of years	Missing data
Afourer	1948/1998	50	VM
Ait Attab	1952/1958 , 1961/1975 , 1981/1990	29	VM
Ait Ichou	1972/1998	26	1986/1988 + VM
Arhbalou Oumlil	1954/1999	45	1990/1992 + VM
Azemmour	1965/1999	34	-
Azilal	1960/1965 , 1971/1998	31	-
Benguerir	1970/2000	30	1998/1999
Bin El Ouidane	1949/1997	48	1975/1980
Boujaad	1977/1997	20	-
Bzou	1952/1998	46	1955/1957 , 1966/1968 ,1977/1978
Daourat	1956/1997	41	-
Demnate	1935/2000	65	1942/1944
Deroua	1949/1997	52	1987/1993
EL KELAA DES SRAGHNA	1980/1995	15	1992/1994
Guisser	-		-
Imfoute	1941/1997	56	1975/1980
KEROUCHEN SUD	1951/1997	46	1974/1975 , 1990/1993 + VM
Khenifra	-		-
Mechraa Ben Abbou	1973/2000	27	VM
Oualidia	1980/1995	15	1988/1989 + VM
OUAOUIZERTH	1957/1989	32	VM
Oued Zem	1935/1996	61	1966/1972 , 1986/1992 + VM

OUIOUANE	1935/2000	65	1939/1950 + VM
Ouled Said	1935/1989	54	63/67 + VM
Senoual	1949/2000	51	1956/1957 ,1970/1971 ,1991/1992 + VM
Sidi Bennour	1989/1995	6	-
Skhour des Rhamnas	-		-
SOUK JEMAA OL.ABBOU	1972/1975 , 1988/1997	12	VM
Youssoufia	1980/1996	16	-
Kasba-Tadla	-		-

- Rainfall index per sub-basin from 1935-2007 (ABHOER)
- Data from the ORMVAT stations

The Tadla Resources Management project (USAid) installed three weather stations to automatically transmit real-time data by radio to the base computer in ORMVAT’s central office, as well as base computers in the perimeter’s three management *arrondissements*. Functioning since 1996, these stations provide data that is used in several ways:

- ✓ Feeding data to the CROPREQ model to calculate crop water needs, thus allowing for more precise irrigation planning and programming.
- ✓ Providing critical information for calculating degree-days, needed to control pests that damage crops
- ✓ Developing a database for use in agro-climatic studies, with data on climate information assessment, the influence of climate parameters on crop development, and other information

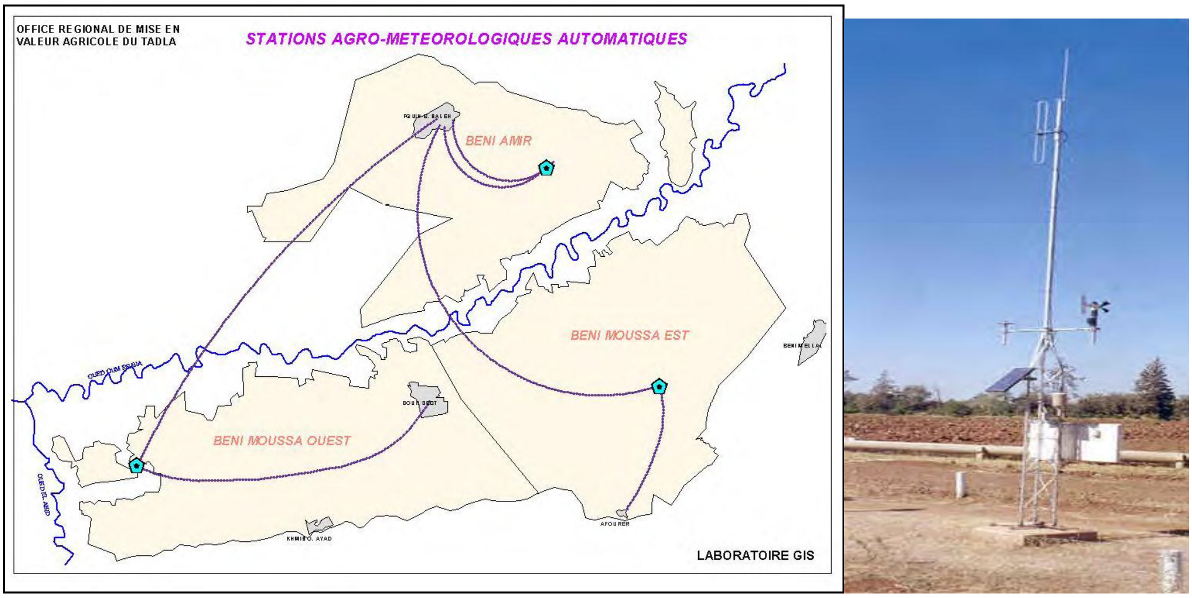


Figure 12-1 Weather stations providing real time data to assist technicians in calculating crop water needs (from TRM project, 1999)

The Ouled Gnaou station (450 m hight, Latitude = 32,3° and Longitude=6.3°) is the automatic meteorological station situated in the Beni-Moussa perimeter within a big experimental station. It is representative of climatologic features of Tadla perimeter.

Data from this station cover all meteorological parameters such as temperature, wind speed, relative humidity,etc..The coverage period is from 1996 until nowadays. Rainfall data from this station are available from 1963.

To achieve accurate flow monitoring, the TRM project also installed 11 automated flow-measurement stations, with 5 stations placed in Béni Amir and 6 in Béni Moussa. Through these stations, canal flow-rate data are automatically gathered and transmitted to a computer in ORMVAT's central office, as well as to base computers in the three management *arrondissements*. As a flow-measurement tool, the stations use broad-crested weir measurement devices. Among its many advantages, this device creates a critical flow, allowing flow rate to be determined by simply reading a water height measurement above the crest, shown as pre-established tables. With a measurement error of 2 percent or less, the device provides real-time information on water flow transiting different nodes. This information allows ORMVAT managers to better control the release of water for irrigation in Tadla and Haouz, while assisting National Office of Electricity officials in releasing controlled volumes of water for energy production. Automatically measuring water flow has improved water transport efficiency and reduced water losses downstream by reducing discharges and allowing safety siphoning. As a result, the project-installed devices have saved significant volumes of water.

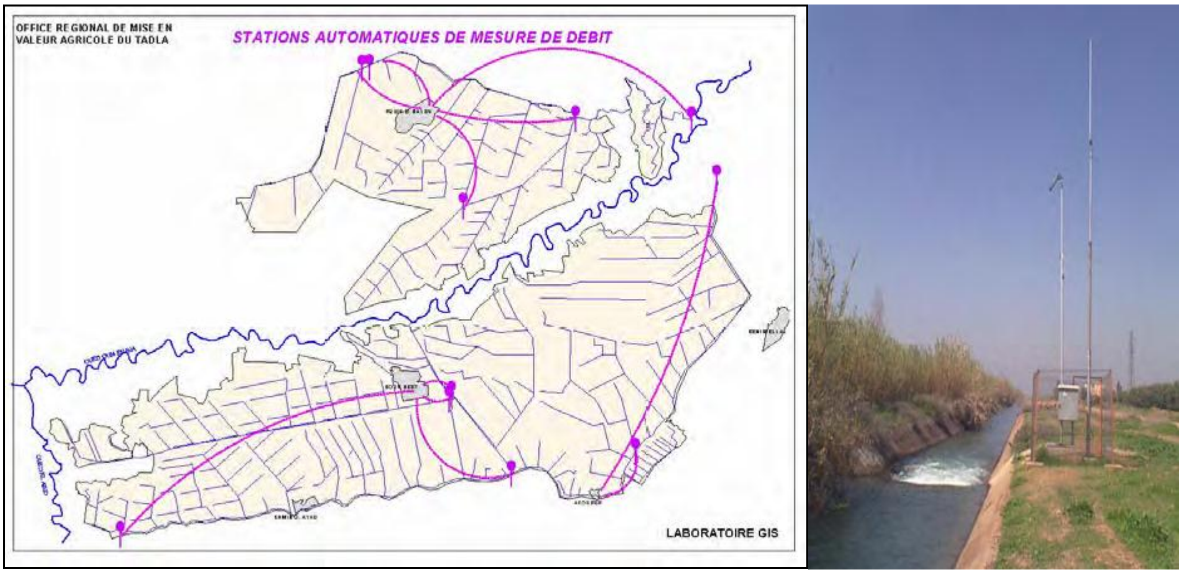


Figure 12-2 Flow monitoring stations automatically send data to help engineers carry out efficient canal operations and water delivery

- Data from Kasba Tadla station (DRA)

Each DRA (El jadida, Settat, Khenifra, Azilal, El kelaa) has a meteorological station. The DRA of Benimellal has an automatic meteorological station with available and reliable data from 2000. A second station was implemented in the mountainous region of Aghbala a year ago.

12.2.3 Soil and water quality monitoring networks

The ORMVAT installed in 1995 a network of soil and groundwater monitoring. Water and soil samples are chosen on the basis of the spatial representativeness in the perimeter, the main soil types and the main hydrogeological variants. The Geographical Information System (SIG) laboratory permits to answer to requirements of temporary and spatial interpretation of the network data and to identify the vulnerable zones (Bellouti *et al*., 2002)

In 1994, the TRM project carried out a diagnostic study on Tadla's environmental characteristics; the project also evaluated ORMVAT's system for monitoring groundwater levels and water and soil quality. Responding to recommendations that emerged from the studies, project personnel introduced an integrated network to allow ORMVAT to track groundwater levels, monitor nitrate and salinity levels in groundwater, and evaluate the impact of agro-chemicals on soil quality.

Monitoring points for the network were selected to ensure full spatial, agro-pedological, and hydro-geological representation. The network included:

- 100 wells geo-referenced to measure groundwater depth and chemical quality
- 40 sites for monitoring soil quality
- 47 typical farms to analyze quantitative and qualitative agro-chemical use

After the network's installation in 1995, ORMVAT Environment Office staff began periodic sample collection and network data analysis. As part of the process, staff members enter monitoring data on water and soil quality, including groundwater nitrate levels, into the ORMVAT geographic information system database. The Geographical Information System (SIG) laboratory permits to answer to requirements of temporary and spatial interpretation of the network data and to identify the vulnerable zones (Bellouti *et al*., 2002)

The completed maps (which describe the current status as well as trends for various environmental parameters) are provided to personnel charged with interpreting network data for ORMVAT managers. By analyzing network data, ORMVAT technicians can identify water pollution sources as well as pinpoint zones most at risk. A powerful management tool, the geographic information system has a variety of other applications that ORMVAT staff members are currently exploring.

12.2.4 Agricultural data (long time series, about 25 years)

- Irrigated perimeters (ORMVA Tadla, ORMVA Doukkala)

Evolution of main crops areas (Fall Cereals, Fodder crops, Sugar beet, Olive trees, Citrus, Vegetables) and yields, livestock situation.

- Rainfed areas (DRA)

Evolution of main crops areas and yields, livestock situation.

12.3 COLLATION AND REVIEW OF EXISTING MODELS

12.3.1 Hydrologic models

Two hydrologic models are currently used at the Oum er-Rbia river basin scale. These are:

- The Ribasim model (Delft Hydraulics) for planification purposes
- The HEC-HMS (US Army Corps of Engineers) as a water management tool. The Hydrologic Modelling System (HEC-HMS) is designed to simulate the precipitation-runoff processes.

The Hydrosplah model was tested in the Tadla perimeter in the frame of the Aquastress project. Hydrosplash is a regional hydrological model (GIS based) which calculates the water balance terms in river basins or large watersheds. The model is used to illustrate the effects of the different scenarios, starting with a reference scenario.

12.3.2 Groundwater resource model

The intensive agriculture practiced in the Tadla plain has had a profound impact on aquifer recharge and quality. Factors contributing to the degradation of aquifer water quality include the following:

- Use of water from the Oum Er-Rbia river, with a natural salinity exceeding 1.7 g/L
- The recycling of groundwater fed by agricultural drainage
- The rise of groundwater levels

Given the prominent role of groundwater degradation in Tadla's water pollution, TRM staff concluded that improving ORMVAT's decision-making capabilities required an effective tool for modeling the impact of groundwater degradation. In early 1996, the project took the MODFLOW hydro-geologic model, originally developed in the United States, and adapted it to local conditions. The model evaluates the aquifer's response to such irrigation practices as pumping, irrigation, precipitation, and infiltration. It can also be used to preview the impact of management actions on groundwater levels, making it easier for water planners to plan strategies for addressing the problem of rising groundwater.

ORMVAT has used the model to determine aquifer hydro-geologic parameters, including transitivity and storage co-efficiency. Office technicians have also used it to visualize groundwater levels at given moments within a steady state. ORMVAT engineers are continuing the model's development: By expanding the model's capacity for incorporating data and extending its capability to simulate transient conditions, ORMVAT is working to improve the tool's accuracy and usefulness within Tadla's complex hydro-geologic environment.

12.3.3 Agro-climatologic and agro-hydrological models

- CROPSYST

CROPSYST is a multi-year, multi-crop, daily time step cropping systems simulation model developed to serve as an analytical tool to study the effect of climate, soils, and management on cropping systems productivity and the environment. CropSyst simulates the soil water and nitrogen budgets, crop growth and development, crop yield, residue production and decomposition, soil erosion by water, and salinity (Stöckle *et al*., 2002).

- CRIWAR

CRIWAR is an agro-hydrological model used for irrigation areas to calculate the irrigation water requirements of cropping patterns for various crop development stages that was tested in the tadla perimeter in the frame of the Aquastress project. One of the capabilities of the CRIWAR model is to calculate crop water requirements in irrigated command areas. The application of the model in the Tadla irrigated perimeter, with different scenarios related to change in cropping patterns and improved irrigation techniques, will give valuable information on possible water savings. Scenarios linked to climate change may give information on future water needs in the Tadla perimeter. CRIWAR is an agro-hydrological model that consists of two modules:

- ✓ Irrigation Water Requirement module

The module determines the daily water demand of the cropped area and can be used to review alternative cropping patterns.

- ✓ Strategy module

The strategy module is a new module developed within the AquaStress project. The CRIWAR strategy module allows to determine an optimal irrigation strategy (irrigation scheduling) to sustain agriculture on one side (leaching of salts and maintain stable groundwater tables) and attain a high productivity on the other side using a crop production function

- CROPREQ

Conceived by USAID/Morocco in cooperation with the Moroccan Ministry of Agriculture and implemented by Chemonics International, the Tadla Resources Management project (TRM) was designed to improve water management and protect the natural resource base supporting the agricultural sector in Morocco from 1993 to 1999. The TRM project developed the **CROPREQ** model to facilitate irrigation programming and scheduling. Based on Visual Dbase, CROPREQ was developed to estimate the water needs of specific land parcels under cultivation as an aid to irrigation planning, both before and after the irrigation season.
The program identifies weekly and monthly crop water needs at the head of each irrigation system branch, determines the water flow necessary to satisfy those needs, and tabulates the effective flow of water in canals. To carry out analyses, CROPREQ relies on data files with the following information:

- ✓ Identification of each perimeter parcel, along with size and farmer’s name
- ✓ Description of the crops and area planted on each parcel
- ✓ General agronomic information on crops, including crop water demand coefficient, vegetative periods, root depth, and date of seeding
- ✓ Daily and monthly weather data
- ✓ Actual and nominal capacities of irrigation canals

(Tadla Resource Management Project, 1999)

12.4 METHODS AND TOOLS TO BE APPLIED

The improvement of agricultural and hydrological drought management in the Oum er-Rbia basin requires the following tools:

- **Medium range and seasonal weather forecasts.**

Irrigated areas:

These areas are primarily served by water from the main dams. During summer time, at the end and on the basis of the previous rainy season and reservoir levels, a planning of water allocation to the users for the forthcoming rainy season is made (until about April of the following year). This planning is subsequently updated mid-term, again to the end of the season in April. The use of medium range forecasts can allow optimisation of releases to irrigators, taking the current weather conditions into account.

Rainfed areas:

These areas remain on rainfall to grow crops, mainly cereals. There is little room for decision making once the crops are planted. However, an important decision is the timing of the planting of the crops at the onset of the rainy season. Currently farmers generally plant once the first rains have fallen. Clearly advance information on when rain is expected at the medium range could be useful in planning the planting process.

Once crops have been planted these are dependent on sufficient rainfall, and little can be done should there be insufficient rain. However, for those farmers with local water resources such as ponds or groundwater extracted from local aquifers can be used to bridge dry spells that could lead to plant stress and yield reduction. Medium range forecasts providing an indication of duration and severity of such dry-spells could be useful in this respect.

- **Hydrological and agricultural models, drought vulnerability assessment**

Hydrological modelling could include the use of the current RIBASIM and/or HEC-HMS models which are actually used in the basin for planification and water distribution purposes. Further discussions with stakeholders from ABHOER will allow us to determine how these models can be coupled with forecasted precipitation data in order to improve hydrological drought forecasting and thus warning.

According to the General Assembly meeting, no new agricultural model will be developed for the Oum er-Rbia basin, but we may try to adapt a methodology previously developed by CSIR on corn to rainfed cereals in the Oum er-Rbia basin.

Agricultural drought vulnerability assessment studies will be conducted according to the different methodologies proposed by our UPM partner during the General Assembly for each of the irrigated and rainfed areas.

Hydrological, meteorological and agricultural data from the Oum er- Rbia basin will be used to run these models.

12.5 EXPECTED OUTCOMES AND PRODUCTS

The expected outcomes of the Dewfora project for the Oum er-rbia basin can be divided in two main parts:

- Drought forecasting and monitoring

Regarding drought forecasting and monitoring, the expected outcomes and products differs in the irrigated and rainfed areas of the basin:

In the irrigated areas, reliable information of expected rainfall over irrigated areas, as well as for inflows to reservoirs will allow the establishment of an optimal water release strategy. Thus, with the medium range forecasts, released to irrigators could be reduced if rainfall is predicted, whilst releases could be augmented to bridge an unexpected dry spell and reduce plant stress. These forecasts will be completed and strengthened by additional monitoring parameters at the time of decision making.

In the rainfed areas, clearly advance information on when rain is expected at the medium range could be useful in planning the planting process while new drought indicators will be usefull for a better monitoring of drought onset, duration and severity. Once crops have been planted these are dependent on sufficient rainfall, and little can be done should there be insufficient rain. However, for those farmers with local water resources such as ponds or groundwater extracted from local aquifers can be used to bridge dry spells that could lead to plant stress and yield reduction. Medium range forecasts providing an indication of duration and severity of such dry-spells could be useful in this respect.

- Drought mitigation and adaptation

The second major outcomes of the Dewfora project will be the development of drought warnings for drought mitigation and analyses of adaptation practices on drought vulnerability. Thus, impacts of agricultural drought in the Oum er-rbia basin will be mitigated through the transfer of the previous drought forecast into drought warnings while recommendations will be made on how to reduce drought vulnerability through the implementation of better adapted agricultural practices.

12.6 HOW RESULTS AND IMPACT WILL BE MEASURED OR DETERMINED

The results and impacts from the Oum er-rbia case study can be determined by:

- The assessment of the skills of medium range weather forecast developed in WP4 for the planification of irrigation schedule (irrigated sector) and for the planification of sowing dates and eventual supplementary irrigation (rainfed sector).
- The assessment of the skills of integrating forecasted precipitation in hydrological models in order to improve hydrological drought forecasting and warning.
- The assessment of the capabilities of transferring drought forecasts and vulnerability assessments into drought warnings and adaptation recommendations and through the evaluation of the results by the local stakeholders, relevant authorities and decision makers.

13. PROPOSED ACTIVITIES AND WORKPLAN FOR THE OUM-ER-RBIA BASIN

13.1 PROPOSED ACTIVITIES

The main activities as we have agreed on during the General Assembly meeting are:

- To investigate whether monthly weather forecasts can be used for a better planification of the irrigation and sowing dates in irrigated and rainfed areas respectively by comparing the long time series of forecasts provided by ECMWF (from 1993 to 2009 hindcasts (1 per week, 5 ensemble members), from 2010 onwards forecast (1 per week 50 ensemble members)) to the effective irrigation and sowing schedules performed during those years.
- To determine the skill of forecasted precipitation to improve hydrological drought forecasting and warning, using the currently used hydrological models (Ribasim and/or HEC-HMS).
- To determine if the methodology used by CSIR for forecasting agricultural drought on corn can be applied to cereals.
- To identify and test the more adapted drought indicators for the Oum er-Rbia basin according to the framework proposed by WP 3.
- To conduct agricultural drought vulnerability assessment studies according to the methodologies proposed by UPM.
- To transfer drought forecasts and drought vulnerability assessments to drought warnings and adaptation recommendations.

13.2 PROPOSED WORKPLAN, MILESTONES AND TIME SCHEDULE

The following table presents the provisional proposed workplan for the Oum er-rbia case study.

Table 13-1 Proposed workplan for the Oum Er-Rbia case study:

Tasks	Responsabile/ Possible collaboration	related deliverables	Due Date	Status
I. **Review of existing data, models and drought management in the oum-er-rbia basin**				
Review of hydrological, meteorological and agricultural data availability	IAV	D 6.1	Oct 2011	OK
Review of hydrological and agricultural existing models	IAV	D 6.1	Oct 2011	OK
Review of institutional drought management in the basin	IAV	D 6.1	Oct 2011	OK
Assessment of drought warning	IAV	D 6.1	Oct 2011	OK

actions in the basin				
Constitution of the stakeholders platform	IAV	D 6.1	Oct 2011	OK
II. Meteorological, Hydrological and Agricultural Drought forecasting and monitoring				
Medium range weather forecasts	IAV, ECWMF, Deltares	D 4.1	Aug 2011	
Hydrological Modelling	IAV, Unesco- IHE	D 4.5 D 4.8 D4.9	Aug 2011 Apr 2013 Oct 2013	
Agricultural modelling	IAV, CSIR	D 4.10 D 4.11	Oct 2012 Apr 2013	
Development of Drought indicators	IAV, UPM, FEUP	D 3.1 D 3.2	Oct 2011 Apr 2012	
III. Drought mitigation and adaptation				
Use of medium weather forecasts for decision planning (irrigation management, sowing dates)	IAV, ECWMF, GFZ, Deltares	D 6.2	Jun 2013	
Transfer of drought forecasts, outputs from hydrological and agricultural models, drought indicators into drought warnings	IAV, UPM, FEUP	D 5.1 D 5.3	Apr 2012 Jun 2013	
Recommendations for more adapted drought adaptation practices	IAV, UPM, U Porto	D 5.4	Jun 2013	
IV. Diffusion of the results				
Presentation and discussion of the results within the stakeholders platform	IAV	D 6.2	jun 2013	

At present, the time schedule for the production of the following milestones is depending on feed-back from other partners involved in the activities mentioned in the previous points and cannot be established.

Milestone 1: Planification of the irrigation and sowing dates in irrigated and rainfed areas.

Milestone 2: Improvement of hydrological drought forecasting and warning.

Milestone 3: Selection of the most adapted drought indicators.

Milestone 4: Agricultural drought forecasting.

Milestone 5: Agricultural drought vulnerability assessment.

Milestone 6: Final results from case study.

14. DESCRIPTION OF THE NIGER BASIN CASE STUDY

14.1 GEOGRAPHICAL AREA

The Niger River’s original name, egerou n-igereou (river of rivers), was given by the Tuareg people to express the exceptional character they attributed to it (Barry et al., 2003). Over the centuries, the Niger River and its tributaries have been vital to those who lived along the river or used it for travel and trade. For travelers coming from the Sahara, the appearance of the Inland Delta as the sea of fresh water was a welcome relief. The existence of the Niger River was already mentioned in the Antiquity (Ptolémée, second century AD), then by arabic historian travelers like Ibn Battuta in the 14th century (Picouet, 1999). It is then described as a tributary of the Nile originated from West Africa (the cartography in Europe will reproduce this theory until the 17th century). It is also discovered by Europeans travelers between the Guinea and Timbuctu like Mungo Park (1796) then, René Caillié (1828)..

Stretching between the Sahara desert and the Atlantic coast, the Niger is the third African river according to the length (4,200 km) after the Nile and the Congo. The entire basin covers 2,170,500 km² (7.5% of the continent) across six agro-climatic zones and ten countries while the *active* basin covers 1,272,000 km^2 spread over nine countries: Benin, Burkina Faso, Cameroon, Chad, Ivory Coast, Guinea, Mali, Niger and Nigeria, which are all members of the Niger Basin Authority (NBA). Starting its journey in the Fouta Djallon Massif and the Guinean Dorsale that separates the Middle Guinea and the Guinean forest from Sierra Leone and from Liberia, the river receives consistently high amounts of rainfall which contributes to flow northeast towards Sahelian and sub-desertic regions traversing a vast spreading flood plain in Mali known as the Inner Niger Delta (IND).The course across the IND dissipates an appreciable portion of its potential hydraulics through absorption and evaporation. Further on, when it reaches the fringes of the Sahara desert, the Niger river turns back by forming a great bend and flowing south and east as the middle Niger river section, then as the lower Niger, to the maritime Niger Delta (20 000 km²) at the Gulf of Guinea, which is reached after being joined by its largest tributary, the Benue River (Andersen et al., 2005).

The basin in general has a low relief with altitudes between 0 and 800 m. The average mean altitude of the basin is about 257m with more than half of the basin in the range of 200 to 300 m. The global slope index is between 25 to 50 cm/km. With the exception of the mountains at the source of the Niger River and its tributaries in Guinea and those at the source of the Benue River in Cameroon and Nigeria, the basin is relatively flat. Even the Upper Niger lies generally on the Mandingue Plane at an altitude of between 400 and 500 m. From this plane there are a number of hills, mountains and plateaux usually less than 1000 m. in height. The topography of upper basin in Mali is similarly north-eastward, sloping small hills, of between 300 m. and 500m. The monotony of the relief is as a result of long term erosion interrupted in places by flat-toped mountains and sandy plateaux. The highest summits are in the Dogon Plateau in Mali and Mont Hombori (1155 m.) (Barry et al., 2003).

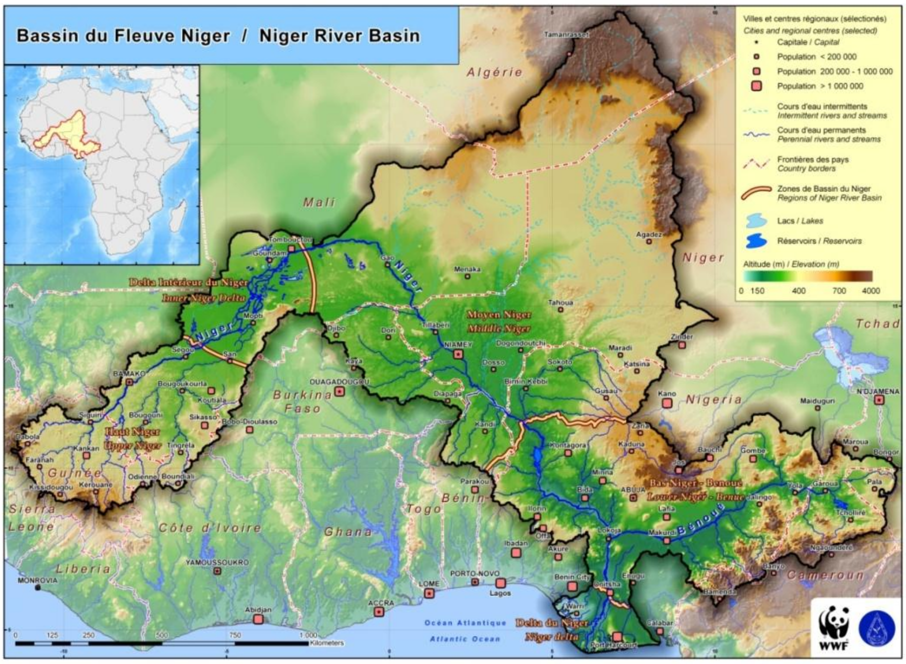


Figure 14-1: Niger River Basin (Source: Niger Basin Atlas, NBA)

From the stand point of water resources, the Niger Basin can be divided into five hydrographic regions, each of which is distinguished by unique topographic and drainage characteristics (Andersen et al., 2005).

The Upper Niger Basin and the Bani Watershed composed the headwaters of the Niger which has an extensive network of steep-sloped tributaries originating in Upper Guinea, whereas the Bani tributary network originates in the low-altitude plateaus of southern Mali and Côte d'Ivoire.

The Inland Delta and Lakes District, entirely situated in Mali, covers a rectangular area facing south west and north east with a length of 420 km and a width of 125 km between Ke-Macina and San in the south and Timbuktu in the north. It has a surface area of 84,000 km2 and comprises four agro-ecological zones: the living delta, the middle Bani-Niger, the dead delta and the lakeside zone between Gao and Timbuktu. It accounts for almost all of the rice cultivation which is the staple food in Mali.

The Middle Niger Basin lies within Mali, Niger, Benin and Ivory Coast. It stretches from Timbuktu to Benin, covering an area of 900,000 km2, 230,000 km2 of which are inactive. It is made up of a series of irrigated terraces. Water flow in this basin largely depends on additional influx from the Inland Delta and navigation is hampered by waterfalls. The right bank is formed by a low-altitude plateau region with a series of tributaries that contribute to most of the Niger River's inflow along this segment. The region of the left bank tributaries is characterized by a wadi network in the upstream reach of this segment, with little contribution to the Niger River and an increased inflow from the tributary network in the lower reaches of the segment.

The Lower Niger Basin lies between Cameroon, Nigeria and Chad. Rainfall varies from 700mm in the North (Sokoto) to more than 3 000 mm in the South next to the Maritime Niger delta. It is characterized by big dams for hydro-electric power production, irrigation and by industrial activities on the rest of the basin. Energy production is mainly derived from the Kainji, Lagdo and Jebba dams which supply 68% of Nigeria's electricity needs and 22% of her total energy needs.

The Maritime Niger Delta is located in Nigeria in a region of high rainfall. The Benue River is a major tributary to the Lower Niger River originating in the high-altitude Adamawa Plateau in Cameroon. The high number of tributaries from the Lower Niger River flows south emptying through the Niger Delta, an area characterized by swamps, lagoons, and navigable channels.

The first two sections display an endorheic behaviour; whereas the total annual mean flow entering the Niger Inner Delta is estimated at 46 km3, the mean annual flow is only 33 km3 at Taoussa, immediately after the inner delta, which can reach 30,000 km² in flood season. Within the Middle Niger, the river loop receives 6 tributaries from Benin and Burkina Faso. The mean annual flow entering the Lower Niger is 36 km3, but with the contribution of its main tributaries (above all the Benue River), the mean annual flow entering the sea at the mouth is 180 km3.

The diverse geographic and climatic characteristics of the Niger River Basin play an important role in water resources availability, which in turn affects a range of water resources–related activities. The Niger River water system is one of the most impressive examples of the influence of topography and climate on the flow conditions of a water system. Such a large basin area cannot be expected to have uniform climatic and rain patterns, and the Niger River traverses a wide range of ecosystem zones in West Africa.

A combination of human population growth, unsustainable resource management and desertification processes threatens the Niger River's ability to supply crucially needed natural resources to the people of the Basin.

The definition of the scales

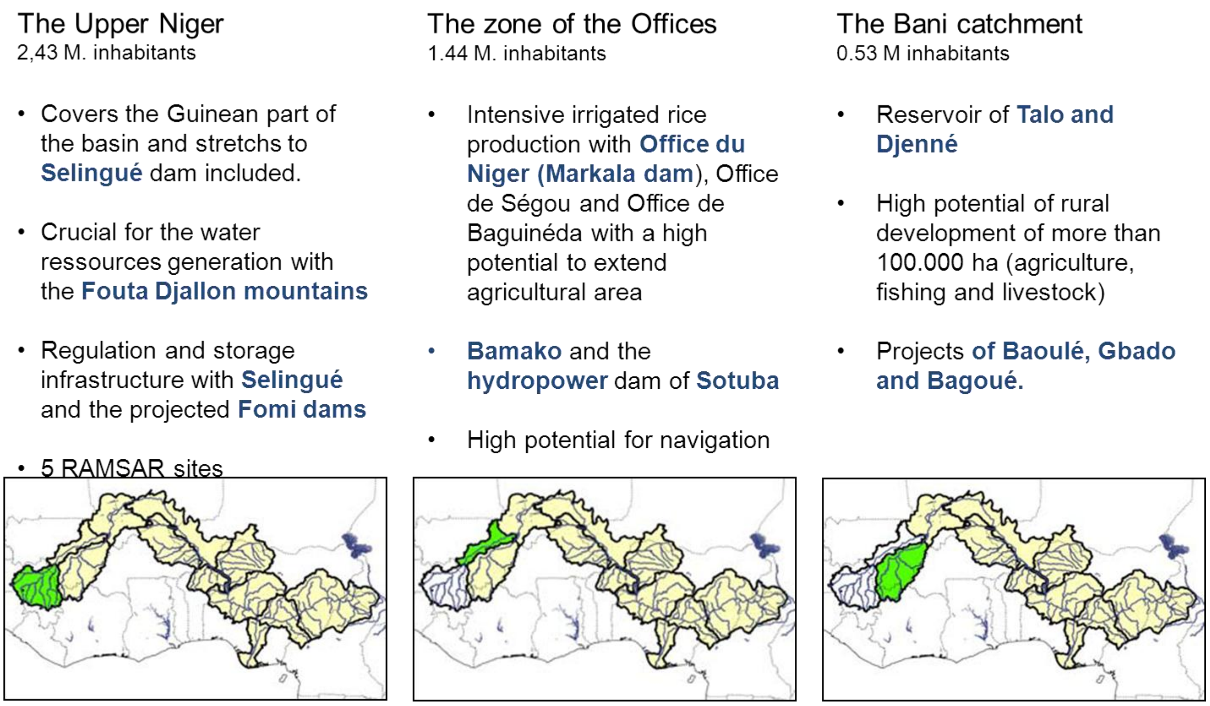
At this step, the notion of scale in the Niger River case study is important to define in order to not confuse the problematics and the issues to address for drought vulnerability and risks. A definition of the terms used to encompass the Niger River case study at different levels is then essential to understand the involvement and the scope of the diverse organizations, initiatives, stakeholders and projects. In this Niger River case study report and in the DEWFORA project, it is agreed to distinguish seven scales with the following terminology:

- the **global scale** refers to the world and the African continent level.
- the **regional scale** refers to the West African or the Sahelian region
- the **river basin scale** refers to the entire Niger river basin which encompasses the nine member countries of the Niger Basin Authority
- the **sub-regional scale** refers to two respective hydrographic regions which encompasses four countries Guinea, Mali, Burkina-Faso, Ivory Coast: the Upper Niger Basin with the Bani tributary and the Inner Niger Delta
- the **national scale** refering to the State of Mali or Guinea.
- the **meso scale** refers to the hydrographic region of the Inner Niger Delta in Mali. It corresponds to the case stufy focus of the DEWFORA project and to the region according to the decentralized Malian administrative units
- the **local scale** refers to the cercles and the communes according to the Malian decentralized administrative units. It corresponds also to the community level encompassing local associations, trades, NGO´s and sectorial water use initatives.

The scale focus of the DEWFORA project

The challenge of the DEWFORA project in this research framework is to proceed to a downscaling approach incorporating the general problematic, advances and constraints of the five upper levels for the action plans to drought preparedness at the meso and local scales. The drought early warning and forecastinng systems in use are generally designed for the needs of national to higher organizations and do not produce adapted information that fit to the meso and local initiatives for developping drought mitigation strategies. The tools have to be optimized to reflect the problematic and the needs of a multiple source of actors. Across the four lower scales (sub-regional to local), the challenge is then to define an integrated vision to mitigate the vulnerability to drought risks among the water uses. With the combined pressure of climate change and of the current sectorial approaches of the water uses, water conflicts emerge and compromise the perenniality of food security and natural conservation of the Inner Niger Delta.

The DEWFORA project aims to focus on the Inner Niger Delta region which is highly dependent from the hydrological contributions of the upstream catchment. The figure below localizes and summarizes the main characteristics of the three upstream development zones (ZD) defined in the Plan d’Action de Développement Durable (PADD) of the Niger Basin Authority.in 2007.



The Upper Niger
2,43 M. inhabitants

- Covers the Guinean part of the basin and stretchs to **Selingué** dam included.
- Crucial for the water ressources generation with the **Fouta Djallon mountains**
- Regulation and storage infrastructure with **Selingué** and the projected **Fomi dams**
- 5 RAMSAR sites

The zone of the Offices
1.44 M. inhabitants

- Intensive irrigated rice production with **Office du Niger (Markala dam)**, Office de Ségou and Office de Baguinéda with a high potential to extend agricultural area
- **Bamako** and the **hydropower** dam of **Sotuba**
- High potential for navigation

The Bani catchment
0.53 M inhabitants

- Reservoir of **Talo and Djenné**
- High potential of rural development of more than 100.000 ha (agriculture, fishing and livestock)
- Projects **of Baoulé, Gbado and Bagoué.**

Figure 14-2 : the three catchments forming the headwaters of the Inner Niger Delta (Source: NBA, PADD, 2007)

The **Inner Niger Delta** (IND), still also referred to as the “Niger River’s inland delta”, “central delta” or “cuvette lacustre” (lake basin), is one of Mali’s most remarkable hydrographic features. The topographical maps of the Institut Géographique National (IGN) reveal that the inundation area measures 36 470 km2, including 5340 km^2 of levees, dunes and other islands within that area. They also show that water coverage declines from 31 130 km^2 in wet periods to 3840 km^2 in the dry period. This vast flooding area stands nestled in the semi-arid Sahel, stretching more than 350 km from Ke-Massina (southwest) and Timbuktu (northeast). It is situated between parallels 13 and 17 north and meridians 2°30 and 6°30 west. The entire floodplain area is included in the 41 195 km2 designated as a Ramsar Wetland Site of International Importance in January 2004. It hosts a very dense and hierarchical network of distributaries fed by the Niger River and the Bani, a tributary that flows into it near Mopti. Between Ke-Massina and Lake Debo, this inland delta comprises a series of potholes and plains that flood every year (provided the swell is substantial enough).. After Lake Debo, naturally-occurring dunes haphazardly feed water through a vast web of thoroughfares and into a number of lakes. (Marie et al., 2007) The Delta contains different types of wetland habitats: swamps, ponds, lakes, floodplains, rice fields, pastures of the *bourgou* grass (*Echinochloa stagnina*), and flooded forests.

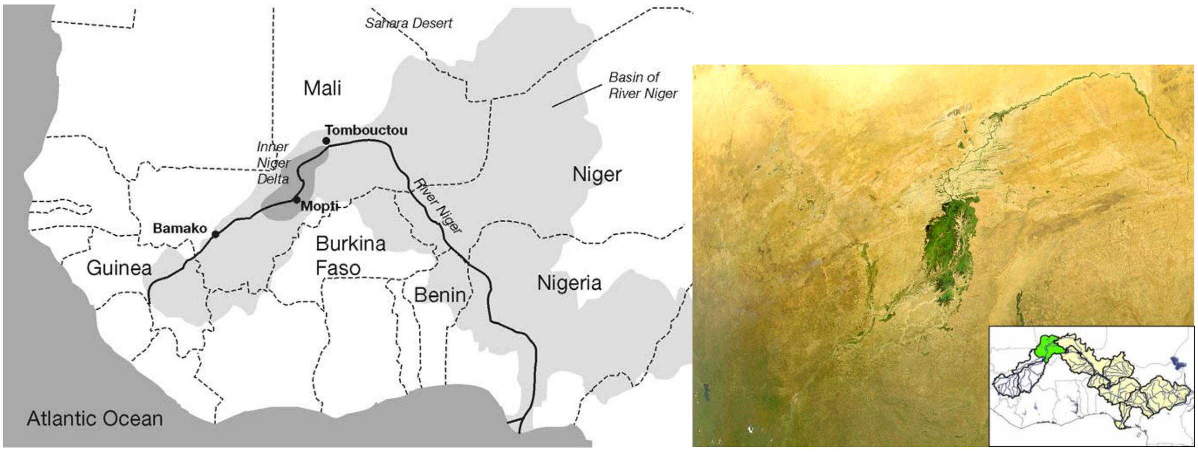


Figure 14-3: The Inner Niger Delta case study (Source: Picouet, 1999)

The Inner Niger Delta mainly covers the districts (‘cercles’) of Mopti, Djenné, Tenenkou, Youwarou, Massina, Niafunká and Diré all in the Mopti, Ségou and Tombouctou regions of Mali. This is an area of national and international strategic importance. It is the largest inland wetland in West Africa, supporting exceptionally diverse, rich and complex ecosystems. The Delta is temporary home to as many as 117 species of waterbirds. Hotspots of the biodiversity, one to two million migratory birds are recorded here every year. They migrate from Europe and Asia and use the Delta as a winter resting grounds or stop-over area before they go back to their summer nesting area. Local people hunt these birds for food or sell them to earn money. In 1999 about 62,500 waterbirds were sold in the market at Mopti, the largest town in the Delta. The annual floods bring up to 25,000 to 30,000 km2 of ‘extra’ land into production (Moorehead 1998 cited by Cotula and Cissé, 2006). The delta contains rich agricultural land, and the highly nutritious dry-season pasture commonly known as burgu (Echinochloa stagnina). It contains some 70% of irrigable land in Mali, and during the dry season it hosts some 50% of the national livestock; fisheries in the delta support the livelihoods of some 300,000 people (CILSS 2005 cited by Cotula and Cissé, 2006). In addition to supporting rural livelihoods, the delta supports the livelihoods of urban groups (traders, government officials, etc), who invest much of their savings in livestock.

Ecology and livelihoods in the delta are shaped by seasonal cycles. During the hot dry season (April to June), water only runs in the river beds of the Niger and Bani rivers, and of their tributaries. During the rainy season (June to September), water rises and spills over the flood plains. Between October and January, a vast area of land is covered by water. The size of this area varies constantly from year to year, depending on rainfall – both in the area and, more importantly, upstream. In the cold dry season (January to March), waters subside progressively along a southwest to northwest transect, with water staying longer around the lakes Debo and Walado in the northwest of the delta. At the end of the dry season, water has retreated into the river beds and floodplains revert to dusty lands (Moorehead 1998 cited by Cotula and Cissé, 2006).

With so much water in a dry area bordering the Sahara, the Delta also encompasses farmland and pastoral areas that, along with the abundant fish, support a million people. The delta hosts three main livelihood activities: farming, herding and fishing. These activities coexist over the same territory, and are combined in a range of production systems (farmers, agro-pastoralists, fishers, farmer fishers, transhumant herders) (Moorehead 1997 cited by Cotula and Cissé, 2006). Farming mainly concerns millet on sandy soils and rice in seasonally flooded areas (Moorehead 1997 cited by Cotula and Cissé, 2006). About 300,000 are rice farmers, from the Marka, Bambara and Rimaibe ethnic groups. They produce about 86,000 t of rice a year (though production varies considerably from year to year). The rice farmers eat most of what they grow themselves, but sell about 10% of their crop. Fishers include local groups and transhumant groups following the seasonal floodings. Another 300,000 people, mainly from the Bozo tribe, earn their living from fishing. The Delta produces 80% of Mali's fish, varying from 40,000 t during weak flood years to 100,000 t during high floods. Herding is practiced by local groups and by transhumant pastoralists which are mainly Peul, who move from dryland areas (sometimes hundreds of kilometers away, in Mauritania and Burkina Faso) to the delta to spend here the dry season (November to May; Moorehead 1997 cited by Cotula and Cissé, 2006). 2 million cattle and 3 million sheep and goats come into the Delta during the dry season to graze on the stubble of crops and remains of the other vegetation that has thrived as the floodwaters subside. Every year, transhumant herders enter the delta from identified crossings posts (the main ones being Diafarabé and Sofara, respectively southwest and southeast of the delta) and generally move northeast along the delta, following the flood retreat. The river that winds its way through the maze of marshes and lakes is the region's major transport artery. Tourism is also important when insecurity does not destabilize the region. The Delta is in Mali's tourist triangle stretching from Djenne to the Dogon Mountains and Tombouctou.

Because of this complex system of overlapping resource uses, the delta has been for a long time a crossroads of different ethnic groups and cultures. Historically dominated by the Fulani herders (Fulbé), the delta is also inhabited by the Bozo and the Somono (traditionally fishers), who first occupied the area, the Bambara (farmers), and other groups. The Rimaibé are the descendents of slaves captured by the Fulani. Slavery was abolished by the French colonisers in 1906. The complexity of resource use patterns and of ethnic composition is reflected in the mosaic of resource tenure systems that coexist over the same territory – not only customary and statutory systems, deriving their legitimacy on 'tradition' and on legislation, respectively; but also different customary systems, ranging from those based on the right of the first occupants (Bozo and Somono agro-fishers) to the sophisticated Dina system established in the 19th century by the Fulani.

Despite this hugely rich natural resource, over 75% of the people in the Mopti region, in the heart of the Delta, are below the poverty line – the highest incidence of poverty in Mali from which women are the most affected compared to the national standard poverty. Of Mopti's children only 22% go to school, compared to 37% for the country as a whole. Only one-third of households have access to tap water. The major diseases in the area are malaria, lung infections, diarrhoea and AIDS. Women are more likely to be poor than men.

Lack of infrastructure is one cause of these high levels of poverty. Another is the degradation and the overexploitation of the natural resources of the Delta: erosion, poor soils, shrinking numbers of fish, and unpredictable water levels. This situation is worsened by increasing demands being put on the Delta by a rising human population and by new infrastructure upstream, such as irrigation schemes and hydropower dams. Less and less water reaches the Delta because of these developments. A shrinking Delta is less able to feed the increasing numbers of fishermen, farmers and herdsmen in the area. It also compromises the perenniality of the traditional management ruled by some local landowners like the Dioros to control the access of natural resources.

Finally, the water uses can be enunciated in eight major thematics listed below. The DEWFORA project aims to introduce in the study the drought vulnerability of the three to five first problematics.

- **Hydropower:** the electricity production is generated nowadays from the existing infrastructure (Sélinguè) and in the future from extensive planned hydrolelectric dams (Fomi, Taoussa, Djenné)
- **Agriculture:** the agriculture can be divided according to five different management practices: fully managed irrigation system, controled submersion (also used in shoals), pumping village irrigated perimeters (PPIV), free submersion, and rainfed. In Mali, the two first irrigation management practices are organized in Office. There are Offices are
- **Fishery** in the Inner Niger Delta and in the reservoirs
- **Pastoralism**
- **Natural conservation** for the maintenance and the regeneration of the biodiversity (waterbird, fish and other endangered species) and of the ecosystems (inundated forest and bourgou)
- **Navigation** for public and private transport
- **Drinking water supply, sanitation and waste management** for urban and rural areas
- **Tourism, hotel and craft activities**

14.2 CLIMATE

The Niger basin has two distinct seasons a rainy summer and a dry winter except for Nigeria, which has four seasons. Situated between the equator and the Tropic of Cancer, the region is generally warm or hot, although the high mountains and Sahara Desert experience extreme temperatures. Along the coast, the annual average temperature range is 21°- 28°C; inland to the north the temperatures fluctuate more according to the season, with an annual average temperature range of 12°- 29°C. Given its geographic setting in West and Central Africa, the Niger Basin is characterized by the climatic conditions associated with the movement of air masses of the Intertropical Convergence Zone north and south of the equator. During the boreal summer (June to November), the rise Intertropical convergence of the Saint Helena high-pressure area toward the north signals the beginning of the monsoon season, with humid and unstable maritime equatorial air and relatively cool temperatures. The monsoons are longer and heavier in the southern part of the Basin. The boreal winter (December to May) is the dry season; under the influence of a Saharan high-pressure zone, the northeastward harmattan wind brings hot, dry air and high temperatures, which last longer in the north. Annual rainfall ranges from fewer than 100 millimeters in the Sahel zone to more than 1,200 millimeters along the pure tropical areas in the Guinea zone. (paragraph based on Zwarts, 2010 and Brooks, 2004)

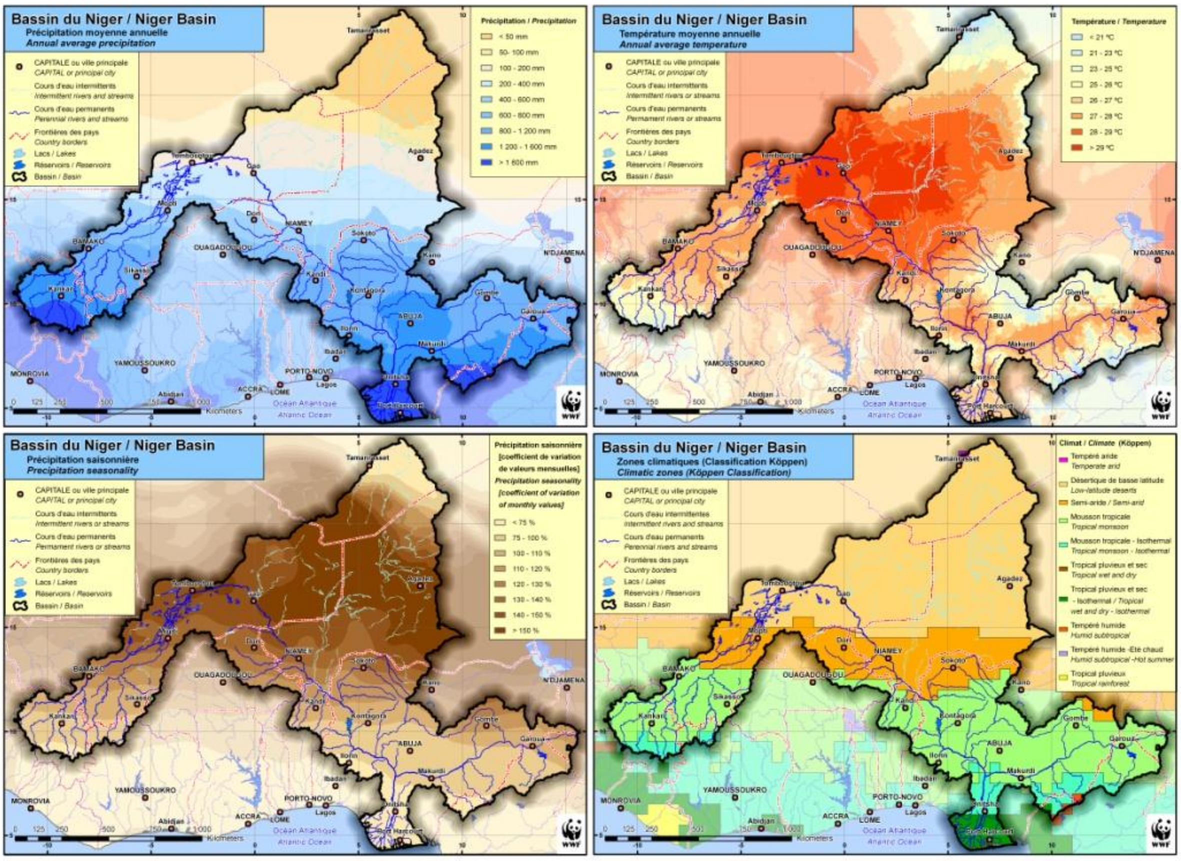


Figure 14-4 *Maps of Annual average precipitation and temperature, of precipitation seasonality (worldclim database) and climatic zone sin the Niger basin. Source: NBA et WWF, 2007*

In Mali, two large subtropical anticyclones govern then the seasons: the northeast-southwest Sahara anticyclone produces the hot and dry Harmattan winds, and the Saint Helen anticyclone produces the southwest/northeast warm and very damp monsoon. The hot and dry northerly Harmattan and the damp southerly monsoon meet in the Inter-Tropical Convergence Zone (ITCZ). Its trace on the earth's surface is called the Inter-Tropical Front (ITF), and rain is associated with its passage. The ITF follows a roughly south-north-south pattern through the year. July, August and September find it in the north, December, January and February in the south. The ITF moves north slowly and erratically over a six-month period, but only takes four months to travel back towards the equator. These atmospheric cycles dictate Mali's climatic year. The dry season lasts nine months in the north and five or six months in the south; the rainy season starts in April and finishes in October in the south of Mali, but only begins in July and ends in September in the north. Rain at the beginning and end of the rainy season is mostly easterly, and linked to particularly important squall lines in the Sahel latitudes. During the dry season, north-easterly winds dry the air and magnify the heat that blankets Mali in April and May. (paragraph based on Marie et al., 2007)

According to the characteristics of the regional climate, the upper half of the Niger River Basin encompasses five climate zones, which are based on the duration and abundance of annual rainfall. The rainy season is centered in the month of August for all these climate zones. The five zones as they extend across the region can be described as follows:

- The Guinean region, which includes the headwaters of the Niger River Basin and its tributaries, is characterized by a transitional tropical climate (tropical de transition) that is often called the Guinean Climate, where the annual rainfall is greater than 1,200 millimeters.
- The Saudi region encompassing Siguiri-Sikasso is characterized by a pure tropical climate, with annual rainfall between 750 and 1,200 millimeters.
- The Sahel zone with the areas around Mopti is characterized by a semiarid tropical climate, with annual rainfall between 300 and 750 millimeters.
- The Sahel zone with the areas of the Inland Delta around Timbuktu has a semiarid desert climate, with annual rainfall between 150 and 300 millimeters distributed over three to four months.
- The Sahara or desert zone (north of the line between Timbuktu and Bourem): Apart of the Inland Delta is characterized by a desert climate (désertique), with less than 150 millimeters of annual rainfall distributed over the three summer months

14.3 HYDROLOGY

This hydrological section uses directly part of the hydrological characteristics of the Niger River basin written in Andersen et al., 2005. The Niger's hydrology is as extraordinary as its hydrography, undergoing remarkable changes in its hydrologic characteristics as it travels from its headwaters to the Gulf of Guinea. From a simple tropical system with abundant rainfall at its headwaters in the Upper Basin, the Niger moves northeast into the Inland Delta, losing both flow volume and velocity as it meanders near the Sahara. Then, as it flows southeast after the Niger Bend, inputs from other tributaries make up these losses little by little. After its confluence with the Benue, the Niger River continues as a large river to the Niger Delta. Unlike other major West African rivers, such as the Senegal and the Volta, the lower reaches of the Niger River are sustained during periods of low flow in the spring by the arrival of the waters from the previous summer's flood in the upper Basin. This phenomenon is known as the black flood in Niger. The annual flood in Nigeria, rich in sediment, is in phase with the summer rains and is known as the white flood.

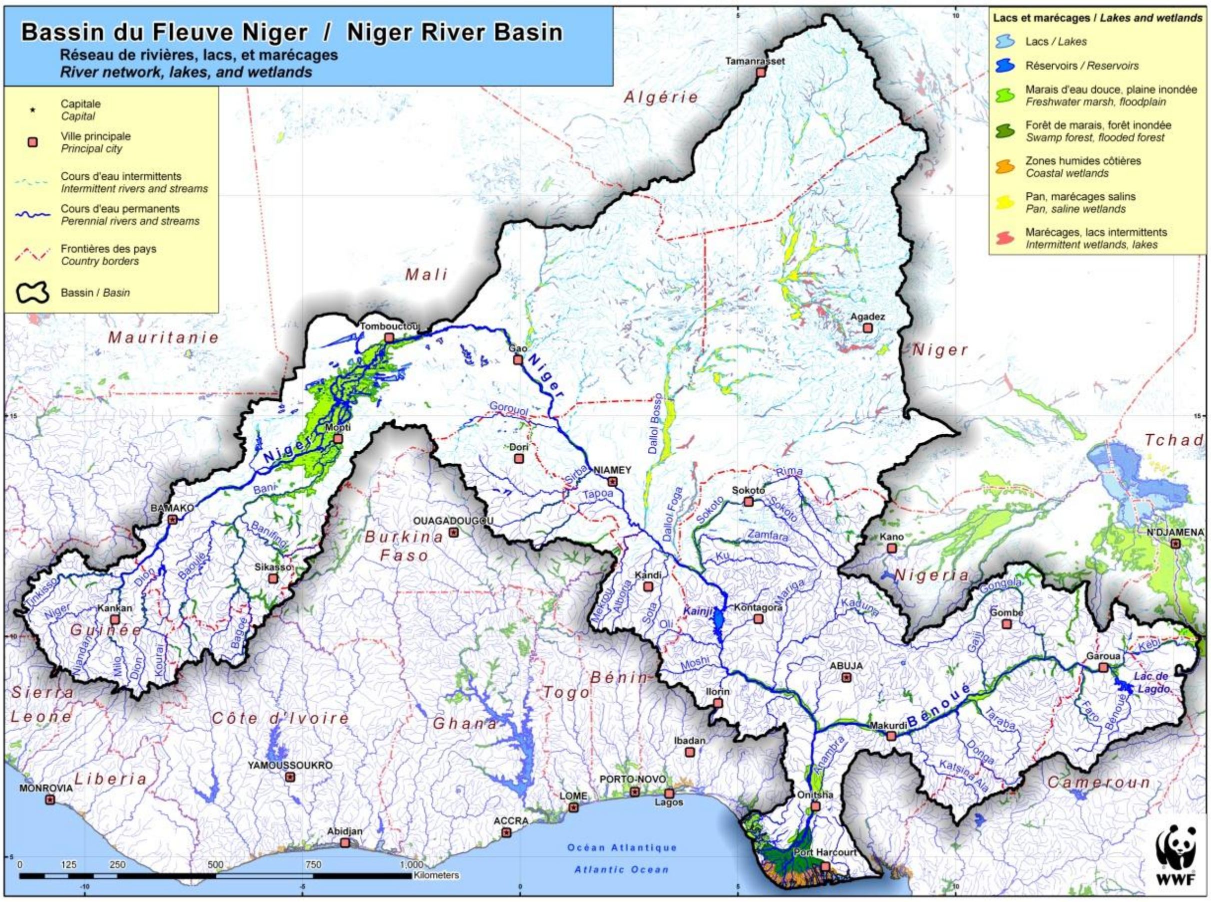


Figure 14-5 *Maps of river networks, lakes and wetlands in the Niger basin. Source: NBA et WWF, 2007*

Because of climatic variations, the annual river flood does not occur at the same time in different parts of the Basin. There are usually high flows from the headwaters in Guinea, a decrease in flow caused by evaporation and expansion in the floodplain of the Inland Delta, followed by an increase in flow from tributary input through the Middle and lower reaches as the river enters the Niger Delta. In the Upper Niger, the high-water discharges generally occur in September, and the low-water season is generally April–May. The Inland Delta has an estimated storage capacity of 70 cubic kilometers but has a high rate of loss caused by evaporation over the thousands of square kilometers of its floodplain. This loss is estimated at about 44 percent of the inflow. The peak flow period that arrives in September is delayed as it spreads out, exiting the Inland Delta three months later.

The Upper Niger Basin

The Upper Basin of the Niger River and the Bani Watershed contains four primary tributaries of comparable size: the Niger, referred to as the Djoliba (watershed of 18,600 square kilometers); the Niandan (12,700 square kilometers); the Milo (13,500 square kilometers); and the Tinkisso (19,800 square kilometers). The first three watersheds receive abundant rain, sometimes more than 2,000 millimeters per year at the headwaters; they are also steep, with high levels of mean annual runoff: 563 millimeters on the Milo, 531 millimeters on the Niandan, and 442 millimeters on the Niger at Kouroussa. Mean annual runoff for the Tinkisso at Ouaranin in the north, by contrast, drops to 244 millimeters. The Upper Basin above Siguiri has a surface area of 67,600 square kilometers and a mean annual flow of 948 cubic meters per second, equaling an annual runoff of 438 millimeters. Over the same 50-year period (1950–2000), the rain received by the watershed was 1,520 millimeters per year; the flow deficit is 1,082 millimeters, which can be attributed solely to actual evapotranspiration. The transitional Guinean Climate system explains the sustained flows observed from June to January, with several flood peaks and a maximum flow typically September–October; the low-flow season lasts only four months, with the lowest level April–May. The Niger River is joined by the Bani River, an important tributary, at the Inland Delta. The Bani is monitored at the Douna station (watershed of 101,600 square kilometers). Between 1953 and 1990, the mean annual flow was 419 cubic meters per second or a specific runoff flow of 4.12 liters per second per square kilometer, three times lower than that of the Upper Niger. The mean annual runoff was 130 millimeters, or 10.8 percent of mean rainfall of 1,200 millimeters. Although having a similar area to the Upper Niger above Koulikoro, the Bani watershed receives less rain and has much lower runoff. The Bani flow therefore represents only 11 percent to 41 percent of the total flow at Koulikoro, depending on the year.

The rainfall pattern over the Upper Niger and Bani watersheds creates a large seasonal variation in flows and monthly distribution of runoff in the watersheds, and causes significant variations between low-water and flood stages. Along the Niger, for six months (January through June) low flows represent less than 8 percent of the total annual flow. The increase in flow begins in May but does not become significant until July. The highest flood level generally occurs during the second half of September, a slight delay from the maximum rainfall in August. More than 80 percent of the annual flow is accounted for during August to November. The flood recession, rapid and rather regular, is characterized by two phases. The first phase corresponds to the depletion of surface water; the second phase, which is characterized by a rapid drop in base flow at the end of November, corresponds to the seasonal depletion of shallow aquifers. Both the Upper Niger River and the Bani River are subject to large annual floods (Rodier, 1964). Heavy rainfall, which is spatially limited, does not necessarily correspond to high annual flows, due to the large size of the watersheds.

The Inland Delta and Lakes District

The Inland Delta, with its system of lakes on both banks of the Niger River, is the result of the immense discharge from the Upper Niger Basin and Bani tributary. The Inland Delta covers approximately 40,000 square kilometers of which 20,000–30,000 square kilometers are floodplains. The hydrological characteristics of the Niger River's Inland Delta and lakes district are largely dependent on

- Exogenous runoff conditions, with most of the water resources coming from upstream areas with higher rainfall; and
- Morphological and climatological conditions specific to the Inland Delta, affecting runoff (water loss, flooding) and water balance (evaporation, infiltration).

A comparison of the average annual flows from Koulikoro to Tossay in three typical years (high, average, and low) enable to draw a synthetic water balance analysis. The year 1954 corresponds to a typical wet year, 1968 to an average year, and 1985 to a typical dry year. An assessment of these flows shows that runoff, monitored at the entry of Diaka and after the Bani confluence at Mopti, had already lost about 18 percent (during a wet year), 14 percent (during an average year), and 6 percent (during a dry year) of its initial contribution. The losses were even more significant when the flooded area increased, with greater inflows from secondary tributaries. In relation to input from the Upper Niger at Ké Macina and the Bani at Douna, the flows at Diré, at the downstream end of the Inland Delta, show a loss within the delta of about 47 percent (a wet year), 37 percent (an average year), and 32 percent (a dry year).

The Inland Delta is then characterized by a high rate of loss caused by evaporation over the thousands of square kilometers of its floodplains. This loss, estimated at about 44 percent of the inflow, constitutes an important source of evaporation in West Africa. An assessment of annual volume losses shows that they can reach 25 cubic kilometers between entry into the Inland Delta and the outlet at Diré for a wet period, and 7 cubic kilometers for a dry period, corresponding to a ratio of 14 to 4. Another characteristic of Inland Delta hydrology is the cushion it provides during the annual floods by slowing the pace of the flow, which spreads out in both space and time. The larger the flood, the more the flow spreads out over the space of the floodplain, and the longer it takes to spread out over time, with maximum decreases in flow downstream appearing later in the season. In general, the peak flow period that arrives in September is delayed as it spreads, exiting the Delta three months later. A phase of receding water extends into February. The downstream impact of flooding on the Middle Niger is such that during a dry year the maximum flow arrives in Niamey in mid-December, whereas in a wet year the maximum flow is not seen until the end of January or early February.

14.4 GEOLOGY

This geological section uses directly part of the characteristics of the Niger River basin described and written in Andersen et al., 2005. In Mali and particularly in the Inner Niger Delta, the investigations launched to sound the geological characteristics are still insufficient to assess with details the groundwater resources. Among all initiatives (USDA, PIRT, IRD, HSM, etc.), the last updated work is certainly from BRGM that completed in 2008 a hydrogeological map of the entire river basin (Cf. Annex). The figure below shows a regional estimation of the groundwater recharge in mm/year from BRGM which follow respectively the rainfall gradient in the Upper Niger Basin and the Inner Niger Delta:

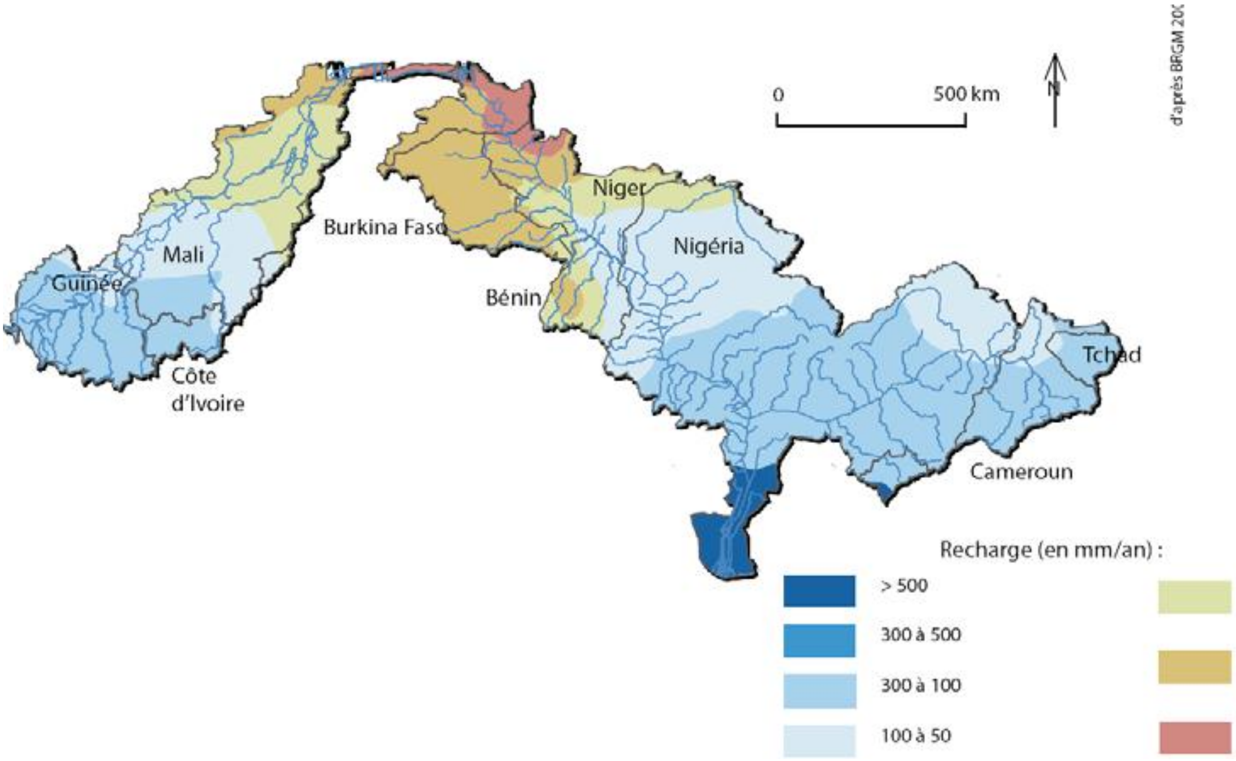


Figure 14-6 Groundwater recharge map from Séguin, 2008, BRGM in Clanet, Jean-Charles, and Andrew Ogilvie. 2009. Synthesis Report. CPWF Working Paper. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.

With the current information given at the regional scale, we can state that the groundwater base flow heavily influences the Niger River, with dry season contributions primarily within the alluvial plains. In general, groundwater tables are affected by annual rainfall and soil permeability. Groundwater is extremely important for potable water supply (which is of excellent quality in most cases exception made for Bamako) for both urban and rural settlements. Several international and bilateral donors and nongovernmental organizations have financed research and development work on small aquifers and village water systems, although more needs to be done to understand the hydrodynamics of the aquifers in the Basin. The Basin’s geology ranges from ancient Archean formations to recent alluvial deposits, each with its own hydrogeologic potential in the Basin’s different hydrographic regions.

An ancient geologic landscape of crystalline rocks characterizes the upstream area of the Upper Niger Basin and most of the river’s right bank. Groundwater occurrence is very limited in these rocks, which are generally impermeable except where they have been fractured or are weathered, which creates small aquifer zones. Groundwater replenishment from the headwaters is therefore generally very low as it is detailed in the various geological formations encountered I the Upper Niger and Inner Niger Delta zone:

An Archean base of granite, gneiss, and mica schist is found in the Guinean section of the Basin, northern Côte d’Ivoire, southwest Mali, most of Burkina Faso, and northern Benin, with a few basic intrusions (dolerite and gabbros) in Guinea at the Fomi site, and in Niger near Tillabery.An Archean base of granite, gneiss, and mica schist is found in the Guinean section of the Basin, northern Côte d’Ivoire, southwest Mali, most of Burkina Faso, and northern Benin, with a few basic intrusions (dolerite and gabbros) in Guinea at the Fomi site, and in Niger near Tillabery. Middle and Early Precambrian schist and quartzite appear in the lower valleys of the Niger tributaries in Guinea and Mali, in the tributaries of the Bani in Côte d’Ivoire and Burkina Faso, and southeast of the Niger Bend in Bourem, Gao, Ansongo, and in the Niamey Valley. Cambrian schist and sandstone extend from Bamako to Sikasso. Ordovician sandstone-quartzite and various sandstones are found in the Dogon region, on the Mandingue Plateau, and on all the plateaus between Koulikoro, Koutiala, and Bandiagara. Downstream of Koulikoro in the Inland Delta, north of Segou, and also in the Gondo depression east of the Dogon region, Quaternary and recent deposits mask the substratum and, in particular, the Eocene to Pliocene Continental Terminal. These recent deposits are either alluvial or dunelike Holocene ergs, with groundwater aquifers linked to the waterways. The Continental Terminal is a continuous stratum aquifer composed of claylike sandstone, sand, and clays, with good water quality. It appears on the left bank of the Niger at Goundam, Timbuktu, and Gourma Rharous, then continues through Bourem and Gao to Niamey and Gaya, with an extension north inclusive of the sedimentary basins of Taoudenni, the Azaouâd, the Tilemsi, and the Azaouâk. The Continental Terminal aquifer is the most significant aquifer in the Basin and is widely used, particularly in Niger. The stratum is immense: It is not unusual to see aquifer thicknesses of over 100 meters extending over tens of thousands of square kilometers. Underneath the Continental Terminal and the Eocene and Cretaceous layers of these sedimentary basins lies the Continental Shale Band aquifer, which borders the Niger River just north of Benin but is also present in the semiarid area of Mali and Niger. This aquifer has abundant groundwater, but is generally of poorer quality than that of the Continental Terminal.

14.5 SOILS

This pedological section uses directly part of the soil characteristics of the Niger River basin described and written in Picouet, 1999, Marie et al. 2007 and Andersen et al., 2005.

The three major soil types of the Niger River Basin, according to the French soil nomenclature (World Bank 1986), are ferralitic soils, tropical ferruginous soils, and hydromorphic soils. The characteristics of these three types of soils determine the nature of agricultural productivity in the Basin. As a result, agricultural development varies in the Basin with the geographic distribution of the specific soil. The characteristics for the main soil type encountered are described below:

- Ferralitic soils are seen in the extreme west of the Guinean basin of the Niger, in the south of the Bani watershed, in the north of Benin, and in the major part of the Niger River Basin in Nigeria, including the Benue watershed. These are thick soils (from 3 to more than 10 meters thick), where geochemical changes are extensive and spread over many millions of years.
- Hardened lateritic layers can be seen on the surface or at short depths on top of a mix of the ferralitic and ferruginous soils; they are found in particular in Guinea and in southern Mali. This concreted and hardened horizontal layer results from an upward migration of ferrous oxides and from their precipitation. Limited spots of tropical brown soil or tropical black clay (vertisols) can also be found.

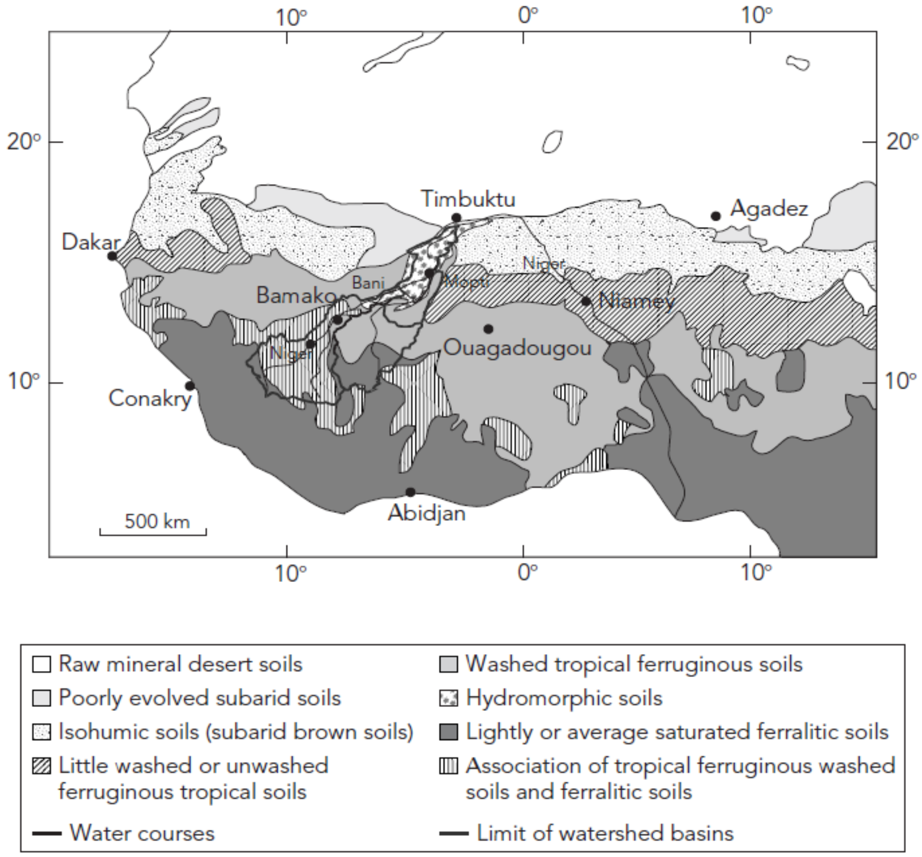


Figure 14-7 *Schematic maps of West African Soils World Bank 1986 modified by Picouet, 1999 in Andersen, 2005*

- Bleached layers of ferruginous tropical soils are seen in the north of the Bani watershed, on the periphery of the Inland Delta in Mali, in the east of Burkina Faso, and along the northern part of the Niger River Basin and Benue watershed in Nigeria and Cameroon. They are associated with ferralitic soils in the Upper Niger River Basin upstream of Bamako and in the Kaduna watershed in Nigeria. Alternating dry and wet seasons, characteristic of the watershed's climate, have caused discontinuous changes in the rock over time. The changing layers have a variable thickness but are always less than 3 meters deep.
- Hydromorphic soils, linked to the presence of a temporary or permanent aquifer that is close to the surface, can be found in lake basins, riverbeds, and low clay plains. Almost all of the soils in the Niger's Inland Delta are of this type; 74 percent are flooded every season in the active Inland Delta

In Mali, on the whole, declining soil fertility is one of the single most important factors inhibiting crop production. Generally speaking, demographic pressure (entailing shorter fallow spells), as well as water and wind erosion, are the causes. However, erosion phenomena, when they occur, often only shift soil fertility without much consequence otherwise. In the Niger River's inland delta in particular, an *in situ* combination of the ecosystem's natural processes and of related traditional production systems (livestock farming in particular) support soil fertility. However, the sediments that the river brings from its upstream basin (in moderate, yet not negligible, quantities) supplement this fertility (all the more so as its generous swells bring considerable flooding). In large irrigated areas (such as *Office du Niger* areas), soil fertility is not only affected by an increase in alkalinity, but also by a drop in organic and mineral fertility (potassium), which is starting to have a perceptible impact, especially in the area of Massina. Soil salinisation is also an issue in these areas, but an in-depth understanding of this phenomenon and its associated risk factors enables authorities to contain it more efficiently. Some risk factors, however, are intensifying. These follow:

- extending crop areas and shrinking water availability curb leaching;
- ongoing irrigation-canal use to feed off-season crops helps refill and raise water tables, which in turn promotes salt concentration on the surface;
- a proliferation of cursory schemes (poor sloping and drainage).

14.6 LAND COVER/LAND USE

Land cover

Along its course, the Niger River traverses almost all the possible ecosystem zones in West Africa. The Niger River's headwaters are located at an altitude of 800 meters, at the fringes of the Guinean moist forests. The river then passes through woody savannas and areas of sedge vegetation. At the western edge of the Inland Delta is a short-grass savanna, with thorny shrubs and acacia wood, followed by a region of tussocky grass interspersed with dense wooded vegetation. The eastern Inland Delta is made up of Sudano-Sahelian flooded grasslands and a labyrinth of 50,000 to 80,000 square kilometers of wetlands and lakes. The floodplains are pastures of bourgou grass that support livestock, wildlife, and fish nurseries. In the wetlands, flora have adapted to extreme fluctuations in water levels. At the Niger Bend, the river reaches the fringes of the desert. The high rainforest belt begins farther south, at Onitsha. This belt merges below Aboh, in Nigeria, with mangrove forests and swamp vegetation in the Niger Delta. (paragraph based on NBA et WWF, 2007)

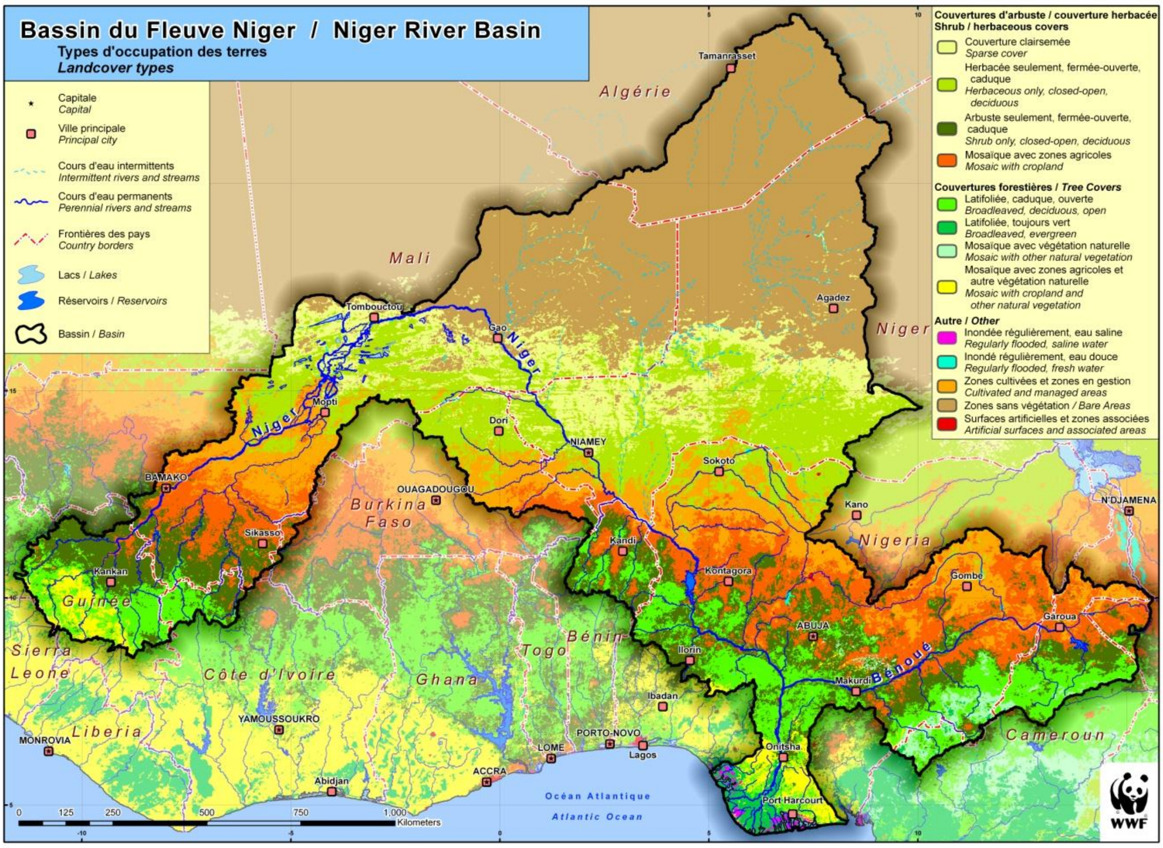


Figure 14-8 *Land cover map Source: NBA et WWF, 2007*

Agricultural land use and productivity (based on Marie et al., 2007)

Cotton is Mali's second foreign-currency earner after gold (612,000 t a year in 2003/2004). Much of it grows in the Niger River's basin, south of a line between Bamako, Segu and San. This cotton area spans the Bani, Baoule and Sankarani tributary basins. Farming, to some extent, can be described as intensive, and fertilizers and pesticides are commonplace. In Mali, cotton is a rain-fed crop. Mali's cereal production has risen from 1,032,000 t. a year (the 1961- 1966 average) to about 2,707,000 t a year (the 1998-2003 average). Production stagnated for a time, but has been growing a healthy 5% a year – comfortably ahead of the population since the 1980s. Outside badweather years (such as 2004), Mali can typically cover more than 100% of its food requirements. Cereal production originally increased in step with the amount of land used to farm it, which has stretched from 1,384,000 ha (the 1961-1966 average) to 2,636,000 ha (the 1998-2003 average). Early attempts at intensive farming subsequently increased yields somewhat. Corn yields rose 49% and rice yields 100%. Millet and sorghum yields, conversely, did not increase markedly. Rice production was subsidiary until the early 1980s, but has since grown to rank alongside millet as Mali's leading crop. Most of that rice is grown by the Niger or tributary rivers. A growing portion of the food grown in Mali, it arguably follows, comes from the Niger River. Rice has become more prominent for two reasons: because rice-farming areas have been growing regularly since the early 1980s and because average yields have grown concomitantly (from 1 t to 2 t/ha). Rice production idled below 200,000 t a year for a fairly long time, but now invariably reaches at least 700,000 t a year (and peaked at a record-breaking 900,000 t in 2001).

Rice consumption is higher in cities than in the country, and will plausibly grow in years to come all the more so as yields still offer considerable room for improvement (the most productive systems produce six tons or more per hectare, the least productive ones less than one ton per hectare).

Mali counts three distinct rice-growing systems. Their relative share in total output and the amount of land they use vary considerably. These systems follow:

- river-fed and rain-fed systems are specific to the river valley and, especially, to the inland delta;
- controlled submersion;
- full water control (the only ones that can be described as irrigated).

Agricultural seasonality (based on Dixon et Holt, 2010)

The seasonal calendar below shows the main agricultural and livestock-related activities that make up the agropastoral year in the Inner Niger Delta:

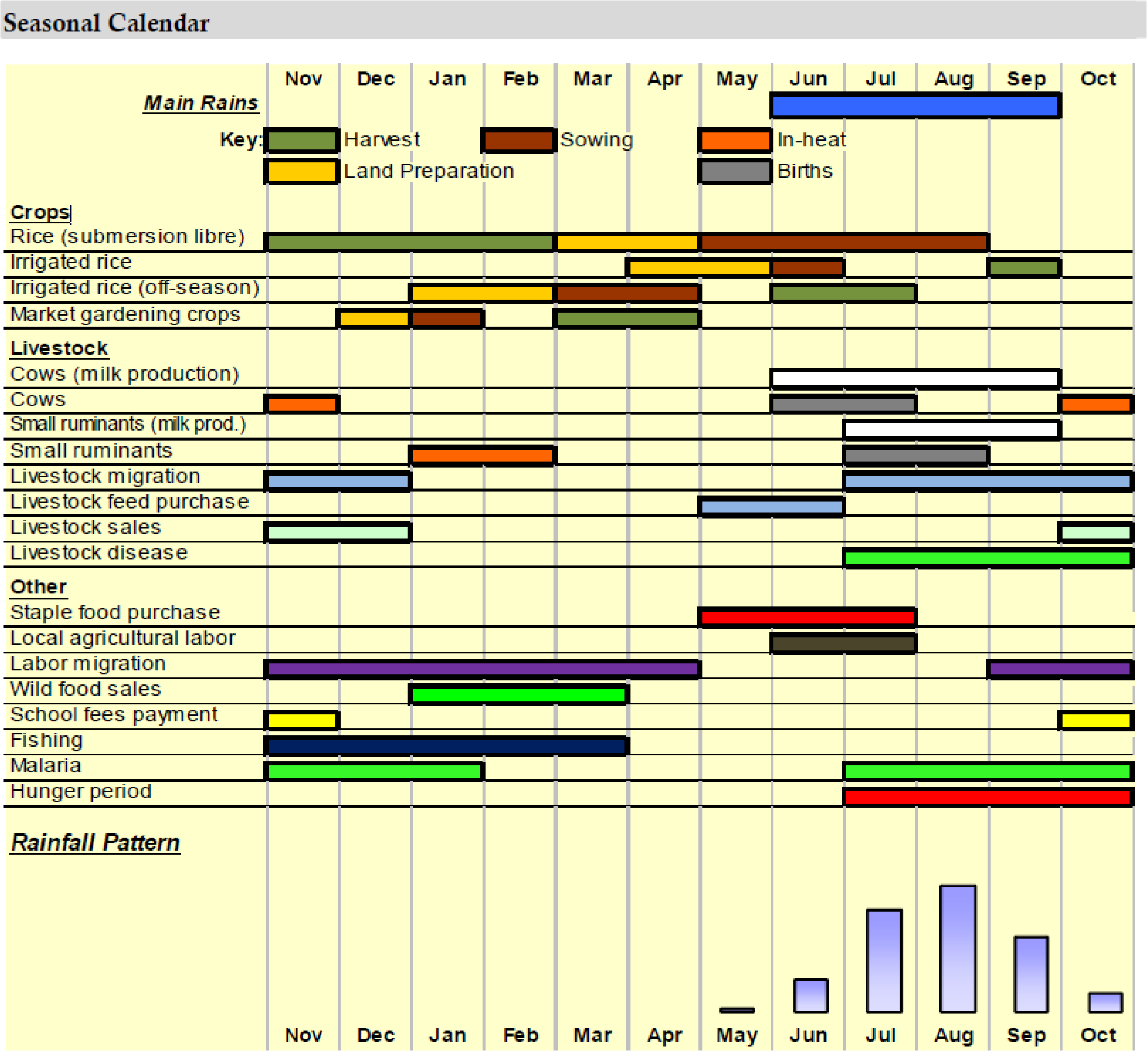


Figure 14-9*USAID Seasonal Calendar for the Inner Niger Delta Source: Dixon et Holt, 2010*

There are three main periods:

- The hunger season runs from July to October until just after the end of the rains in September. These are the hardest months of the year, particularly for the poorest households whose harvests have long since run out and for whom cash is scarce. Malaria is also at its peak during this period and can prevent able-bodied householders from working and necessitate extra expenditure on medication at the leanest time of year. The disease is particularly a problem in this zone and high incidence of malaria continues until January. From September, some able-bodied householders migrate in search of labor, often in large towns or abroad; some also find work in parts of zone 4 (for example in Bankass and Koro) where labor is required for the millet harvest. Poorer households may also sell cowpats in these months, which are used for fuel. In terms of livestock, these are the peak months of milk production, following the new births from June to August and the improvement in pastures that comes with the rains. (Small ruminants can also give birth from January-February, but July-August is more common). Livestock start leaving the delta from July to take advantage of pastures. The last animals leave by the end of August, to return to the delta from January, when pastures elsewhere have dried up. Livestock sales are at their peak from October to December when the condition of animals is good; this gives the wealthier households, who sell the most livestock, a boost in income from October, a month before the end of the of the hunger season. It is worth noting that the poor may be forced to sell their livestock earlier and are thus less likely to benefit from these good prices.

- The main rice harvest from November to February marks the end of the hunger period and the beginning of the new consumption year. Livestock also start to return to the delta at this time and wild foods (such as jujube) are collected and sold by poorer households.
- The period from March to June is the hottest time of the year. Market gardening crops are harvested from March to April and provide an important source of cash for poorer households, becoming available as they start to have used up their rice harvest. March to June are the most difficult months for livestock as pasture becomes increasingly scarce. Animals are in their worst condition and those who can afford it buy livestock feed, particularly in May and June. Most seasonal migrants also return in time for the rains and to sow the next year's rice crop.

14.7 NATURAL RESSOURCES: BIODIVERSITY AND HABITATS

The Niger River system sustains an extensive biological community, hosting diverse ecosystems that harbor numbers of species of freshwater fish partly endemic to Africa. Species in the river range from West African manatees and hippopotamuses to crocodiles. There is a rich collection of transmigratory birds found in the Inland Delta, among them black crowned cranes, herons, egrets, and storks; pelicans and flamingos are found in the upper Benue.

On February 1, 2004, the Inner Delta was designated by the State of Mali as an internationally important wetland or Ramsar site, the third largest Ramsar site in the world (4,119,450 ha). The Inner Delta, a vast alluvial plain, is made up of a mosaic of biotopes subject to strong seasonal and inter-annual variations, what gives to the area exceptional halieutic productivity. The very productive vegetation of the Delta is a source of life within the flood plains ecosystem. The Niger River's inland delta harbors a wide variety of wetland habitats (marshes, lakes, ponds, flooding plains and flooding forests). Fish, reptile, mammal and water-bird colonies find food and suitable breeding conditions in these habitats. Some colonies live here throughout the year; others only stay for a season. The floating bourgou fields are critical as growth areas for alevins, ensuring for them both protection and food.

Beside its ecological value, the bourgou has a huge economic importance for the fishing and agriculture sectors. The area with a high biodiversity value supports two of the most important colonies to date of herons and nesting cormorants in Africa. Besides, the Delta supports 3 to 4 million of migratory water birds, both resident and migratory, coming from Europe and Asia. The Niger Delta also includes an extensive mangrove forest, crucial for hosting waterbirds nestings. For the halieutic resources, Daget (1954) argues that there are between 130 and 140 species in the Upper Niger and its inland delta. However, half of those species are relatively unknown because they cannot really count for fish resources (human consumption). Although subject to a strong human pressure, the aquatic fauna, notably hippos, the West Africa manatee are still there. (paragraph based on Zwarts et al., 2005)

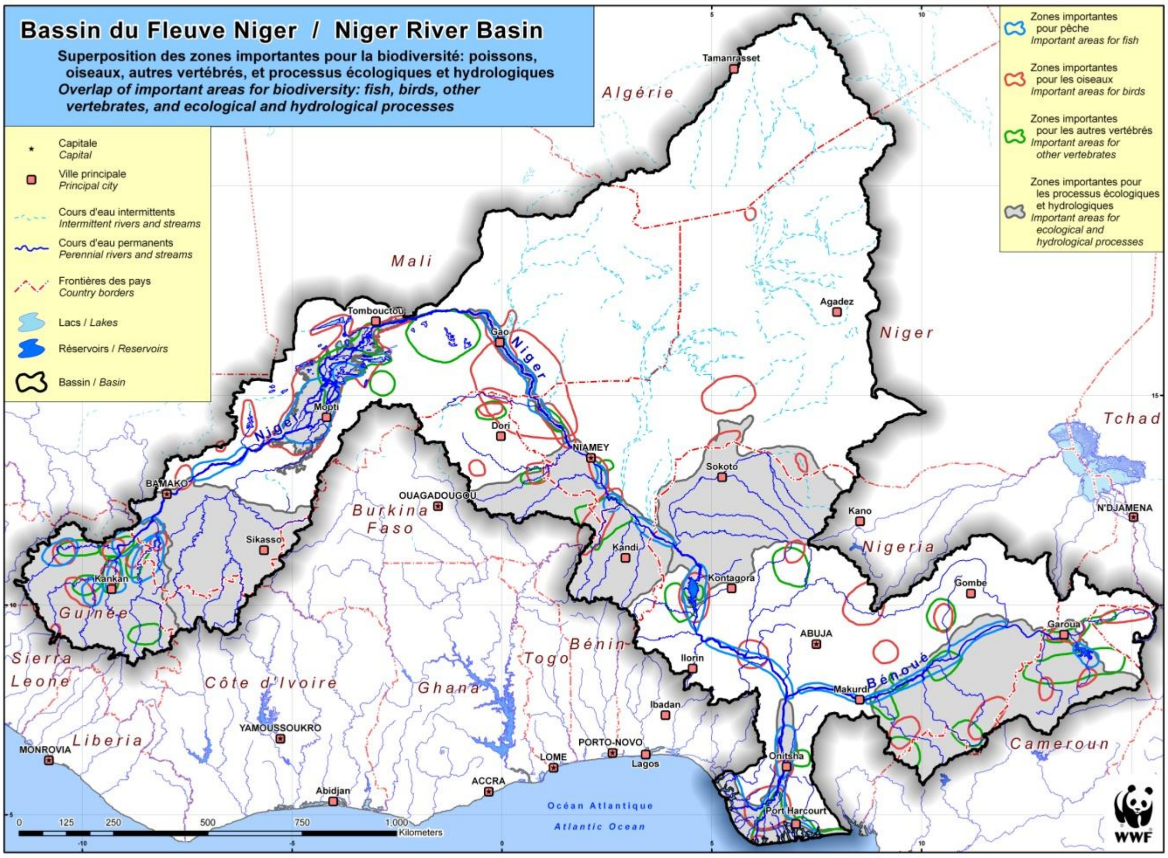


Figure 14-10 *Maps overlapping important zones for biodiversity in the Niger basin. Source: NBA et WWF, 2007*

The delta's forests (Marie et al., 2007)

According to the Wood Resource Inventory Project, forest stands cover 4.5 million ha across Mopti, and plantations and fallow land span 1.8 million ha. Sparse shrub savannas and a variety of palm stands make up the bulk of those areas. Different thicket varieties are part of the landscape as well. The inland delta and north-western Farimaké plains count three different stand families:

- flooded Acacia kirkii forests withstanding 4-metre-deep water. These forests span 5,000 ha and play a critical role in water-bird reproduction;

- Acacia nilotica and Acacia seyal forests, mainly watered by percolation, but sometimes secondarily watered by swells (water levels do not exceed 0.6 m). These forests span 115,000 ha;
- dry woodlands growing on mounds or skirting the delta, spanning 425,000 ha. South of this area, we can also find park-type stands made up mainly of Faidherbia albida, a tree that also grows on the sandy savannah benches along with Andropogon gayanus and surrounding rice paddies.

There have been no surveys into changes in the inland delta's vegetation in general or into its forests in particular. Observers agree that the forests have been facing serious threats for the last three decades, due to the compounded effects of the drought, scant flooding since the late 1970s, and anthropogenic pressure on resources. The survey suggests that forests in the Mopti region could produce 1.8 million tons of energy wood a year (i.e. that forests could export that much wood a year without damaging their "capital"). The Mopti region's total energy-wood stock, estimates suggest, totals 40 million m^3 (including 3.5 million of deadwood).

The delta's grasslands (Marie et al., 2007)

Most of the inland delta's plant formations are grasslands, encompassing grassland savannahs and aquatic prairies proving exceptionally rich pastures.

Varieties include the following:

- *bourgoutières* (floating grass). This grass grows on plains withstanding 4 to 5 m of water a year, but only survives the deep-water submersion if the water levels rise slowly. These are the delta's most productive courses (20 t/ha) and span about 160 000 ha;
- *vétiveraies* cover about 30% of the delta (640,000 ha). Their average production varies from 10 to 12 t/ha, depending on environmental conditions;
- *wild rice paddies* cover 15.4% of the delta (about 340,000 ha) and produce between 6 and 8 t/ha;
- *eragrostaies* cover 190,000 ha. Their grazing value varies between 5 and 8 t/ha;
- very low-flooding varieties *(andropogoneae*, *panicaie,* etc.) covering about 200,000 ha and producing around 5 t/ha.

The model DELMAISG developed to study how the inland delta's grasslands have grown in relation to poor flooding delivers crucial results to understand the consequences of drought and low flooding pattern in the Inner Niger Delta to biodiversity maintenance and pastureland.

To conclude this section, many economic activities undertaken in the basin depend directly on the exploitation of natural resources. In addition to hydraulic developments and works, extensive or small-scale farming, pastoral and mining activities in particular are practiced. In this respect, the rural economy depends largely on the environment. Forests are cleared at a higher speed, particularly in the Upper Niger, the Niger Delta and the Lower Niger-Bénoué, than required for natural regeneration and the degraded environments provide fewer resources to the poor whose number is growing day by day. The hydrological and related ecological conditions in the Inner Delta largely determine the population size and the potential regeneration of habitats. Combined with climate change, the upstream water management with the construction of new dams and the extension of irrigations schemes indirectly imply that the last large breeding colonies of cormorants, ibises, herons and egrets in West Africa could be pushed to the edge of existence. (paragraph based on NBA et WWF, 2007)

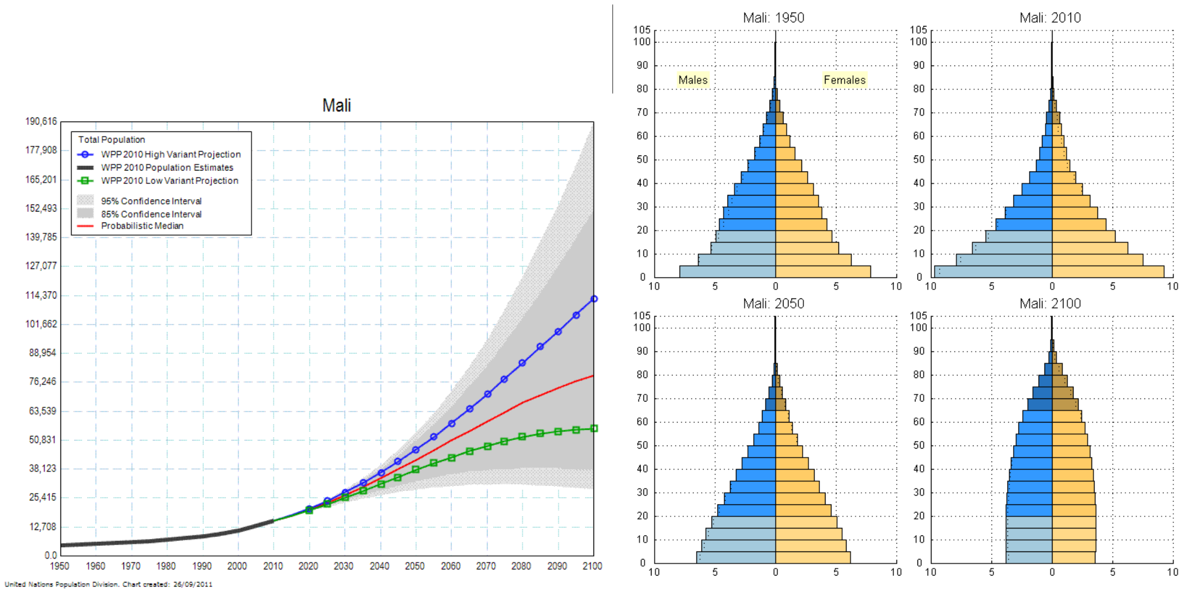
14.8 DEMOGRAPHY PRESSURE AND FOOD/ENERGY REQUIREMENTS

Demographic characteristics

This paragraph is extracted from Marie et al. 2007 based on the Mali 2025 National Outlook Study. Mali's 9.8 million inhabitants are spread unevenly. In 1987, 65% of the population lived on 25% of the land (in the south). This worsened in 1998, when only 30% of the territory was home to 91% of the resident population. Mali's average population density grew from 6.2 inhabitants per km^2 in 1987 to 7.9 inhabitants per km^2 in 1998, with sharp contrasts from one region to another. The Timbuktu region, for instance, counts less than 1 inhabitant per km^2. Segu, on the other hand, counted 25.9 inhabitants per km^2 in 1998. Lastly, the rate of natural increase stood at 3.7% between 1976 and 1987, and remained above the 3% mark from 1987 to 1998. This is high: excluding migration, it means that the population is doubling every 24 years. Extensive emigration, however, relieves some of the pressure and puts Mali's population increase in a relatively moderate bracket. The resident population only increased 1.8% a year on average from 1976 to 1987, and 2.3% from 1987 to 1998. The average annual increase over this last period was contrasted: the urban population rose 4.5% but the rural population only 1.2%. Different scenarios suggest that Mali will count between 16 and 20 million inhabitants in 2025. The rural population should shrink from 73% today to only 51% of the total (i.e. to about 9 million). Bamako should see the sharpest surge (its population should double). Other cities in northern Mali should see sharp population increases as well. However, in absolute terms, population concentration should be the highest in and around Bamako and Segu-Mopti (which will count 2.9 million and 2.4 million inhabitants respectively). This Bamako-Segu-Mopti triangle, in other words, will be home to three-quarters of Mali's urban population. Also, the consequences of economic imbalances and of the environmental degradation are thus felt notably through (i) the attraction of rural populations towards cities, what leads to an urbanized lifestyle based essentially on the resources of the rural area; (ii) an increase of the urban population and a strong demand in energy which is generally met through the use of wood and charcoal, thus contributing to the degradation of the plant cover and the soil erosion of the exploitation areas.

Population growth scenario

The two figures below present the 2010 to 2100 projection for the population growth and it pyramidal structure in Mali according to UN- Population Division. The first chart shows estimates and projections of the total population for Mali in 2010. The projections are based on the probabilistic fertility projections from the 2010 Revision of the World Population Prospects. These probabilistic projections of total fertility had been carried out with a Bayesian Hierarchical Model. The figures display the high, medium and low variant of the 2010 Revision of the World Population Prospects, as well as the probabilistic median and the 95 as well as 80 percent confidence intervals of the projections. In the second chart, the population by age groups and sex (percentage of total population in Mali is presented in four periods (past, present and two projected. The dotted line indicates the excess male or female population in certain age groups. Age groups are in percent of the total population in 1950, 2010, 2050 and 2100, respectively.



United Nations Population Division. Chart created: 26/09/2011

Figure 14-11 *and Figure* 14-12 *: UN Division population 2010 projections: evolution of the population structure and growth in Mali*

Source Left Chart: United Nations, Department of Economic and Social Affairs, Population Division (2010): Population projections using probabilistic projections of total fertility and life expectancy at birth, based on a Bayesian Hierarchical Model (BHM). New York (internal data set)

Source Right Chart: United Nations, Department of Economic and Social Affairs, Population Division (2011): World Population Prospects: The 2010 Revision. New York

The figure below is the result of a work achieved in the Niger Basin Focal Project. The maps represent the correlated population density dynamic in the Niger River Basin according to the low variant of the UN Population Division 2010 above scenario.

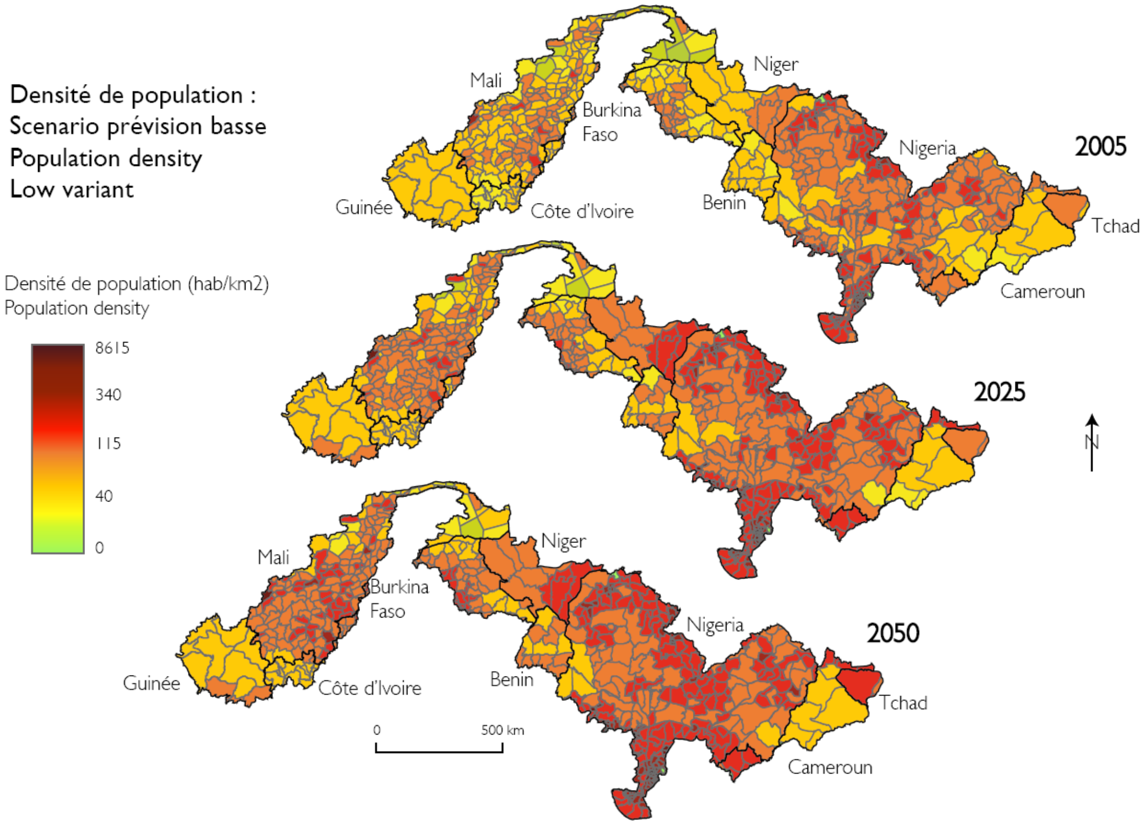


Figure 14-13 *population density Low variant UN Division population 2010 projection Source: Clanet, Jean-Charles, and Andrew Ogilvie. 2009. Synthesis Report. CPWF Working Paper. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.*

Population growth and Food security (Marie et al., 2007)

Malians consume cereal mainly (204 kg per person and per year), along with limited amounts of meat, fish and vegetables. City dwellers consume a little less cereal (180 kg per person and per year) but more meat, fish and vegetables than the average (the population is still predominantly rural). By 2025, Mali will have to produce between four and five million tons of cereal a year to keep up with its growing population. With the exception of cereal ("only" 40% of which will be consumed in cities), urban markets will absorb the biggest share of the fish, meat, fruit and vegetable production in 2025 (55 to 75%, compared to less than half in 1995). Consumption of domestically-produced food in cities is expected to rise 3.5 times faster than that in rural environments over the period from 1995 to 2025. Cereal, fish, fruit, vegetable and red-meat production, it follows, will have to double – or triple – by 2025. Farming more land will not be enough. Improving yields, it follows, is the key.

Population growth and energy (Marie et al., 2007)

Traditional sources of energy (wood and charcoal, basically) are still predominant (accounting for about 90% of the total). Vehicle fuel and household gas also account for fairly significant portions of Mali’s energy consumption. Electric power – i.e. the source of energy that has a direct relationship with river management – is still relatively marginal, but growing fast. Power production and consumption are evolving pretty much in tandem, making Mali practically self-sufficient in electric power. It neither imported nor exported electricity until 2002. This has since changed: Mali is not exporting power from a balance-of-trade angle, but nonetheless supplying Senegal and Mauritania from Manantali. The National Outlook Study (NOS, 2003) states that power production grew 4.8 times from 1980 to 2002, i.e. 6.99% a year on average. This growth outruns the overall population increase (1.8% a year) and urban population growth rates (4.5% a year) – as electricity networks only cover cities at this point. But it is important to point out that the network only reached large cities in the 1980s, but has since stretched to encompass a growing number of medium-sized and even small towns (26 towns had electricity in 2002). In other words, the number of consumers is growing faster than the urban population. For example, 66,000 people were using network electricity in 1995 and 102,000 were doing so in 2001. The annual growth rate here, 7.25%, is similar to the increase in power generation. According to this same study, Mali’s urban population should continue to increase at 4.5% a year to 9.15 million people in 2025 (up from 3.2 million in 2002). Plans to hook up every city with more than 20,000 inhabitants and a number of cities counting fewer (93 cities in total) should put the total covered population at 8.4 million inhabitants (44% of the country’s total).´As a point of comparison, there were 1.75 million inhabitants (i.e. 16.5% of the total population) in the 26 connected cities in 2002. So it makes sense to say that power consumption will grow at the same pace as it has been growing over the past two decades (6.5% to 7% a year) over the two decades to come. This growth rate suggests that effective power consumption will swell fourfold to fivefold, from 0.43 terawatt-hours in 2003 to about 2.00 terawatt-hours in 2025.

14.9 INFRASTRUCTURES

This section uses directly part of the catchment characteristics of the Niger River basin described and written in Zwarts et al. 2005 and Hassane et al. 2002. Compared to other large rivers around the world, it is fair to say that the Niger is still fairly untapped. This is especially true in the case of its upper and middle reaches. There are only three consequent dams between the springs and Niamey: Selingue, Sotuba and Markala (in that order, downstream). They are all in Mali but vary somewhat in size.

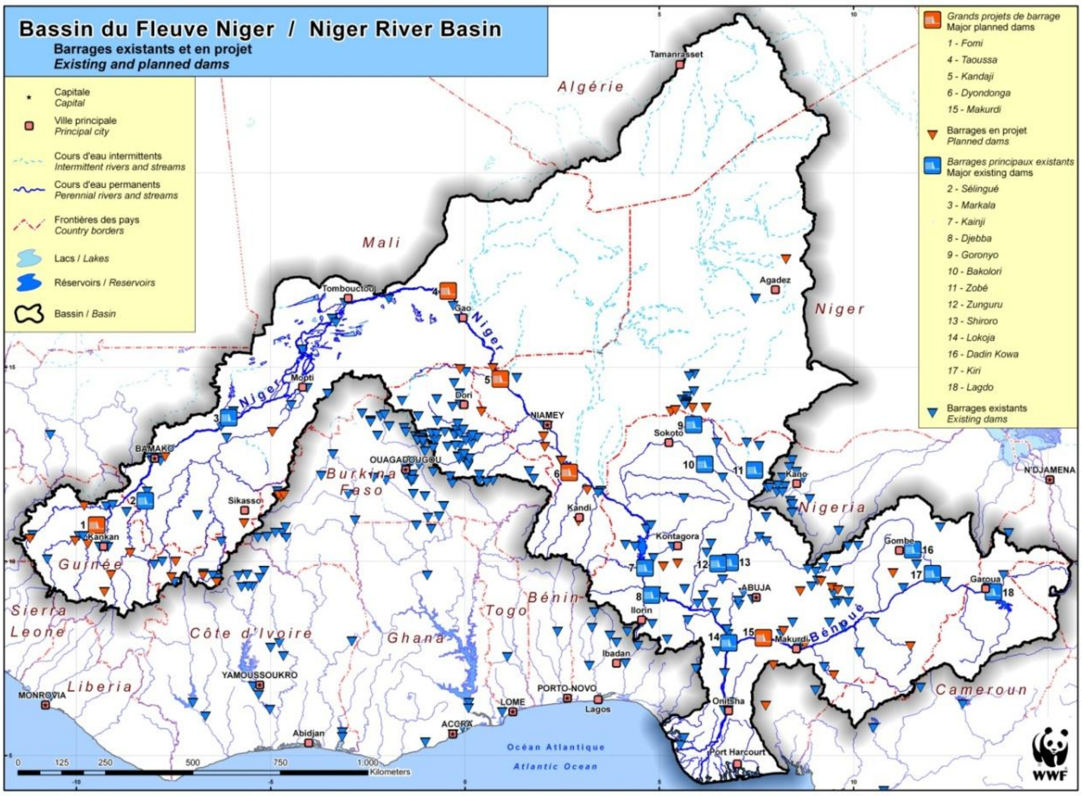


Figure 14-14 *Existing and planned dams. Source: NBA et WWF, 2007*

Selingue

Selingue is on the Sankarani, one of the Niger River's tributaries, about 60 km from the junction, 150 km upstream of Bamako. It has regulated the Niger River's flow to some extent since 1982. It is an earth dam. Its two sections measure 600 m in total and nestle the eight 13 x 5 m^2 overflow flaps that make up the weir and the central 14 x 11 m^2 valve. This weir is designed to discharge a one-in-a-thousand-year flood, estimated at 3,500 m^3/s. Four 11.9-MW Kaplan turbines in the power station generate electricity. An irrigation valve diverts water to the 1,500 ha for people displaced by the dam (Selingue, however, only deflects very small quantities of water for irrigation). The impoundment area spans two river valleys (65 km long each). When the impoundment lake is full (i.e. when it reaches the 348.5-meter mark in late September every year), it holds 2.63 billion m^3 of water and covers 430 km^2.

Selingue dam remains full for a few weeks between late July and 20 September, thanks to the natural annual flood. Then it starts releasing water and feeding its turbines to generate electricity and regulate the flow downstream. This lasts from January to June. The impoundment lake is practically empty (below 10% of full capacity) in early July. So, from an annual perspective, this dam's impact on downstream flow is simple to describe: it regulates water levels, smoothing swells and compensating lulls. Selingue is indeed the only dam that can do the latter, supplying water to the Office du Niger scheme at the end of the dry season and supplying Niamey (which is nonetheless 1,500 km downstream).

Administrators are intent on this dam's lull-counterbalancing role. In particular, they have specified the need to keep the minimum level at 60 cm in Koulikoro and to guarantee a 40 m^3/s flow downstream from Markala. How filling the impoundment affects the Sankarani River's flow (and hence the Niger's flow downstream), conversely, has received little attention.

Estimates suggest that Selingue diverts about 400 m^3/s from the flow peak (which would otherwise feed into the Niger). Filling about 2 billion m^3 in eight weeks involves diverting about 413 m^3/s on average during that period of time. It is also worth pointing out that this filling (diverting) phase lasts throughout the Sankarani's natural swell (peak included), as it stretches on to 20 September.

Sotuba

A very small hydropower plant is located in the Niger, directly downstream from Bamako at Sotuba. The dam was built in 1929, but the run-of-river power plant is operational since 1960. It has a capacity of 5.2 MW. The estimated head between intake and outlet is 4 meters. The plant can pass a maximum of 60 m^3/s and is able to continue to work at a minimum discharge in the river of 95 m^3/s. The structure itself is not important for this study as it has no important storage volume and as such does hardly have any impact on the hydrology of the Niger River. However, the same canal that feeds the plant also feeds a canal for irrigation that is able to pass 10 m^3/s with a minimum river level of 316 meters, but because of the power production, the maximum amount of water diverted for irrigation is 6.37 m^3/s. The water is used to irrigate the area of Baguinéda (3500 ha). The average intake is 0.215 km^3 per year.

Markala

This run-of-river dam stands some 250 km down the Niger from Bamako, and has been operating since 1947. Its 1,813-meter-long wall and 816-meter-long dam housing multiple-position collapsible spillway gates hold a lake during low-water periods and disappears completely during medium- and high-water periods. Its diversion valve feeds a lake that irrigates nearby Office du Niger schemes by gravity.

The channels emerging left of the pond comprise the feeder channel (designed to carry 200 m^3/s) which splits into the Sahel canal, Massina canal and Costes-Ongoïba canal. These canals feed 77,200 ha of Office du Niger full-water-control land growing rice and market produce, 3,000 ha of controlled- submersion Office Riz Ségou land growing rice and 5 000 ha growing sugar cane in the Sukala agro-industrial area. Markala diverts about 2.6 billion m^3 a year into Office du Niger schemes. In absolute terms, this is not much (the Niger carries about 46 billion m^3 of water a year through this area). But it is about 50% to 80% of the river's water during the low-water stage. Markala also diverts a fairly substantial 150 m^3/s during the swell (returning practically none of it to the river).

Planned Dam Fomi

At present, the Fomi reservoir is seriously being considered. The reservoir is planned to be constructed in the Niandan tributary in Guinea. The reservoir is meant for hydropower in combination with irrigation and flood control. The reservoir is planned to contain almost three times as much water as Lac Sélingué. Compared to the Sélingué Lake, the Fomi reservoir will be 2.5 times deeper (i.e. 12 m, on average).

Planned damTalo

This plan involves building a threshold dam on the Bani River, by Talo, to irrigate some 24,000 ha and thereby develop farming. There are no plans for power generation. In Talo, the Bani splits into two canals creating an island. A spillway will close the shallower (north-side) canal (the minimum bed level is 270.50 m) and an embankment will close the deeper (southside) canal (minimum bed level is beneath 268.00 m). Simulations show that water would spill at the 277-metre mark. Upstream, water would spill over the left and right banks in two places, flooding a total of 150 km^2. Precisely what areas would flood, however, was not clear (the topographical information used for this simulation lacked accuracy). Downstream effects were run through a simulator as well: building a dam in Talo would delay the Bani's downstream swell by a week, especially in Djenné but should not have a measurable impact on the peaks in

Djenné, Mopti or across the delta. This comes as no surprise (this dam is a spillway and fairly small). It should, however, slightly compensate the lull in March and April.

Planned dam Djenné

This project can be regarded as Talo's rival. The goal, here, is to flood 85,000 ha of plains (the Pondori, which the river's swell does not reach during poor years) and to generate enough electricity for the neighbouring city. This dam should be small, not unlike Talo, and, similarly, have little if any impact on the rest of the inland delta.

There are plans for another small run-of-water dam in Kénié, between Bamako and Koulikoro. This dam should have no effect on downstream flow rates. Fomi, lastly, is in the upper basin in Guinea. When it is built, this dam will most probably be used to generate electricity (like Selingue). The impoundment lake will probably hold 6 billion m^3 of water, meaning it will probably have a substantial impact on the river's flow rate, and play an even more important role smoothening high-water and low-water flow variations (which, no doubt, will have palpable consequences on flooding in the Niger's inland delta).

14.10 REGIONAL WATER RESOURSES USE

Regional economic and politic context

In order to get a clear and detailed overview of the evolution of the Niger River Basin from the origin to the current emergence of a shared integrated river management vision developed among the members of the Niger Basin Authority, we invite the lectors to refer to the descriptions of the crucial historical steps written in Andersen et al., 2007.

Regarding the economy, the Niger basin gathers mostly poor nations belonging to the least developed countries (LDCs). Some are sahelian, landlocked countries subject to a tropical climate similar to the sudan-sahelian one characterized by repeated droughts during these last decades and a growing desertification. In addition to this bleak physical environment, these countries live in a hard economic context dominated by agriculture and cattle-breeding. These activities generate 40 to 60% of their export earnings and involve 80 to 90% of their active population. The non LDC countries remain nonetheless poor despite the existence of resources other than farming but still insufficiently or badly exploited (mines, gold, oil, etc.).

The economic context of the member States of the Niger Basin Authority has been marked for decades by the implementation of wide structural adjustment programs with the support of the Bretton Woods Institutions. These successive structural adjustment programs have ended up with economic liberalization and the implementation of economic and structural reforms. Combined with the devaluation of the CFA Franc in 1994, these reforms have significantly contributed to the improvement of macro-economic performances. The overall GDP of the nine countries of the Niger Basin Authority reached 70 billion of CFAF in 2000, with an average growth rate of 3%. The average GDP per capita was estimated at $350 /annum in 2000.

This modest economic growth not being followed by real wealth redistribution, the situation of the already poor populations which are largely the majority in the countries of the Niger Basin Authority, has not stopped deteriorating. Poverty has reached worrying proportions in most of the countries and above all in sahelian countries (Burkina Faso, Mali, Niger and Chad). The poverty line is equal to 38.4% in Côte d’Ivoire, 46.4% in Burkina Faso, 50% in Cameroon, 60% in Chad, 63% in Niger and with predominance in rural areas: 96% of the poor are rural dwellers in Burkina Faso, 86% in Niger, 75% in Côte d’Ivoire and 74% in Mali. Women and young people are the most affected by poverty. This poverty situation which affects most of the population explains the low level of human development of these countries.

The socio-economic context of the basin includes practically similar characteristics to the ones in all the countries with however a predominance of problematic linked to the sustainable management of natural resources and in particular water resources. The basin remains an area of fairly old peopling characterized by an ethnic diversity which is at the basis of the multiple conceptions of social life organizations and production relations. It is nowadays a migratory area because of the more favorable agro ecological conditions. Social conflicts linked to the exploitation of the resources of the basin occur fairly often between farmers and cattle breeders or between native populations and migrants.

Beside these recurrent social aspects, the economy of the basin is affected by the weakness and insufficiency of infrastructures and socioeconomic equipment. All these insufficiencies bring about adverse consequences and increase the poverty of these populations.

The incomes of the member countries of the Niger Basin Authority are essentially generated both by a rent economy (oil, uranium, cocoa, coffee, cotton) and subject to the fluctuations of the global market, or by a primary economy based on food agriculture and traditional activities generating a low added value.

Water use, Ecosystem services and threats from upstream activities in the Inner Niger Delta

The figure below is the result of one investigation carried out by the Niger Basin Focal Project. Maidnuddin used a simple water use-accout model to represent the water distribution among the regions of the Niger River Basin. The results show that water avaibility is shared between woodland net runoff and Grassland with predominance for woodland in the Upper Niger Basin and Grassland for the Inner Niger Delta.

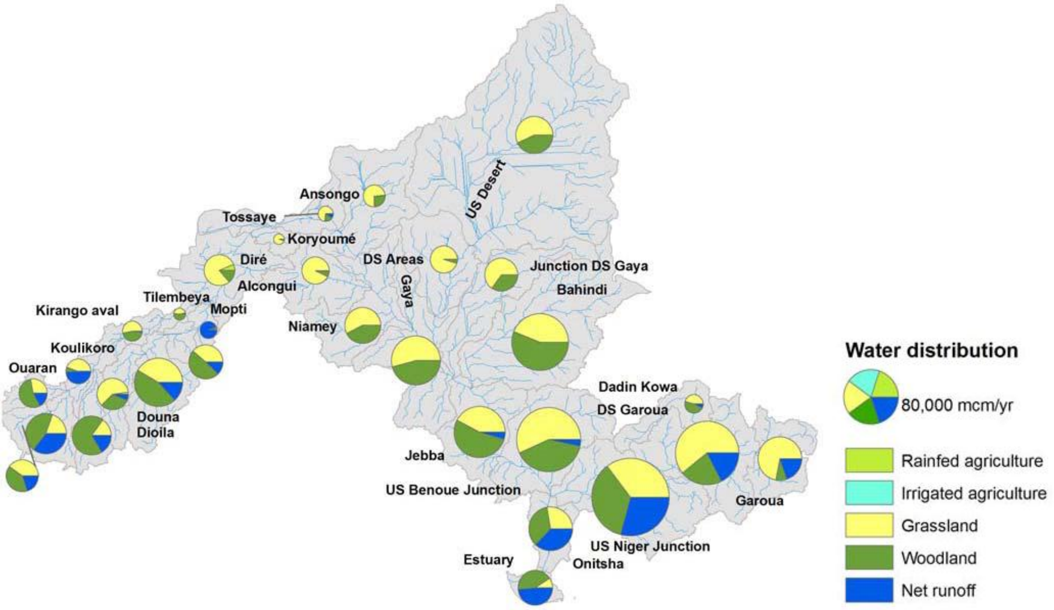


Figure 14-15 *Regional water distribution in the Niger River Basin using a simple water use account model Source: Maidnuddin in Clanet, Jean-Charles, and Andrew Ogilvie. 2009.* Synthesis Report. *CPWF Working Paper. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.*

To conclude this section, the two following figures illustrate within one page the main ecosystem services delivered by the Inner Niger Delta ecosystem and the anthropogenic threats from upstream activites.

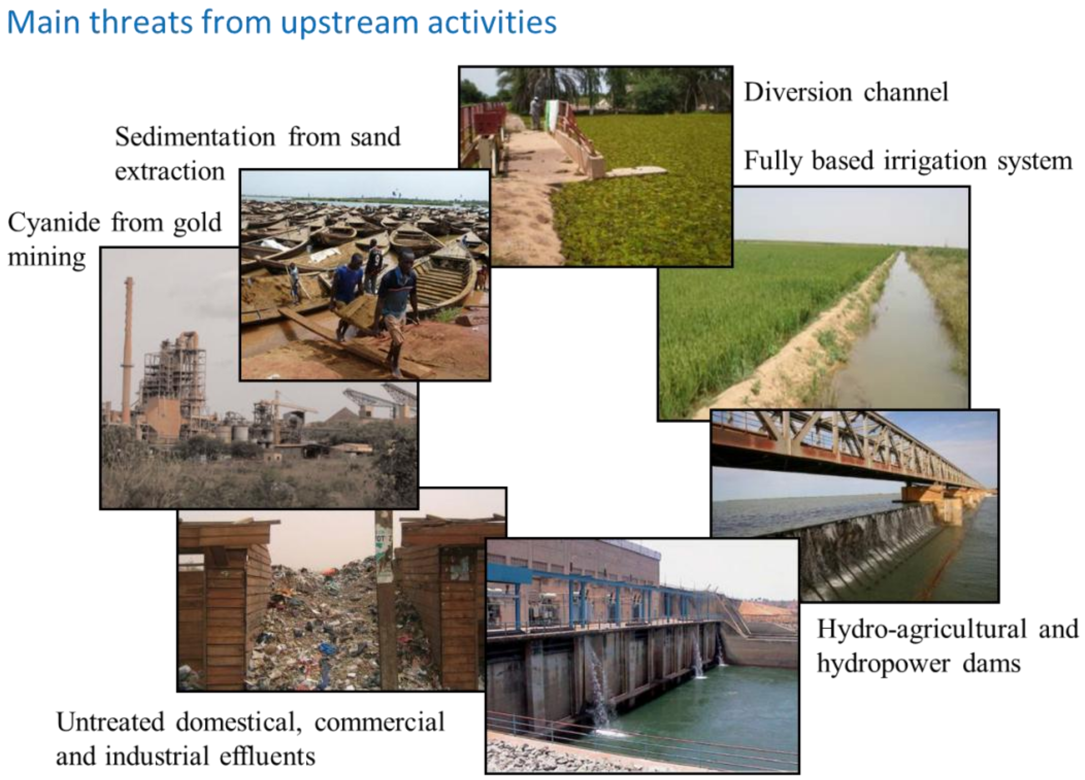


Figure 14-16 *and* Figure 14-17 *: Existing and planned dams. Source: Photo: Wetlands International, A&W, Gilles Belaud; Data: Zwartset al. , 2005*

14.11 HISTORICAL INFORMATION ON DROUGHTS

The Sahel region of West Africa experiences marked multidecadal variability in rainfall, associated with changes in atmospheric circulation and related changes in tropical sea surface temperature patterns in the Pacific, Indian and Atlantic Basins (e.g., ENSO and the AMO). Very dry conditions were experienced from the 1970s to the 1990s, after a wetter period in the 1950s and 1960s. The rainfall deficit was mainly related to a reduction in the number of significant rainfall events occurring during the peak monsoon period (July to September) and during the first rainy season south of about 9°N. The decreasing rainfall and devastating droughts in the Sahel region during the last three decades of the 20th century are among the largest climate changes anywhere. Sahel rainfall reached a minimum after the 1982/83 El Niño event. Modelling studies suggest that Sahel rainfall has been influenced more by large-scale climate variations (possibly linked to changes in anthropogenic aerosols), than by local land-use change.

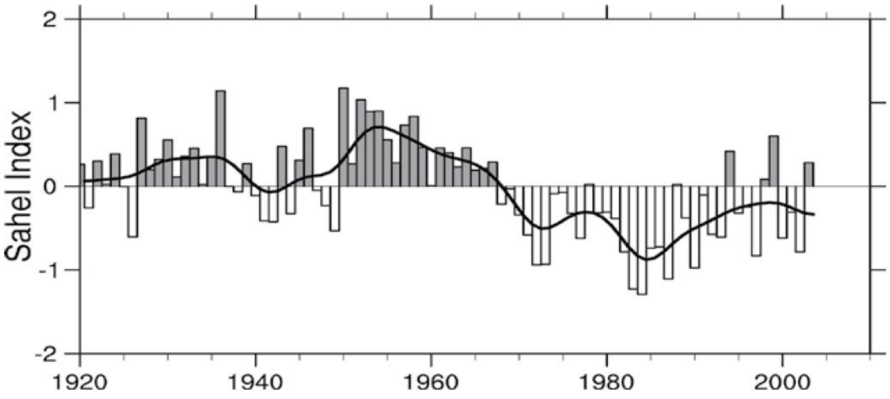


Figure 14-18 *Time-series of Sahel (10°N–20°N, 18°W–20°E) regional rainfall (April–October) from 1920 to 2003 derived from gridding normalised station anomalies and then averaging using area weighting. Positive values (shaded bars) indicate conditions wetter than the long-term mean and negative values (unfilled bars) indicate conditions drier than the long-term mean. The smooth black curve shows decadal variations. Source: Bates et al., 2008 adapted from Dai et al. 2004*

There are huge numbers of scientific publications investigating the historical drought. In order to further illustrate drought history in the particular case of the Inner Niger Delta case study, two extracts respectively from Marie et al. 2007 and Zwarts, 2010 are presented below sounding the climate variability and a recent review of the effects of climate change. All references are given in the respective sources:

Climate variability

Hulme (2001) argued that there was no such thing as “normal” average rainfall for the northern Saudi and Sahel areas. What is “normal” here, however, are ample weather swings occurring over several overlapping periods of time. These overlapping variations, however, obscured the forcing factors behind the weather changes and therefore hampered efforts to identify trends and model changes. The term “trend”, as an aside, warrants a word of caution: what may look like a trend over a given period of time may, in fact, be part of a longer cycle. Ward (1998) showed the point of distinguishing climatic oscillations spanning different periods of time (or frequencies). We will be following this approach, dissecting the Sudan-Sahel climate’s several components and showing which ones intertwine into what its people can perceive as a “trend” on a ten-year basis.

Variability of the internal structure of the rainy season

Le Barbe and Lebel (1997) found a link between the Sahel’s dwindling rainfall over recent decades and a drop in rainfall in the middle of the rainy season (in July and August). The rainy season as such, they argue, has not grown considerably longer or shorter. D’Amato and Lebel (1998) go a step further linking this to a decline in the frequency of cyclone passages during those two mid-season months. Thus, the study of changes in the structure of the rainy season can cast light on the mechanisms underlying monsoon processes and, taken a step further, hint at the factors governing the medium-term and long-term trends in total rainfall figures.

Inter-annual variability of total rainfall

This variability characterises the variations recorded between one year and the next, or between one two-year or three-year period and the next. This variability scale exists but, relatively speaking, is rather less significant than in other parts of Africa. Five-, three- or two-yearly fluctuations only account for 15% to 20% of the total variability. This, generally speaking, means that rainfall figures for one year are roughly like (or at least resemble rather than differ from) those of the previous year. Meteorologists have found this pattern in statistics spanning the last century. But the past decade, conversely, has brought sharp year-on-year oscillations including dry years (1996, 1997, 2000, 2002 and 2004) intertwined with rainy years (1994, 1995, 1998, 1999, 2001, 2003, and 2005).

Decade-on-decade variability of total rainfall

Much of the Sudan-Sahel climate’s variability is due to these patterns (low-frequency fluctuation). Moron (1997) suggested that quasi-decade-ondecade cycles (spanning 12 to 13 years) would explain a full 12% to 14% of the variability. “Typical” dry or rainy periods, in this light, should last about 5 to 10 years. The two dry decades in a row (1973 to 1993) could fit into this variability pattern even if they were abnormally long.

Multi-decade variability of total rainfall

This category can encompass changes spanning the last century or longer historical periods. There appears to be – certainly since the late 19th century and probably since the 17th century (Hulme, 2001) – a gradual downward slope in rainfall. This downward trend also seems to be affecting the Sahara (which, as an aside, was greener and had more wildlife in prehistoric days than it has today). However, sharp decade-on-decade variability within this historical trend brings very rainy periods spanning a number of years. The latest ones date back to the middle of the 20th century. The future may bring more such episodes.

Surface conditions seem to amplify the climate fluctuations outlined above, adding a form of inertia to existing rainfall patterns (positive feedback). This could explain why decade-on-decade variability predominates over year-on-year variability.

Changes that people have noticed and noted

Colonial records dating back to the early 19th century mention a series of damp and rainy episodes. We know that the first half of the 19th century also saw a very dry patch (probably as dry and as long as the 1973-1993 drought). The early 20th century brought another very dry period. The 1950s and 1960s, conversely, were very rainy and brought some severe flooding. Today, the notion that the rainfall decline is here to stay is all-too-often considered an indisputable fact and pegged to the notion of desertification. However, desertification is more a case of soil erosion than of the desert sprawl.

Global warming – another noteworthy parameter, naturally – seems to be hitting West Africa in pretty much the same way as it has been affecting the rest of the world since the early 20th century. How it might reshape the rainy seasons is not yet clear.

Climate Change

The six warmest years in northern Africa since 1860 were registered after 1998. The rise in temperature since 1970 has been even faster in the Sahara-Sahel zone than worldwide, with a 0.2°C rise per decade in the 1980s. This rate increased to 0.6°C per decade at the end of the 20th century.

Global Circulation Models predict a further warming of Africa in the 21st century, varying between 0.2 and 0.5°C per decade (Hulme *et al.* 2001; Caminade *et al.* 2006). The warming is expected to be even greater in the Sahel. Consequently, the temperature may therefore raise another 2-7°C the next 80 years – a daunting prospect!

Global Circulation Models also provide predictions about rainfall. Given the important role that ocean surface seawater temperatures exert on rainfall in Africa, it is to be expected that a continuing warming of the tropical oceans would lead to a further reduction of rainfall. However, global warming may also impact the temperature gradient in tropical and subtropical oceans, which would complicate predictions of African rainfall.

Also more recent studies still struggle with the processes leading to more or less rainfall in the Sahel (as reviewed by Giannini *et al.* 2008, Caminade & Terray 2010). There are major mechanisms leading to *less* or more rain:

1. A cooling of the southern hemisphere oceans and a warming of the northern hemisphere oceans leads to more rainfall in the Sahel, while a warming of the southern hemisphere oceans and a cooling of the northern hemisphere oceans will have the opposite effect. The latter appears to be the case, so this would lead to less rain in the Sahel.
2. There will also be less rain in the Sahel if the Indo-Pacific Ocean gets warmer (causing a more stable troposphere). This appears to be the case too.
3. Also a desertification of the Sahel will lead to less rain. In contrast to these three mechanisms leading to less rain, there are two reasons to assume that there might be *more* rain in the Sahel, one worldwide, and one specific for the Sahel.
4. At a higher temperature, the warmer atmosphere is expected to hold more water, thus moister and hence wetter.
5. Due to the higher temperature, for two reasons the Hadley cell will become more intense, leading to more rain. There is hardly any doubt that the Sahara will become warmer, causing more rain in the Sahel, whereas for the same reason the difference in temperature above the African continent and the Atlantic Ocean will become larger.

Since there are several competing mechanisms leading to more or to less rain in the Sahel, it is extremely difficult to predict whether there will be more or less rainfall in the Sahel. After comparing four climate change scenarios and seven global climate models, Hulme *et al.* (2001) concluded that annual rainfall in the western Sahel would possibly remain at the same level, but that a decrease of 10-20%, or even 40%, is more likely.

One of the problems with Global Circulation Models is that, when applied to the Sahel, they are not able to capture the Great Drought in the 1980s. Recently, however, Held *et al.* (2005) presented a model that appears to simulate 20th century rainfall reliably for the Sahel. They predict that rainfall until 2020-2040 will remain at about the same low level as the last twenty years of the 20th century, but will then gradually decrease by about 20% in the next 50-100 years.

Biasutti & Giannini (2006) showed that 16 of the 19 models being used in the 4th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 4AR), do reproduce a drier Sahel at the end of the 20th century. They conclude that aerosol emissions from industrialization, causing global dimming, and thus cooling, in the northern hemisphere, may have played a role in causing the Sahel drought. At least 30% of the observed negative rainfall trend over the 1930–2000 period was estimated to be externally— and most likely anthropogenically—forced.

Caminade & Terray (2010) compared 21 different climate scenarios and concluded from this: “our results converge with those highlighted in Held *et al.* (2005), namely that the prediction of twenty-first century drying over sub-Saharan Africa could be considered as a plausible but not certain scenario". The reports made by ACMAD (Centre Africain pour les Applications de la Météorologie au Développement 2009a & 2009b) for the *Autorité du Bassin du Niger* (ABN) gives more details about the statistical power of the different climate models and the predicted increase of the temperature and likely decline of the local rainfall until 2025.

Agrhymet (2009) used the predicted climate change in the basin of the Niger to forecast the river flow of the Niger between 2011 and 2040. Since five of the six climate models being analysed show a decline of the rainfall in the Upper Niger, this study concludes it has to be taken into account there will be a decline of the river flow (but see the next chapter for an analysis of the relationship between rainfall and river flow).

In conclusion, still much is uncertain, but a decline of the rainfall in the Sahel seems to be likely. Since human influences are assumed to be substantial, this gives reasons to worry about the future.

14.12 PURPOSE OF THE CASE STUDY

The Niger Inner Delta is an example of complex ecosystems where the water flow, the dynamics of the natural environment and human activities are closely associated. It is composed of a system of small channels which draws the water towards the plains during the rainy season and, conversely, ensures the withdrawal of the water towards the streams during the dry season. This is an area where are concentrated human activities: agriculture, cattle-breeding, fishing, gathering, navigation, tourism, etc.

Although the flood plain of the Delta is one of the rare plains where water flows freely in the Sahel, the impact of human activity on this area is still high. The Niger Inner Delta covers unique ecosystems of international interest and a huge agro-sylvo-pastoral and halieutic potential valued by the different socio-professional groups. It supports numerous populations and livestock. Hundreds of thousands of bovines, ovines and capra live in the fresh pastures of the delta. They receive every year nearly 5 million of cattle heads investing its rich bourgou pastures. This livestock comes from Mali, Mauritania, and Burkina Faso conferring to this system an international status.

The Delta allows the fishing of 40 to 130 000 tons of fish on average per year, even if this production has been experiencing a downward trend these last years, because of overexploitation and irrelevant fishing techniques. The pressure exercised by fishing activities is too high. But it has been also subject since decades to various degradation processes of resources, and a reduction of flood plains, linked to natural and human factors. These factors turn the Delta into a semi-natural habitat. Nevertheless, this is one of the last vast flood plains in the world having matchless ecological values.

The sustainability of the exploitation systems of the Niger Inner Delta is today a key issue, this system being half way between almost natural systems and river systems strongly modified by man. The key stake of development is to move from the scaling-up of the exploitation to a resource management by taking into account (i) the long term dynamics of physical, biological and anthropic systems and (ii) the needs and uses of populations. The

Niger Inner delta ecosystem is complex, leading as a consequence to multiple criteria and decision constraints

The Inner Delta plays a very important role at an international level, especially because of the rich biodiversity of its aquatic ecosystems. The IND cannot be overlooked in the efforts of Mali for the attainment of food self-sufficiency and food security.

Coupled with anthropogenic changes in the catchment, climate change and variability can increase greatly the vulnerability to meet regional food security and biodiversity maintenance. Last decade, the Inner Niger Delta and the upstream catchments faced really severe and continuous drought that modified deeply the flood propagation and the societal organization of the activities that are dependent on the floodplain to generate livelihoods. The preparedness to drought passes through the improvement of the current early warning system platform by understanding the interdependencies and accounting for all the parameters ruling drought events. The path from meteorological to hydrological drought and finally from agricultural to socio-economic drought may encompass rainfall, catchment retention, water management with reservoir, diversion channels, runoff propagation within a downscaling approach.

14.13 DESCRIPTION OF NEEDS AND PROBLEMS TO BE ADRESSED BY THE CASE STUDY

Bad-weather years (such as 2004) have a huge social and economic impact. The rural populations can face food shortages during the following year’s gap phase: cereal can indeed run out in May or June, when the following harvest is not due until October or November. The country’s economy as a whole suffers as well: the balance of trade weakens (Mali has to import rice and frozen sea fish) and growth sputters (or the economy goes into recession).

Bad-weather years are one of the harshest chronic woes that authorities in Sudan-Sahel countries such as Mali have to cope with. They have a number of options:

- sending food aid to help affected rural populations (and targeting it not to shake the agro-product market’s balance). This is what the World Food Programme does at the SAP’s (*Système d’alerte précoce*/Advance Warning System) request;
- building large irrigation schemes to shelter parts of the farming population from these hazards (provided, of course, that these schemes can stock up enough water upstream);
- trying to contain the impact by circulating information that will help people avert hazards a few weeks before they occur, and handle them more efficiently once they

do (for example altering their annual crop strategy or investments in fishing; the Agrhymet regional system).

DEWFORA project aims to Improved Drought Early Warning and FORecasting to strengthen preparedness and adaptation to droughts in the Niger case study. This general statement can be then decomposed in to two major axes that correspond to the general downscaling process presented in the general research framework scheme:

1. **Improve drought early warning and forecasting system and regional climate change impact assessment**

- Apply a wider range of climate change projections and weather forecast simulations to analyze the reproduction of hydroclimatic extremes
- Couple weather forecast and protected climate change simulations with an hydrological model through the application of downscaling and bias-correction methods
- Enhance the hydrological model to better represent upstream river basin management and the flood dynamics in the Inner Niger Delta
- Assess flood variability and hydrological drought according to upstream river basin management and climate change scenarios
- Predict Flood/Runoff variability and hydrological drought according to upstream river basin management and weather forecast scenarios
- Formalize the interactions of food security and ecological integrity with flood propagation to extend the analysis from hydrological drought to socio-economic and ecologic vulnerability
- Communicate the uncertainties in any applied methods and scenario results

2. **Stakeholder involvement to strengthen preparedness and adaptation to droughts**

- Find an adapted balance of power among institutionalized and traditional representatives and among the different water users to converge the local actors into an integrative approach in the Inner Niger Delta respecting central authority and traditional regulations
- Tailor the technical framework of a drought impact assesment and of a drought early warning and forecasting system and define the relevance of the methods and of the indicators to the needs of the stakeholder platform and the local actors
- Develop new instruments and channels to disseminate and make accessible the information of drought impact assessment, drought forecast and adaption strategies to a large audience

- Explore emergency, mid-term and long-term adaptive capacities to organize the water uses for drought prepardness
- Integrate scientific early warning and forecasting system tools and drought assessment to reduce the effect of variability and strengthen the preparedness to drought
- Find synergies to couple the forecast products to the current flood forecast system applied in the Inner Niger Delta OPIDIN
- Select pilot projects for each water use and identify adapted solutions to secure food production and biodiversity maintenance in a complex environment
- Promote a lobbying with the authorities and the local and regional decision makers to defend a new paradigm for the Inner Niger Delta and to promote an institutionalized platform to negotiate appropriate trade-offs between upstream and downstream water use (electricity, fully governed irrigation agriculture against fishery, breeding, free submersion and semi controlled irrigation farming, biodiversity maintenance and ecosystem conservation)

15. DROUGHT MANAGEMENT PRACTICES IN THE NIGER BASIN

Across rural Africa, natural resource legislation struggles to be properly implemented, and most resource users gain access to resources on the basis of local tenure systems. Although such systems claim to draw their legitimacy from ‘tradition’ and are commonly referred to as ‘customary’, they have been profoundly changed by decades of colonial and post-independence government interventions, and are continually adapted and reinterpreted as a result of diverse factors like cultural interactions, population pressures, socio-economic change and political processes. Such tenure systems are extremely diverse, possibly changing from village to village. This diversity is the result of a range of cultural, ecological, social, economic and political factors.The delta has also witnessed important changes in the economy and society. These include the monetarisation of the local economy, the growing fragmentation of the extended family, and a shift in power from the traditional aristocracy, which reflects the interests of Fulani herders, in favor of agriculture (backed by the government) and of ‘purchasing power’, i.e. the power deriving from access to financial resources. The latter has enabled urban elites (traders, government officials, etc.) to purchase large numbers of cattle and, in some cases, to rent out or even buy land for their exclusive use. These and other socio-economic changes will be discussed in greater detail below. (paragraph based on Cotula et Cissé, 2006)

The Fulani ruled the Inner Delta from the early 19th century until the arrival of the French in 1893. They imposed a system of resource management, called the Dina, on all major production systems. The Dina divided the area into a number of grazing territories and by doing so, formalized the already existing resource management system. The Dioro, the head of a Fulani clan, ruled each territory. The actual management of the floodplains was done by the “masters of the water” (maître d’eau) and the ‘masters of the land’ (maître de terre). The master of the water managed the access to the fishing grounds and the master of the land did the same to the floodplains when dry. In practice, the two masters managed the same area but in different seasons. Studies of Gallais (1967), Moorehead (1991) and others showed that this socio-economic system was already in crumble half a century ago. Due to population growth, the pressure from outside people increased. Although the rural communities were still the owners of the terrain, the masters no longer had sufficient power to deny right of access to the growing number of outsiders. After independence in 1960, the State started to build its own administration with technical services, such as ‘Eaux & Forêts’. This new control system further weakened the traditional system of community-based resource management. The new policy of decentralization since 1992 can be considered as an attempt to integrate traditional management into modern society. (paragraph based on Zwarts et al., 2005)

For centuries, the natural resources of the Inner Delta were neatly divided among the people. The Fulani herders came with their cattle to graze on the floodplains in the dry period, where the Bozo and Somono people had been fishing some months earlier. The farmers (Marka, Bambara, Sonrai, etc.) planted rice in the rainy season, just before the flood covered the area, to harvest it some months later during receding water. In this traditional system, each ethnic group produced a part of the daily diet while the remaining food was complemented through local trade. According to an estimate for the early 1980s, about 30% of the Delta inhabitants were fishermen, 30% belonged to the agricultural community and the remainders were herders.

The traditional system of exploitation of the natural resources of the Inner Niger Delta encompassed:

- Semi-sedentary farmers, growing rice and millet,
- Semi-nomadic fishermen,
- Semi-nomadic herders, raising cattle, sheep, goats, etc.

According to Zwarts et al. 2005, The Great Drought in the 1970s and early 1980s forced many rural people in the Inner Delta to abandon their specialization. Fishermen started to grow rice on the side, while farmers began to fish and raise cattle as well. Some Fulani even began to cultivate rice. Such mixed ways of exploitation have become more prominent in recent years, and in fact have now been transformed into new professions, i.e.:

- agro-pastoralist,
- agro-fishermen.

15.1 CURRENT DROUGHT MANAGEMENT SYSTEM

Increasing the control of water resources is a direct method for managing the risk associated with climate variability and water storage is the most common approach to increasing water control (Brown and Hansen, 2008). Storage options range from bunding and on farm impoundments to retain runoff from individual storms for supplemental irrigation, to large scale dams that can retain high flows, reducing the damage from floods and also providing water during dry seasons or droughts large scale storage may also accommodate a second growing season. In contrast, small scale and community managed irrigation have been generally more successful, although most existing studies were completed at the pilot scale only. A variety of studies have examined the economic viability of various approaches at local scales but there are few studies of there reliability in response to climate variability at a planning perspective. Smaller scale storage offers the benefit of more local control and less externalities in terms of submerged area. Pilot studies of surface impoundments (farm ponds) in Kenya and Burkina Faso have found significant potential increases in yield and productivity through supplemental irrigation and extending the growing season (Brown and Hansen, 2008).

Improved water control may also be achieved through methods that focus on the control of evaporation, such as conservation farming, drip irrigation, furrowing and leveling of fields. Large-scale public irrigation system are surface water systems typically with large storage volumes collecting water from sizeable contributing areas and delivery systems covering a large area. These systems are designed to provide resilience to most droughts and to allow multiple cropping seasons and provide the highest potential protection against climate risks. Still, actual reliability of water supply for an individual farmer depends on one’s location and priority within the system. For example, reservoir systems where water is shared with drinking water supply systems and hydroelectricity production often place the lowest priority on agricultural water and the reliability of agricultural water deliveries is compromised.

While improved water management is a crucial element, a portfolio of synergistic interventions is the most promising approach to covering the full spectrum of climate risks that confront farmers and impede the investment needed to realize the potential benefits of water management. According to Brown and Hansen, 2008, several options are available for managing the risk that feasible water management strategies cannot cover. A few new ways to use new types of climate information, climate informed livelihood strategies have not yet been fully explored or exploited.

Climate risk management for agriculture includes:

- Systematic use of climate information and climate knowledge in strategic planning (e.g., water control design, breeding) and adaptive decision making;
- Climate-informed technologies (e.g., agricultural water management, drought-tolerant germplasm) and management strategies (e.g., livelihood diversification) that reduce vulnerability to climate variability;
- Climate-informed policy (e.g., early warning and response systems, safety nets) and market-based interventions (e.g., insurance, credit) that transfer risk from vulnerable rural populations.

In the Inner Niger Delta, one million people make a living from agriculture, fisheries and cattle farming. Water is the lifeblood of this system. Upstream dams (one built for electricity generation and another for irrigation) affect this downstream multifunctional use of water. Zwarts et al. 2005 intends to prove that building new dams is not an efficient way to increase economic growth and reduce poverty in the region. In fact, such efforts are counter-effective. Instead development efforts should improve the efficiency of the existing infrastructure as well as economic activities in the Inner Niger Delta itself. The adoption of general guideline to drought risk management do not really fit to the specificity of the Inner Niger Delta inherent to the flooding pattern dependent on upstream discharges ruled modified partly by water management.

R.A et al., 2011 presented effective drought preparedness measures adapted to the Inner Niger Delta. The plan presented short and long term action to counteract the effects of 2011 drought in the Inner Niger Delta. The short term is to adapt the traditional and the modern agriculture systems to this new deal and to establish a robust food aid program to manage the food reserves, the stocks of inputs, fodders and other extra food. The long term targets are to incentivize the farmers to generate 2 to 3 crop seasons and particularly to support a second campaign or rice and gardening. The test and the promotion of dry varieties of rice or other cereals (technical and social aspects) has to be developed. The authorities may encourage fencing the irrigated perimeters. Alternative source of energy may be implemented in pilot site pumped irrigated perimeters with solar energy. A landscape planning has to privilege the concentration of the irrigated perimeters next to the main channels as the drought risk is higher than the inundation. Also, an early and concentrated campaign to adjust fishing capture to the potential regeneration of the fish population has to be conducted. In parallel, the promotion of culture in bourgou and the promotion of fish farming in ponds can generate stable sources of food and fodders. Finally the potential of groundwater resources has to be adequately explored to figure out the profitability against heavy investments and maintenance. For the transport activities, a new approach has to be developed with the stakeholders in order to provide adapted information to the main water users. A program can be also developed to manage boats and find construction adapted to low water levels.

The next sub-sections present the characteristics of the different water-uses ruling the delta.The charcteristics of the different water use are mainly inspired and extracted from the work done in Marie et al., 2007 and Hassane et al. 2007. Having a full understanding is necessary to develop a critical and adapted for the implementation of drought management practices.

15.1.1 Agricultural System and Irrigation Schemes

To cope with low and extremely variable water resources, many different irrigation systems were developed in the agricultural sector in the Inner Niger Delta and in the upstream catchments. The section presents the characteristics of all the irrigation schemes encountered in the case study and the upstream catchments.

Traditional river-fed and rain-fed rice growing (unsupported)

This ancient system does not involve any hydraulic infrastructure. It involves using local varieties of “floating rice” that can handle water levels of up to three meters. Farmers choose a location for their paddy according to where they believe the water levels will rise during the high-water season (based on their experience). They may also move their paddies from one year to the next. They plough in February or March (after the harvest), or in May or June (just before the rain returns). They scatter the seeds, rainfall triggers the growth process, and then the floods take over. Floating-rice varieties derived from Oryza Glaberrima can survive in three-meter deep water, provided the level does not rise more than five centimeters a day. Farmers then harvest the rice in the water between late October and December (depending on the variety they farm). This rice-growing method is very common in the inland delta. It spanned about 160,000 ha in the late 1980s, and probably spans between 180,000 and 200,000 ha today. Yields are very poor (less than 900 kg/ha on average) and have not changed since the 1950’s. They are also erratic: flooding can be inadequate, and rainfall insufficient or untimely (late rainfall will not allow the rice to grow enough before the flood). Plantation mobility is another of this system’s hallmarks. During good years, as many as 10,000 t of rice can be sold outside the delta (Kuper and Maiga, 2002). Bad years bring rice shortages. Usable farmland can indeed vary considerably from one year to the next. In 1994, for instance, three-quarters of the delta were suitable for floating-rice plantations. In 1972, conversely, only a fraction was viable (Marie, 2000). These sharp variations explain why paddies move about so much. Yield, however, is still unpredictable. Paddies would shift about 10 km in the 1950s (Gallais, 1967), but started moving much further in the 1980s, when flooding became much more erratic. Farmers have left the Niger/Diaka plains and flocked to lower areas (Kootya, in the middle of the delta, for instance). Healthy flooding in 1994, conversely, covered the Kootya area's hamlets attracting farmers back and triggering new rice-paddy migration.

Irrigated farms (scheme-supported)

Here, farmers can count on irrigation systems diverting surface water into their farms. A wide variety of systems, ranging from controlled submersion to full water control, fall into this category. The Niger's tributary basin in Mali counts about 250,000 ha of irrigable land, including some 100,000 ha with full-water-control schemes. Mali has ranked water control high on its list of strategic priorities, both to meet its population's needs and in the interest of sustainable development. Accordingly, it has been working on an irrigation-development plan to tap existing potential. Doing so will involve building hydro-agricultural infrastructure to flood an additional 50,000 ha of full-water-control land and 14,000 ha of land on shallow-flooding, submersion and other systems, by 2007. The longer-term goal is to extend the Office du Niger's total irrigated area by 120,000 ha, to 200,000 ha, in the next 20 years.

Controlled submersion

Accounts for 60% of the surface prepared for rice plantations. The schemes are publicly-funded and run by relatively autonomous government agencies. The two most important ones are:

- Office Riz Mopti (ORM): 34,000 ha;
- Office Riz Ségou (ORS): 34,676 ha.

These schemes involve building small walls and inlets at specific levels to govern submersion. This in effect, curbs some of the risk associated with rainfall: in theory, farmers can plant their rice later on in the year and make sure the seedlings are out of the ground before the flooding begins (and authorities controlling the dam can delay the flooding if and as required). But most of these systems were designed in the late 1960s, when the Niger brought healthy and relatively regular swells (the average maximum level in Mopti between 1960 and 1969 was 693 cm). Today, however, these dams are too high up and therefore ineffectual when flooding is inadequate – which, alas, is often the case today (the average maximum level in Mopti between 1980 and 1989 was 539 cm). Average yields are very poor (often less than one ton per hectare) and only a fraction of sown areas are actually harvested.

In ORM plots, for instance, the ratio between harvested and sown areas stands below 0.33 when high-water levels fail to reach the 550 cm mark, and does not reach 0.75 when high-water levels rise above 620 cm. During very bad years (1984), there can be no harvest at all.

This system is inadequate due to swell variability and uncertainty. In most cases, it cannot guarantee production or earn farmers a decent income. It is inflexible, as well: rain- and river-fed systems may be less productive but can, at least, move to where conditions seem most propitious.

Gravity-governed full water control

These schemes use upstream impoundment lakes with guaranteed water which release water by gravity. The Office du Niger's "large-scale" schemes (spanning 83,000 ha, including 5,000 for sugar cane), Baguineda (3,000 ha) and Selingue (1,000 ha) are three examples. They are all linked to dams. Water management, here, involves building a network of canals to route water from the lake to the farms, crisscross it around the plots, and then allow it to flow downstream into the drainage network. This rice-growing system ranks third in terms of farmland size (it covers slightly less than 100,000 ha across Mali). But it produces nearly 80% of this country's rice in an average year (different authors put yields between 4.5 and 6.0 t/ha). These areas have also attracted sizeable populations (farmers and their families, mostly). The extended Office du Niger area (i.e. all the land under Office du Niger management) spans 28,174 km^2. Its eight hydraulic schemes span 19,074 km^2 and were home to some 321,069 people in 1998, putting their average population density at 16.83 inhabitants per km^2.

These schemes, in other words, are efficient. But running them can entail a number of problems and they have a number of sensitive aspects. Monitoring and servicing heavy-duty hydraulic equipment is one issue. Administrating the land and cost distribution (water costs, in particular) among the parties is another sensitive area. Protecting the soil's fertility and, more generally, preserving the environment, is yet another concern. Public agencies in charge of these large areas are working hard to fine-tune and implement sustainable policies in line with central-government guidelines. Doing so, however, entails hiring qualified staff and experts which, of course, carry a cost as well. Another issue, from an ecological standpoint, is that most of the water that this large system diverts from the river is never replaced. These large systems, in other words, divert considerable amounts of water, and therefore have a negative impact on downstream water availability during both seasons: during low-water stages they divert more than 50% of the river's waters (and as much as 80% at peak times); during high-water stages they divert water into gravity-governed schemes and into Selingue's impoundment lake concurrently.

How much water is diverted into large gravity-governed systems (the Office du Niger's schemes, mainly) of course hinges on the size of the area in question. But it also hinges on the system's efficiency (i.e. its ability to divert no more water than the irrigated areas need). These irrigation systems, however, appear to waste water at present.

In the case of the Office du Niger, one cubic meter of water produces about 0.13 kg of rice (320.106 kg divided by 2,500.106 m^3). This, of course, is after deducting the water that goes to sugar-cane plantations and non-farming uses (drinking water for livestock, etc.). This is also mediocre: the “norm” in Asia, for example, is at least 0.2 kg of rice per cubic meter of water.

Pump-assisted total-water-management irrigation

Pump-assisted irrigation started developing here in the early 1980s, when rainfall and swells started dwindling. The main schemes on the Niger River are in Mopti, Gao and Timbuktu. These schemes are generally small, and run by private concerns or village communities, i.e. “Village Irrigation Areas”, often backed by NGO-sponsored “projects”. The inland delta counted 154 of these operations, spanning a total 1,400 ha, in 1998 (Ducrot et al., 2002). In these schemes, a motor pump feeds a stilling pool and water then spreads across the plantations by gravity. The results are usually good or very good: yields generally exceed 6 t/ha, and can be as high as 9 t out of season (in the dry season). The problem, here, is that building these schemes entails considerable investment and that they will only prove cost-effective if the area they cover is large enough.

Experience, especially in the Senegal valley, has shown that these schemes are not cost-efficient in small operations. Operating costs (high pump-fuel costs, especially), community management, and heavy maintenance requirements can cause a number of problems, and indeed lead users to abandon the entire scheme or at least part of it after using it for a longer or shorter period of time.

Low-water and off-season farming on the river banks

These schemes are especially developed in the north of the Niger River’s delta and oxbow, and in the lake region. There are seventeen large lakes, mainly on the right bank. The shores of these lakes, and the shores of a large complex of permanent and semi-permanent ponds, are used to grow sorghum or tubers and vegetables (potatoes, tomatoes, etc.) as soon as the swell starts receding in late January or in February. These receding-flood crops are vital for people living in these Sahel or desert areas, who can no longer count on rain-fed crops for subsistence. The size of the tillable area, here, is linked to the area covered by the flood, and therefore linked to swell levels. The potential, however, seems largely untapped.

15.1.2 Water Resources

Fisheries (based on Mare et al. 2007 and Zwarts et al, 2005)

About 500,000 people and 300,000 in the Inner Niger Delta (children and elderly included) live off fishing (i.e. fishing accounts for all or for a sizeable portion of their livelihood). A small portion of Mali’s fish production comes from the Senegal River basin (from the Manantali dam lake). The bulk of it comes from the Niger River basin. As do the production swings, which can range from 55,000 t. one year to 140,000 t the next (fresh weight equivalent). The bulk of the Niger River basin's production, in turn, is fairly concentrated: about 80% of it (40,000 to 120,000 t a year) comes from the Niger River's inland delta (broadly, from Ké-Massina to Diré, encompassing the lakes). The rest comes from the Selingue's impoundment lake (4,000 t a year), from the Niger River upstream of Massina, from the Niger River's oxbow between Diré and Gao, and from the southern tributaries (Baoulé). This healthy production makes Mali practically self-sufficient in fish, at least when it has average or generous high-water stages (which put production in excess of 100,000 t). Small amounts of frozen sea fish are imported and consumed in the capital, and some fresh and smoked fish is exported to Burkina Faso and Côte d'Ivoire.

The annual fish production in the Inner Niger Delta, recorded since 1966, highly depends on the flood of the preceding year. The close relationship between annual fish trade in Mopti and flood level in the preceding year allows for the assessment of the average impact of Office du Niger and Sélingué on fish trade. Fish trade in the Inner Delta would have been 6% higher in absence of Office du Niger and an additional 13% higher without the Sélingué reservoir. The analysis predicts that fish trade will be reduced by another 37% in case of the construction of the Fomi Dam. These losses are partly compensated by fisheries in Lac Sélingué, where about 4000 ton fish is captured annually.

To conlude, fishing has huge potentialities and is a major development sector of the basin. Its development may be hampered by several factors including rainfalls, over-exploitation and irrelevant fishing techniques, the disappearance of some species, the lack of monitoring of fishing resources, the insufficiency and bad quality of fishing equipments, the difficulties related to sales, the proliferation of aquatic plants and agricultural as well as industrial pollution, etc. For a sustainable fishing activity in the Niger basin, there is a need to build the capacity and resources of actors, develop the marketing channels and safeguard in particular the existing fishing potential.

Livestock (based on Mare et al. 2007 and Zwarts et al, 2005)

Estimates suggest that there are 7.6 million head of cattle in Mali. Figures are relatively stable in the large traditional cattle-breeding area in the north of the country (Mopti), and growing in the south. In Sikasso, for example, there were 336,000 head in 1970 and 741,000 (121% more) in 1995. However, in absolute terms, Mopti is still Mali's leading livestock-farming area. An aerial census in the 1980s suggests that there are some 1.6 million head, including about 1.2 million in and around the Niger River's inland delta.

The inland delta plays a very special role in Mali's livestock-farming sector. This is because its flooded pastures are exceptionally fertile and stay "green" for 7 to 8 months. The best pastures, the *bourgoutières*, produce between 20,000 and 30,000 kg of dry matter per hectare per year and supply green feed from December to July (Sahel pastures, as a point of comparison, rarely produce over 2 t of dry matter and are only green for four months a year). The inland delta, in other words, is the only natural region in Mali – and in West Africa – that provides generous pastures over vast areas. It spans only 1.5% of the country's land but counts about 20% of Mali's cattle.

When the swell starts flooding the inland delta in August, herders leave on their long seasonal migration to the Sahel's pastures. They return in November or December, depending on how fast the water recedes. They take their herds across the delta through a complex of trails and shelters, which they use by strict unwritten traditions. Other than the water that cattle drink, herders do not, strictly speaking, consume water resources. Yet, not unlike fishers, they depend on the annual flooding (high-water levels dictate how much fodder they will find for their herds). Poor flooding (5.1 m) will cut fodder production by almost 40%. The same swell (5.10 m), however, would flood 80% of the area that a 6.6 m swell would flood. So the loss in fodder production is considerably less significant than the drop in flooded areas. This is because plant formations that are not under water can still grow thanks to rain and rising groundwater. So flood variability does not affect fodder production in a straight, directly-proportional way: changes in total flooded area only account for some of the change in fodder production. In environmental terms, we can infer that the delta can support 1.5 million head during a very good year, but only sustain 900,000 during a bad year (after a poor flood). Fodder production, however, seems to be resilient: after one or two poor floods and commensurately poor production, a healthy swell will allow fodder to thrive again.

According to Zwarts, 2005, during the Great Drought, many cows died and the herders lost more than half of their cattle. The collapse was due to reduced food resources as a consequence of the lack of rain and the reduction of the inundated area of the Inner Delta with two thirds. The situation further deteriorated due to overgrazing. Up to now the livestock has not yet arrived at the pre-Great Drought level. In Zwarts et al., 2005, some calculations reveal that the number of cattle, sheep and goat in the regions of Mopti and Tombouctou are expected to increase on average by roughly 4 to 5% per year, in the absence of Office du Niger irrigation and the Sélingué reservoir. The maximum amount of livestock is likely to be reduced by 10-15% due to the construction of the Fomi dam.

Navigation

Low flood events can play a detrimental factor for the navigation in the Niger River. The figure below details the period of navigation for each river sections of the Upper Niger Basin. In the Inner Niger Delta, drought events shorten drastically the period for transport and navigation.

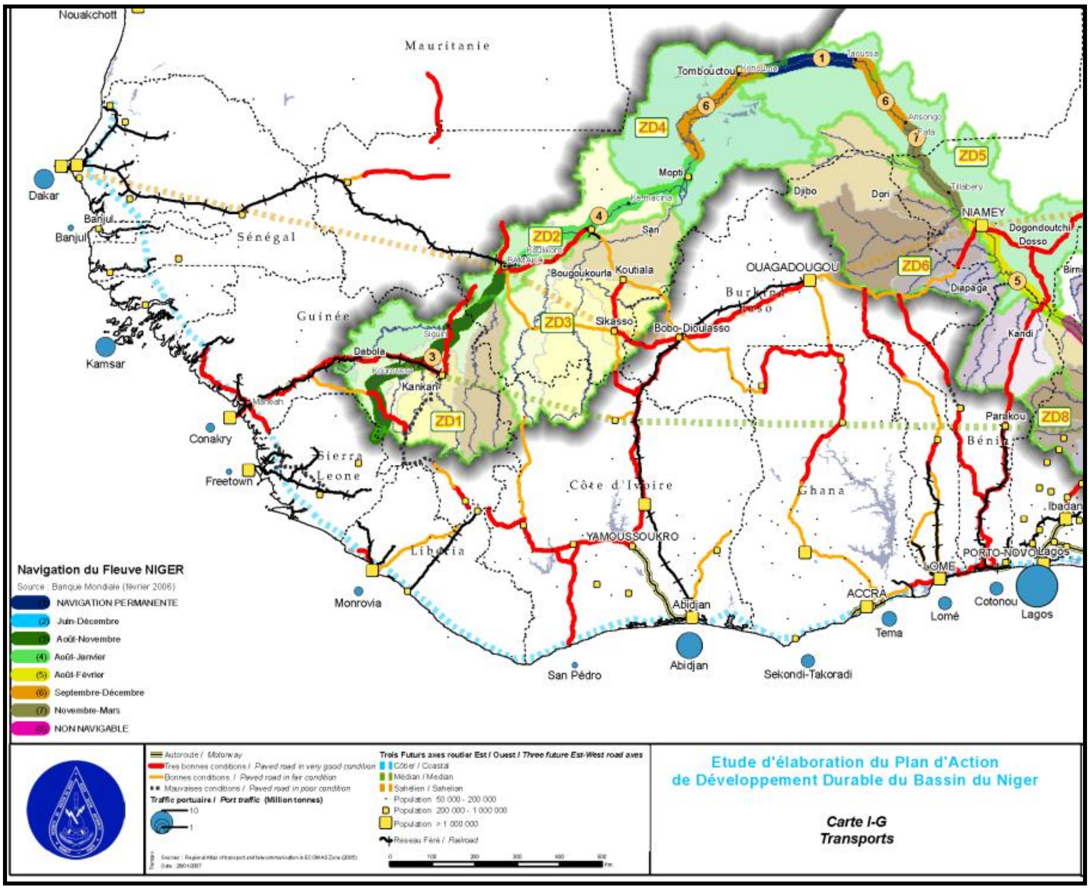


Figure 15-1 *Navigation of the Upper Niger Basin: period of practicability for the different river sections Source, BRL, and DHI. PADD, 2007*

15.1.3 Human health

(Based on Coertjens, 2011 and UNEP, 2011)

Water-related diseases such as cholera, diarrhea and Guinea worm represent more than 80 per cent of all illnesses in Mali (WWAP 2006). The availability of clean drinking water is highly limited in the country accessible by only 56 per cent of the population in 2008 (WHO/UNICEF, 2010). As a result, many depend on unimproved water supplies to meet their daily needs. Much of Mali's rural population, which makes up just under 70 per cent of the total, rely directly on untreated water from the Niger and Senegal Rivers, which serve as a breeding ground for disease.In recent years, there has been a resurgence of cholera in Mali, especially during the hot season of April to June with the outbreaks aff ecting the Mopti region in particular.

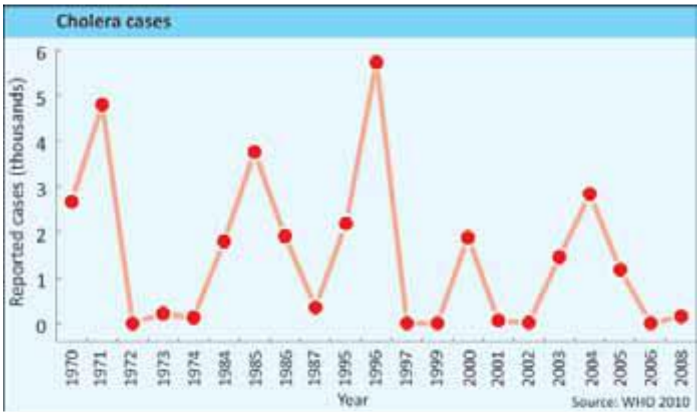


Figure 15-2 *Reported case of Cholera in Mali in thousands from 1970 to 2008. Source: UNEP, 2011 adapted from WHO, 2010*

Onchoncerosis, or river blindness, is another water-related condition that is prevalent throughout Mali. *Onchoncerosis* affects all of the river basins in Mali, spanning a total area of 350 000 km^2, placing millions of people at severe risk of exposure (AAAS 1998). Water-quality levels are further affected by agricultural, industrial and domestic pollution. Nearly all effluents from Bamako, the capital, are released untreated into the Niger River. Additional water contamination occurs from the use of pesticides and fertilizers.

15.1.4 Water use conflicts

The aim of this section is to summarize the main tensions among the different water-users that emerged or are exacerbated during drought events. The problem were mostly enunciated in Marie et al. 2007, Zwarts et al., 2005, Hassane et al., 2007. A participatory approach and a stakeholder platform are needed to mitigate the problems encountered and support the improvement of the drought preparedness with an integrated approach.

National steer investments to meet food security through the development of upstream hydro-electrical and agricultural schemes impact water use and ecosystems in the Inner Niger Delta

The population increase will also spell considerable changes in population structure. In 30 years' time, about 50% of the population will live in cities. This means that the 50% of the population living in rural areas will have to produce enough food for themselves and for the other half. As unpredictable weather patterns hamper rain-fed crop yields in general and cereal production (millet) in particular, this is an issue.

That is why the government has focused on boosting rice production (which "took off" in the late 1980s). To do so, authorities have put water management at the core of its agricultural-development agenda. This strategy, SNDI (for Stratégie nationale de développement de l'irrigation/ national irrigation-development strategy) involves building controlled- irrigation schemes for an extra 50,000 ha by 2007, plus shallow-water and controlled-submersion schemes for another 14,000 ha. By 2025, the goal is to extend the Office du Niger's irrigated land area by 120,000 ha, to a total 200,000 ha.

Even if these gravity-governed schemes were radically more efficient, irrigating the new areas would still involve diverting more water from the river during high-water and low-water stages alike. This would take us back to the critical scenario outlined above, involving the need to build a new storage/discharge dam upstream to support low-water flow. This would take an extra toll on the swell (especially when it reaches the delta) and therefore shrink flooded areas further. The risk, in other words, is that boosting rice production could tax meat and fish production (and fish production only barely covers the population's needs today). Lastly, developments in the world rice market are a factor that warrants consideration in farming-development policies, especially when arbitrating between the various options. As a reminder, one of this market's features today is the slight surplus coming from Asia. But this could change in coming years: Asia's population will continue to increase, available farmland continue to shrink (from 0.15 to 0.09 ha per person), and the green revolution should wane. Paradoxically, this scenario would be good news for Mali, as it would help its rice trade develop

Tensions between farming and transhumant livestock farming over sharing land during the flood recession and dry season (extracted from Marie et al, 2007)

In 1989, flood-fed rice plantations spanned 160,000 ha in the delta. These plantations were nomadic: farmers moved their paddies according to where they believed the swell would benefit them. The last 50 years have seen these crop areas grow in tandem with the population. Poor flooding in the 1970s and 1980s drove rice farmers to deeper basins, where they cleared the inland delta's best pastures (the bourgoutières, in particular). Back in 1952, bourgoutières were only rarely cleared. By 1989, however, 51,252 ha had been cleared and turned into rice paddies, sparking friction between farmers and herders. The hardest-hit areas are around Mopti and Tenenkou, Yongari-Mangari to the south, and along an imaginary line from Mourra to Sorme through Togoro Kotia. At that point, in other words, a quarter of the bourgoutières had been cleared. This phenomenon has not hit every area homogeneously. Clearance rates, by the yardstick used in today's rural communes can swing from 0% in one area to 82% in another. This is worrying for two reasons: first, it means herders are losing substantial amounts of grassland; second, it generates conflicts. Herding "infrastructure" (trails and shelters) is also under serious threat. In 1989, herders could not access 242 of the delta's 1,014 shelters because of plantations. In other words, about 24% of the delta's shelters were planted over. That, incidentally, was about how much bourgoutière had been cleared. A little later in the season, when the low-water stage came around (in the hot season), other issues surfaced emerged. Small village irrigation areas were "on" or "near" the paths that herds followed to water (which, of course meant that cattle trod on intensive crops). Settling these problems is a constant worry for territorial authorities and, today, for communal councils.

Farming schemes could jeopardize fish production on the plains (based on Zwarts et al. 2005)

Controlled-submersion rice plantations and, to a lesser extent, village irrigation areas, are at issue here. Fish need unobstructed access (or at least unobstructed paths) to different areas in the water environment they dwell in (at least during the swell) to breed. Almost all fish species need to access the plains to breed, feed and grow. The proliferation of facilities (small dams and gate structures) by the river (to postpone paddy and bed flooding) obstruct access and end up denaturing the flooding-plain environment. Many species are scared of venturing into the narrow whirling courses created by the valves and spillways, and end up deserting these areas. Only a few species such as the Tilapia zillii can thrive on those plains. However, as they can damage crops, rice farmers build barriers along the small internal canals to block them (understandably, after all). Unchecked, these efforts to turn plains into controlled-submersion rice paddies could well hamper fish production across the delta. But there are schemes that allow rice and fish production to coexist (and indeed create synergies). These schemes are used extensively in Asia, but have not yet attracted enough attention in Africa's rice-growing areas (especially in the Sahel region) in spite of their self-evident potential (Cofad, 2002). Threats to nation-wide food security

Poor scheme water efficiency

Poor water efficiency seems to be the weakness affecting gravity-governed schemes such as those run by the Office du Niger. It is also true that scant pressure on water resources in recent years did little to promote efficiency. Higher efficiency, however, is one of the key issues in efforts to develop these schemes and to improve overall river-water management. It is worth pointing out that large gravity-irrigated schemes are expanding at a steady pace and should continue to do so in years to come. Firstly, the networks waste a lot of water. First of all, there are huge differences between flow rates in Markala and flow rates entering the primary canals: data collected in the 1995-1996 campaign show that nearly 40% of the 36 000 m^3/ha that enter the scheme are wasted. Large pipes and *falas* (infiltration, evaporation and discharges to regulate water levels) explain some of the loss. Off-bed plantations explain another portion (water supply, in this case, can not always be controlled). But efficiency in second-tier and third-tier networks is also a problem: some divisors and irrigators supply less water than an area theoretically needs, and others supply twice as much water as necessary. Based on PSI (*Pôle système irrigué*/irrigated system unit) research, we can summarise the situation as follows.

- Water loss in hydraulic systems upstream of the *Office du Niger* (Sahel canal, Molodo *fala*, etc.) account for 40% of the total volume delivered by Markala. In other words, 60% of the water reaches the irrigation canals and beds.
- Of the 60% that reaches irrigation channels:
  - 20 to 25% (i.e. 12 to 15% of the total delivered by Markala) is lost to infiltration in the irrigation canals themselves, especially off season;
  - 35% (i.e. 20% of the total delivered by Markala) is lost to bed drainage during the rice-farming season;
  - 40% (i.e. 25% of the total delivered by Markaka) is actually used by plantations.

Also, out of season, water that enter the scheme are far higher than plantation requirements. This water builds up in groundwater tables and rises back to the surface by capillarity. When it does so, it brings salt with it. This damages paddy fertility. To a certain extent, we can hope that extending irrigated areas will in itself spur greater efficiency. Stretching irrigated areas will involve stretching water resources, and therefore entail administrating it more efficiently, even if doing so involves improving network and paddy upkeep, improving infrastructure, and improving work-organisation and planning. Whatever the case, implementing the various technical and management instruments to improve efficiency seems to be a *sine qua non* in efforts to extend irrigated systems with equanimity (which, in turn, is a political goal). The impact that these systems have on high-water and low-water flow levels has to accommodate users downstream. Diverting substantially more water into irrigation schemes will necessarily involve building a new storage and discharging dam upstream to support low-water flows and to keep them at the prescribed 40 m^3/s downstream from Markala – which, at the end of the day, would be tantamount to diverting more swell water.

15.1.5 Current drought early warning and adaptation

The aim of this paragraph is to present a non-exhaustive summary of the main initiatives taken at different scale to support the development of an early warning system and adaptations to drought in the Niger River basin and especially in the Inner Niger Delta. This section do not emphasize on the organizations and the institutes which are detailed in the “Stakeholder” section 15.4 neither on the forecast system and hydrological modelling products which are outlined in the next section 15.2 and in the section 16.3 “Collations and review of existing models”.

Global scale initiatives

The **GIEWS/SMIAR** provide up to date information on the **food security situation** of developing countries with a range of specialized reports including Country Briefs updated no less than four times per year, Crop Prospects and Food Situation., updated four times a year and Food Outlook a biannual publication, Special reports updated for particular food supply difficulties and the Sahel Weather and Crop Situation, published on a monthly basis from June to October. Other complementary tools are available in this platform including Food Price Data and Analysis Tool, Country Policy Monitoring, Interpolated Estimated Decadal Rainfall and the NDVI NDVI evolution. The GIEWS/SMIAR organization is also described in the Stakeholder section 15.4.1.

The **University of Princeton** developed a pan African early warning drought system platform in collaboration with the CILSS **(**http://hydrology.princeton.edu)**.** The monitoring system comprises two parts:

- First, a historic reconstruction (1950 – 2008) of the water cycle forced by a merged reanalysis/observational meteorological data set; this forms the climatology against which current conditions are compared.
- Second, a real-time monitoring system (2009 – present) driven by remote sensing precipitation and atmospheric analysis data that tracks drought conditions in near real-time.

Drought is estimated primarily in terms of low soil moisture, which is given as a drought index based on soil moisture percentiles. The index is calculated by determining the percentile of the daily average of relative soil moisture at each grid cell with respect to its empirical cumulative probability distribution function provided by the historical simulations (1950 – 2008). The drought index (and all hydrological variables and meteorological forcing) is available for the entire record between 1950 and real-time. Using the daily land surface model output, multiple hydrologic variables and derived drought products are estimated for more than 800 catchments over Africa. It corresponds to the Global Runoff Data Center (GRDC) network and Food and Agriculture Organization (FAO) reservoir database. The variables include: simulated discharge and basin averaged water cycle variables including precipitation, evaporation, surface runoff, baseflow, and the soil moisture drought index.

FEWS NET professionals in the Africa, Central America, Haiti, Afghanistan and the United States monitor and analyse relevant data and information in terms of its **impacts on livelihoods and markets** to identify potential threats to **food security**. Once these issues are identified, FEWS NET uses a suite of communications and decision support products to help decision-makers act to mitigate food insecurity. These products include monthly food security updates for 25 countries, regular food security outlooks, and alerts, as well as briefings and support to contingency and response planning efforts. More in-depth studies in areas such as livelihoods and markets provide additional information to support analysis as well as program and policy development. FEWS NET also focuses its efforts on strengthening early warning and food security networks with the support of satellite imagery. Activities in this area include developing capacity, building and strengthening networks, developing policy-useful information, and building consensus around food security problems and solutions. The FEWS NET organization is further described in the section 15.4.1.

DIXON, Sam, and Julius HOLT. 2010. *Zones Et Profils De Moyens D'existence Au Mali*. Special FEWS NET. Réseau du Système d'Alerte FEWS NET, USAID, FEG Consulting.

HAPEX-Sahel (Hydrological and Atmospheric Pilot Experiment in the Sahel) is an international land-surface-atmosphere observation program that was undertaken in western Niger, in the West African Sahel region. The overall aims were to improve the understanding of the role of the Sahel on the general circulation, in particular the effects of the large interannual fluctuations of land surface conditions in this region and, in turn, to develop ideas about **how the general circulation is related to the persistent droughts** that have affected the Sahel during the last 25 years. The field program obtained **measurements of atmospheric, surface and certain sub-surface processes** in a 1deg x1deg area that incorporates examples of many of the major land surface types found throughout the Sahel. An important consideration was that the data must to be applicable to the scales of current **general circulation models** (GCM).

Arnaud, Yves, Jean-Denis Taupin, and Henri Laurent. 1996. "Validation D'estimations De Précipitation Par Satellite Avec Le Réseau Dense d'Epsat-Niger." In *Interactions Surface Continentale/atmosphère : L'expérience HAPEX-Sahel*, 521–532. Colloques Et Séminaires. ORSTOM. http://www.documentation.ird.fr/hor/fdi:010008374.

Barbe, L.L., and T. Lebel. 1997. "Rainfall Climatology of the HAPEX-Sahel Region During the Years 1950-1990." *Journal of Hydrology* 188: 43–73.

Gash, J.H.C., P. Kabat, B.A. Monteny, M. Amadou, P. Bessemoulin, H. Billing, E.M. Blyth, et al. 1997. "The Variability of Evaporation During the HAPEX-Sahel Intensive Observation Period." *Journal of Hydrology* 188–189 (0) (February): 385–399. doi:10.1016/S0022-1694(96)03167-8.

Goutorbe, JP, T. Lebel, AJ Dolman, JHC Gash, P. Kabat, YH Kerr, B. Monteny, et al. 1997. "An Overview of HAPEX-Sahel: a Study in Climate and Desertification." *Journal of Hydrology* 188: 4–17.

Lebel, T., and L. Le Barbé. 1997. "Rainfall Monitoring During HAPEX-Sahel. 2. Point and Areal Estimation at the Event and Seasonal Scales." *Journal of Hydrology* 188: 97–122.

Leduc, Christian, John Bromley, and Pierre Schroeter. 1997. “Water Table Fluctuation and Recharge in Semi-arid Climate: Some Results of the HAPEX-Sahel Hydrodynamic Survey (Niger).” *Journal of Hydrology* 188-189 (February): 123–138. doi:10.1016/S0022-1694(96)03156-3.

Toma, A., and P. Hubert. 1996. “Estimation De La Pluie Par Simulation Conditionnelle Utilisant Des Mesures Provenant De Différents Instruments De Mesure.” In *Interactions Surface Continentale/atmosphère : L’expérience HAPEX-Sahel*, 373–381. Colloques Et Séminaires. ORSTOM. http://www.documentation.ird.fr/hor/fdi:010008364.

SIEREM (Système d'Informations Environnementales sur les Ressources en Eau et leur Modélisation_ www.hydrosciences.fr/sierem) is developed by the VAHYNE team of the mixed research unit HydroSciences Montpellier. This team studies at the **regional scale the hydrological variability** on the African continent. The team studies the impact of water resources under climate variability. SIEREM is a **metadatabase covering the African continent** presenting relevant elements structuring the environment and associated products (climate stations, soil, vegetation, etc.).

BOYER- J F, DIEULIN C , ROUCHE N, CRES A, SERVAT E, PATUREL J E & MAHÉ G – 2006, SIEREM an environmental information system for water resources. 5th World FRIEND Conference, La Havana - Cuba, November 2006 in Climate Variability and Change – Hydrological Impacts IAHS Publ. 308, p19-25, 2006.

The **ROSELT** (Réseau d’Observatoires de Surveillance Écologique à Long Terme_ http://193.95.75.173/roselt/) of the **OSS** (Observatoire du Sahara et du Sahel (Cf. Section 15.4.1)) is conceived to generate transboundary synergies of scientific and technical potentials and knowledge to mitigate and fight against desertification. ROSELT/OSS was primarily designed as a **long-term monitoring network** (a period of several decades) with continual collection of “ecological” data, covering all aspects of the rural environment. In order to promote harmonized methodologies for information collection and processing, and also to better understand the mechanisms which lead to desertification, ROSELT/OSS also retains the function of a **research platform**. At present, 30 circum-Saharan observatories received ROSELT/OSS certification. Amongst these, 12 are pilot **observatories**.

Loireau, M., M. Sghaier, M. Fétoui, M. Ba, M. Abdelrazik, J. M d’ Herbès, J. C Desconnets, et al. 2007. “Système D’information Sur L’environnement à L’échelle Locale (Siel) Pour Évaluer Le Risque De Désertification: Situations Comparées Circumsahariennes (réseau Roselt).” *Science Et Changements planétaires/Sécheresse* 18 (4): 328–35.

Loireau, M., and Jean-Marc d'Herbès. 2002. "Espaces, Ressources, Usages : Proposition Méthodologique Pour Le Suivi De La Désertification Dans Le Cadre Du Réseau Roselt-OSS." In *Gestion Intégrée Des Ressources Naturelles En Zones Inondables Tropicales*, 903–916. Colloques Et Séminaires. IRD ; CNRST. http://www.documentation.ird.fr/hor/fdi:010030407.

AMMA (African Monsoon Multidisciplinary Analyses_www.amma-international.org) is an international scientific group following three main goals:

- To improve our understanding of the West African Monsoon and its influence on the physical, chemical and biological environment, regionally and globally.
- To provide the underpinning science that relates variability of the WAM to issues of health, water resources, food security and demography for West African nations and defining and implementing relevant monitoring and prediction strategies.
- To ensure that the multidisciplinary research carried out in AMMA is effectively integrated with prediction and decision making activity.

AMMA is currently funded by a large number of agencies, especially from France, UK, US and Africa. It has been the beneficiary of a major financial contribution from the European Community's Sixth Framework Research Programme. The AMMA project **includes in situ measurements at many locations of West Africa** and in the Gulf of Guinea, an intensive use of **satellite data and diverse modelling studies**. Therefore, the AMMA database aims at storing a great amount and a large variety of data, and at providing the data as rapidly and safely as possible to the AMMA research community. In order to stimulate the exchange of information and collaboration between researchers from different disciplines or using different tools, the database provides a detailed description of the products and uses standardized formats. It is AMMA's aim to provide the African decision makers with improved assessments of similar rainfall changes which are likely to occur during the 21st century due to natural fluctuations and as a result of **anticipated global climate change**. An essential step in that direction is to improve the ability to **forecast the weather and climate in the West African region**.

Lebel, T., B. Cappelaere, S. Galle, N. Hanan, L. Kergoat, S. Levis, B. Vieux, et al. 2009. "AMMA-CATCH Studies in the Sahelian Region of West-Africa: An Overview." *Journal of Hydrology* 375 (1-2): 3–13.

River basin scale initiatives

In 1985, the **HYDRONIGER** (Hydrological Forecasting System in the Niger River Basin) project became operational when the International Center for Hydrological Planning in

Niamey was commissioned, under the direction of the Niger Basin Authority (NBA). This project provided a reception station, installation of 65 **data collection platforms**, a supply of data processing software (Hydrom) designed by the ORSTOM (Office pour la Recherche Scientifique et Technique d'Outre Mer), and training of hydrology technicians. Financed by the United Nations Development Programme (UNDP), the European Economic Community, and the Organization of Petroleum Exporting Countries, the project is managed by the World Meteorological Organization (WMO). Currently, only 15 stations are operational.

A pilot West and Central Africa–Hydrological Cycle Observing System (**AOC-HYCOS**) project was launched in 1996 in Ouagadougou, Burkina Faso, with French funding and was renewed in January 2000. The focus of this project was to allow national hydrological departments to post and share observations on a central Web site created by the Ecole Inter-Etats d'Ingénieurs de l'Equipement Rural (Interstate Institute for Rural Engineering) in Ouagadougou. Subsequently, the project was headquartered in Niamey, Niger, at the NBA's Centre Inter-Etats de Prévision (Interstate Forecasting Center; CIP), in association with the Centre Régional de Formation et d'Application de la Météorologie et de l'Hydrologie Opérationnelle (Regional Center for Training and Application of Meteorology and Operational Hydrology; AGRHYMET). Within AOC-HYCOS, the **Niger-HYCOS** carries out the development of the **WHYCOS** initiative in the case study basin.

WHYCOS. *NIGER – HYCOS SYSTÈME D'INFORMATION HYDROLOGIQUE AU SERVICE D'UNE GESTION INTÉGRÉE DES RESSOURCES EN EAU POUR LE BASSIN DU NIGER Composante Régionale Du Système Mondial D'observation Du Cycle Hydrologique (WHYCOS)*. WHYCOS.

In the frame of the **Water for Food and Ecosystems programs**, 22 case studies were investigated including the Inner Niger Delta, For this case study, the aim of this Malian and Dutch initiative is the development of a **decision-support system for integrated river management in the Upper Niger**, in which **ecological and social-economic impacts** and benefits of dams can be analysed in relation to different **water management scenarios** based on a sound hydrological, socio/economic and ecological data set.

In the frame of the Challenge Program on Water and Food (**CPWF**), The **Niger Basin Focal Project** is a multi-institutional research initiative that published Research Report series to carry out a diagnosis of the hydrologic and agronomic potential, before attempting to identify how good **agricultural water management** may reduce **vulnerability** in the region, and preserve local ecosystems. Major future threats and opportunities, as well as the influence of institutions on water and agricultural development are discussed.

Clanet, Jean-Charles, and Andrew Ogilvie. 2009. *Synthesis Report*. CPWF Working Paper. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.

The **NBA** (Niger Basin Authority) has worked to create a Master Plan for Development and Management of the Niger Basin under **the Action Plan for the Sustainable Development of the Niger Basin (SDAP)** which translates the 2025 Shared Vision into tangible actions to alleviate poverty, protect the Niger Basin environment and strengthen cooperation between NBA member countries. The definition of the **shared vision** was adopted in 2005 by the NBA council of ministers: "The Niger Basin, a shared region of sustainable development achieved through the comprehensive, integrated management of water resources and their associated ecosystems, to improve everyday living standards and prosperity by 2025."

The Action Plan for Sustainable Development is divided into three fields which are consistent with the priority areas of the Shared Vision.

- Field 1: The development of socio-economic infrastructure into 3 components
- Field 2: Ecosystem conservation and resources protection into 6 components
- Field 3: Capacity building and stakeholder involvement in IWRM into 4 components

The strategic guidelines for development and the operational instructions and technical principles for its implementation are derived directly from the nine principles of the Paris Declaration. Their consistency with the five mandatory goals of the NBA (in the 1987 revised NBA convention) has been ensured. They are listed below:

- Harmonize and coordinate national policies to develop the basin's water resources,
- Plan the basin's development by preparing an integrated development plan for it,
- Promote and participate to the design and operation of infrastructure and joint interest projects.
- Ensure surveillance and control of all forms of navigation on the river, its tributaries and subtributaries in agreement with the Act of Niamey, and
- Take part in the formulation of applications for support services and funding for the studies and works necessary to develop the basin's resources.

BRL and DHI. 2007a. Etudes Sur L'élaboration Du Plan d'Action De Développement Durable (PADD) Du Bassin Du Niger: Phase 1: Bilan Diagnostic. NIGER BASIN AUTHORITY (NBA).

———. 2007b. Etudes Sur L'élaboration Du Plan d'Action De Développement Durable (PADD) Du Bassin Du Niger: Annexes. NIGER BASIN AUTHORITY (NBA).

———. Etudes Sur L'élaboration Du Plan d'Action De Développement Durable (PADD) Du Bassin Du Niger: Phase II : Schéma Directeur D'aménagement Et De Gestion. NIGER BASIN AUTHORITY (NBA). 2007.

Sub-regional initiative

The project **RESSAC** (vulnérabilité des Ressources en Eau Superficielle au Sahel aux évolutions Anthropiques et Climatiques à moyen terme_www.hydrosciences.fr/ressac) is a scientific project initiated by Hydroscience, G-eau, ESO and Tetis. Focused on the Bani catchment basin, the project can be broken down into three objectives:

- The development of physically based and global model
- The analysis of actual and past situation based on hydrological measurements and satellite imageries to study the environment of the Bani and understand the vulnerability of the sahelian territory to meteorological, hydrological and agricultural drought under climate change observed since 1970
- The study of climate and socio-economic scenario to assess the change in water resources avaibility and management.

At the sub-regional level, the **GHENIS** (Gestion hydro-écologique du Niger supérieur Mali-Guinée) project supported data collection platforms and remote satellite transmission, including hydrometric sensors and water quality measurement sensors (for example, conductivity, turbidity, and temperature) in the Upper Niger River Basin (Mali and Guinea) from Bamako.

Based on this previous initiative, the **GIRENS** (Integrated water resources management of the Upper Niger basin) developed an action plan in 2007 (**PAGIRE/NS**) for the next five years to maintain the conditions of a sustainable socioeconomic development and to promote a balance between the needs to valorise the water resources and the requirements of the natural environment in order to achieve the conservation of the biodiversity and the sustainability of water resources. The actions are proposed by country, for easier implementation, but the global approach of the plan at the level of the basin constitute an example in cross-border management. 93 actions are proposed for Mali and 80 for Guinea.

Plan D'action Guinee-mali Pour La Gestion Integree Des Ressources En Eau Du Bassin Du Niger Superieur (pagire/ns). Ministère de l'Energie, des Mines et de l'Eau, REPUBLIQUE DU MALI / MINISTERE DE L'HYDRAULIQUE ET DE L'ENERGIE, REPUBLIQUE DE GUINEE.

National scale initiative

The problematic of drought hazard, mitigation, impact and vulnerability is a transsectorial issue concerning a large range of administrative levels and entities. The table below enunciates in Mali the political milestones for the inclusion of drought preparedness within an integrated framework into the formulation of national plans.

Table 2: summary of the national scale political initiative

Political milestones for the inclusion of drought preparedness problematic into national plans			
Date	**Acronym**	**National plan**	**Administration**
1998	**PNAE**	Plan National d'Action Environnementale	Ministère de l'Equipement de l'Aménagement du Territoire de l'Environnement et de l'Urbanisme, République du Mali
2001	**SSDR**	*Schéma Directeur du Secteur Développement Rural*	Ministère du développement rural, République du Mali
2001	**CDB**	Convention sur la Diversité Biologique	Ministère de l'Equipement de l'Aménagement du Territoire de l'Environnement et de l'Urbanisme, République du Mali
2004	**UNCCD**	Mali national report for the UNCCD	Ministère des Mines, de l'Energie et de l'Eau, République du Mali
2005	**PNIR**	Plan National d´Infrastructure Rural	Ministère de l´agriculture, République du Mali
2006	**CSCRP / CSLP**	Cadre Stratégique pour la Croissance et la Réduction de la Pauvreté / Cadre Stratégique de luute contre la Pauvreté	Conseil des Ministres, République du Mali
2006	**PNDE**	Politique Nationale De l'Eau	Assemblée Nationale du Mali, République du Mali
2006	**LOA**	Loi d´Orientation Agricole	Ministère de l´agriculture, République du Mali
2007	**PAGIRE**	National action plan for integrated water resources management First and Second part	Ministère de l'Energie, des Mines et de l'Eau, République du Mali
2007	**NAPA**	Programme d'Action National d'Adaptation Aux Changements Climatique	Ministère de l´équipement et des transports, République du Mali

Finally, a particular attention can be delivered to the **SAP** (Système d'Alerte Précoce du Mali), an early warning support decision system to prevent food crisis in Mali. Under the supervision of the CSA (Food Security Committee) and financed nowadays by the PRMC (Programme de Restructuration du Marché Céréalier), the system is based on a monthly data collection provided by regional administration services and NGO´s. The members of the SAP meets on a monthly basis to publish national to regional bulletins and maps summarizing the monitoring agro-climatic shocks and their impacts on food production.

Case study scale initiatives

The table below presents research project initiated the two last decades by the french institute IRD with the Malian institutes CNRST and IER. The mid-term partnership supported the formation of the CERDIN a joint scientific group between Malian and French scientists.

Table 3: Scientific projects conducted with IRD related to water management in the IND

Scientific projects conducted with IRD related to water management in the IND			
Date	**Acronym**	**National plan**	**Reference**
1986-1994	**Programme d'Etudes Halieutiques du Delta Central du Niger**		Quensière, Jacques, ed. 1994. *La Pêche Dans Le Delta Central Du Niger : Approche Pluridisciplinaire D'un Système De Production Halieutique*. ORSTOM ; Karthala. http://www.documentation.ird.fr/hor/fdi:40722.
1992-1997	**Equanis**	Programme hydrologique: Environnement et Qualité des Apports du Niger au Sahel	Orange, Didier, Robert Arfi, Marcel Kuper, Pierre Morand, and Yveline Poncet, eds. 2002. *Gestion Intégrée Des Ressources Naturelles En Zones Inondables Tropicales*. Colloques Et Séminaires. IRD ; CNRST. http://www.documentation.ird.fr/hor/fdi:010030354.
1997-2000	**GIHREX**	Gestion Intégrée, Hydrologie, Ressources et systèmes d'Exploitation	
1997	**ZADIN**:	Zone atelier du delta intérieur du Niger, GIP Hydrosystèmes	
1999	***EIDES-DIN***	Etude intégrée de la dynamique des processus ecobiophysiques et socio-économiques d'une zone humide tropicale : le delta interieur du Niger	
?	**SIMES Wise-dev**	Système d'Information Multimédia Pour l'Environnement Subsaharien	

Beside research initiative, many national and international NGO´s support sustainable management of natural resources in the Inner Niger Delta with the involvement of local authorities and local communities. The actions are diverse and cover many domains:

- formation and sensitization of communities
- knowledge dissemination and collection on the ecology of the delta
- conservation and regeneration of inundated forest and inundated pastureland
- capacity building of technical services
- development of master plan for the management of inundated forest and of local agreement for the management of inundated forest, pastureland and fisheries
- Construction of infrastructures to control water and develop irrigation schemes: small dams and reservoirs pumped irrigated methods…

To illustrate, in 2009-2011, the **REDDIN** (*Rehabilitation des Ecosystemes Degrades du Delta Interieur du Niger*) initiated by the UICN, Wetlands International and SIDA investigated the ecosystem degradation of the Inner niger Delta. Based on the diagnosis, they elaborate in collaboration to local authorities and local communities strategic axes to support a master plan for the regeneration and the conservation of the wetland milieu.

UICN. 2009. *REHABILITATION DES ECOSYSTEMES DEGRADES DU DELTA INTERIEUR DU NIGER (REDDIN) 2009-2011*.

The conclusion of REDDIN was addressed in recommendations and supported the creation of the **Strategic Development Plan for the Inner Niger Delta (PDD-DIN)** which was recently (2011) presented under the umbrella of the Ministère de l'Environnement et de l'Assainissement. The plan recognizes an important role of early warning and forecasting system. The general objective of the PDD-DIN is to '*Construire et développer une Vision partagée autour des priorités de lutte contre la pauvreté et du développement durable dans le Delta Intérieur du Niger*'. The PDD-DIN is based on a solid assessment of the current hydrological, socio-economic and ecological situation (Etats des Lieux), and a shared vision of the future of the IND of national, regional (and local?) stakeholders (vision commune). The PDD-DIN defines concrete priorities, objectives and results to be achieved for three domains: I. institutional capacity building, II: infrastructures and III. Integrated conservation of natural resources and the ecosystem in the delta. The core issue in the context of the PDD DIN is, that existing and planned upstream infrastructures, including the envisaged extension of the Office du Niger, will result in a significant reduction of the floodplain. At the same time IWRM is promoted as well as the conservation of the current ecosystem. The current PDD DIN is not (yet) steering the future direction of the IND. The impact of existing and planned upstream interventions seems to eclipse the importance assigned to the flood-dependent ecosystem and socio-economy of the delta. This will hinder the actual implementation of INR and IWRM in the delta. Within the last domain IWRM and INRM are specifically worked out. The spatial planning tool **OPIDIN** (l´Outil de Prédiction de l´inondation dans le Delta Intérieur du Niger) is recognised as an important tool to predict flooding and flood performance for users groups in the delta. Also, it is envisaged to elaborate and test OPIDIN for (wider) use and management in the delta.

PROGRAMME DE DÉVELOPPEMENT DURABLE DU DELTA INTÉRIEUR DU NIGER Programme d'Investissement Triennal Pour Le Delta Vif (2011 – 2013) (Version Définitive). 2011 Formulation du Programme de Développement Durable du Delta Intérieur du Niger (PDD-DIN). Le Ministère de l'Environnement et de l'Assainissement pour le Gouvernement de la République du Mali.

PROGRAMME DE DÉVELOPPEMENT DURABLE DU DELTA INTÉRIEUR DU NIGER Programme d'Investissement Triennal Pour Le Delta Vif (2011 – 2020) (Version Définitive). 2011Formulation du Programme de Développement Durable du Delta Intérieur du Niger (PDD-DIN). Le Ministère de l'Environnement et de l'Assainissement pour le Gouvernement de la République du Mali.

Leten, James, and Jean-Luc Frerotte. 2010. *PROGRAMME DE DEVELOPPEMENT DURABLE DU DELTA INTERIEUR DU NIGER - Document De Programme De Développement Du Delta Intérieur, 2010 - 2020 – - Document De Programme D'investissement Pour Le Delta Vif, 2011 – 2013* -. Formulation du Programme de Développement Durable du Delta Intérieur du Niger (PDD-DIN). Royal Haskoning, Le Ministère de l'Environnement et de l'Assainissement pour le Gouvernement de la République du Mali.

Leten, James, Leo Zwarts, Salikou Sanogo, and Marcel Porna Koné. 2010. *Etat Des Lieux Du Delta Intérieur- Vers Une Vision Commune De Développement* -. Formulation du Programme de Développement Durable du Delta Intérieur du Niger (PDD-DIN). Bamako, Mali: Royal Haskoning/A&W/GID, Le Ministère de l'Environnement et de l'Assainissement pour le Gouvernement de la République du Mali.

15.2 EXISTING DROUGHT MONITOR PRODUCTS

From all the initiatives and stakeholders detailed through four of the sections within this report (15.1.5, 15.3, 15.4, 16.2 and 16.3), the GIEWS/SMIAR, FEWS-NET, ACMAD with PRESAO, the Princeton University, the SAP, the SIP and the OPIDIN are all early warning platform producing updated meteorological, agricultural and hydrological drought and alerts indexes. Indexes are based on many different sources from satellite imagery to various climate products and field assessment. As an illustration, three ranges of products derived from satellite imagery are presented:

- The Interpolated Estimated Decadal Rainfall is produced for the nine Provinces of Mali (GIEWS/SMIAR with METEOSAT derived Cold Cloud Duration imagery and data on observed rainfall (GTS-Global Telecommunication System by the NOAA Climate Prediction Centre))
- The decadal NDVI anomaly from 1998-2004 mean in North and West Africa (GIEWS/SMIAR with SPOT-4 from FAO-ARTEMIS)
- Normalized Difference Vegetation Index, Rainfall Estimation, Water Requirements Satisfaction Index, Inter-Tropical Convergence Zone (FEWS-NET from NOAA, NASA, and USGS remote-sensing satellite imagery)

The objective of the DEWFORA study is to obtain an indicator referring to the four drought categories as it is defined in Mishra and Singh, 2010:

- Meteorological drought is defined as a lack of precipitation over a region for a period of time. Considering drought as precipitation deficit with respect to average values, several studies have analysed droughts using monthly precipitation data. Other approaches analyse drought duration and intensity in relation to cumulative precipitation shortages.

- Hydrological drought is related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system. Streamflow data have been widely applied for hydrologic drought analysis. In the case of the Inner Niger Delta, the hydrological drought will be better expressed with the analysis of the flood extent data.

- Agricultural drought, usually, refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources. In the Inner Niger Delta, the agriculture relies on the flood. Therefore, agricultural drought will also be expressed with hydrological parameters such as flood duration and flood peak.

- Socio-economic drought is associated with failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an economic good (water) (AMS, 2004). In the Inner Niger Delta, hydrological parameters also govern the food and water supply.

Referring to this terminology, the impact of drought will be measured with:

- Meteorological Drought indicators: RAI (Rainfall Anomaly Index) and SPI (Standardized Precipitation Index)

The standardized precipitation index (SPI) for any location is calculated, based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero

- Hydrological drought indicators: DAI (Discharge Anomaly Index and SRI (Standardized Runoff Index)

  This index is based on the concept of standardized precipitation index (SPI), discussed earlier. Shukla and Wood (2008) derived standardized runoff index (SRI) which incorporates hydrologic processes that determine the seasonal loss in streamflow due to the influence of climate. As a result, on month to seasonal time scales SRI is a useful complement to SPI for depicting hydrological aspects of droughts

- Drought agricultural indicators

The agricultural production in the Inner Niger Delta is not based on rainfed agriculture. It depends mainly on the flood regime. Specific flood indexes will be built according to the particularity of the case study and according to the stakeholder's requirements and depending on the improvements of the SWIM Inundation model capabilities: The Maximum Annual Flood Extent Index or the Potential Area with Adapted Flooding could be used as extended indexes to address agricultural drought vulnerability in the delta.

- Socio economic drought indicators:
  A correlation between the other indicators with socio economic variables such as Hydropower production, National/Regional GDP growth, National/Regional agricultural production (according to agricultural schemes), National/Regional Fish capture, Regional waterbirds census, Regional total number of livestock will be studied. The workshop in Mali will allow identifying with the stakeholders the socio economic data available to perform this task.

Finally, the annual and monthly spatio-temporal variability of the climate products will be then translated into basic meteorological and hydrological drought indexes (SPI; SRI and a Maximum Annual Flood Extent Index MAFEI). The correlation between the meteorological and hydrological droughts will be then investigated and presented. Additionally, if the improvement of the inundation module in the hydrology section allows reproducing the inundation mechanism in the Inner Niger Delta at a scale which enables to represent the potential uses of the water resources, some special flood indexes could be then further calculated, for instance the area that would potentially fits to support an activity that requires suitable flooding conditions for the cultivation of rice paddies.

15.3 CURRENT DROUGHT FORECASTING TOOL

The drought forecasting product, tool and model used in DEWFORA project (ECMWF and SWIM) are described in the chapter 16. For the rest, three type of drought forecasting tool can be dissociated for the application of the Niger case study:

Meteorological forecast

West Africa's Seasonal Outlook Forum, **PRESAO**, was established in 1998, and has occurred annually each May to provide a consensus forecast for the coming July September rainfall season. The PRESAO brings together scientists and hydrologists from National Meteorological and Hydrological Services (NMHSs), and climate forecasting centres from across the region (ACMAD, AGRHYMET) and the world (Met Office, Meteo France, the International Research Institute for Climate and Society [IRI], the National Oceanic and Atmospheric Administration Africa Desk, the World Meteorological Organization), to discuss and agree on the forecast for the July-August- September rainy (JAS) season over west Africa. Hosted every year in May by the African Centre of Meteorological Applications for Development (ACMAD), this consensus forecast issued at the end of the PRESAO forum, is the most authoritative voice on conditions most likely to prevail over the upcoming JAS season in West Africa, Cameroon and Chad.

Meteorological to hydrological drought forecast

In Bader et al., 2006 and 2009 and in Bader, 2008a and 2008b, a statistical adaptation was applied between Koulikouro gauge in the Upper Niger basin to the seasonal rainfall forecast from Arpege Climat calculated at the beginning of August and September and presented in monthly indexes on a 300 km grid resolution covering all West Africa. Three versions of Arpege were successively studied Arpege forced 3 and 4.6 and Arpege 4.5 coupled.

.

Bader, J.C., J.P. Piedelievre, and J.P. Lamagat. 2006. “Prévision Saisonnière Du Volume De Crue Du Fleuve Sénégal: Utilisation Des Résultats Du Modèle ARPEGE Climat.” *Hydrological Sciences Journal* 51 (3): 406–417.

Bader, Jean-Claude. 2008a. *Prévision Saisonnière Des Volumes De Crue Sur Les Fleuves Sénégal Et Niger à Partir Des Sorties Du MCGA Arpege (versions 3 Et 4.6 Forcé Et 4.5 Couplé) : Synthèse Des Résultats Obtenus Entre 2000 Et 2008*. IRD. http://www.documentation.ird.fr/hor/fdi:010046998.

———. 2008b. *Prévision Saisonnière Du Volume Naturel De Crue Des Fleuves Sénégal Et Niger, Basée Sur Les Résultats Du Modèle ARPEGE Climat “Couplé”*. IRD. http://www.documentation.ird.fr/hor/fdi:010046993.

Bader, Jean-Claude, Laurence Casenave, and J.P. Piedelièvre. 2007. *Relation Entre Prévisions Saisonnières De Pluie Du Modèle ARPEGE Et Volume De Crue Du Fleuve Niger*. IRD ; CNRM. http://www.documentation.ird.fr/hor/fdi:010046995.

Hydrological to Flood forecast

The **SPIAC** (Système de Prédiction, d´Information et d´Alerte sur les crues) was a platform managed by the DRH (Direction Regionale de l´Hydraulique) with the involvement of Malian partners (IER, ORM, OPM, DRA, AGRHYMET). This flood prediction tool is not anymore monitored and updated.

The **SIP** (**Informatic Forecast System**_ http://nigerhycos.abn.ne/portal/spip.php?article228) also simply called the **Hydrological forecast** aims to predict in advance the flood based on the information provided by a network of hydrometeorological stations. Created in 1984, the system was updated and transferred in 2010 to the Interregional Forecast Centre and to the basin observatory of the NBA (Niger Basin Authority) that publish an hydrological forecast on a monthly step. Groups of models were developed to simulate prediction from 2 to 5 days, from 1 to 2 weeks, from 1 to 2 months or 150 days ahead on two specific sites in Mali (Diré and Ansongo).

OPIDIN (Outil de Prédiction de l´inondation dans le Delta Intérieur du Niger is a predictive model to forecast the flooding of the Inner Niger Delta. A first version of OPIDIN2 was developed in 2009 within a study carried out by Royal Haskoning, Altenburg & Wymenga Ecological Consultants and Wetland International. This study was financed by “Partners for Water”, a joint initiative of six departments of the Government of the Netherlands. Wetlands International (Sévaré) took the initiative to explore the possibilities to extend the model and asked A&W to investigate how OPIDIN may be extended and improved.

The work was done in the framework of the Wetland & Livelihoods Project: *GIRE (Gestion integrée de resources naturelles)*. OPIDIN functions as an early warning system and is thus an essential tool for the people, being either fishermen or farmers, to achieve food security. The existing model is based on the daily measurements of the water level in Mopti and in Akka (central part of the Inner Niger Delta) since 1956. The data were made available by DNH in Bamako and in Sévaré. For each year the maximal water level, and the correlated date was related to the water level measurements with linear regression functions taken the same year on 10 July, 20 July, 30 July, 10 August, 20 August, 30 August, 10 September, 20 September and 30 September. With this method, the water levels in Mopti and in Akka are analysed to predict the timing and the level of the peak flood in Mopti and Akka. Measured water level in July-September in Akka to predict the timing and the level of the peak flooding also in Akka*,* OPIDIN published tables with the predicted peak flooding (date and level), being usually in November, as a function of the measured water level in August and September. The analyses clearly showed that there is no relationship between the peak flood and the water level such as measured in July. The predictions appeared to be not precise in August, but rather accurate in September. To conclude, there are many possible extensions and improvements of OPIDIN that were already detailed by the developers of OPIDIN.

- Extend OPIDIN to hydrological stations located in the headwaters
- Correlate statistically the rainfall of the Upper Niger Basin with the water level
- Extend the time series of water level to the last decade
- Improve the confidence interval with the use of other regressions approaches

- Study the impact in the statistical prediction from the alteration of flow regime due to the implementation of new river basin infrastructures (construction of dams and channel diversion for irrigated schemes).
- Extrapolate the prediction to the estimation of the flood extent with the conversion into digital water maps based on satellite imagery from LANDSAT during flooding and deflooding

Wetlands International, and Altenburg & Wymenga. 2007a. “OPIDIN: Un Outil D’aide à La Décision Pour Les Usagers Des Eaux D’inondation Du Fleuve Niger Dans Le Delta Intérieur” July, Sévaré, Mali.

———. 2007b. “OPIDIN: Un Outil Pour Prédire La Crue” July, Sévaré, Mali.

Zwarts, Leo. 2009. *Predicting the Annual Peak Flood Level in the Inner Niger Delta. A&W-rapport 1254. Altenburg & Wymenga, Ecological Consultants, Feanwâlden.* A&W-report. Altenburg & Wymenga ecologisch onderzoek.

———. 2010. *Towards a Further Extension of the OPIDIN tool/Vers Une Nouvelle Extension De L’outil OPIDIN*. A&W-report. Altenburg & Wymenga ecologisch onderzoek.

15.3.1 Existing gaps in management systems, organization and information

Despite the large number of research, project, programs, organizations, stakeholders and scales concerned with the problematic of early warning drought system and preparedness, the initiatives remain uncoordinated at best, and haphazard and disjointed at worst, leading to the sorry observation that climate forecasting does not play a major role in the region. The system in place is still concatenated according to scientific discipline and sectorial uses. A drought system may account to a transdisciplinary approach and multisectorial information to serve the different stakeholders and communities acting at different scales and in a large range of activities (food security, meteorological forecast, hydrological forecast, desertification process, natural resources management (vegetation cover, halieutic system), climate change impact,...). Early Warning-Early Action based on forecast information is a concept that can be rendered operational in West Africa, provided there is a common desire from both climate scientists and user communities to work together and endeavour to overcome the plethora of obstacles thwarting communities’ access and use of climate information.

According to Tall, 2010, “the increase in forecast skill has not translated itself into improved decisions and increases in social welfare, and climate forecasting has not fulfilled its promise

of aiding society in better managing climate risk and better anticipating and preparing for climatic
hazards. West Africa, one of the world's lowest income regions, is one of such area where forecasts are not useful to society. Despite the significant potential of early information about likely climatic hazards to save lives and preserve livelihoods in this highly climate sensitive region, only a few instances exist of successful transmission and use of available climate and weather forecasts and other climate risk management tools by policymakers and communities at risk across the region."
Tall highlights the remaining gaps into six main obstacles by describing the experience in 2008 from Red Cross volunteers to disseminate the prevention of seasonal forecast to the grassroots level and to the communities:

1. Bridging the gap between forecasters and community-level decision-makers and vulnerable groups: Initiating forums that bring together national-level forecasters and local-level stakeholders and open communication lines between the two will enable community access to contextual forecasts.
2. Overcoming language barriers: The current format and content of the forecast bulletins routinely produced by National Meteorological and Hydrological Services constitute a limiting factor to vulnerable communities' uptake of forecasts. Simplifying the content of forecast bulletins and ensuring that they highlight potential actions/decisions that can be endeavoured by individuals and based on the forecast will render forecast information actionable and more easily absorbed by communities.
3. Overcoming communication system barriers: Building the capacity of Red Cross volunteers and other trusted community level actors (for instance, agricultural extension workers and in some cases, the local military) and media (for example, community radio) to serve as community relays of climate information is an example of how information sharing channels can be established from the national to district level on to communities drawing on existing institutions. This will be needed to enable the trickling down of timely and salient climate information to communities at risk.
4. Developing a trust relationship between communities and providers of climate information is key; indeed communities will not incorporate new information that they do not trust or deem reliable.
5. All these measures will prove ineffective, however, unless they are on-going in tandem with development and poverty reduction programs that strive to reduce the overall vulnerability of communities and enable them to build their resilience to all shocks (climatic, economic, social, political). Such programs are imperative to build the capacity of communities to act on received forecasts and empower them to link early information with early actions.
6. Overcoming scientific barriers: Investing in climate research and data collection equipment to promote better skill and forecasting ability over the West Africa region is important so that climate forecasting may be able to continually deliver information salient to users' needs. The focus of current efforts ought to be, however, on making currently existing climate information

(from seasonal forecast information to short-range weather advisories) widely available to and usable by communities that need it.

To conclude this section, Amany, 2006 highlights capital lessons learned from the tentative of establishing a Flood Forecasting System for Integrated Natural Resources Management in the Niger Inner Delta in Mali

1. The importance of the participatory approach to define the stakeholders needs;
2. The importance of consultation framework for exchanging of information;
3. The implication of the stakeholders in the construction of the forecasting model based on their real needs;
4. Presentation of the forecasting model to stakeholders to have their feedback to improve the model

15.4 STAKEHOLDERS

The aim of this section is to present all the organizations and the stakeholders concerned with the problematic of the DEWFORA project for the Inner Niger Delta case study. We can distinguish the organizations and the stakeholders into four scales.

15.4.1 Producers of available monitoring and forecast products

International to regional organizations: the West African or Sahelian scale

International organizations concerned with the IWRM for the Niger river in Mali			
International organizations	**International Research Institute**	**Early warning, forecasting and aid systems**	**Technical partners**
United Nations Convention to Combat Desertification (UNCCD)	Institut de recherche pour le développement (IRD, ex-ORSTOM)	Weather and Climate Centre with African continental competence (ACMAD)	United Nations Development Programme (UNDP), United Nations Development Capital Funds (UNCDF)
United Nations Framework Convention on Climate Change (UNFCCC)	Centre Regional Agrhymet (CRA)	Food crisis prevention network (RCPA)	
Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel (CILSS)	Sahel Institute (INSAH)	USAID Famine Early Warning Systems Network (FEWS NET)	World Bank, African Development Bank Group (BAD), West African Development Bank Group (BOAD), Inter-American Development Bank (IADB), Arab Bank for Economic Development in Africa (BADEA)
Sahel and West Africa Club (CSAO/SWAC)	African Monsoon Multidisciplinary Analyses (AMMA)	FAO Global Information and Early Warning System (GIEWS/SMIAR)	
RAMSAR Convention on Wetlands	International Crops Research Institute for the Semi-Arid Tropics (ICRISAT)	Office for the Coordination of Humanitarian Affairs (OCHA)	Cooperation from European Union, France (Agence Francaise de développement (AFD)), Luxemburg, ,Netherlands, Switzerland, Belgium, Danemark, Germany, Canada, Japan...
Economic Community Of West African States(ECOWAS)	Observatoire du Sahel et du Sahara (OSS)	European Community Humanitarian Office (ECHO)	
World Meteorlogical Organization: WHYCOS Niger-Hycos	Other international and french research units: IWMI, CIRAD, G-eau, Hydroscience...	Other experimental systems: Princeton, IRD, G-eau...	Funds from Saoudian Arabia, Koweit , OPEC (Organization of Petroleum Exporting Countries)

International organizations

In 1993, the WMO promoted a global observation system for the hydrological cycle (World Hydrological Cycle Observing System; **WHYCOS**_ http://www.whycos.org/cms/), using monitoring reference stations (hydrological observatories) with real time or near real time data transmission. The current application in the Niger River is called Niger HYCOS and is further described in the section 15.1.5.

The **ECOWAS/CEDEAO** (Economic Community Of West African States_ http://www.ecowas.int/) is a regional group of fifteen countries, founded in 1975. Its mission is to promote economic integration in "all fields of economic activity, particularly industry, transport, telecommunications, energy, agriculture, natural resources, commerce, monetary and financial questions, social and cultural matters ....." The ECOWAS Commission and the ECOWAS Bank for Investment and Development, more often called The Fund are its two main institutions designed to implement policies, pursue a number of programmes and carry out development projects in Member States. Such projects include intra-community road construction and telecommunications; and agricultural, energy and water resources development. ECOWAS published in 2008 the “Atlas de l´intégration régionale en Afrique de l'Ouest”, Série environnement with the CSAO

The **CSAO/SWAC** (Sahel and West Africa Club_ www.oecd.org/csao) is a group of West African regional organizations, countries and international organizations that work together towards the development and integration of the West African region. The Club’s mission is to pool together Members’ experiences, ideas and perspectives to help build more effective regional policies. Drawing on factual studies and independent analyses, the Club devises strategic guidelines and policy tools for Members and other stakeholders. The Club is also a space for policy dialogue. As a member of the OECD Development Cluster, the SWAC Secretariat contributes to the work of the Organization and ensures that West African concerns and initiatives are taken into account in global debates, particularly those on food, energy and security issues.

Three international conventions have a strong link to drought hazard problematic in the Niger River. Established in 1994, the United Nations Convention to Combat Desertification (**UNCCD**_ www.unccd.int) is the sole legally binding international agreement linking environment and development to sustainable land management. The Convention addresses specifically the arid, semi-arid and dry sub-humid areas, known as the drylands, where some of the most vulnerable ecosystems and peoples can be found. In the ten-year Strategy of the UNCCD (2008-2018) that was adopted in 2007, Parties to the Convention further specified the aim for the future to be *..."to forge a global partnership to reverse and prevent desertification/land degradation and to mitigate the effects of drought in affected areas in order to support poverty reduction and environmental sustainability"*. In 1992, countries joined an international treaty, the United Nations Framework Convention on Climate Change (**UNFCC**_www.unfcc.int), to cooperatively consider what they could do to limit average global temperature increases and the resulting climate change, and to cope with whatever impacts were, by then, inevitable. Finally, the Convention on Wetlands (**Ramsar**_www.ramsar.org, Iran, 1971) -- called the "Ramsar Convention" -- is an intergovernmental treaty that embodies the commitments of its member countries to maintain the ecological character of their Wetlands of International Importance and to plan for the "wise use", or sustainable use, of all of the wetlands in their territories.

The **CILSS** (Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel_ www.cilss.bf) is an intergovernmental organization created in 1973 representing nine countries supporting regional support program and initiatives to mitigate drought and desertification processes and food security issues to find a new ecological balance in the Sahel. The CILSS has also two specialized organizations called CRA (Centre Regional Agrhymet) and INSAH (Sahel Institute). The university of Princeton In collaboration with the university of Washington created recently an African drought monitor platform.

International research institute

The **INSAH** (Sahel Institute_ www.insah.org) is a specialized institute of CILSS that aims to contribute to facilitate the exchange between national systems that operate in the research domain (agriculture/population/development) to impulse a dynamic of cooperation and propose actions to sustain productive agriculture and a better management of the natural resources. The INSAH shares experiences though an online data base and archives.

The **CRA** (Centre Regional Agrhymet_ http://www.agrhymet.ne) is a specialized institute of CILSS that aims to contribute to food security and the increase of food production in the members countries of CILSS and to support the improvement of the natural resources management in the Sahel. The CRA publishes monthly and decadal bulletins addressed to decision-makers and stakeholder. The CRA has an extensive database covering socio-economic statistics, meteorological, hydrological indicators GIS and satellite products.

IRD (Institut de recherche pour le développement) is a French research organism emphasizing interdisciplinary and focusing since 65 years on the relations between the society and the environment especially in intertropical. The research, formation, and innovation activities aim to contribute to the social, economic and cultural development of southern countries. The section 15.1.5 presents the long term involvement of this organization in the development of research project in Mali.

The **Observatoire du Sahel** et du Sahara (OSS) is an independent international organization founded in 1992 and incorporating 22 members countries that aims to improve early warning and monitoring systems for agriculture, food security and drought in Africa. The experience is capitalized though the access of a virtual library. ROSELT presented in the section 15.1.5.

The **ICRISAT** (International Crops Research Institute for the Semi-Arid Tropics_ http://www.icrisat.org) conducts research for the adaptation to climate change in relation to crops. They developed the WASA (West Africa Seed Alliance), a system whose primary role is the adaptation and the selection of appropriate seeds to the climate condition imposed by climate change in six West African incorporating countries.

Created in 1987 by the Conference of Ministers of the United Nations Economic Commission for Africa (UNECA) and the World Meteorological Organisation (WMO), the **ACMAD** (Weather and Climate Centre with African continental competence) is composed of 53 Member African States. ACMAD's mission is the provision of weather and climate information and for the promotion of sustainable development of Africa (notably within the context of national strategies for poverty eradication), in the fields of agriculture, water resources, health, public safety and renewable energy.

Early warning, forecasting and aid systems

The **RCPA** (Food crisis prevention network_ http://www.food-security.net/) is an exchange and decision support platform created in 1985 under the initiative of the CSAO/SWAC (Sahel and West Africa Club) and the CILSS (Comité permanent Inter-Etats de Lutte contre la Sécheresse dans le Sahel) between the following members: FEWS NET (Famine Early Warning Systems Network), GIEWS/SMIAR (FAO *Global Information and Early Warning System* on Food and Agriculture), WFP (United Nations *World Food Programme*), *OCHA* (Office for the Coordination of Humanitarian Affairs), HIC (Humanitarian Information

Centres), ECHO (European Community Humanitarian Office), Afrique verte Internationale, RELIEFWEB (United Nations website providing information to humanitarian relief organizations). The RCPA publishes collective bulletins related to the West African Food security situation.

The **FEWS NET** (Famine Early Warning Systems Network_ http://www.fews.net) is a USAID-funded activity that collaborates with international, regional and national partners to provide timely and rigorous early warning and vulnerability information on emerging and evolving food security issues. FEWS NET products are detailed in the section 15.1.5.

The **GIEWS/SMIAR** (FAO Global Information and Early Warning System on Food and Agriculture_ www.fao.org/giews/english/index.htm) is an open forum for the exchange of information on food security. The system continually receives economic, political and agricultural information from a wide variety of official and unofficial sources. Since 1975, institutional links and information-sharing agreements have been established with several UN organizations, 115 governments, 4 regional organizations and 61 NGOs. A description of the products delivered by GIEWS/SMIAR is presented in the section 15.1.5.

*The **OCHA*** (Office for the Coordination of Humanitarian Affairs), **ECHO** (European Community Humanitarian Office) are the respective humanitarian office of the United Nations and the European Union. **RELIEFWEB** and **HIC** (Humanitarian Information Centres) are the respective United Nations and EU website providing information to humanitarian relief organizations.

15.4.2 Regional Climate outlook forums

The NBA (Niger Basin Authority_ http://www.abn.ne/**)** is an intergovernmental organisation in West Africa aiming to foster co-operation in managing and developing the resources of the basin of the River Niger between the nine membered nations: Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, Niger and Nigeria. The group is referred to by both French and English acronyms, **NBA** or **ABN**. The Niger Basin Authority defines its purpose as the promotion of cooperation among member countries to ensure integrated development of resources. The organisation originally defined its mission as the cooperative management of water resources, most notably, but not limited to, the Niger River. While centering of water and hydroelectric resources, the NBA nations use the organisation to harmonize development of energy, agriculture, forestry, transport, communications, and industrial resources of the member nations. A very detailed description of the historical development of the NBA is given in Andersen et al., 2005. The NBA itself has been ceded no sovereign power over resources or management, and therefore all regulation must be imposed by individual sovereign governments. The regional institutional architecture of the NBA today includes the Conference of Heads of State and Governments (the ultimate decision-making entity), the Council of Ministers, the body in charge of establishing the general policy and of control, and the Executive Secretariat, which is the executive entity of the NBA. It is planned to complete the organisation with new entities competent at basin level; these entities would ensure solidarity and reciprocity between the Member States the Permanent Technical Committee and the Regional Consultative Panel. In Mali, the ABFN (Agence du Bassin du Fleuve Niger) was also created in 2002 to group the Malian actors into an effective national and political platform. While not the original focus of the NBA, environmental protection from the threats of desertification, deforestation and pollution of the rivers by agriculture and industry have become a major theme of their work.

15.4.3 Users requirements for a drought forecast system

The table lists the authorities in Mali at different administration level that is associated in the integrated river basin management. More details can be found in the section “15.1.5 Current drought early warning and adaptation: National scale initiative“ and in the two following documents:

Plan d’Action National De Gestion Intégrée Des Ressources En Eau (1ère Partie), 2007, Etat Des Lieux Des Ressourcesen Eau Et De Leur Cadre De Gestion. Ministère de l’Energie, des Mines et de l’Eau, REPUBLIQUE DU MALI.

Plan d’Action National De Gestion Intégrée Des Ressources En Eau (2ème Partie). 2007, Ministère de l’Energie, des Mines et de l’Eau, REPUBLIQUE DU MALI.

National authorities to decentralized administrative units			
Ministries	**Ministerial departments**	**Technical services and national companies**	**Decentralized administrative units and consultative structures**
Ministère de l'Energie, des Mines et de l'Eau	Direction Nationale de la Météorologie (DNM)	Division Hydraulique Rurale	Assemblée Régionale
Ministère de l'Environnement et de l'Assainissement	Direction Générale de l'Autorité de l'Aménagement de Taoussa,	Division Aménagements Hydrauliques	Conseil de Cercle
Ministère de l'Elevage et de la Pêche	Direction Nationale de l'Energie (DNE)	Division Inventaire des Ressources Hydrauliques	Conseil Communal
Ministère de l'Agriculture	Direction Nationale du Génie Rural (DNGR)	Division Normes et Réglementation.	Conseil National de l'Eau
Ministère de la Santé	Direction Nationale de l'Assainissement et du Contrôle des Pollutions et des Nuisances (DNACPN)	Division de l'Hydraulique Urbaine	Conseils Régionaux et Locaux de l'Eau
Ministère de l'Administration territoriale et des Collectivités locales	Direction Nationale de la Conservation de la Nature (DNCN)	Directions Régionales de l'Hydraulique et de l'Energie (DRHE)	Comités de bassins ou de sous bassins
Ministère de l'Economie, de l'Industrie et du Commerce	Direction Nationale de la Santé (DNS)	Services Subrégionaux de l'Hydraulique et de l'Energie (SSRHE)	Commission de Régulation de l'Eau et de l'Electricité (CREE).
Ministère des Affaires Etrangères et de la Coopération Internationale	Direction Nationale des Collectivités Territoriales (DNCT)	Compagnie Malienne de Navigation (COMANAV)	
Ministère des Finances	Direction Générale de l'Agence du Bassin du Fleuve Niger (ABFN)		
Ministère du Logement, des Affaires foncières et de l'Urbanisme	Direction Administrative et Financière		
Ministère de l'Equipement et des Transports	Direction Nationale de la Géologie et des Mines		
	Direction Nationale de l'Energie		
	Direction Nationale de l'Hydraulique (DNH)		
	Direction Nationale des Transports		

15.4.4 Sectorial stakeholders

The stakeholders can be presented using sectorial approaches. For education and research in Mali, the following organizations listed conduct research project for the development of an integrated river basin management approach. The role of the **CNRST (Centre National de la Recherche Scientifique et de la Technologie)** in the development of research project is also of prime importance. To account for the view of farmers using irrigated systems the organization in Mali of irrigated agriculture fields into Office (see Section 15.1.1) facilitates the approach. To account for farmers using free submersion, local associations may be then approached. For fishing and herding communities, some active associations defend the interest of the activities. Finally, the association of the Dioros is particularly important to account for customary practices.

Sectorial stakeholders				
Irrigated agriculture	**Fishery, Pastoralism**	**Ecology, biodiversity and NGO´s**	**Others (Tourism, Hydropower, Drinking water supply)**	**Education and research**
Office du Niger (ON)	Association des Dioros	Groupe d'Actions pour la Sauvegarde du Fleuve Niger (GASFN)	Comité des utilisateurs du Bassin du Niger	Ecole Nationale des Ingénieurs de Bamako (ENI)
Office Riz Ségou (ORS)	Fédération Malienne des Groupements de la Filière Poisson (FMGFP)	Wetlands International (WI)	Sociétés d'exploitation hydro énergétiques	Ecole Centrale pour l'Industrie, le Commerce et l'Administration
Office Riz Mopti (ORM)	Association des Pêcheurs Résidents au Mali (APRAM)	Union International Conservation de la Nature (UICN)	Office Malien du Tourisme et de l'Hôtellerie (OMATHO)	Centre de Perfectionnement des Métiers de l'Eau (EDM-SA)
Office de la Haute Vallée du Niger (OHVN)	Association des Pêcheurs et Pisciculteurs du Mali (APPM)	Care Mali	Centre National de Promotion de l'Artisanat (CNPA)	Université de Bamako
Office du Péimètre Irrigué de Baguineda (OPIB)	Associations de pêcheurs du Delta Central du Niger, de Sélingué etc...	International Institute for Environment and Development (IIED)	Associations d'Usagers d'Adduction d'Eau Potable (A U E P)	Institut polytechnique rural (IPR-IFRA) de Katibougou
Office du Développement Rural de Sélingué (ODRS)	Associations régionales et locales d´éleveurs	SOS Sahel	Coordination des Associations des Professionnels de l'Eau et de l'Assainissement (CAPEA)	Institut d'Economie Rurale (IER)
Office des Produits Agricoles du Mali (OPAM)	Fédération Nationale des Groupements Interprofessionnels de la filière Bétail, Viande			Groupe des Ecoles Inter Etats de l'hydraulique et de l'équipement rural
Association Malienne d'Irrigation et de Drainage (AMID)				École Inter-États de l'équipement rural (EIER)
Association des agriculteurs à l´échelle communale				École Inter Etat des techniciens supérieurs de l'hydraulique et de l'équipement rural (ETSHER)

Some NGO´s with a regional branch and office in Mali actively support environmental diagnosis and application of conservation practices.

The **GWI** (Global Water Initiative) in West Africa is a consortium of five organizations (International Institute for Environment and Development (IIED), International Union for the Conservation of Nature (IUCN), Catholic Relief Services (CRS), CARE International, SOS Sahel (UK)) that support the development of long term access to water supply and sanitation addressed to vulnerable and poor population. The program aims also to protect and manage ecosystem services and hydrographic basins.

To conclude, **Wetlands International** in Mali capitalizes a long experience in the Inner Niger Delta. They are involved in research, governmental and community projects (OPIDIN, Bio-right, AFROMAISON, and WETWIN). Wetlands International publishes reports on the natural resources management and the conservation of the biodiversity and the ecology of the diverse habitats forming the Inner Niger Delta wetland.

Wetlands International. 2009. *Planting Trees to Eat Fish Field Experiences in Wetlands and Poverty Reduction*. Wetlands International report.

Wetlands International / Altenburg & Wymenga conseillers écologiques / Alterra / RIZA.. *Impact of Dams on the People of Mali*. Wetlands International report.

MAIGA, Mohamed Alhousseiny. 2009. *Evaluation Du Projet De Réduction De La Pauvreté Dans Le Delta Intérieur Du Niger (PRPDIN), Région De Mopti Composante Bio-Rights Rapport Final*. Wetlands International / Care Mali.

UICN, Wetlands International, and Sida. 2010a. *Projet De Rehabilitation Des Ecosystemes Degrades Du Delta Interieur Du Niger (reddin) Rapport Technique*.

———. 2010b. *RAPPORT TECHNIQUE PROJET DE REHABILITATION DES ECOSYSTEMES DEGRADES DU DELTA INTERIEUR DU NIGER (REDDIN), COMPOSANTE 4 : Recherche Action*.

Wymenga, Eddy, Bakary Kone, Jan van der Kamp, and Leo Zwarts. 2002. *Delta Intérieur Du Niger. Ecologie Et Gestion Durable Des Ressources Naturelles*. A&W report / Mali-pin publication 2002-01. Wetlands International / Altenburg & Wymenga conseillers écologiques / Alterra / RIZA.

Zwarts, L., P. van Beukering, B. Kone, and E. Wymenga. 2005. *The Niger, a Lifeline, Effective Water Management in the Upper Niger Basin*. RIZA IVM / WISO / A&W. http://www.altwym.nl/uploads/file/133Executive%20summary%20-%20The%20Niger,%20a%20lifeline.pdf.

15.4.5 DEWFORA stakeholder workshop

The table summarizes the preliminary list of the stakeholder organizations from which representatives will potentially join the workshop in April 2012 in Sélingué. The stakeholders selected mostly represent the actors from the Inner Niger Delta as the first objective is to disseminate the information at the case study scale the Inner Niger Delta but also at the local level. Therefore, a focus on four study zones in the Inner Niger Delta was suggested by Wetlands International to test locally the implementation. The stakeholders representing Diafarabé, Mopti, Akka and Lac Faguinibé are listed below. The actual list will be updated to fit to the needs of the AFROMAISON and DEWFORA project.

Acronym	Organisation	General	Diafarabe	Mopti	Akka	Lac. nord
	Assemblée régionale de Mopti	+		+		
	Association des agriculteurs des communes de Youvarou et Deboye				+	
DIOROS	Association des Dioros	+				
	Association des éleveurs des communes de Youvarou et Deboye				+	
	Association des pêcheurs des communes de Youvarou et Deboye				+	
ABN	Autorité du Basin Fleuve Niger	+				
	Care Mali	+				
	Comité de gestion des bourgoutières de Akka et Guidio				+	

	C. des utilisateurs du Bassin du Niger (Markala et Selingué)	+			
	Conseil de cercle de Youvarou			+	
DRA	Direction Régional Agriculture	+			
DRP	Direction Régional de la Peche	+			
DRH	Direction Régional Hydraulique (DNH)	+			
DRPIA	Direction Régional Production Industrie Animale	+			
	Direction Régionale Agriculture	+			
	Direction Régionale de la Pêche	+			
DRE	Direction Régionale Elevage	+			
	Direction Régionale Hydraulique (DNH)	+			
	Energie du Mali EDM	+			
FODESA	Fond du Development au Sahel (FIDA)	+			
	Mairie de la commune de Deboye				
	Mairie de la commune de Dialloubé				
ON	Office du Niger ON	+			
ORM	Office du Riz Mopti	+	+		
	Partenariat Nationale de l'eau	+			
	Projet Lac Faguibine				+
	Projet de développement durable du DIN PDD-DIN	+			
UICN	Union International Conservation de la Nature	+			
WI	Wetlands International	+			

15.4.6 Users requirements for a drought forecast system

As a profound basis for the development of promising tools and strategies in the context of DEWFORA, it is necessary to get hold on the gaps in knowledge, constraints and lessons learned concerning the application and the use of drought forecast system. Apart from literature study and lessons learned from past projects, the first important step will be the workshop in April 2012, where this will be specific issue to be discussed and inventoried.

So far, ´the requirements emitted from the OPIDIN steering committee are to predict the timing and the maximum height of the peak flood level and to evaluate the date at which the water level will be fallen at a certain level during the deflood. The information will support the community to know when the bourgou, a typical pasture fields in the Inner Niger Delta will become available for grazing, when a certain agriculture can be started, when transport in pinasse and pirogue will be restricted. Also, the flood may be categorized into five classes (very poor, poor, average, good, and very good) which are characterized according to historical flood events. It is then crucial to sound the collective memory on the annual peak flooding to see if our classes and indicators make sense to the communities. Also, the introduction of the DEWFORA products to an extended stakeholder platform with a new range of meteorological and hydrological climate change and forecast outputs to the stakeholders will be an important step to discuss the improvement of the current OPIDIN system. Also, a particular attention will be given to weather forecast products. The prediction of rainfall locally will form a real benefit for the community to decide the appropriate date for seeding

In parallel, AFROMAISON project will initiate a field inventory on the existing information system and indicators for flood performance users groups that are used to plan – in time and space – the exploitation of natural resources. The basic inventory is to perform a science-based questionnaire among individual farmers (depending on the possibilities: some hundreds to have a large sample size), herders, fishermen and others users evenly distributed over the study areas. The hypothesis is that many of them use traditional ways but also many may have lost their cues. It has to be sorted out which constraints they encounter and what kind of information they would use in daily life. This activity will be prepared, carried out and analysed by 2iE, in narrow consult with Wetlands International and partners in AFROMAISON project including PIK. The inventory can be communicated with the stakeholders in April 2012. It will form a solid baseline for the actual way the timing and planning of the use of natural resources is being done. In this context, AFROMAISON fp7 initiative would also support the implementation of DEWFORA products.

16. DETAILED CASE STUDY APPROACH AND METHODOLOGY IN THE NIGER BASIN

From 1968 to 2002, the Sahel experienced fairly abrupt, severe and continuous dry episodes. The main reason is the oceanic forcing ruling the West African monsoon dynamic. Also, a combinative effect of climate and anthropogenic changes (demographic pressure on land associated to inappropriate land-use practices) initiates and supports the interactive processes of drying and land cover degradation forming a complex land atmosphere feedback convection which reinforced desertification processes.

The Great Drought in Mali largely affected the regional food security, the human societies and economic development and the conservation of wet and semi-arid ecosystems. It results in an increasing competition and conflicts for water access between vulnerable local stakeholders (rainfed and semi-controlled irrigation farming, nomad pastoralism, traditional fishing) and expanding steers national investments with the construction of dams and diversion channels for the development of hydropower energy and fully governed irrigated agriculture.

In the Inner Niger Delta, the activities ensuring the regional food security mainly depend on the annual flood variability driven by the monsoon and by upstream river basin management. On the one hand, the flood regime is now modified with a decrease of the peak water level during the rainy season and a water level artificially maintained higher through dam management. On the second hand, severe drought tends to be more frequent in the last decades.

The annual flooding pattern of the Inner Niger Delta is crucial for the regeneration of landscapes like the grasslands so called “bourgou”, the inundated forests and the different crop fields with free submersion and semi controlled irrigation technics pending on the peak water level. Therefore, the crop production, the hosting capacity of the ecosystem for cattle, fish and waterbird are vulnerable to the flood variability. When facing a continuous and inter annual extreme event, a high threat for the regional food supply in all sectors and for the biodiversity maintenance can be outlined. The decrease of the river flow in the basin leads to deforestation and farming of fragile soils contributing through erosion to sedimentation in river channels. Waterborne diseases increases and invasive aquatic species spread, choking river channels. Driven by a demographic pressure, the context of socio-economic poverty and the lack of alternative resources lead to unsustainable practices with a non-respect of traditional and modern rules (especially for fishery and livestock), an increasing pressure on the productive sites and an overuse of the natural resources. Moreover, the actual insecurity problems that face the region reduce drastically external investments and the development of other activities like tourism which are important sources of alternative income. Similarly, the food supply from other region is then likely to be less influent to mitigate the raising of prices. Also, the scientific and the NGO´s sphere acting to find trade-offs to solve the increasing rate of conflicts between the water users, supporting the emergence of an integrated approach and developing further applied adaptive capacities are then weakened. Finally, inadequate financial resources are provided to mitigate the combined impacts of upstream river basin management and climate variability and change.

The aim is then to contribute to poverty reduction and biodiversity protection by putting in place a participatory and sustainable management process for local development in the Inner Niger Delta. The improvement of an early warning system will contribute on a long term to the emergence from the stakeholder platform of an integrative approach to reduce multi-actor pressure on natural resources and limit steady degradation by promoting local development activities for regional stakeholders.

16.1 APPROACH TO BE FOLLOWED

Research subject and framework: a downscaling process

The research subject of the Niger case study is to formalize the interactions between the flood propagation, the food security and the biodiversity maintenance in the Inner Niger Delta in order to address drought vulnerability assessment and adaptation strategies to upstream water resources and river basin management under climate change and variability.

The research framework adopted a downscaling process approach to investigate the drought hazard at different scales that can be linked to three different approaches of drought: meteorological drought from global to regional scale, hydrological drought from regional to basin scale and socio-economic drought (including agricultural) from basin to local scales. Three major sections are identified to integrate the local scale to the context of regional change resulting from climate forcing and upstream adaptation strategies.

To pass from global to regional scale, the uncertainties in the climate distribution and trends will be outlined for three distinct objects of study: the past climate, the monthly or seasonal weather hind/forecast and the climate change. All the selected climate products are further detailed in the next sub-sections. The climatology section implies further working steps:

First, the climate datasets are selected and analysed. When the datasets are available on a daily time step, the data are then formatted to the ecohydrological model SWIM inputs standard, bias-corrected and validated through a statistical comparison of the rainfall variability and of discharge simulations against the selected observed or base line past climate and runoff data sets.

Second, the spatio-temporal variability of the different climate data sets will be investigated for the temperature and the rainfall. Based on meteorological data, an analytical comparison will be performed to sound the capacity of the different climate products to integrate the monthly, seasonal, annual or decadal variability of the case study.

Third, a particular attention will be given to test the reproduction of the discharge in two specific gauges located in the Niger and the Bani tributaries before entering the Inner Niger Delta. This test will be conducted for the simulations of the three objects but with a more detailed investigation for the monthly weather hindcast products.

Finally, the annual and monthly spatio-temporal variability of the products will be then translated into basic meteorological and hydrological drought indexes (SPI; SRI and a Maximum Annual Flood Extent Index MAFEI). The correlation between the meteorological and hydrological droughts will be then investigated and presented. Additionally, if the improvement of the inundation module in the hydrology section allows reproducing the inundation mechanism in the Inner Niger Delta at a scale which enables to represent the potential uses of the water resources, some special flood indexes could be then further calculated. The area that would potentially fits to support an activity that requires suitable flooding conditions such as rice paddies.

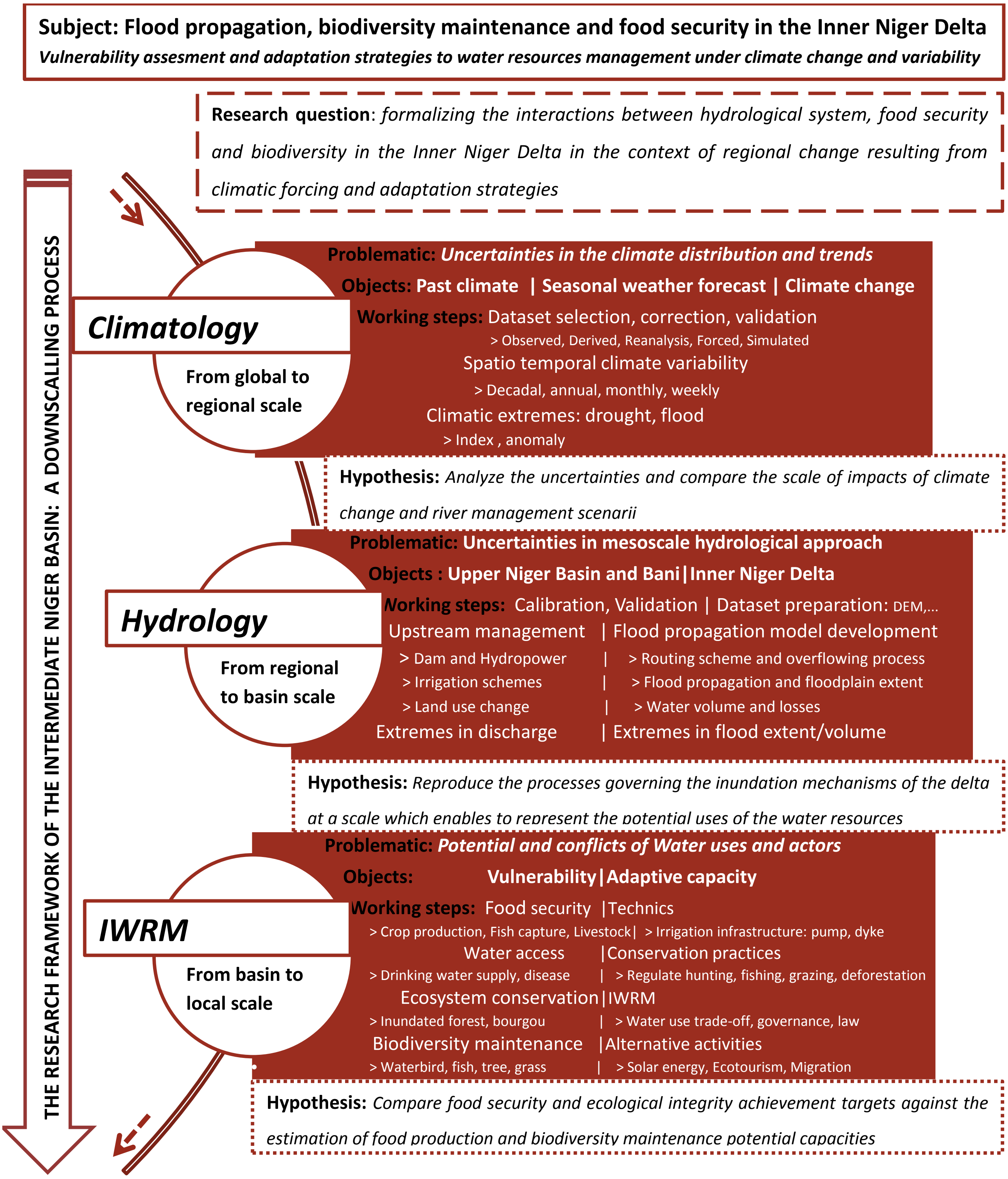
To pass from regional to basin scale, the uncertainties and the limitations in the application of the eco-hydrological model SWIM will be outlined for two objects of study: the upper Niger Basin including the Bani and the Inner Niger Delta. This work implies three working steps:

First, the GIS data sets required are formatted into the SWIM inputs standards. The model is then calibrated and validated against the discharge time series of two different gauges corresponding to the two inlets of the Inner Niger Delta. The climatic and GIS data inputs, the limitations of the methods, the calibration and the validation process and the physical aspects that the methods encompass will be examined.

Second, SWIM model needs further development to represent crucial water transfer and hydrodynamics processes. To account for the implementation of dams and for hydropower generation, a reservoir module will be integrated to the original version of SWIM. A module will be also developed to account for water transfer into irrigated schemes. An inundation module is also created to represent the complex flood dynamics of the Inner Niger Delta. This module was the object of further investigation in the fp7 project Wetwin. The module still requires further improvements to optimize the internal flood propagation. The model and the modules are further described two sections below.

Third, the use of a large range of climate change scenario will allow comparing the scale of impacts of climate change and upstream water resources and river basin management scenarios on the return period of low flow events.

From basin to local scale, the IWRM section will first concentrate on understanding the potential and the conflicts of the different water uses introducing the societal status, the right of use and the spatial dynamics of the activities ruling the delta. Second, the work will consist of identifying statistical correlations between the meteorological and hydrological indicators with socio-economic and ecological indicators (agricultural production, GDP, hydropower production, fish capture, waterbirds census, waterborne diseases, and number of cattle...) that may provide clear messages and interpretations of the scales of impacts. Finally, the challenge is to fit to the particularity of the Niger case study and to tailor the work to the need of the stakeholders. Therefore, the selection of the indicators will be discussed with the stakeholders during the workshop in Mali. The potential for integrating the weather and hydrological forecast system from DEWFORA to the current flood forecast system in the Inner Niger Delta will be further established and planned with the stakeholders.



Subject: Flood propagation, biodiversity maintenance and food security in the Inner Niger Delta

Vulnerability assesment and adaptation strategies to water resources management under climate change and variability

Research question: *formalizing the interactions between hydrological system, food security and biodiversity in the Inner Niger Delta in the context of regional change resulting from climatic forcing and adaptation strategies*

THE RESEARCH FRAMEWORK OF THE INTERMEDIATE NIGER BASIN: A DOWNSCALLING PROCESS

Climatology

From global to regional scale

Problematic: ***Uncertainties in the climate distribution and trends***

Objects: Past climate | Seasonal weather forecast | Climate change

Working steps: Dataset selection, correction, validation

> Observed, Derived, Reanalysis, Forced, Simulated

Spatio temporal climate variability

> Decadal, annual, monthly, weekly

Climatic extremes: drought, flood

> Index , anomaly

Hypothesis: *Analyze the uncertainties and compare the scale of impacts of climate change and river management scenarii*

Hydrology

From regional to basin scale

Problematic: Uncertainties in mesoscale hydrological approach

Objects : Upper Niger Basin and Bani | Inner Niger Delta

Working steps: Calibration, Validation | Dataset preparation: DEM,...

Upstream management | Flood propagation model development

> Dam and Hydropower | > Routing scheme and overflowing process

> Irrigation schemes | > Flood propagation and floodplain extent

> Land use change | > Water volume and losses

Extremes in discharge | Extremes in flood extent/volume

Hypothesis: *Reproduce the processes governing the inundation mechanisms of the delta at a scale which enables to represent the potential uses of the water resources*

IWRM

From basin to local scale

Problematic: ***Potential and conflicts of Water uses and actors***

Objects: Vulnerability | Adaptive capacity

Working steps: Food security |Technics

> Crop production, Fish capture, Livestock| > Irrigation infrastructure: pump, dyke

Water access |Conservation practices

> Drinking water supply, disease | > Regulate hunting, fishing, grazing, deforestation

Ecosystem conservation | IWRM

> Inundated forest, bourgou | > Water use trade-off, governance, law

Biodiversity maintenance |Alternative activities

> Waterbird, fish, tree, grass | > Solar energy, Ecotourism, Migration

Hypothesis: *Compare food security and ecological integrity achievement targets against the estimation of food production and biodiversity maintenance potential capacities*

Figure 16-16-1: Scheme of the general research framework for the Niger case study

16.2 COLLATION AND REVIEW OF EXISTING DATA

16.2.1 Climate data

The collation and review of climate data in use for the Niger case study will follow the same structure of the section Climatology presented in the last figure: Past Climate, Weather Forecast and Climate change. At the end of the section, a table summarizes all the climate data in use in the Niger case study.

Past Climate data sets

Rainfall stations

A set of 88 synoptic, pluviometric and climatologic daily rainfall stations from the Direction Nationale de la Météorlogie Malienne) is available in the Upper Niger Basin only for restricted scientific use. The figure below shows the number of rainfall stations available according to the period in the Niger case study.

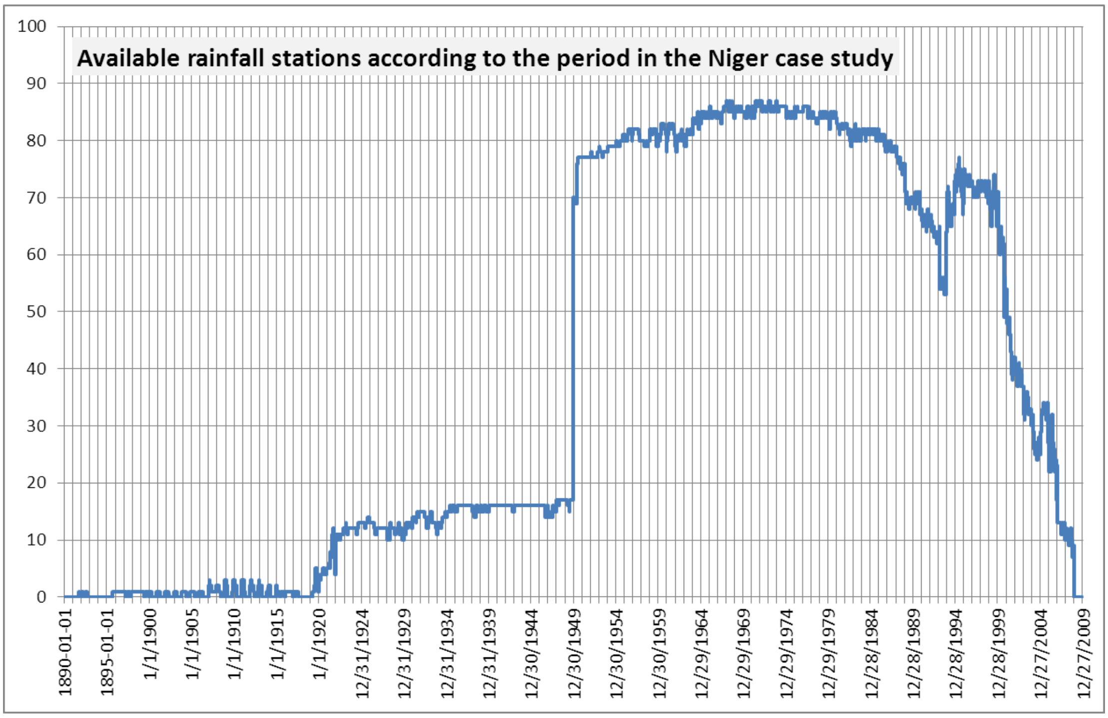


Figure 16-2: number of available rainfall stations in the Niger case study according to the periods of study

Reanalyse data: WATCH product

The Integrated Project Water and Global Change (WATCH), is funded under the EU FP6, and brings together the hydrological, water resources and climate communities to analyse, quantify and predict components of the current and future global water cycles. The project is coordinated by the Centre for Ecology and Hydrology (CEH, UK) and benefits from the contributions made by a variety of external partners, including PIK. One output from the project is the WATCH forcing dataset (1958-2001): A meteorological forcing dataset for land-surface and hydrological models. The data is derived from the ERA-40 reanalysis product via sequential interpolation to half-degree resolution, elevation correction and monthly-scale adjustments based on CRU (corrected-temperature, diurnal temperature range, cloud-cover) and GPCC (precipitation) monthly observations combined with new corrections for varying atmospheric aerosol-loading and separate precipitation gauge corrections for rainfall and snowfall.

16.2.2 Weather forecast

The ECMWF Seasonal Forecasting System

The system consists of an ocean analysis to estimate the initial state of the ocean, a global coupled ocean-atmosphere general circulation model to calculate the evolution of the ocean and atmosphere, and a post-processing suite to create forecast products from the raw numerical output. A detail description is presented in the deliverable D4.1 Meteorological drought forecasting (monthly to seasonal forecasting) at regional and continental scale.

The atmospheric initial conditions come from ERA Interim for the period 1981 to 2010 and from ECMWF operations from 1st January 2011 onwards. The seasonal forecasts consist of a 51 member ensemble. The ensemble is constructed by combining the 5-member ensemble ocean analysis with SST perturbations and the activation of stochastic physics. The forecasts have an initial date of the 1st of each month, and run for 7 months. Forecast data and products are released at 12Z UTC on a specific day of the month. For System 4, this is expected to be the 7th. Every seasonal forecast model suffers from bias - the climate of the model forecasts differs to a greater or lesser extent from the observed climate. Since shifts in predicted seasonal climate are often small, this bias needs to be taken into account, and must be estimated from a previous set of model integrations. Also, it is vital that users know the skill of a seasonal forecasting system if they are to make proper use of it, and again this requires a set of forecasts from earlier dates. A set of re-forecasts (otherwise known as hindcasts or back integrations) are thus made starting on the 1st of every month for the years 1981-2010. They are identical to the real-time forecasts in every way, except that the ensemble size is only 15 rather than 51. The data from these forecasts is available to users of the real-time forecast data, to allow them to calibrate their own real-time forecast products using their own techniques.

Statistical Regional Climate Model (*STAR)*

The Statistical Regional Model (STAR) was developed by PIK to generate regional climate projections for the near future (for the next 50-60 years). The approach is based on the assumption that weather states from segments of the observational period may occur again or very similarly during the simulation period. Hence, simulated series are constructed by resampling from segments of observation series, consisting of daily observations. This methodology thus produces results which can be considered physically consistent, and unlike some other downscaling techniques the STAR model is not driven by GCM-simulated circulation patterns, which are generally considered to lack reliability (Murphy J., 2004). STAR instead performs a simplified forcing method which seeks to constrain the simulated series to a pre-described regression line. In practical terms the forcing describes the long-term level and linear increase of a key variable (typically temperature) over the simulation period. As well as forcing, the method incorporates a set of heuristic rules which ensures that the resulting series exhibits properties such as annual cycles and persistence which are coherent with the observed series. STAR will be applied to the Watch data set to project 100 realizations of climate scenario for 2050 and based on different temperature forcing.

Table 16-1: Summary of the collation and review of the climate data for the Niger case study:

CLIMATE FOCUS	**PAST CLIMATE** **non included: (TRMM, NCEP, GPCP…)**			**SEASONAL WEATHER FORECAST** ***7 months prospective***		**CLIMATE CHANGE**				
DATA NAME	**WATCH**	**SIEREM**	**DNM**	**HINDCAST**	**FORECAST**	**CCLM**	**REMO**	**STAR**	**CCAM**	**CORDEX**
DATA TYPE	Reanalyzes ***ERA-40*** Monthly adjustment ***CRU*** ***GPCC***	Observed rainfall Source ***IRD*** ***CRU*** ***SIEREM***	Observed Rainfall Stations ***SYNOPTIC*** ***CLIMATOLOGIC*** ***PLUVIOMETRIC***	15 ensemble members Initial state: ***ocean analysis*** ***ERA-Interim***	51 ensemble members Initial state ***ocean analysis*** ***ERA-Interim***	RCM ***A1B realization*** AOGCM: ***ECHAM5***	RCM ***A1B realization*** AOGCM: ***ECHAM5***	Statistical regional climate ***WATCH*** ***Forcing temperature variable***	RCM **6realizations** ***Details will be given by CSIR***	ensemble of multiple dynamical and statistical downscaling models considering multiple forcing GCMs
PERIOD COVERAGE	Daily 1900-2001	Monthly 1940-1998	Variable 1880-2007	Daily 1981-2010	Daily 1981-2010	Daily 1981-2100	Daily 1961-2100	Daily 2001-2050	Daily 1961-2100	Daily
SPATIAL COVERAGE	Grid West Africa 0.5°	Grid West Africa 0.5°	80 stations Upper Niger	Grid Niger Basin 0.5°	Grid ? Niger Basin 0.5°	Grid West Africa 50km	Grid West Africa 50 km	Grid West Africa 0.5°	Grid WestAfrica 0.5° & 8km	Grid Africa

Regional Climate Models

The nonhydrostatic fully compressible COSMO-CLM (CCLM) Model has been developed to meet high-resolution regional forecast requirements of weather services and to provide a flexible tool for various scientific applications on a broad range of spatial scales. It has been designed for meso-β and meso-γ scales where nonhydrostatic effects begin to play an essential role in the evolution of atmospheric flows.

REMO has two different parameterization schemes - the original one called DWD physics and additional the ECHAM4 physics, which is the same parameterization scheme as in the global climate model at MPI. The dynamical scheme is in both cases identical. REMO at MPI can be integrated in forecast as well as in climate mode.

The Conformal-Cubic Atmospheric Model (CCAM) from CSIR will deliver six simulations is presented in details in the deliverables D3.3 and D3.4.

CCLM, REMO and CCAM runs are based on ECHAM. ECHAM is a comprehensive general circulation model of the atmosphere. Depending on the configuration the model resolves the atmosphere up to 10 hPa. The former model has been used extensively to study the climate of the troposphere; the latter allows including also the middle atmosphere.

The COordinated Regional climate Downscaling Experiment CORDEX is an ensemble of multiple dynamical and statistical downscaling models considering multiple forcing GCMs applied to Africa. This product will be normally available within the year 2012. Depending on the date of acquisition, the CORDEX runs would be integrated to the investigations of DEWFORA.

16.2.3 Hydrological Data

Discharge data are provided by the Global Runoff Data Centre (GRDC) who works under the auspices of the World Meteorological Organisation (WMO) (hosted by the German Federal Institute of Hydrology (BFG)). This source is completed with water level information coming from the archives of Wetlands International. The water level information is available on six gauges in the Inner Niger Delta.

16.2.4 GIS data

Within catchments, the hydrologist is faced with a wide variety of interacting features which affect the relationship between rainfall and runoff. The most important features are: the topography (e.g. altitude, slope), vegetation (e.g. leaf area index, biomass and root depth), soils (e.g. permeability, fertility), geology (e.g. porosity, hydro-chemical conditions) and land use patterns (e.g. land cover, fertilizer application, surface roughness).Because of their importance for the local water cycle, these features have to be represented in the model description of the river basin. The table below presents the types and the sources of the data and parameterization applied in the Niger catchment.

Table 16-2: Summary of catchment basin data sources for SWIM model implementation

Domain	Name	Source: direct link
Digital Elevation Model	SRTM Version 4, 90m resolution by the Shuttle Radar Topographical Mission	http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php
Land use	Global Land Cover 2000	http://bioval.jrc.ec.europa.eu/products/glc2000/glc2000.php
Soil classification	FAO 74	http://www.fao.org/ag/agl/agll/wrb/soilres.stm#maj
Soil information	Harmonized World Soil Data Base v1.1	http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/index.html

16.2.5 Socio-economic and ecological indicators

Wetlands International has capitalized across his long term implementation in the Niger case study crucial reports, statistical data and census concerning the evolution of the agricultural production, the numbers of cattle, the fish capture, the health incidence and the census of waterbirds at the Inner Niger Delta and at the local scale. The archives of Wetlands International will largely support the creation of drought vulnerability indicators in the Work Package 6.

16.3 COLLATION AND REVIEW OF EXISTING MODELS

The collation and review of existing models was broken down into two parts. The first part presents chronologically a non-exhaustive list of scientific references supporting the understanding of the hydrology, the water resources management and the ecosystem interaction of the Upper Niger basin and the Inner Niger Delta. The second part focuses on hydrological model application.

16.3.1 Monography and main scientific references

Jean Gallais is a French geographer who conducted pioneer investigations in the understanding of the Inner Niger Delta territory. He investigated the physical geography of the Inner Niger Delta and delivered a crucial understanding of the societal balance of power and the spatial behaviour of groups ruling the cultural and ecological use of the environment and of the natural resources in the delta.

Gallais, J. 1962. “Signification Du Groupe Ethnique Au Mali.” *L’Homme* 2 (2): 106–129. doi:10.3406/hom.1962.366487.

———. 1967. “Le Delta Intérieur Du Niger Et Ses Bordures: Étude Morphologique”. Paris, France: Editions du CNRS.

———. 1972. “Les Sociétés Pastorales Ouest-africaines Face Au Développement.” *Cahiers D’études Africaines* 12 (47): 353–368. doi:10.3406/cea.1972.2751.

In 1960, **Claude Auvray** describes in a **ORSTOM monograph** the hydrographic regions, the hydrological data, the hydrological regime, the water balance and the discharge pattern synthesis of the Upper Niger Basin with the Bani tributary and the Inner Niger Delta.

Auvray, Claude. 1960a. *La Cuvette Lacustre. 1. 1ère Et 2ème Parties. Facteurs Conditionnels Du Régime. 3ème Partie. Données Hydrologiques*. ORSTOM. http://www.documentation.ird.fr/hor/fdi:32719.

———. 1960b. *La Cuvette Lacustre. 2. Interprétation Des Résultats D’observations. Eléments Caractéristiques Du Régime*. ORSTOM. http://www.documentation.ird.fr/hor/fdi:32720.

———. 1960c. *La Cuvette Lacustre. 3. Bilan Hydrologique. Synthèse De L’écoulement*. ORSTOM. http://www.documentation.ird.fr/hor/fdi:32721.

———. 1960d. *La Cuvette Lacustre. 4. Annexes (Ecoulements Journaliers)*. ORSTOM. http://www.documentation.ird.fr/hor/fdi:32721.

In 1986, **Bruno-Moret et al.** wrote the **ORSTOM Hydrological Monograph** No. 8 with a new realization of the flow curves in all the available gauges sites of the Upper Niger basin including the Bani and the Inner Niger Delta up to 1979.

Brunet-Moret, Y., Chaeron, J.P. Lamagat, and Molinier. 1986a. *Monographie hydrologique du fleuve Niger: Cuvette lacustre et Niger moyen*. Institut français de recherche scientifique pour le développement en coopération.

———. 1986b. *Monographie hydrologique du fleuve Niger: Niger supérieur*. Institut français de recherche scientifique pour le développement en coopération.

In 1994, **Quensière et al.** presented a **multidisciplinary study** targeting the Central Niger delta **halieutic system** based on the results achieved under “the Programme d’Etudes Halieutiques du Delta Central du Niger”.

Quensière, Jacques, ed. 1994. *La Pêche Dans Le Delta Central Du Niger : Approche Pluridisciplinaire D'un Système De Production Halieutique*. ORSTOM ; Karthala. http://www.documentation.ird.fr/hor/fdi:40722.

With the support of MAE/France, Unesco/PHI, UICN/Suisse and the embassy from Netherlands in Mali, the project **GIHREX** (département Milieux et Environnement de l'IRD) and the group **CERDIN** (CNRST, Mali) organized an international seminar in Bamako the 20 to 23 of June 2000 called **"Integrated management of natural ressources in tropical inundated areas"** under the scientific edition board of **Orange et al..**

Orange, Didier, Robert Arfi, Marcel Kuper, Pierre Morand, and Yveline Poncet, eds. 2002. *Gestion Intégrée Des Ressources Naturelles En Zones Inondables Tropicales*. Colloques Et Séminaires. IRD ; CNRST. http://www.documentation.ird.fr/hor/fdi:010030354.

The INSAH published a **sahelian monograph** written by **Hassane et al., 2007** focused on the constraints, the stakes and the perspectives of water availability in the Niger River for the hydro-agricultural management.

Hassane, A., S. Hamadou, M. Kuper, and A. (ed.) Kuper. 2002. *Les Disponibilites En Eau Du Fleuve Niger : Enjeux Et Perspectives Pour Les Amenagements Hydro - Agricoles. Le Cas Du Niger*. Bamako: INSAH. http://publications.cirad.fr/une_notice.php?dk=517500.

In narrow co-operation with the Malian authorities and institutions, two multidisciplinary studies with a strong focus on the **biodiversity and the ecological impact of dam on the Inner Niger Delta** have been carried out with the strong involvement of **Wetlands international** and **A&W**. Wymenga et al., 2002 reports a large campaign of species identification and census in the Inner Niger Delta. This work results from the initiative 'Contribution à la gestion des zones humides et des oiseaux d'eau du Delta Intérieur du Niger' (1998-2002) with the support of "Programme de Gestion Internationale de la Nature (PIN)".The Lifeline report was developed under the framework of the interdepartmental Dutch Partners for Water programme "Water for food and ecosystems" and the PREM-programme (Poverty Reduction and Environmental Management) of the Dutch Ministry of International Cooperation. The lifeline report describes the hydrology of the delta with a **statistical approach based on satellite imageries from LANDSAT**. The statistical tool **OPIDIN** is developed in continuation to those initiatives. The statistical model OPIDIN is presented in detail in the section 15.3 Current Drought Forecasting Tool.

Wymenga, Eddy, Bakary Kone, Jan van der Kamp, and Leo Zwarts. 2002. *Delta Intérieur Du Niger. Ecologie Et Gestion Durable Des Ressources Naturelles*. A&W report / Mali-pin publication 2002-01. Wetlands International / Altenburg & Wymenga conseillers écologiques / Alterra / RIZA.

Zwarts, L., P. van Beukering, B. Kone, and E. Wymenga. 2005. *The Niger, a Lifeline, Effective Water Management in the Upper Niger Basin*. RIZA IVM / WISO / A&W. http://www.altwym.nl/uploads/file/133Executive%20summary%20-%20The%20Niger,%20a%20lifeline.pdf.

In 2005, two outstanding reports were published by the **World Bank** on the Niger River Basin. Andersen et al., 2005 focused particularly on physical nd hydrological characteristics of the Niger river and on the institutions, the political constraints to achieve a transboundary and integrated river basin vision. Benson et al., 1998 illustrate water management problem with the case study of an irrigation scheme work in the Upper Niger Basin.

Andersen, I., Dione, O., Jarosewich-Holder, M. Olivry, J-C, 2005, The Niger River Basin, AVision for Sustainable Management, Washington DC: The International Bank for Reconstruction and Development / The World Bank.

Aw, Djibril, and Geert Diemer. 2005. *Making a Large Irrigation Scheme Work : a Case Study from Mali*. Directions in development. Washington DC: The International Bank for Reconstruction and Development / The World Bank.

Benson, Charolette, and Edward Clay. 1998. *The Impact of Drought on Sub-Saharan African Economies A Preliminary Examination*. World Bank.

With the financial support of the FED (Fonds européen de développement), UICN (Union mondiale pour la nature), GTZ (Coopération technique allemande pour le développement) and MAE (Scac-Ambassade de France au Mali), **"The Niger River's Future"** synthesizes the work from 12 experts to answer river and environmental management problematic to public institutional decision makers based on the scientific knowledge from **IRD** (Institut de recherché pour le développement) and **IER** (Institut d'économie rurale, Mali).

Marie, J., Pierre Morand, and H. N'Djim, eds. 2007. *The Niger River's Future : Synthesis and Recommendations, Analytical Chapters*. Expertise Collégiale. IRD ; IER. http://www.documentation.ird.fr/hor/fdi:010041819.

In the frame of the Challenge Program on Water and Food (**CPWF**), The **Niger Basin Focal Project** is a multi-institutional research initiative that published Research Report series to carry out a diagnosis of the hydrologic and agronomic potential, before attempting to identify how good agricultural water management may reduce vulnerability in the region, and preserve local ecosystems. Major future threats and opportunities, as well as the influence of institutions on water and agricultural development are discussed.

Clanet, Jean-Charles, and Andrew Ogilvie. 2009. *Synthesis Report*. CPWF Working Paper. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.

16.3.2 Decision support and hydrological modeling tool

CARIMA is a commercial licensed physically based hydrodynamical model from SOGREAH. The model was implemented in the eighties for the Niger Basin Authority. The aim of the study was the construction of a mathematical model of the Inner Niger Delta from Markala to Timbuktu and from Timbuktu to Malanville calibrating on the basis of the seasonal floods of 1975-1976 and 1969-1970. The upstream part from Sélingué to Markala was analysed in previous studies in the seventies. CARIMA is the result of research and development in computational hydraulics carried out at SOGREAH since 1970. This operational model for use by engineers has been used and validated on a large number of river basins, rivers and estuaries subject to tidal action, deltas, irrigation and drainage systems, involving a wide range of hydrological and hydraulic conditions.

SOGREAH. 1985a. MODELE MATHEMATIQUE DU FLEUVE NIGER ANNEXE N° 10 ETUDE DETAILLEE DES ETIAGES ENTRE SELINGUE (MALI) ET NIAMEY (NIGER). AUTORITE DU 'BASSIN DU NIGER.

———. 1985b. MODELE MATHEMATIQUE DU FLEUVE NIGER ANNEXE N° 11 CONSTRUCTION ET REGLAGE DU MODELE DU DELTA DU NIGER DE MARKALA A TOMBOUCTOU (MALI). AUTORITE DU 'BASSIN DU NIGER.

———. 1985c. MODELE MATHEMATIQUE DU FLEUVE NIGER ANNEXE N° 6 CONSTRUCTION ET REGLAGE DU MODELE AU MALI DE SELINGUE A MARKALA (MALI). AUTORITE DU 'BASSIN DU NIGER.

———. 1985d. MODELE MATHEMATIQUE DU FLEUVE NIGER ANNEXE N° 8 ETUDE SUR MODELE MATHEMATIQUE DE LA REGULATION DU CANAL DU SAHEL EN REPUBLIQUE DU MALI. AUTORITE DU 'BASSIN DU NIGER.

———. 1987. MODELE MATHEMATIQUE DU FLEUVE NIGER ANNEXE N° 9 AMENAGEMENTS HYDROAGRICOLES ENTRE LABEZANGA ET DOLE EN REPUBLIQUE CALCUL DES NIVEAUX DE CRUE. AUTORITE DU 'BASSIN DU NIGER.

DELMASIG is an integrated GIS application dedicated to the management and the decision support of agropastoralist problematic of the Inner Niger Delta. The aim is to support the definition of local master plan. Developped by **Marie**, DELMASIG tool was developed to represent:

- The diversity of vegetation in the Delta into 120 formations (flora, ecological conditions, fodder production)
- The inundated areas according to the water level in Mopti with the use of a derived 3D model based on the calculation of the vegetation formation.
- The strategy of use for the rice producers since 1952 according to the soil and the flooding condition The land stakes and the conflicts between herders and farmers for the pastures and the network of pastoral tracks.

Marie, J. 2000. “Delmasig: Hommes, Milieux, Enjeux Spatiaux Et Fonciers Dans Le Delta Intérieur Du Niger (Mali).” *HDR, Univ. Paris-X*.

The Integrated Inner Niger Delta Model (**MIDIN**) is a multi-layer GIS model representing the behavior of water users in the Delta based on the available resources. The main objective is to represent the spatio-temporal relations and anticipate the dynamics of the systems. In the context of the Inner Niger Delta, MIDIN is a tool available for the community of persons (decision makers, thematicians…) to explore possible management strategies in the Delta according to three given hydrological scenario: 1993 low flood scenario, 1994 high flood scenario and 1995 mean flood scenario with a time step discretized to 15 days. The model integrates six layers which are hydrography, hydrology, hydrobiology, systems of production: fish agriculture and pastoralism. The hydrography is represented with a network of 109 plains, lakes and channels.

Kuper, M. 2002. “Stratégies D’exploitation En Zones Inondables Tropicales.” In Gestion Intégrée Des Ressources Naturelles En Zones Inondables Tropicales, 387–394. Colloques Et Séminaires. IRD ; CNRST. http://www.documentation.ird.fr/hor/fdi:010030378.

Kuper, M., A. Hassane, Didier Orange, A. Chohin-Kuper, and M. Sow. 2002. “Régulation, Utilisation Et Partage Des Eaux Du Fleuve Niger : Impact De La Gestion Des Aménagements Hydrauliques.” In Gestion Intégrée Des Ressources Naturelles En Zones Inondables Tropicales, 411–430. Colloques Et Séminaires. IRD ; CNRST. http://www.documentation.ird.fr/hor/fdi:010030380.

Kuper, M., C. Mullon, Y. Poncet, and E. Benga. 2003. “Integrated Modelling of the Ecosystem of the Niger River Inland Delta in Mali.” Ecological Modelling 164 (1): 83–102.

Kuper, M., Christian Mullon, Yveline Poncet, E. Benga, Pierre Morand, Didier Orange, Gil Mahé, Robert Arfi, and F. Bamba. 2002. “La Modélisation Intégrée D’un Écosystème Inondable : Le Cas Du Delta Intérieur Du Niger.” In Gestion Intégrée Des Ressources Naturelles En Zones

Inondables Tropicales, 773–798. Colloques Et Séminaires. IRD ; CNRST. http://www.documentation.ird.fr/hor/fdi:010030399.

Poncet, Yveline, M. Kuper, Christian Mullon, Pierre Morand, and Didier Orange. 2001. “Représenter L’espace Pour Structurer Le Temps : La Modélisation Intégrée Du Delta Intérieur Du Niger Au Mali.” In Représentations Spatiales Et Développement Territorial, 143–163. Hermès. http://www.documentation.ird.fr/hor/fdi:010025760.

In 2004, the model **RIBASIM** was implemented by Ron Passchier et al. with a monthly time step from 1980 to 2000 within the project Integrated water resources modelling of the Upper Niger River (Mali). Parts of the results were integrated in the Niger lifeline report from Wetlands International. RIBASIM (River Basin Simulation Model) is a generic model package developed by Deltares for analysing the behaviour of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool which links the hydrological water inputs at various locations with the specific water-users in the basin. RIBASIM enables the user to evaluate a variety of measures related to infrastructure, operational and demand management and the results in terms of water quantity and water quality. RIBASIM generates water distribution patterns and provides a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs. It provides a source analysis, giving insight in the water's origin at any location of the basin. RIBASIM follows a structured approach to river basin planning and management

Passchier, Ron, Rob Maaten, and Karen Meijer. 2003. Integrated Water Resources Modelling of the Upper Niger River (Mali) Inception Report.

———. 2004. Integrated Water Resources Modelling of the Upper Niger River (Mali) Final Report.

Mike Basin is a commercial licensed software implemented in 2007 to model the entire Niger basin during the **PADD** (Elaboration of an action plan for the sustainable development of the Niger Basin), a project under the initiative of the Niger Basin Authority The software was also used to model economic scenario of the Sélingué dam. MIKE BASIN is an extension of ArcMap (ESRI) for integrated water resources management and planning. It provides a framework for managers and stakeholders to address multi-sectorial allocation and environmental issues in river basins. It is designed to investigate water sharing issues at international or interstate level, and between competing groups of water users, including the environment. MIKE BASIN is developed by DHI Water.Environment.Health. MIKE BASIN can be used for providing solutions and alternatives to water allocation and water shortage problems, improving and optimizing reservoir and hydropower operations, exploring conjunctive use of groundwater and surface water, evaluating and improving irrigation performance, solving multi-criteria optimization problems, establishing cost-effective measures for water quality compliance.

BRL, and DHI. 2007a. *Etudes Sur L'élaboration Du Plan d'Action De Développement Durable (PADD) Du Bassin Du Niger: Annexes*. NIGER BASIN AUTHORITY (NBA).

———. 2007b. *Etudes Sur L'élaboration Du Plan d'Action De Développement Durable (PADD) Du Bassin Du Niger: Phase 1: Bilan Diagnostic*. NIGER BASIN AUTHORITY (NBA).

———. *Etudes Sur L'élaboration Du Plan d'Action De Développement Durable (PADD) Du Bassin Du Niger: Phase II : Schéma Directeur D'aménagement Et De Gestion*. NIGER BASIN AUTHORITY (NBA). 2007.

GIRE-DecidAid is a statistical excel tool integrating hydrology, economy and environment to optimize surface water infrastructures planning and management in the Niger basin Based on the relationships between discharges and water levels which describe the behavior of the flood in the Inner Delta of the Niger river, the tool allows simulation of scenarios of surface water structures planning and their management in relation to current situation.

Cissé. 2010. "Integrated Water Resources Management in the Niger Basin Upstream Taoussa Decision Support Tool : GIRE DecidAid" presented at the World Water Week, Stockholm.

SWAT ''Soil and Water Assessment Tool'' is a mechanistic time-continuous model that can handle very large watersheds in a data efficient manner. The model is spatially distributed and accounts for differences in soils, land use, topography and climate. Applying the model, **Schuol** et al., 2006 and 2008 quantified the freshwater availability for a 4-million km^2 area covering some 18 countries in West Africa. The procedure includes model calibration and validation based on measured river discharges, and quantification of the uncertainty in model outputs using ''Sequential Uncertainty Fitting Algorithm'' (SUFI-2). The aggregated results for 11 countries are compared with two other studies.

Schuol, J., K.C. Abbaspour, R. Srinivasan, and H. Yang. 2008. "Estimation of Freshwater Availability in the West African Sub-continent Using the SWAT Hydrologic Model." *Journal of Hydrology* 352 (1): 30–49.

Schuol, J., KC Abbaspour, and others. 2006. "Calibration and Uncertainty Issues of a Hydrological Model (SWAT) Applied to West Africa." *Advances in Geosciences* 9: 137–143.

The project **HYDRODIN**, carried out by G-eau, TETIS, HSM, ABN, DNH & DNM, aims to dévelop hydrological knowledge of the Inner Niger Delta with an extended physically based hydrodynamical model with the support of teledetection, topography and altimetry. The model developed will support the operational management of river infrastructures. In addition, an application of a 2D bidimensionnal model (RUBAR) is on-going.

Belaud, Gilles, Jean-Claude Bader, Ludovic Cassan, Nicolas BERCHER, and Thibaut FERET. 2010. "Calibration of a Propagation Model in Large River Using Satellite Altimetry". G-eau IRD, Montpellier Supagro) Montpellier, france.

Belaud, Gilles, Jean-Claude Bader, and Andrew Ogilvie. 2010. "L'inondation Dans Le Delta Intérieur Du Niger: Un Modèle Hydrodynamique Pour Analyser Les Changements Futurs". UMR G-eau (IRD, Montpellier Supagro) June, Niamey.

Different methods of Water balance, Lumped hydrological or Reservoir model were applied in the Upper Niger Basin to reproduce monthly discharge. Three methods were applied to 49 west african catchments in Dezetter et al., 2008, Paturel et al., 2006 and 2007: the **GR2M** model, the model of **Yates** and the **Water Balance Model from Thronthwaite** modified by Conway and Jones. The Thronthwaite method was also modified and applied by Maidment et al. in the Upper Niger basin. Picouet et al., 2001 and 2009 used statistical approach and a lumped conceputal model to represent the suspended sediment load in the Upper Niger Basin. Also, simple static **Water-use accounting and Water holding capacity** methods were performed in the **BFP Niger project** to assess the consequences of economic growth, the contribution of economic sectors to environmental problems, the implications of environmental policy measures (such as regulation, charges, and incentives) allowing to identify the status of water resources and the consequences of management actions, the scope for savings and improvements in productivity.

Dezetter, A., S. Girard, J.E. Paturel, G. Mahé, S. Ardoin-Bardin, and E. Servat. 2008. "Simulation of Runoff in West Africa: Is There a Single Data-model Combination That Produces the Best Simulation Results?" *Journal of Hydrology* 354 (1-4): 203–212.

Maidment, D. R, F. Olivera, Z. Ye, S. M Reed, and D. C McKinney. "Water Balance of the Niger Basin." In , 3411–3416. http://cedb.asce.org/cgi/WWWdisplay.cgi?9602556.

Mainuddin, M., J. Eastham, and M. Kirby. 2010. *Water-use Accounts in CPWF Basins: Simple Water-use Accounting of the Niger Basin*. CPWF Working Paper. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.

Paturel, J. E., C. Barrau, G. Mahé, A. Dezetter, and E. Servat. 2007. "Modelling the Impact of Climatic Variability on Water Resources in West and Central Africa from a Non-calibrated Hydrological Model." *Hydrological Sciences Journal* 52 (1) (February): 38–48. doi:10.1623/hysj.52.1.38.

Paturel, Jean-Emmanuel, Eric Servat, Alain Dezetter, Jean-François Boyer, C. Laroche, L. Mounirou, Hélène Lubes Niel, and Gil Mahé. 2006. "Modélisation Hydrologique Et

Régionalisation En Afrique De l'Ouest Et Centrale." In *Large Sample Basin Experiments for Hydrological Model Parameterization : Results of the Model Parameter experiment-MOPEX*, 278–287. AISH - Publication. AISH. http://www.documentation.ird.fr/hor/fdi:010041857.

Picouet, Cécile, Benoît Hingray, and Jean Claude Olivry. 2009. "Modelling the Suspended Sediment Dynamics of a Large Tropical River: The Upper Niger River Basin at Banankoro." *Hydrological Processes* 23 (22) (October 30): 3193–3200. doi:10.1002/hyp.7398.

Picouet, C., B. Hingray, and J.C. Olivry. 2001. "Empirical and Conceptual Modelling of the Suspended Sediment Dynamics in a Large Tropical African River: The Upper Niger River Basin." *Journal of Hydrology* 250 (1–4) (September 1): 19–39. doi:10.1016/S0022-1694(01)00407-3.

Ward, John, David Kaczan, and Anna Lukasiewicz. 2009. *Work Package 1 A Water Poverty Analysis of the Niger Basin, West Africa*. CPWF Project Report. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.

Working Paper No. 3: MAPPING WATER POVERTY: Water, Agriculture and Poverty Linkages. CPWF Project Report. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.

The assessment of the **annual maximum flood plain extent** of the Inner Niger Delta was the object of a range of publications based on different methodologies. **Orange et al. 2002** compare the results obtained from the **agro-ecological model from Cissé et Gosseye, 1990** with the **water balance approach from Olivry, 1995**. **Zwarts** in the Niger lifeline report, publication presented in one paragraph above, developed a **statistical approach based on satellite imagery from LANDSAT**. Mahe et al. 2011 show with a statistical approach the correlations between the heights of water levels at gauging stations in the Delta and the flooded areas based on the satellite imagery from **NOAA/AVVRR** analyzed in **Mariko, 2003, Mariko et al. 2002.**

MAHE, G., D. ORANGE, A. MARIKO, and J. P BRICQUET. 2011. "Estimation of the Flooded Area of the Inner Delta of the River Niger in Mali by Hydrological Balance and Satellite Data." *IAHS-AISH Publication*: 138–143.

Mahé, G., F. Bamba, A. Soumaguel, D. Orange, and J. C. Olivry. 2009. "Water Losses in the Inner Delta of the River Niger: Water Balance and Flooded Area." *Hydrological Processes* 23 (22) (October 30): 3157–3160. doi:10.1002/hyp.7389.

Mariko, A. 2003. "Caractérisation Et Suivi De La Dynamique De L'inondation Et Du Couvert Végétal Dans Le Delta Intérieur Du Niger (Mali) Par Télédétection". Université de Montpellier 2 ; IRD. http://www.documentation.ird.fr/hor/fdi:010036291.

Mariko, Adama. 2003. "Caractérisation Et Suivi De La Dynamique De L'inondation Et Du Couvert Végétal Dans Le Delta Intérieur Du Niger (Mali) Par Télédétection." Université de Montpellier 2, Hydroscience.

Mariko, A., Gil Mahé, Didier Orange, A. Royer, A. Nonguierma, A. Amani, and E. Servat. 2002. "Suivi Des Zones D'inondation Du Delta Intérieur Du Niger : Perspectives Avec Les Données De Basse Résolution NOAA/AVHRR." In *Gestion Intégrée Des Ressources Naturelles En Zones Inondables Tropicales*, 231–244. Colloques Et Séminaires. IRD ; CNRST. http://www.documentation.ird.fr/hor/fdi:010030368.

Olivry, J.C. 1995. "Fonctionnement Hydrologique De La Cuvette Lacustre Du Niger Et Essai De Modélisation De L'inondation Du Delta Intérieur." Grands Bassins Fluviaux Périatlantiques: Congo, Niger, Amazone. ORSTOM, Paris: 267–280.

Orange, Didier, Gil Mahé, L. Dembélé, C.H. Diakité, M. Kuper, and Jean-Claude Olivry. 2002. "Hydrologie, Agro-écologie Et Superficies D'inondation Dans Le Delta Intérieur Du Niger." In Gestion Intégrée Des Ressources Naturelles En Zones Inondables Tropicales, 209–229. Colloques Et Séminaires. IRD ; CNRST. http://www.documentation.ird.fr/hor/fdi:010030367.

16.4 METHODS AND TOOLS TO BE APPLIED

The method selected consists of using the regional climate model projections and the weather forecast simulations summarized in the table of the preceding sub-section as climate inputs into the eco-hydrological model SWIM. The objective is to support a downscaling process in order to translate meteorological forecast into hydrological responses from the regional scale to river basin and local scales. If the coupling of monthly weather forecast system with SWIM with the application of downscaling and bias-correction methods allows reproducing hydroclimatic extremes in the Upper Niger Basin with a reasonable uncertainty, the results can be then further used and implemented for the improvement of the current flood forecast system applied in the Inner Niger Delta. The Flood Predicting Tool for the Inner Niger Delta (OPIDIN) is a forecasting tool estimating the occurrence and the extent of the maximum water height with the flood recession at a specific date allowing users to plan their activities. The statistical tool OPIDIN is presented in detail in the section 15.3 Current Drought Forecasting Tool. Therefore, this section will focus on the description of the hydrological model applied to the Niger case study within the DEWFORA project.

Hydrological Model

The D4.5 Available continental scale hydrological models and their suitability for Africa describes a large range of hydrological model for continental scale application. The two hydrological models selected for the Niger case study were already described in the previous deliverables in this term:

PCR-GLOBWB is a grid-based model (coded in PCRaster) of global terrestrial hydrology. It is essentially a leaky bucket type of model applied on a cell-by-cell basis. The model calculates for each grid cell (0.5° x 0.5°) and for each time step (daily) the water storage in two vertically stacked soil layers (max. depth 0.3 and 1.2m) and in an underlying groundwater layer (of infinite capacity), as well as the water exchange between the layers and between the top layer and the atmosphere. The model also calculates canopy interception and snow storage. The input data include precipitation, actual evapotranspiration, snow and ice dynamics. The meteorological forcing is supplied at a daily time step and assumed constant over a grid cell. Sub-grid variability is taken into account by considering separately tall and short vegetation, open water and different soil types. Canopy interception store is finite and subject to open water evaporation. The total specific runoff of a cell consists of saturation excess surface runoff, melt water that does not infiltrate runoff from the second soil reservoir and groundwater runoff from the lowest reservoir. Groundwater reservoir characteristic response time is parameterized based on a world map of lithology. River discharge is calculated by accumulating and routing specific runoff along the drainage network taken from DDM30 and includes dynamic storage effects and evaporative losses from the GLWD (Global Lakes and Wetlands Database) inventory of lakes, wetlands and plain. Also, it contains a routine for lateral transport of latent heat from which the water temperature and river ice thickness can be calculated (van Beek and Bierkens, 2009). The model includes new schemes of sub-grid surface runoff, interflow and baseflow and incorporates explicit routing of surface water flow using the kinematic wave approximation (Sperna Weiland et al., 2010).

SWIM is a comprehensive GIS-based tool for hydrological and water quality modelling in mesoscale watersheds (from 100 to 10,000 km^2) which was based on two previously developed tools: SWAT and MATSALU. The weather parameters necessary to drive the model are daily precipitation, air temperature and solar radiation. In addition, data for soils, crop management, and point sources of pollution have to be provided. River discharge and concentrations of nitrogen in the basin outlet are needed for model validation. SWIM belongs to the intermediate class of models, combining mathematical process description with some empirical relationships. (Krysanova et al., 1998). As represented in the following figure, ´the model integrates hydrology erosion, vegetation, and nitrogen/phosphorus dynamics at the river basin scale and uses climate input data and agricultural management data as external forcing.

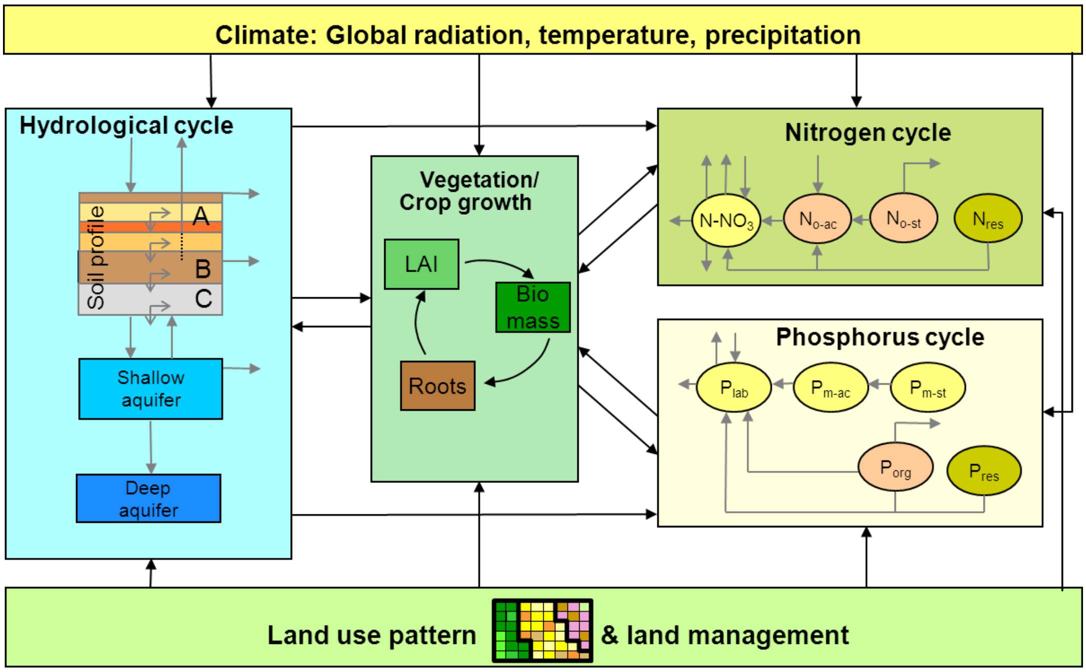


Figure 16-3: SWIM modelling integrative framework and capabilities

In the next figure, the hydrological module is based on the water balance equation, taking into account precipitation, evapotranspiration, percolation, surface runoff, and subsurface runoff for the soil column subdivided into several layers. The simulated hydrological system consists of four control volumes: the soil surface, the root zone, the shallow aquifer, and the deep aquifer. The percolation from the soil profile is assumed to recharge the shallow aquifer. Return flow from the shallow aquifer contributes to the streamflow. The soil column is subdivided into several layers in accordance with the soil data base. The water balance for the soil column includes precipitation, evapotranspiration, percolation, surface runoff, and subsurface runoff. The water balance for the shallow aquifer includes ground water recharge, capillary rise to the soil profile, lateral flow, and percolation to the deep aquifer.

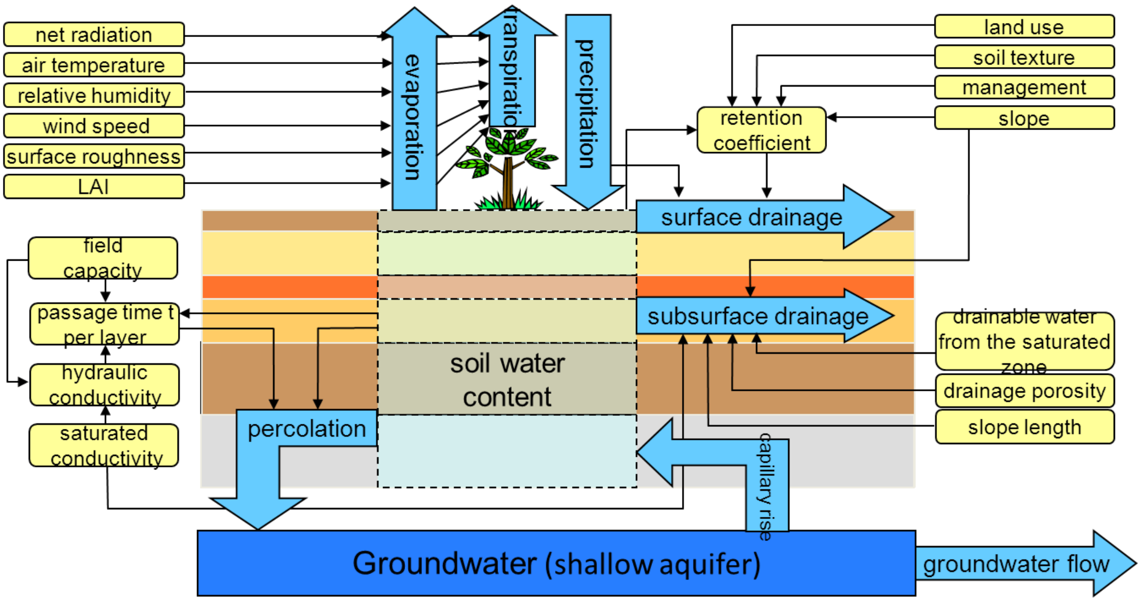


Figure 16-4: The governing processes in SWIM for the simulation of the hydrological cycle

The model interface is built in GIS and operates on a daily time step. The recommended resolution of the DEM varies from 30 m cell size up to 1000 m, depending on the application (Krysanova and Wechsung, 2000). Krysanova et al. (1998) indicated that very flat areas with many lakes, where travel-time becomes large, are excluded in the model. A three-level disaggregation scheme is implemented in SWIM for mesoscale basins (from 100 to 10,000 km^2), which implies 1) basin, 2) sub-basins, and 3) hydrotopes inside sub-basins as it is illustrated in the figure 16-5.

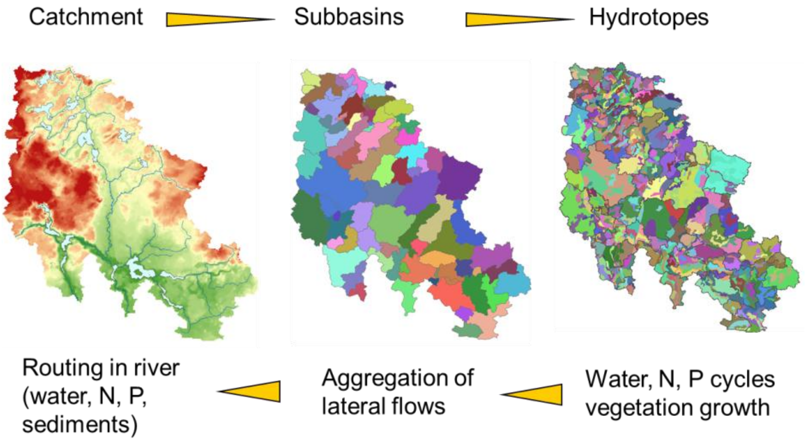


Figure 16-5: The three disaggregation levels in the model SWIM

SWIM has been developed as a tool to serve this purpose at the mesoscale and regional scale. Model applications in a number of river basins in the range of about 100 to 24,000 km^2

drainage area have shown that the model is capable to describe realistically the basic ecohydrological processes under different environmental conditions, including a) the spatial and temporal variability of main water balance components (evapotranspiration, groundwater recharge, runoff generation), b) the cycling of nutrients in soil and their transport with water considering the dynamics of the controlling climate and hydrological conditions, c) vegetation/crop growth and related phenomena, d) the dynamical features of soil erosion and sediment transport, and e) the effect of changes in climate and land use on all these interrelated processes and characteristics (Krysanova and Wechsung, 2000). Krysanova et al. (1998) indicate that the model has to be further tested, especially for upscaling purposes in basins up to several thousands km^2 with 'nested' sub-basins and with different resolutions of input data.

SWIM: Reservoir module

A reservoir module (Koch et al., 2011) was developed and integrated into the SWIM model in order to account for impacts of medium to large dams on river discharge. The model provides three different reservoir management options:

1. Variable daily minimum discharge to meet environmental or other targets downstream under consideration of maximum and minimum water levels in the reservoir,

2. Daily release based on firm energy yield by a hydropower plant at the reservoir (the release to produce the required energy is calculated depending on the water level),

3. Daily release depending on water level (rising/falling release with in- creased/falling water level, depending on the objective of reservoir management).

SWIM: Inundation module

The inundation module is a semi-explicit process based model. The Inner Niger Delta is divided into sub-basins that respect the routing of the model SWIM. Within the sub-basins and according to a refined digital elevation model, inundation zones are delimited based on the water height and allow to estimate the water volumes stored within the inundation zone and within the ponded area. The flooding simulation encompassing backwater effects, evaporation (water surface), percolation, release (see next figure) is driven by three main parameters: a flow-threshold for flooding (cross-sectional area), a parameter for release (linear storage), and a backwater subbasins input file.

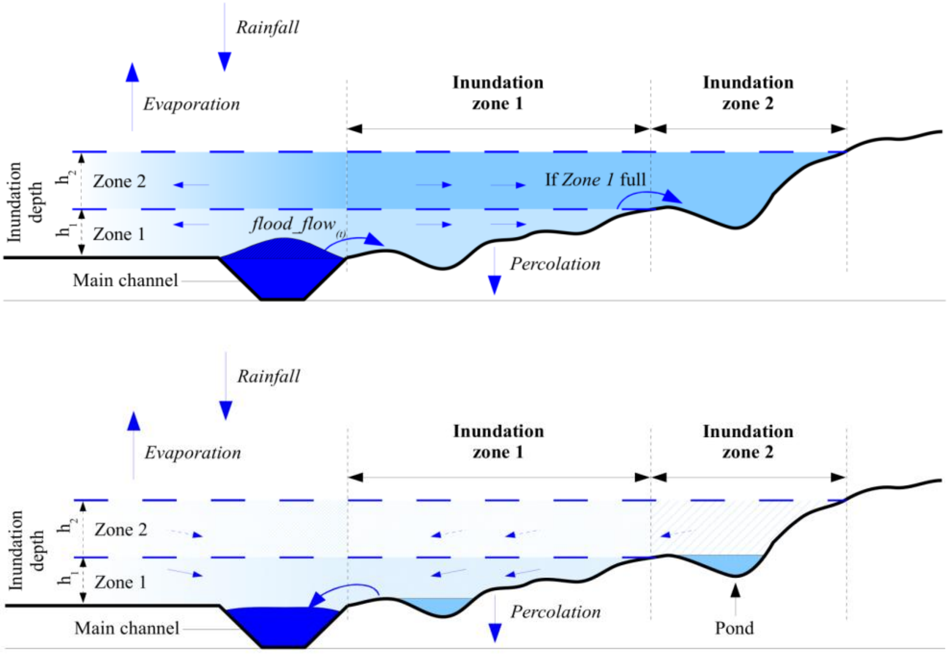


Figure 16-6: Scheme of overflowing process and Backwater processes in the SWIM Inundation Module

SWIM: Water allocation module

The concept of a Water allocation module illustrated in the figure below aims to transfer water between hydrotope, shallow or deep aquifer, reservoir, point source, reach and diversion channel (Scheme 2) with the most flexible specifications for the water volume inputs and outputs (constant, yearly, monthly, daily values, fraction of volume, unlimited, triggered by plants, triggered by soil content …). Due to the large range of sources, the challenge is to create a module flexible enough to be called at different stages of SWIM process respecting the water balance fundaments.

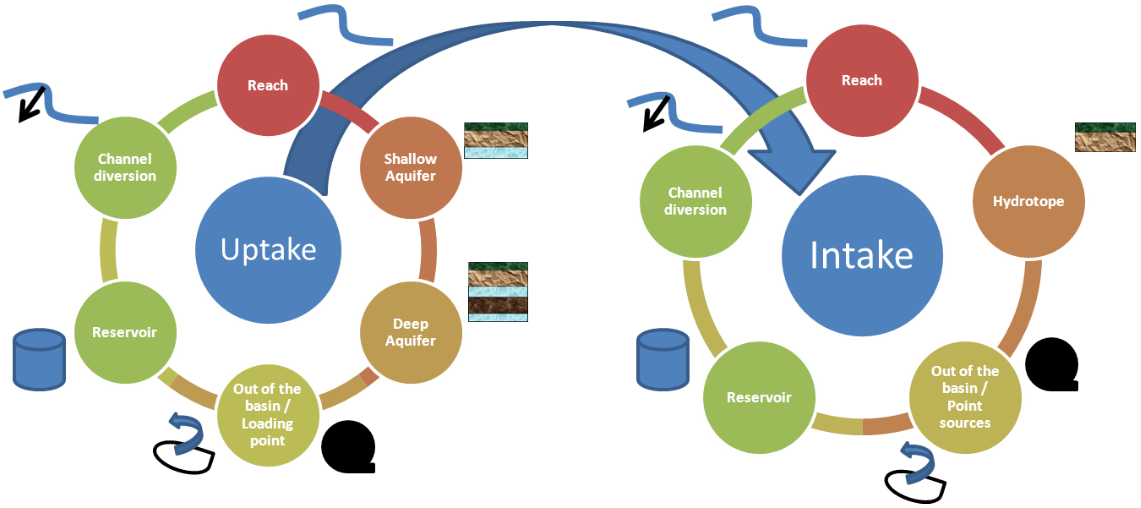


Figure 16-7: Schematic of the possible water transfer processes to develop in the model SWIM

16.5 EXPECTED OUTCOMES AND PRODUCTS

The Niger case study: specific objectives and research question

DEWFORA project aims to Improved Drought Early Warning and FORecasting to strengthen preparedness and adaptation to droughts in the Niger case study. This general statement can be then decomposed in to two major axes that correspond to the general downscaling process presented in the general research framework scheme:

3. **Improve drought early warning and forecasting system and regional climate change impact assessment**

- Apply a wider range of climate change projections and weather forecast simulations to analyse the reproduction of hydroclimatic extremes
- Couple weather forecast and protected climate change simulations with an hydrological model through the application of downscaling and bias-correction methods
- Enhance the hydrological model to better represent upstream river basin management and the flood dynamics in the Inner Niger Delta
- Assess flood variability and hydrological drought according to upstream river basin management and climate change scenarios
- Predict Flood/Runoff variability and hydrological drought according to upstream river basin management and weather forecast scenarios
- Formalize the interactions of food security and ecological integrity with flood propagation to extend the analysis from hydrological drought to socio-economic and ecologic vulnerability
- Communicate the uncertainties in any applied methods and scenario results

4. **Stakeholder involvement to strengthen preparedness and adaptation to droughts**

- Find an adapted balance of power among institutionalized and traditional representatives and among the different water users to converge the local actors into an integrative approach in the Inner Niger Delta respecting central authority and traditional regulations
- Tailor the technical framework of a drought impact assesment and of a drought early warning and forecasting system and define the relevance of the methods and of the indicators to the needs of the stakeholder platform and the local actors
- Develop new instruments and channels to disseminate and make accessible the information of drought impact assessment, drought forecast and adaption strategies to a large audience

- Explore emergency, mid-term and long-term adaptive capacities to organize the water uses for drought prepardness
- Integrate scientific early warning and forecasting system tools and drought assessment to reduce the effect of variability and strengthen the preparedness to drought
- Find synergies to couple the forecast products to the current flood forecast system applied in the Inner Niger Delta OPIDIN
- Select pilot projects for each water use and identify adapted solutions to secure food production and biodiversity maintenance in a complex environment
- Promote a lobbying with the authorities and the local and regional decision makers to defend a new paradigm for the Inner Niger Delta and to promote an institutionalized platform to negotiate appropriate trade-offs between upstream and downstream water use (electricity, fully governed irrigation agriculture against fishery, breeding, free submersion and semi controlled irrigation farming, biodiversity maintenance and ecosystem conservation)

16.6 HOW RESULTS AND IMPACT WILL BE MEASURED OR DETERMINED

The contents of D3.1 Conceptual framework for definition of drought vulnerability across Africa, D3.2 Methods for mapping drought vulnerability at different spatial scales will support the selection of appropriate methods to map and represent drought vulnerability. This base line will be discussed during the stakeholder workshop in Mali in April 2012 to select adapted parameters for the use of the stakeholders and the decision makers in the Niger River basin. The application of the indexes and mapping will be then developed and tested according to different forecast and climate change scenario through the three major tasks that carried the essential scientific development and results of the Niger case study.

The final objective is to obtain an indicator referring to the four drought categories as it is defined in Mishra and Singh (2010):

- Meteorological drought is defined as a lack of precipitation over a region for a period of time. Considering drought as precipitation deficit with respect to average values, several studies have analysed droughts using monthly precipitation data. Other approaches analyse drought duration and intensity in relation to cumulative precipitation shortages.

- Hydrological drought is related to a period with inadequate surface and subsurface water resources for established water uses of a given water resources management system. Streamflow data have been widely applied for hydrologic drought analysis. In the case of the Inner Niger Delta, the hydrological drought will be better expressed with the analysis of the flood extent data.
- Agricultural drought, usually, refers to a period with declining soil moisture and consequent crop failure without any reference to surface water resources. In the Inner Niger Delta, the agriculture relies on the flood. Therefore, agricultural drought will also be expressed with hydrological parameters such as flood duration and flood peak.
- Socio-economic drought is associated with failure of water resources systems to meet water demands and thus associating droughts with supply of and demand for an economic good (water) (AMS, 2004). In the Inner Niger Delta, hydrological parameters also govern the food and water supply.

Referring to this terminology, the impact of drought will be measured with:

- Meteorological Drought indicators: RAI (Rainfall Anomaly Index) and SPI (Standardized Precipitation Index)

The standardized precipitation index (SPI) for any location is calculated, based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed to a normal distribution so that the mean SPI for the location and desired period is zero

- Hydrological drought indicators: DAI (Discharge Anomaly Index and SRI (Standardized Runoff Index)

This index is based on the concept of standardized precipitation index (SPI), discussed earlier. Shukla and Wood (2008) derived standardized runoff index (SRI) which incorporates hydrologic processes that determine the seasonal loss in streamflow due to the influence of climate. As a result, on month to seasonal time scales SRI is a useful complement to SPI for depicting hydrological aspects of droughts

- Drought agricultural indicators

The agricultural production in the Inner Niger Delta is not based on rainfed agriculture. It depends mainly on the flood regime. Specific flood indexes will be built according to the particularity of the case study and according to the stakeholder’s requirements and depending on the improvements of the SWIM Inundation model capabilities: The Maximum Annual Flood Extent Index or the Potential Area with Adapted Flooding could be used as extended indexes to address agricultural drought vulnerability in the delta.

- Socio economic drought indicators:

A correlation between the other indicators with socio economic variables such as Hydropower production, National/Regional GDP growth, National/Regional agricultural production (according to agricultural schemes), Natonal/Regional Fish capture, Regional waterbirds census, Regional total number of livestock will be studied. The workshop in Mali will allow identifying with the stakeholders the socio economic data available to perform this task.

17. PROPOSED ACTIVITIES AND WORKPLAN FOR THE NIGER BASIN

17.1 PROPOSED ACTIVITIES

The activities for the Niger case study follow the Work Packages and the Tasks of the DEWFORA framework. The table, standing at the end of the section, refers to the DEWFORA framework and outlines the interdependencies between the deliverables for the Niger case study. This figure allows identifying three major tasks for the Niger case study achievements:

- Task 3.2 Impact of climate change on drought hazard
- Task 4.2 Development of hydrological drought forecasting models at river basin scale
- Task 6.4 Case study Tasks

In **task 3.2**, the activities developed in the D3.5 Hydrological climate scenarios for Africa will allow to sound the effects of climate change on changes in occurrence and persistence of meteorological and hydrological droughts from a set of high resolution climate simulations for the period 1961-2100 (REMO, CCLM, CCAM, CORDEX, STAR) forming the inputs for the hydrological model SWIM. The trends of low flow events in the future projections will be compared with past trends using hydrological drought indicators. For this propose, the D3.4 Meteorological climate scenarios for Africa will provide adapted CCAM simulations as inputs for the hydrological model SWIM. Also, the D3.2 Methods for mapping drought vulnerability at different spatial scales will support the definition of applied methods to represent and compare drought vulnerability at different scale.

In **task 4.2**, the D4.1 Meteorological drought forecasting (monthly to seasonal forecasting) at regional and continental scale provide a set of high resolution of monthly and seasonal weather forecast and hindcast simulations. The objective is to test the application of monthly forecast system incorporated in SWIM to produce a hydrological forecast system in the Upper Niger Basin and to sound the prediction of low flow events. In D4.7 Downscaled and tailor made hydrological models for the Limpopo and Niger case study basins, a description of the set-up, the calibration and the validation of the hydrological model SWIM will be then delivered. The modules developed to represent upstream management and the flood propagation of the Inner Niger Delta will be further described. In D4.8 Skill of developed regional hydrological models to forecast hydrological drought, the application of the monthly seasonal weather forecast will be presented.

In **task 6.4**, the objective is to compile all the advancements made from the other Work Packages. Additionally, the meteorological and hydrological drought indexes will be correlated to socio economic indicators in order to interpret the scale of impacts of the early warning tools. The vulnerability to upstream management planning and the adaptive capacities will be enounced and discussed. An intermediate and informal report will be delivered in August to present the advancements made on the combined impacts of upstream water management and regional climate change forcing.

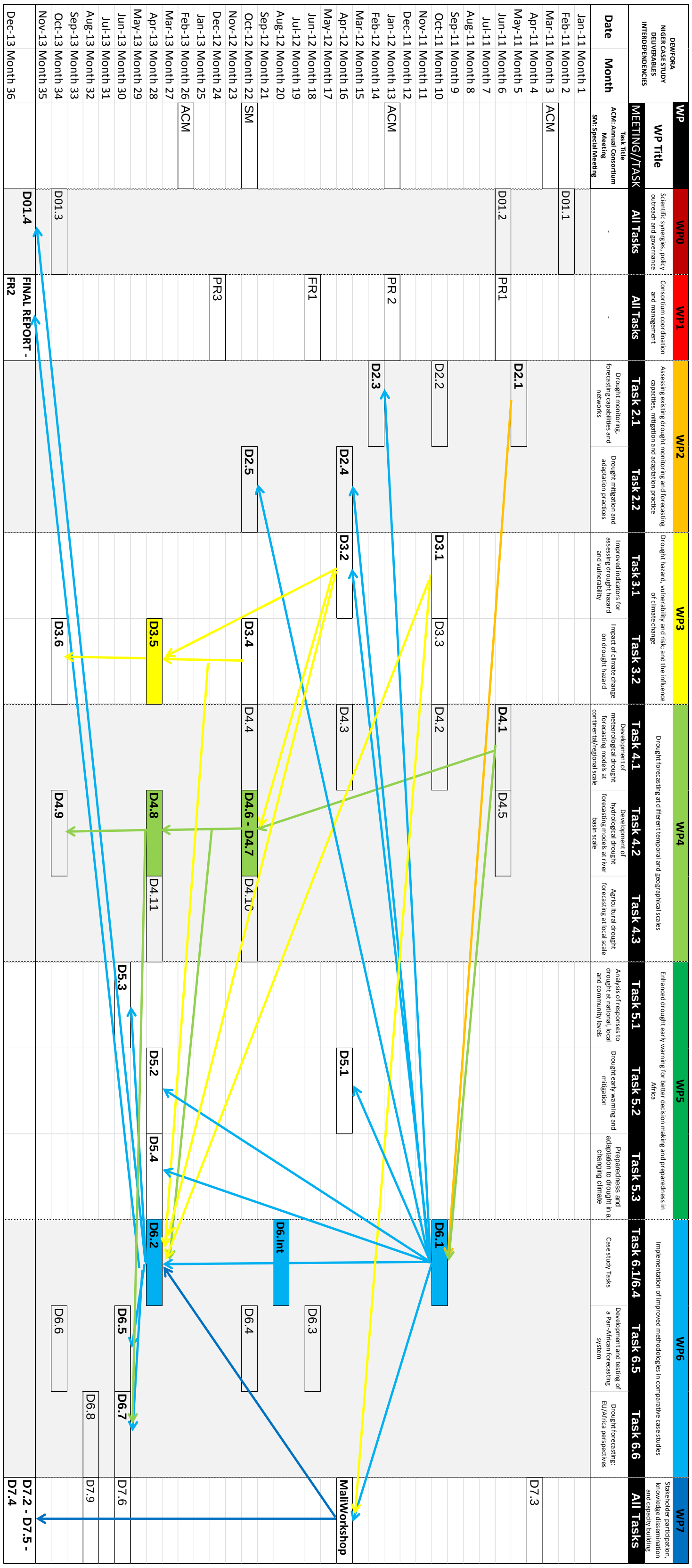


Figure 17-1: Niger case study integration and interdependencies in the WP, Task and Deliverable in DEWFORA

The figure above also allows identifying interdependencies with other sensible Work Packages, Tasks and Deliverables:

Task 3.1 Improved indicators for assessing drought hazard and vulnerability

The contents of D3.1 Conceptual framework for definition of drought vulnerability across Africa, D3.2 Methods for mapping drought vulnerability at different spatial scales will support the selection of appropriate methods to map and represent drought vulnerability. This base line will be discussed during the stakeholder workshop in Mali in April 2012 to select adapted parameters for the use of the stakeholders and the decision makers in the Niger River basin. The application of the indexes and mapping will be then developed and tested according to different forecast and climate change scenario through the three major tasks that carried the essential scientific development and results of the Niger case study.

WP5 Enhanced drought early warning for better decision making and preparedness in Africa

There are no particular inputs from WP5 that especially contribute to the Niger case study. In return, the D6.1 Inception report for each case study and the D6.2 Final report for each case study will be important sources to achieve the four reports of the WP5 which are D5.1 Outline of framework for drought warning and mitigation in Africa, D5.2 Chart of institutional responsibilities and communication lines for drought response, D5.4) Recommendation for enhancing drought preparedness at the local and regional scales and D5.3 Framework for drought warning and mitigation from national to local scale.

WP6 Implementation of improved methodologies in comparative case studies

For the Task 6.5 Development and testing of a Pan-African forecasting system, the integration of sensible indicators from the case study developed at the basin scale of the Niger case study into the pan African map server will the object of discussion based on the associated results from D3.5 Hydrological climate scenarios for Africa, D4.8 Skill of developed regional hydrological models to forecast hydrological drought and D6.2 Final report for each case study all due in Month 28. This integration will contribute to enhance the D6.5 Integration of drought forecasting tools for Africa into the Pan-African map serve and the D6.6 Development and implementation of Pan-African map server. For the Task 6.6 Drought forecasting: EU/Africa perspectives, D6.7 Performance of the proposed improved drought forecasting methods applied to selected river basins and D6.8 Comparative review of drought forecasting in Europe and Africa will produce the evaluation based on the outputs from D4.8 Skill of developed regional hydrological models to forecast hydrological drought and D6.2 Final report for each case study.

WP7 Stakeholder participation, knowledge dissemination and capacity building

The Niger case study partners contributes to the achievment of D7.4 Newsletters: Project Newsletters and particularly to D7.2) Proceedings from End-user workshops with the organization of an additional stakeholder workshop jointly with the fp7 project AFROMAISON and IMPACT2C in April 2012. This additional workshop will contribute to the dissemination and the implementation of the products developed under DEWFORA project. Also, the D7.6 Training courses still need to be further clarified.

17.2 PROPOSED WORKPLAN, MILESTONES AND TIME SCHEDULE

Current achievements

For the climatology section in the research framework, the table below summarizes the current advancements in the climate data acquisition the formatting to SWIM inputs standards, the analysis and the application into SWIM. The first task will be to then acquire as soon as possible the monthly weather forecast system from ECMWF and CCAM to perform the same steps.

Table 17-1: Summary of the advancements for climate data preparation

CLIMATE FOCUS	**PAST CLIMATE** **non included: (TRMM, NCEP, GPCP…)**			**SEASONAL WEATHER FORECAST** **1 months prospective**		**CLIMATE CHANGE**				
DATA NAME	**WATCH**	**SIEREM**	**DNM**	**ECMWF HINDCAST**	**CCAM FORECAST**	**CCLM**	**REMO**	**STAR**	**CCAM**	**CORDEX**
DATA TYPE	Reanalyzes ***ERA-40*** Monthly adjustment ***CRU*** ***GPCC***	Observed rainfall ***IRD*** ***CRU*** ***SIEREM***	Observed rainfall stations ***SYNOPTIC*** ***CLIMATOLOGIC*** ***PLUVIOMETRIC***	15 ensemble members Initial state: ***ocean analysis ERA-Interim***	51 ensemble members Initial state: ***ocean analysis + ERA-Interim***	RCM ***A1B realization*** AOGCM: ***ECHAM5***	RCM ***A1B realization*** AOGCM: ***ECHAM5***	Statistical regional climate ***WATCH*** ***Forcing temperature variable***	RCM ***A2B realization***	ensemble of multiple dynamical and statistical downscaling models considering multiple forcing GCMs
PERIOD COVERAGE	Daily 1900-2001	Monthly	Variable	Daily 1981-2010	Daily 1981-2010	Daily	Daily	Daily	Daily 1961-2100	
SPATIAL COVERAGE	Grid WA 0.5°	Grid WA 0.5°	80 stations UN	Grid UN 0.5°	Grid ? 0.5°	Grid WA 50km	Grid WA 50 km	Grid WA 0.5°	Grid WA 0.5°	
CURRENT ADVANCEMENTS										
ACQUISITION	**X**	**X**	**X**	**X**	**-**	**X**	**X**	**X**	**Soon**	**2012**
FORMATTING	**X**	**X**	**X**	**X**	**-**	**X**	**X**	**X**	**-**	**-**
ANALYSIS	**X**	**X**	**X**	**-**	**-**	**X**	**X**	**X**	**-**	**-**
APPLICATION	**X**	**-**	**-**	**-**	**-**	**X**	**X**	**X**	**-**	**-**

For the hydrological section presented in the research framework, PIK already calibrated and validated SWIM model to WATCH products. SWIM Inundation module was further enhanced but needs further improvements. The SWIM reservoir module is in the working phase for a complete integration into SWIM model. The water transfer module still needs to be achieved to account for upstream uptakes from irrigations schemes. PIK operated some runs with Watch products, 100 realizations of STAR and three from non-bias corrected REMO and CLLM.

For the IWRM section presented in the research framework, the stakeholder workshop was postponed and is now scheduled in April 2012. The different forecasting systems in use in Mali were investigated and the vulnerability and the potential adaptive capacities of the different water use are discussed in the satkeholder platforms. Concerning the advancements for the creation of sensible drought vulnerability indicators, PIK in collaboration with Wetlands International compared rice production target to meet regional food security against the simulated potential capacities for rice production from flooding criteria in SWIM. This study was realized under the 100 STAR realizations.

Scientific workplan

The table below summarizes the planned monthly activities and reporting for the Niger case study. The work to achieve can be summarized according to the research framework plan:

In the climatology part, the acquisition of new products: ECMWF and CCAM Forecast, Cordex and Ccam are crucial to opearte new sounding simulations. Also, the application of drought/rainfall index will be further investigated to compare the low rainfall pattern of the different climate data products

In hydrology, some SWIM modules needs to be developed or further improved. The application of streamflow and/or flooding indexes to compare the low hydrological response of the different climate data products will be also applied.

In the IWRM part, the objective is to extend the vulnerability analyzis to other crop production or water uses. This will be performed by investigationg the correlation of drought indicators with socio-economic and ecological parameters. A trade-off analysis between upstream and downstream water uses will be also performed. The table below gives an appropriate schedule to accomplish the three work phases.

Table 17-2: Monthly scientific workplan for the Niger case stufy

Scientific workplan		**Niger Case Study**
Feb-12	Month 14	Climate data preparation
Mar-12	Month 15	CCAM/ECMWF Data acquisition and preparation SWIM Reservoir module improvement
Apr-12	Month 16	Climate model intercomparison: Rainfall and Temperature spatio-temporal analyzis Meteorological Drought Indexes Stakeholder meeting in Mali: selection of Drought indicators, definition of adaptive capacities
May-12	Month 17	First Hydrological runs Bias-correction implementation
Jun-12	Month 18	Hydrological Runs RCM´s product Swim water transfer module development
Jul-12	Month 19	Hydrological Runs Forecast products Swim inundation module improvement
Aug-12	Month 20	Climate Model Intercomparison: Hydrological Drought Indexes **Reporting: D6.1.5 Intermediate deliverables**
Sep-12	Month 21	Hydrological Runs RCM´s product including upstream management scenario
Oct-12	Month 22	Climate Model Intercomparison: Flooding Drought Indexes **Reporting D3.4 + D4.7**
Nov-12	Month 23	Correlation Meteo/Hydro/Flood Drought Indexes
Dec-12	Month 24	Options to merge and improve OPIDIN and SWIM Forecast
Jan-13	Month 25	Drought Vulnerability: Correlation drought Indexes with SOCIO-ECONOMY
Feb-13	Month 26	Drought Vulnerability: correlation drought Indexes with HEALTH-ECOLOGY
Mar-13	Month 27	Investigate adaption strategies to drought hazard
Apr-13	Month 28	**Finalizing reports D3.5, D4.8, D6.2**

To conclude, the recent political instability in Mali with the upcoming presidential election, the conflicts with the Tuaregs and the increased threats for foreigners outside Bamako do not facilitate the implementation of the DEWFORA project. Wetlands International must for example transfer all the local stakeholders of the Inner Niger Delta to Bamako for the organization of a stakeholder meeting. This independent variable can unfortunately affect the integration of research results into the regional and local framework and will potentially challenge the project coordination.

<table>
<tr><td rowspan="3">WP6</td><td colspan="10">Title: Implementation of improved methodologies in comparative case studies</td></tr>
<tr><td colspan="10">Objectives:
▪ To serve as demonstration sites for the implementation of the improved methodologies developed
in work packages 3, 4, and 5.
▪ To develop and test a pre-operational pan-African system for drought monitoring and forecasting.
▪ To provide a comparative review of drought forecasting in Europe and Africa.</td></tr>
<tr><td></td><td>2011</td><td colspan="4">2012</td><td colspan="4">2013</td></tr>
<tr><td>WP6</td><td></td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td><td>Q1</td><td>Q2</td><td>Q3</td><td>Q4</td></tr>
</table>

	Deliverables									
	D.6.1 An inception report									
	Activities									
	A1: Assess the existing drought monitoring and forecasting networks									
	A2: Investigation of current problems to drought									
	A3: Collect available hydro-meteorological data									
	A4: Survey on drought management practices	▨								
	A5: Survey on stakeholders involved in drought management	▨								
	A6: Identify key stakeholders in the region to be invited to participate in the Stakeholders Platform and provide this information to work package 7	▨	▨							
	A7: Collect case specific meteorological and ground data	▨								
	A8: Provide this information to work package 4.	▨								
	D.6.2. Final report for each case study									
	Activities									
	A9: Collect information on regional water resources use for identification of indicator thresholds in	▨								

	A10: Collect information on preparedness to droughts & food security 586 days? Mon 3-1-11 Mon 1-4-13	▨								
	A11: Synthesize the current state of the art of climate research in the basin	▨	▨	▨						
	A12: Identify and maintain contact with end-users throughout the project	▨	▨	▨	▨	▨	▨	▨	▨	▨
	A 13: Concluding specific case study objectives and findings									
	A14: Present results to local stakeholders, relevant authorities and decision makers						▨	▨		
	D.6.3: Testing of drought indicators at Pan-African level									
	A15: Apply eco-hydrological model (hydrology & agriculture & vegetation types)									
	A16: Test drought indicators				▨					
	A17: Pilot drought preparedness by predicting hydrological &agricultural drought risk through climate predictions (using WP 3, 4 and 5)									
	A18: Produce Map									

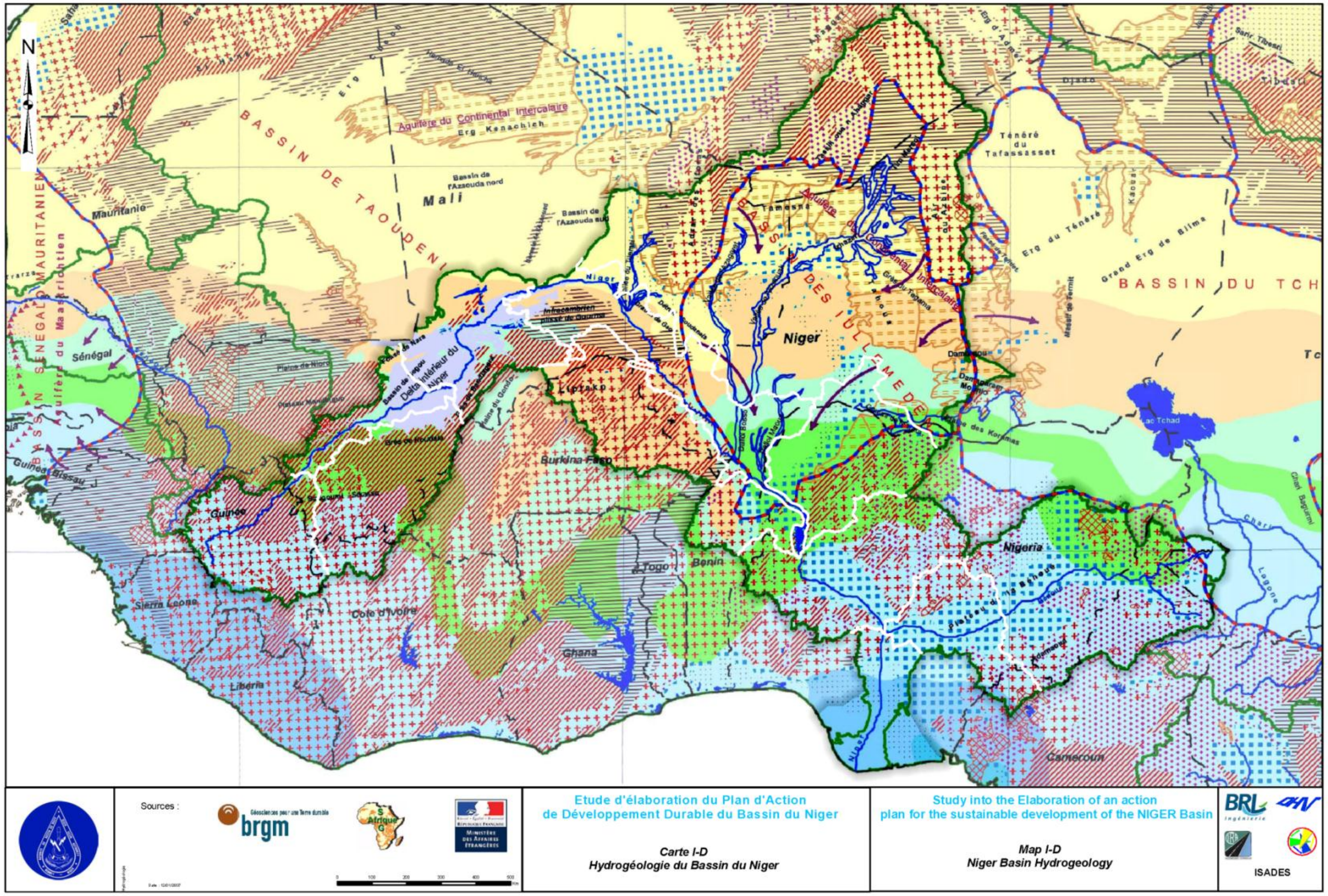
	D.6.4: Integration of drought vulnerability and hazard into risk maps at the Pan African level									
	A19: Assist with integration of drought vulnerability & hazard into risk maps					▨				
	D.6.5 Integration of drought forecasting tools for Africa into Pan-African map server									
	A20: Assist with integration into map server									
	D.6.6 Development and implementation of Pan-African map server									
	A21: Assist with integration into map server									
	D.6.7 performance of the proposed improved drought forecasting methods applied to selected river basins									
	A22: Apply improved forecasting methods to the river basin									
	A23: Evaluate the performance of the forecasting method									
	D6.8 Comparative review of drought forecasting in Europe and Africa								▨	
	A24: Link activities of the case study to								▨	

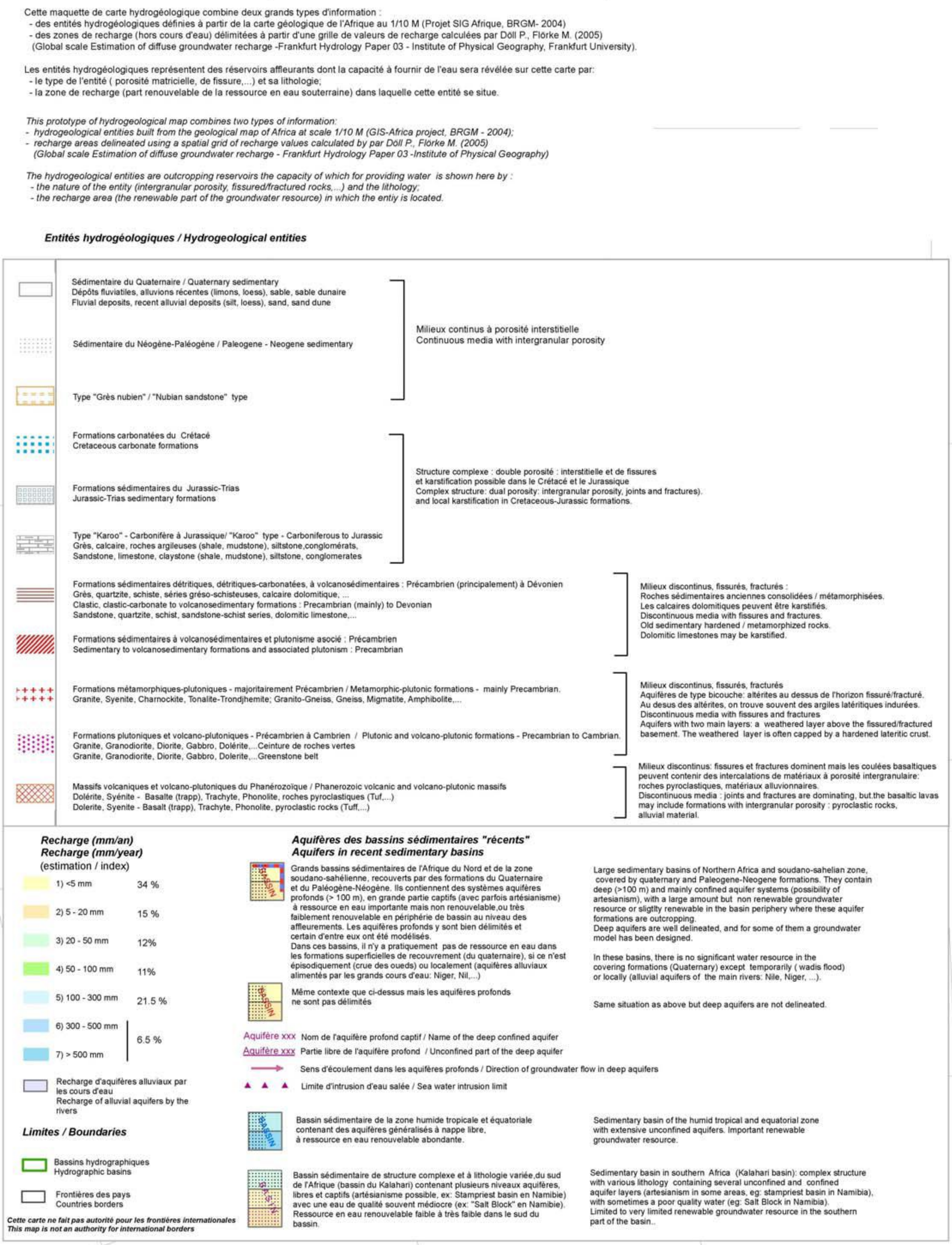
	other relevant initiatives in the region								▨	
	A25: Assist/provide feedback to the comparative review									
	Meeting1									
	Meeting2									
	Meeting3									
	Meeting4									
	Meeting 5									
	Meeting6									
	Meeting7									
	Liaise with Management Team	▨	▨	▨	▨	▨	▨	▨	▨	▨

ANNEX

Niger River hydrogeology BRGM map and legends:

Source: BRL, and DHI. 2007. *Etudes Sur L'élaboration Du Plan d'Action De Développement Durable (PADD) Du Bassin Du Niger: Phase 1: Bilan Diagnostic*. NIGER BASIN AUTHORITY (NBA).


Study into the Elaboration of an action plan for the sustainable development of the NIGER Basin
Map I-D
Niger Basin Hydrogeology
Etude d'élaboration du Plan d'Action de Développement Durable du Bassin du Niger
Carte I-D
Hydrogéologie du Bassin du Niger
Sources :
brgm
BRL ingénierie
ISADES
N
BASSIN DE TAOUDENI
BASSIN DES IULLEMEDEN
BASSIN DU TCH
BASSIN SENEGALO MAURITANIEN
Aquifère du Continental Intercalaire
Erg Kanachich
Bassin de l'Azaouda nord
Bassin de l'Azaouda sud
Mali
Mauritanie
Sénégal
Guinée
Guinée Bissau
Sierra Leone
Liberia
Côte d'Ivoire
Ghana
Togo
Benin
Burkina Faso
Niger
Nigeria
Cameroun
Delta intérieur du Niger
Ténéré du Tafassasset
Erg du Ténéré
Grand Erg de Bilma
Lac Tchad
Chari
Logone
Infracambrien plissé du Gourma
Liptako



Cette maquette de carte hydrogéologique combine deux grands types d'information :
- des entités hydrogéologiques définies à partir de la carte géologique de l'Afrique au 1/10 M (Projet SIG Afrique, BRGM- 2004)
- des zones de recharge (hors cours d'eau) délimitées à partir d'une grille de valeurs de recharge calculées par Döll P., Flörke M. (2005) (Global scale Estimation of diffuse groundwater recharge -Frankfurt Hydrology Paper 03 - Institute of Physical Geography, Frankfurt University).

Les entités hydrogéologiques représentent des réservoirs affleurants dont la capacité à fournir de l'eau sera révélée sur cette carte par:
- le type de l'entité (porosité matricielle, de fissure,...) et sa lithologie;
- la zone de recharge (part renouvelable de la ressource en eau souterraine) dans laquelle cette entité se situe.

This prototype of hydrogeological map combines two types of information:
- *hydrogeological entities built from the geological map of Africa at scale 1/10 M (GIS-Africa project, BRGM - 2004);*
- *recharge areas delineated using a spatial grid of recharge values calculated by par Döll P., Flörke M. (2005) (Global scale Estimation of diffuse groundwater recharge - Frankfurt Hydrology Paper 03 -Institute of Physical Geography)*

The hydrogeological entities are outcropping reservoirs the capacity of which for providing water is shown here by :
- *the nature of the entity (intergranular porosity, fissured/fractured rocks,...) and the lithology;*
- *the recharge area (the renewable part of the groundwater resource) in which the entiy is located.*

Entités hydrogéologiques / Hydrogeological entities

Sédimentaire du Quaternaire / Quaternary sedimentary
Dépôts fluviatiles, alluvions récentes (limons, loess), sable, sable dunaire
Fluvial deposits, recent alluvial deposits (silt, loess), sand, sand dune

Sédimentaire du Néogène-Paléogène / Paleogene - Neogene sedimentary

Type "Grès nubien" / "Nubian sandstone" type

Milieux continus à porosité interstitielle
Continuous media with intergranular porosity

Formations carbonatées du Crétacé
Cretaceous carbonate formations

Formations sédimentaires du Jurassic-Trias
Jurassic-Trias sedimentary formations

Type "Karoo" - Carbonifère à Jurassique/ "Karoo" type - Carboniferous to Jurassic
Grès, calcaire, roches argileuses (shale, mudstone), siltstone,conglomérats,
Sandstone, limestone, claystone (shale, mudstone), siltstone, conglomerates

Structure complexe : double porosité : interstitielle et de fissures
et karstification possible dans le Crétacé et le Jurassique
Complex structure: dual porosity: intergranular porosity, joints and fractures).
and local karstification in Cretaceous-Jurassic formations.

Formations sédimentaires détritiques, détritiques-carbonatées, à volcanosédimentaires : Précambrien (principalement) à Dévonien
Grès, quartzite, schiste, séries gréso-schisteuses, calcaire dolomitique, ...
Clastic, clastic-carbonate to volcanosedimentary formations : Precambrian (mainly) to Devonian
Sandstone, quartzite, schist, sandstone-schist series, dolomitic limestone,...

Formations sédimentaires à volcanosédimentaires et plutonisme asocié : Précambrien
Sedimentary to volcanosedimentary formations and associated plutonism : Precambrian

Milieux discontinus, fissurés, fracturés :
Roches sédimentaires anciennes consolidées / métamorphisées.
Les calcaires dolomitiques peuvent être karstifiés.
Discontinuous media with fissures and fractures.
Old sedimentary hardened / metamorphized rocks.
Dolomitic limestones may be karstified.

Formations métamorphiques-plutoniques - majoritairement Précambrien / Metamorphic-plutonic formations - mainly Precambrian.
Granite, Syenite, Charnockite, Tonalite-Trondjhemite; Granito-Gneiss, Gneiss, Migmatite, Amphibolite,...

Formations plutoniques et volcano-plutoniques - Précambrien à Cambrien / Plutonic and volcano-plutonic formations - Precambrian to Cambrian.
Granite, Granodiorite, Diorite, Gabbro, Dolérite,...Ceinture de roches vertes
Granite, Granodiorite, Diorite, Gabbro, Dolerite,...Greenstone belt

Milieux discontinus, fissurés, fracturés
Aquifères de type bicouche: altérites au dessus de l'horizon fissuré/fracturé.
Au desus des altérites, on trouve souvent des argiles latéritiques indurées.
Discontinuous media with fissures and fractures
Aquifers with two main layers: a weathered layer above the fissured/fractured basement. The weathered layer is often capped by a hardened lateritic crust.

Massifs volcaniques et volcano-plutoniques du Phanérozoïque / Phanerozoic volcanic and volcano-plutonic massifs
Dolérite, Syénite - Basalte (trapp), Trachyte, Phonolite, roches pyroclastiques (Tuf,...)
Dolerite, Syenite - Basalt (trapp), Trachyte, Phonolite, pyroclastic rocks (Tuff,...)

Milieux discontinus: fissures et fractures dominent mais les coulées basaltiques peuvent contenir des intercalations de matériaux à porosité intergranulaire: roches pyroclastiques, matériaux alluvionnaires.
Discontinuous media : joints and fractures are dominating, but.the basaltic lavas may include formations with intergranular porosity : pyroclastic rocks, alluvial material.

Recharge (mm/an)
Recharge (mm/year)
(estimation / index)

🟨	1) <5 mm	34 %
🟧	2) 5 - 20 mm	15 %
🟩	3) 20 - 50 mm	12%
🟩	4) 50 - 100 mm	11%
🟦	5) 100 - 300 mm	21.5 %
🟦	6) 300 - 500 mm	6.5 %
🟦	7) > 500 mm	

Recharge d'aquifères alluviaux par les cours d'eau
Recharge of alluvial aquifers by the rivers

Limites / Boundaries

Bassins hydrographiques
Hydrographic basins

Frontières des pays
Countries borders

Cette carte ne fait pas autorité pour les frontières internationales
This map is not an authority for international borders

Aquifères des bassins sédimentaires "récents"
Aquifers in recent sedimentary basins

BASSIN — Grands bassins sédimentaires de l'Afrique du Nord et de la zone soudano-sahélienne, recouverts par des formations du Quaternaire et du Paléogène-Néogène. Ils contiennent des systèmes aquifères profonds (> 100 m), en grande partie captifs (avec parfois artésianisme) à ressource en eau importante mais non renouvelable,ou très faiblement renouvelable en périphérie de bassin au niveau des affleurements. Les aquifères profonds y sont bien délimités et certain d'entre eux ont été modélisés.
Dans ces bassins, il n'y a pratiquement pas de ressource en eau dans les formations superficielles de recouvrement (du quaternaire), si ce n'est épisodiquement (crue des oueds) ou localement (aquifères alluviaux alimentés par les grands cours d'eau: Niger, Nil,...)

Large sedimentary basins of Northern Africa and soudano-sahelian zone, covered by quaternary and Paleogene-Neogene formations. They contain deep (>100 m) and mainly confined aquifer systems (possibility of artesianism), with a large amount but non renewable groundwater resource or sligtlty renewable in the basin periphery where these aquifer formations are outcropping.
Deep aquifers are well delineated, and for some of them a groundwater model has been designed.

In these basins, there is no significant water resource in the covering formations (Quaternary) except temporarily (wadis flood) or locally (alluvial aquifers of the main rivers: Nile, Niger, ...).

BASSIN — Même contexte que ci-dessus mais les aquifères profonds ne sont pas délimités

Same situation as above but deep aquifers are not delineated.

Aquifère xxx Nom de l'aquifère profond captif / Name of the deep confined aquifer

<u>Aquifère xxx</u> Partie libre de l'aquifère profond / Unconfined part of the deep aquifer

→ Sens d'écoulement dans les aquifères profonds / Direction of groundwater flow in deep aquifers

▲ ▲ ▲ Limite d'intrusion d'eau salée / Sea water intrusion limit

BASSIN — Bassin sédimentaire de la zone humide tropicale et équatoriale contenant des aquifères généralisés à nappe libre, à ressource en eau renouvelable abondante.

Sedimentary basin of the humid tropical and equatorial zone with extensive unconfined aquifers. Important renewable groundwater resource.

BASSIN — Bassin sédimentaire de structure complexe et à lithologie variée,du sud de l'Afrique (bassin du Kalahari) contenant plusieurs niveaux aquifères, libres et captifs (artésianisme possible, ex: Stampriest basin en Namibie) avec une eau de qualité souvent médiocre (ex: "Salt Block" en Namibie). Ressource en eau renouvelable faible à très faible dans le sud du bassin.

Sedimentary basin in southern Africa (Kalahari basin): complex structure with various lithology containing several unconfined and confined aquifer layers (artesianism in some areas, eg: stampriest basin in Namibia), with sometimes a poor quality water (eg: Salt Block in Namibia). Limited to very limited renewable groundwater resource in the southern part of the basin..

18. REFERENCES

Blue Nile Case Study References

Daly C. Neilson P. Phillips DL. 1994. A statistical–topographical model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology 33, 140–158.

UNEP Africa Water Atlas, 2010.

GSA Today, September 2007.

Soils of central Sudan, by J. Buursink, 1971.

International Institute for Environment and Development, Indigenous Soil and Water Conservation in Africa, (GATEKEEPER SERIES NO.27).

Water Resources and Irrigation Development in Ethiopia, (working paper 123).

Climate Change Impacts on Hydrology and water resources of the upper Blue Nile river basin in Ethiopia, (search report 126), By Ugtae Kim Jagath J.Kaluarachchi.

Consulting Report on Data Availability, Needs, and Gaps for NFC Hydrological Models, and Database Structure, By Dr. Hatem Faheem Hassan (May 2010).

The Lake Nasser Flood and Drought Control / Integration of Climate Change Uncertainty and Flooding Risk (LNFDC/ICC), Volume I, March 2008.

The Lake Nasser Flood and Drought Control / Integration of Climate Change Uncertainty and Flooding Risk (LNFDC/ICC), Volume VIII, March 2008.

Modeling Rainfall, Runoff and Soil Loss Relationships in the Northeastern Highlands of Ethiopia, By Tegenu Ashagrie Engda, August 2009.

The Nile Basin volume IX, 1959.

Beyene, A., and Abdelsalam, M.G., 2005, Tectonics of the Afar Depression: A review and synthesis: Journal of African Earth Sciences, v. 41, p. 41–59

Davis, P.M., and Slack, P.D., 2002, the uppermost mantle beneath the Kenya dome and relation to melting, rifting and uplift in East Africa: Geophysical Research Letters, v. 29

Collet, B., Taud, H., and Parrot, J.F., 1999, Altimetric anomalies in the Afro-Arab zone: Eclogae Geologicae Helvateae, v. 92-Sengör, A.M.C., 2001, Elevation as indicator of mantle-plume activity, in Ernst, R.E., and Buchan, K.L., eds., Mantle Plumes: Their identification through time: Geological Society of America Special Paper 352

Hofmann, C., Courtillot, V., Feraud, G., Rochette, P., Yirgu, G., Ketefo, E., and Pik, R., 1997, Timing of the Ethiopian flood basalt event and implications of Plume birth and global change: Nature, v. 389, p. 838–841

Mohr, P., and Zanettin, B., 1988, the Ethiopian Flood Basalt Province, in McDougall, J.D., ed., Continental Flood Basalts: Dordrecht, Netherlands, Kluwer Academic Publishers, p. 63–110.

Kieffer, B., Arndt, N., Lapierre, H., Bastien, F., Bosch, D., Pecher, A., Yirgu, G., Ayalew, D., Weis, D., Jerram, D.A., Keller, F., and Meugniot, C., 2004, Flood and shield basalts from Ethiopia: Magmas from the African Superswell: Journal of Petrology, v. 45, p. 793–834

Capaldi, G., Chiesa, S., Manetti, P., Orsi, G., and Poli, G., 1987, Tertiary anorogenic Granites of the western border of the Yemen Plateau: Lithos, v. 20, p. 433–444

Manighetti, I., Tapponnier, P., Courtillot, V., Gallet, Y., Jacques, E., and Gillot, P.Y., 2001, Strain transfer between disconnected, propagating rifts in Afar: Journal of Geophysical Research, v. 106, p. 13,613–13,665

Wolfenden, E., Yirgu, G., Ebinger, C., Deino, A., and Ayalew, D., 2004, Evolution of the northern Main Ethiopian rift: Birth of a triple junction: Earth and Planetary Science Letters, v. 224, p. 213–228

WoldeGabriel, G., Aronson, J.L., and Walter, R.C., 1990, Geology, geochronology, and rift basin development in the central sector of the Main Ethiopia Rift: Geological Society of America Bulletin, v. 102, p. 439–458

Bonini, M., Corti, G., Innocenti, F., and Manetti, P., 2005, Evolution of the Main Ethiopian Rift in the frame of Afar and Kenya rifts propagation: Tectonics, v. 24

Chorowicz, J., Collet, B., Bonavia, F.F., Mohr, P., Parrot, J.F., and Korme, T., 1998, The Tana basin, Ethiopia: Intra-plateau uplift, rifting and subsidence: Tectonophysics, v. 295

Shahin, M., 1985. Hydrology of the Nile Basin. Developments in water science ; 21. Elsevier, Amsterdam ; Oxford.

Conway, D. and Hulme, M.: Recent fluctuations in precipitation and runoff over the Nile sub-basins and their impact on main Nile discharge, Climate. Change, 25, 127–151, 1993.

Sutcliffe, J.V. and Parks, Y.P., 1999. The hydrology of the Nile. IAHS Special Publication No. 5. International Association of Hydrological Sciences, Wallingford, UK.

Mesinger, F., 1984: A blocking technique for representation of mountains in atmospheric models. Riv. Meteor. Aeronautica, 44, 195-202.

Mesinger, F., and Z. I. Janjic, 1974: Noise due to time-dependent boundary conditions in limited area models. The GARP Programme on Numerical Experimentation, Rep. No. 4, WMO, Geneva, 31-32.

Mesinger, F., Z. I. Janjic, S. Nickovic, D. Gavrilov, and D. G. Deaven, 1988: The step-mountain coordinate: model description and performance for cases of Alpine lee cyclogenesis and for a case of an Appalachian redevelopment. Mon. Wea. Rev., 116, 1493-1518.

Janjic, Z. I., 1990: The step-mountain coordinate: Physical package. Mon. Wea. Rev., 118, 1429-1443.

Mesinger, F., and L. Lobocki, 1991: Sensitivity to the parameterization of surface fluxes in NMC's eta model. 9th Conf. on Numerical Weather Prediction, Denver, CO, Amer. Meteor. Soc., 213-216.

Black, T. L., 1994: The new NMC mesoscale Eta Model: Description and forecast examples. Weather Forecasting, 9, 265-278.

Mesinger, F., and D. Jovic, 2004: Vertical coordinate, QPF, and resolution.The 2004 Workshop on the Solution of Partial Differential Equations on the Sphere, Frontier Res. Center for Global Change (FRCGC), Yokohama, Japan, 20-23 July 2004.

Janjic, Z. I., 1984: Nonlinear advection schemes and energy cascade on semi-staggered grids. Mon. Wea. Rev., 112, 1234-1245.

Betts, A. K., and M. J. Miller, 1986: A new convective adjustment scheme. Part II: Single column tests using GATE wave, BOMEX and arctic air-mass data sets. Quart. J. Roy. Meteor. Soc., 112, 693-709.

Ferrier, B. S., Y. Jin, Y. Lin, T. Black, E. Rogers, and G. DiMego, 2002:Implementation of a new grid-scale cloud and precipitation scheme in the NCEP Eta Model. 19th Conf. on Weather Analysis and Forecasting/15th Conf. on Numerical Weather Prediction, San Antonio, TX, Amer. Meteor. Soc., 280-283.

Lacis, A. A., and J. E. Hansen, 1974: A parameterization of the absorption of solar radiation in the earth's atmosphere. J. Atmos. Sci., 31, 118-133.

Fels, S. B., and M. D. Schwarzkopf, 1975: The simplified exchange approximation: A new method for radiative transfer calculations. J. Atmos. Sci., 32, 1475-1488.

Mesinger, F., 2005: Eta Model at NCEP: Challenges overcome and lessons learned. Lecture notes, Workshop on "Design and Use of Regional Weather Prediction Models", The Abdus Salam International Centre for Theoretical Physics, Miramare, Trieste, Italy, 11-19 April 2005, 42 pp.

Altshuler, E., M. Fennessy, J. Shukla, H. Juang, E. Rogers, K. Mitchell, and M. Kanamitsu, 2002: Seasonal simulations over North America with a GCM and three regional models. COLA Tech. Rpt. 115, 66 pp.

Chou, S. C., J. F. Bustamante, and J. L. Gomes, 2005: Evaluation of seasonal precipitation forecasts over South America using Eta model.Nonlin. Proc. Geophys., 12, 537-555;

Katsafados P., A. Papadopoulos, and G. Kallos, 2005: Regional atmospheric response to tropical Pacific SST perturbations. Geophys. Res. Lett., 32, L04806, doi:10.1029/2004GL021828.

Emergency Food Security Assessment (EFSA), Blue Nile State Sudan, May 2010.

Solomon, Cheere. 2006. Irrigation Policies, Strategies and Institutional Support Conditions in Ethiopia. in: Awulacew, S.B.; Menkir, M.; Abesha, D.; Atnafe, T.; Wondimkun, Y. (Eds). 2006. Best Practices and Technologies for Small Scale Agricultural Water Management in Ethiopia. Procedings of a MoARD/MoWR/USAID/IWMI symposium and exhibition held at Ghion Hotel, Addis Ababa, Ethiopia 7-9 March, 2006 Colombo, Srilanka, International Water Management Institute.

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2004. National development report for Ethiopia, UNESCO, World Water Assessment Program, December 2004.

Werfring, A. 2004. Typology of Irrigation in Ethiopia. A thesis submitted to the University of Natural Resources and Applied Life Sciences Vienna. Institute of Hydraulics and Rural Water Management in partial fulfillment of the degree of Diplomingeieur.

MoFED (Ministry of Finance and Economic Development). 2006. Ethiopia: Building on Progress, A Plan for Accelerated and Sustained Development to End Poverty (PASDEP) 2005/06-2009/10, September, 2006, Addis Ababa: Ethiopia.

MOH (Ministry of Health) and World Development Report. 1997. In National Development Report for Ethiopia (Final), World Water Assessment Program (UNESCO). 2004.

Halcrow and MCE (Metaferia Consulting Engineers). 2006. Awash Basin flood protection and watershed project. Annex WP3. Unpublished report.

CSA (Central Statistical Agency of Ethiopia). 1998. Statistical Abstract of Ethiopia. Central Statistics Authority. Addis Ababa: Ethiopia.

Beyene, T.; and Abebe, M. 2006. Potential and Development Plans in Ethiopia. Hydropower and Dams, Issue Six, 2006.

Awulachew, S.B.; Merrey, D.J.; Kamara, A. B.; Van Koopen, B.; De Vries, F. Penning; and Boelle, E. 2005. Experiences and Opportunities for Promoting Small-Scale/Micro Irrigation and Rainwater Harvesting for Food Security in Ethiopia. IWMI Working Paper 98, 2005.

"Hydro power in Ethiopia - the staged construction of Tekeze Arch Dam".waterpowermagazine. Retrieved 2011-04-27.

Webster's New Geographical Dictionary, Springfield, Massachusetts: Merriam-Webster Inc., 1984, ISBN 0-87779-446-4, p. 1,194.

"Climate, 2008 National Statistics (Abstract)", Table A.1. Central Statistical Agency website (accessed 26 December 2009)

Eritrea - Ethiopia Boundary Commission Decision Regarding Delimitation of the Border..., pp. 97, 101

Translated with commentary in G.W.B. Huntingford, The Historical Geography of Ethiopia (London: British Academy, 1989), pp. 56-59.

Augustus B. Wylde, Modern Abyssinia (London: Methuen, 1901), p. 352

Barker, A. J., The Rape of Ethiopia 1936, New York: Ballantine Books Inc., 1971, pp. 84, 91.

China People's Daily Online. Accessed 20 April 2006.

"Construction of Tekeze Hydro Electric Power Project nearing completion" (Walta Information Center), accessed 2 December 2007.

Also these websites have been used as a source:

http://www.fao.org/nr/water/aquastat/countries/sudan/index.stm, last accessed 22 September 2011

http://adroub.net/default.aspx?page=Climate.%20Drought%20A, last accessed 22 September 2011

EzineArticles , Ethiopia Population - A Brief Look at the Demographics of Ethiopia , http://EzineArticles.com/2033300, last accessed 22 September 2011

http://en.wikipedia.org/wiki/Blue_Nile

http://countrystudies.us

http://en.wikipedia.org/wiki/Atbara_River

Macro International Inc. 2008. "Ethiopia Atlas of Key Demographic and Health Indicators, 2005." Calverton, Maryland, USA: Macro International Inc, last accessed 6 May 2009

2007 Ethiopian census, first draft, Ethiopian Central Statistical Agency , last accessed 6 May 2009

Ethiopian Sports Federation in North America-ESFNA, http://www.esfna.net/view.php?category=1270326585, last accessed 2011/9/25.

http://www.mmm.ucar.edu/mm5/

Limpopo Case Study references

Alemaw BF and N. Sebusang (2009). Dam safety and agricultural water risk mitigation of irrigation dams: A case study of Botswana for improved agricultural water supplies in the Limpopo Basin.Limpopo Basin Focal Project Working Document: FANRPAN-WRCA/CCL-Report 1.7. 35pp.

Alemaw BF, Scott K, Sullvian A. (2009) Draft Final Report: Work Package 2 – Water Availability and Access in the Limpopo basin. The CGIAR Challenge Program on Water and Food. FANRPAN Report.

Babugura, A. A. (2005) Vulnerability to climate variability in Botswana 1972-2002, School of Geography, Archaeology and Environmental Studies, University of the Witwatersrand, PhD Thesis, Johannesburg.

Benson, C., Thomson, A. & Clay, E. (1997). The macroeconomic impact of drought. In Proc. Highlevel Regional Drought Policy Seminar, SADC, 1–19 November. Gaborone

Bhalotra, Y.P.R. 1987b. Climate of Botswana. Part II: elements of climate.

CGIAR (2003) Limpopo Basin Profile: Strategic research for enhancing agricultural water productivity.Water for Food Challenge Programme.

Challenge Program on Water and Food (CGIAR). 2003.Limpopo Basin: Profile. ARC-Institute for Soil, Climate and Water, ARC-Institute for Agricultural Engineering.

Centre for Applied Social Sciences, U. o. Z. (2008) Report on the Limpopo Basin Population Database, Waternet Challenge Program, http://www.waternetonline.ihe.nl/challengeprogram/AR13%20Limpopo%20Population.pdf.

FAO. 1997. Irrigation potential in Africa. A basin approach. Land and Water Bulletin No. 4. Rome

FAO (2004) Drought impact mitigation and prevention in the Limpopo River Basin, A situation analysis, http://www.fao.org/docrep/008/y5744e/y5744e00.htm, FAO, Natural Resources Management and Environment Department, web pages.

FAO-ISRIC. 2003. Soil and terrain database for southern Africa. Land and Water Digital Media Series 25.

Gaborone, Dept. Met. ServicesFewsNet. 2011. Mozambique food security outlook January to June 2011. http://www.fews.net/docs/Publications/Mozambique_FSOU_2011_03_final_en.pdf

Government of Botswana - Ministry of Mineral Resources and Water Affairs (GOB-MMRWA). 1991. Botswana national water plan study. Volume 1, Summary. Prepared by SMEC/WLPU/SGAB. Gaborone.

Government of Botswana - MOA (2000). Ministry of Agriculture. National Master Plan for Agricultural Development. By TAHAL. Gaborone, Botswana. (Vol. 1-4)

Government of Botswana - DWA (2006a)Department of Water Affairs - Botswana National Water Master Plan Review: Vol8, Agriculture. Prepared by SMEC and EHES, Government of Botswana, Gaborone, Botswana.

Government of Botswana - DWA (2006b)Department of Water Affairs - Botswana National Water Master Plan Review: Vol3, Surface Water Resources. Prepared by SMEC and EHES, Government of Botswana, Gaborone, Botswana.

Government of Mozambique - National Water Directorate (GOM-DNA). 1995. National Water Policy. National Directorate of Water (available at www.dna.mz).

International Union of Soil Sciences (IUSS). 2006. World reference base for soil resources 2006. 2nd edition. World Soil Resources Reports No. 103. FAO, Rome.

Köppen, W. 1918. Klassifikation der Klimate nach Temperatur, Niederschlag und Jahresveraluf. Permatermans Mitteilungen 64.

Kundell, J. (Topic Editor for the FAO) (2007) "Water profile of Mozambique". Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment).[First published in the Encyclopedia of Earth June 7, 2007; Last revised June 22, 2007;

Leira, E.M., Rafael, J., Bata, M.O., Mechisso, M., McNabb, M., Engelbrecht, R. Maló, S. 2002. Atlas for Disaster Preparedness and Response in the Limpopo Basin. Available online at: http://edmc1.dwaf.gov.za/library/limpopo/index.htm Accessed on February 1, 2010.

Limpopo Basin Permanent Technical Committee (LBPTC). 2010. Joint Limpopo River Basin Study Scoping Phase. Final Report. BIGCON Consortium.

Loveland, T.R., Reed, B.C., Brown, J.F., Ohlen, D.O., Zhu, J, Yang, L., and Merchant, J.W., 2000. Development of a Global Land Cover Characteristics Database and IGBP DISCover from 1-km AVHRR Data. International Journal of Remote Sensing, v. 21, no. 6/7, p. 1,303-1,330.

Love D. Twomlow S. Mupangwa W. van der Zaag P. Gumbo B. 2006. Implementing the millennium development food security goals - challenges of the southern African context. Physics and Chemistry of the Earth31, 731-737. doi:10.1016/j.pce.2006.08.002

Love D. UhlenbrookS.Twomlow S. van der Zaag P. 2010. Changing hydroclimatic and discharge patterns in the northern Limpopo Basin, Zimbabwe. Water SA36, 335-360

Love D. UhlenbrookS.Corzo-Perez G. Twomlow S. van der Zaag P. 2010. Rainfall-interception-evaporation-runoff relationships in a semi-arid catchment, northern Limpopo Basin, Zimbabwe. Hydrological Sciences Journal55, 687-703 doi:10.1080/02626667.2010.494010.

Love D. Uhlenbrook S. van der Zaag P. 2011. Regionalising a meso-catchment scale conceptual model for river basin management in the semi-arid environment. Physics and Chemistry of the Earthdoi: 10.1016/j.pce.2011.07.005

McCourt, S. & Armstrong, R.A. 2001. The architecture and evolution of the northern Kaapvaal-Limpopo terrane, southern Africa (available at www.cg.nrcan.gc.ca).

McKee, T.B.; N.J. Doesken; and J. Kleist. 1993. The relationship of drought frequency and duration to time scales. Preprints, 8th Conference on Applied Climatology, pp. 179–184. January 17–22, Anaheim, California.

Magombeyi MS. Taigbenu AE. 2008. Crop yield risk analysis and mitigation of smallholder farmers at quaternarycatchment level: Case study of B72A in Olifants river basin, South Africa. Physics and Chemistry of the Earth33, 744-756doi:10.1016/j.pce.2008.06.050

Moon, B.P. & Dardis, G.F., eds. 1988. The geomorphology of southern Africa. Cape Town, South Africa, Southern Books

Mupangwa W., Walker S. Twomlow S. 2011a. Dead level contours and infiltration pits for risk mitigation in smallholder cropping systems of Southern Zimbabwe. Physics and Chemistry of the Earthdoi:10.1016/j.pce.2011.06.011

MupangwaW., Walker S. Twomlow S. 2011b. Start, end and dry spells of the growing season in semi-arid southern Zimbabwe. Journalof Arid Environments11, 1097-1104 doi:10.1016/j.jaridenv.2011.05.011

Ncube B. Magombeyi M.Munguambe P. Mupangwa W. Love D. 2009. Methodologies and case studies for investigating upstream-downstream interactions of rainwater water harvesting in the Limpopo Basin. In: Humphreys L. (ed.). Proceedings of the Workshop on Increasing the

Productivity and Sustainability of Rainfed Cropping Systems of Poor, Smallholder Farmers, Tamale, Ghana, 22-25 September 2008. The CGIAR Challenge Program on Water and Food, Colombo, 209-221.

Ncube B. Manzungu E. Love D. Magombeyi M. Gumbo B. Lupankwa K. 2010.The Challenge of Integrated Water Resource Management for Improved Rural Livelihoods: Managing Risk, Mitigating Drought and Improving Water Productivity in the Water Scarce Limpopo Basin. Challenge Program for Water and Food, SriLanka. 160 pp. (CPWF Project Report Series).

Ropelewski,C.F. and Halpert,M.S. (1987) Global and regional scale precipitation patterns associated with the El Nino/Southern Oscillation Mon. Wea. Rev., 115, 1606-1626.

Ropelewski,C.F. and Halpert,M.S. (1989) Precipitation patterns associated with the high phase of the Southern Oscillation J. Climate, 2, 268-284.

Tankard A.J., Jackson M.P.A., Eriksson K.A., Hobday D.K., Hunter D.R., Minter W.E.L. , (1982) Crustal evolution of southern Africa: New York, Springer-Verlag, 523 p.

UN-HABITAT, U. (2007) Limpopo Basin Strategic Plan for Reducing Vulnerability to Floods and. Droughts. Draft for Discussion with Riparian Governments, http://www.google.co.uk/url?sa=t&rct=j&q=limpopo%20basin%20strategic%20plan&source=web&cd=1&ved=0CDIQFjAA&url=http%3A%2F%2Fwww.undp.org.mz%2Fwaterswindsfires%2Fcontent%2Fdownload%2F2036%2F12113%2Ffile%2FLimpopo%2520Basin%2520Strategic%2520Plan.pdf, UN-HABITAT, UNDP, 23 pages.

Rouault, Mathieu. 2005. “Intensity and spatial extent of droughts in southern Africa.” Geophysical Research Letters 32 (15): 2-5. doi:10.1029/2005GL022436. http://www.agu.org/pubs/crossref/2005/2005GL022436.shtml.

South African Development Community (SADC). 2009. Explanatory Brochure for the South African Development Community (SADC) Hydrogeological Map & Atlas. Accessed at: http://www.sadc-hgm.com Accessed on: May 21, 2010.

Southern African Development Community (SADC). 2011. SADC Groundwater and Drought Management Project website. Online at: http://sadc-groundwater.org/objective.php . Accessed on 2011-01-31.

SADC AIMS (2007) Proceedings of the Agricultural Information Management Systems (AIMS) meeting, 26-27 March, 2007, Johannesburg, South Africa, http://www.sadc.int/fanr/aims/documents/AIMSMarch07.pdf, Southern African Development Community (SADC), 110 pages.

SADC REWS (2011) SADC Regional Early Warning System, http://www.sadc.int/fanr/aims/rews/index.php, Southern African Development Community, SADC, web pages.

SADC RVAA (2011) SADC Regional Vulnerability Assessment & Analysis Programme, http://www.sadc.int/fanr/aims/rvaa/index.php, Southern African Development Community (SADC), web pages.

Schulze, R. E. 1997. South African atlas of agrohydrology and climatology. Pretoria, South Africa

Van Koppen, B. 2008. Redressing inequities of the past from a historical perspective: the casenof Olifants basin, South Africa, Water SA 34,no.4, 432-438

Oum er-Rbia Case Study references

ABHOER., http.abhoer.ma

ABHOER., 2007. Etude de modélisation des nappes profondes de Tadla. Mission I : Synthèse hydrogéologique et actualisation des données relatives aux nappes profondes du TADLA. Mission II : Elaboration d'un modèle de gestion des ressources en eau des nappes profondes Agence du bassin hydraulique d'Oum Er Rbia.

AquaStress., 2005. Tadla test site Info day,September 29th - 30th, 2005.Tadla, Morocco.

Bellouti A., F. Cherkaoui, M. Benhida, A. Debbarh, B. Soudi et Badraoui M., 2002. Mise en place d'un système de suivi et de surveillance de la qualité des eaux souterraines et des sols dans le périmètre irrigué du Tadla, au Maroc. Actes de l'atelier du PCSI, Montpellier, France, 28-29 mai 2002.

Berrada A. 2009. Assessment of drip irrigation in Morocco with particular emphasis on the plain of Tadla. Research grant report

Bouzza A., 1990. Water conservation in wheat rotations under several management and tillage systems in semi-arid areas. PhD. Thesis. Univ. of Nebraska. Nebraska.

Boutfirass, M., M. Karrou and M. El Mourid. 1994. Irrigation supplémentaire et variétés de blé dans les zones semi-arides du Maroc. Dans « Actes de la conférence sur les acquis et perspectives de la recherche agronomique dans les zones arides et semi-arides du Maroc. El Gharous, M., Karrou , M et El Mourid, M. (eds). Rabat 24-27 Mai 1994.

Chati M. T, 1995. Stratégies hydro-agricoles et crises climatiques. anafide.org/doc/HTE%2097/97-4.pdf

Debbarh A. and M. Badraoui, 2002. Irrigation et environnement au Maroc: Situation actuelle et perspectives. In : Serge Mallet et Pierre Ruelle (Eds). Vers une maitrise des impacts environnementaux de l'agriculture. Actes de l'atelier du PSCI. 28-29 mai 2002.Montpellier, France. CEMAGREF, CIRAD, IRD, Cédérom du CIRAD.

Guemimi A., 2004. Plan d'action d'économie d'eau d'irrigation dans le périmètre des Doukkala. Projet INCO-Wademed seminar, 19-21 April, Rabat, Morocco.

Hammani, A.,2002. Modélisation couplée du drainage souterrain et du drainage de surface : Application à la conception du drainage agricole dans le périmètre irrigué du Gharb. Thèse de Doctorat Es-Sciences agronomiques de l'IAV Hassan II, et Doctorat Es-Sciences de l'eau de l'ENGREF, soutenue le 02 Février 2002.

Hammani A., M. Kuper, S. Bouarfa, A. Debbarh, M. Badraoui et Bellouti A.,. 2004. Evolution de l'utilisation conjointe des eaux de surface et des eaux souterraines dans le périmètre irrigué du Tadla (Maroc). INCO-Wademed seminar, 19-21 April, Rabat, Morocco.

Hammani A., Kuper M., Boutfiras M., Debbagh A., Badraoui M., A Bellouti ., 2005. Evolution de l'utilisation conjointe des eaux de surface et des eaux souterraines dans le périmètre irrigué du Tadla (Maroc). In Hammani A., Kuper M., Debbarh A. (éds. sci.). 2005. Modernisation de l'agriculture irriguée. Actes du 1er séminaire euro-méditerranéen Wademed, 19-23 avril 2004, Rabat, El Jadida, Maroc, tome 1 : 330-337.

Hammani, A., M. Kuper., 2007 Caractérisation des pompages des eaux souterraines dans le Tadla, Maroc. Economies d'eau en systèmes irrigués au Maghreb. Actes de 3ème atelier du projet Sirma. Nabeul, Tunisie 4-7 juin 2007. Cirad, Montpellier. France. Colloque-cédérom.

Hellegers P.J.G.J, C.J. Perry, and Petitguyot T., 2007. Water pricing in Tadla, Morocco. In: Molle & Berckoff (Eds), Irrigation water pricing, CAB International 2007.

http://www.ada.gov.ma/Plans_agricoles/plan_agricole_region_tadla_azilal/Diagnostic_agriculture.php

http://www.google.co.ma/imgres?q=tadla+azilal&um=1&hl=fr&sa=N&rlz=1C2DVCL_enMA395&biw=1013&bih=660&tbm=isch&tbnid=Mz

INECO, 2009. Institutional and framework and decision-making practices for water management in the Oum er-Rbia basin, Morocco. Towards the development of a strategy for increasing efficiency in irrigation water use. Final report of the INECO project prepared by Iskane Ingenieries with the collaboration of the Hydraulic Basin Agency of Oum er-Rbia.

Karrou,M. 2002. Climatic change and drought mitigation: Case of Morocco. The first technical workshop of the Mediterranean, Component of CLIMAGRI project on Climate Change and agriculture, Rome, Septembre 25-27.

Knippertz P., M. Christoph, et Speth P.,2003.Long term precipitation variability in Morocco and the link to the large-scale circulation in recent and future climats. Meteorology and Athmospheric Physics.83: 67-68.

Kobry, A., A. Eliamani, 2004, L'irrigation localisée dans les périmètres de grande hydraulique, atouts et contraintes dans le périmètre du Tadla au Maroc, Projet INCO-WADEMED, Actes du Séminaire Modernisation de l'Agriculture Irriguée, Rabat, du 19 au 23 avril 2004.

Laamari, L., and M. El-Mourid. 1998. Drought management in Morocco: From 1969 to 1995 cropping year. Mashreq and Maghreb Project Workshop on Policy and Property Rights Research in the Low-Rainfall Areas of the Mashreq and Maghreb Regions, November 26–29, 1998. Hammamet, Tunisia.

Laaroussi, M. 2005. Maîtrise de l'irrigation pour une gestion durable du périmètre irrigué du Tadla. 19th Congress and 56th International Executive Council Meeting.10-18 September 2005.Beijing, China.

MADRAPM, 2007. Programme national d'Economie d'Eau d'Irrigation (PNEEI), 2008-2022: Note de synthèse. Juillet 2007. Royaume du Maroc. Ministère de l'Agriculture du Développement Rural et des Pêches Maritimes. Administration du Génie Rural. Rabat, Morocco.

Messaadi, Ahmed. 2008. Développement de l'irrigation sous pression dans la zone d'action de la direction provinciale d'agriculture de Béni Mellal. Pp. 116-119 In Benchokroun Taieb (editor & moderator) Conférence électronique sur l'économie d'eau en irrigation du 11 Février au 11 Mai 2008. Rapport final, Volume no. 4. Centre d'information sur l'eau agricole et ses usages (CISEAU). Comite Marocain de la CIID et de la CIGR/ANAFIDE, Rabat, Maroc.

ORMVAT. 2008. Situation de la qualité des eaux de la nappe phréatique dans le périmètre irrigué du Tadla. Situation Octobre 2008. Ministère de l'Agriculture du Développement Rural et des

Pêches Maritimes, Office Régional de Mise en Valeur Agricole du Tadla. ORMVAT/DGRID/SER/Bureau Environnement, Fquih Ben Saleh, Maroc.

Ouassou A., T. Ameziane, A. Ziyad et M. Belghiti, 2007. Application of the drought management guidelines in Morocco. (Part 2. Examples of application). Options méditerranéennes, série B, n° 158: 343-372.

PDAIRE, 2008. Plan d'Aménagement Intégré des Ressources en Eau du bassin de l'Oum er-Rbia.

Petitguyot T. and T. Rieu. 2004. Dam's releases as a tool to improve conjunctive use of groundwater and surface supplies: Application to the Tadla irrigation scheme in Morocco. Proceedings of the international seminar on Water resources management for local development: Governance Institutions and Policies. November 8-10- 2004. Aventura Loskopdam, South- Africa.

Petitguyot,T. 2003. Agriculture irriguée et utilisation durable des ressources en eau souterraines et de surface. Une exploration micro-économique de la plaine du Tadla, Maroc. Mémoire de DEA, ENGREF, Université Paris X, CEMAGREF Paris, France. 112 p + Annexes.

Plan Maroc Vert, Région de Doukkala-Abda : http// www.ada.gov.ma

Plan Maroc Vert, Région de Tadla –Azilal : http// www.ada.gov.ma

Stöckle C.O, M. Donatelli et R. Nelson. 2002. Crop-Syst, a cropping systems simulation model. Europ. J. Agronomy (18) 2003: 289-307.

Svoboda M., 2004. Recent development in drought monitoring. Communication to Medroplan workshop of Moroccan team on drought risk analysis. IAV Hassan II and NDMC, University Lincoln, Nebraska, Rabat 29 september 2004.

Swearingen, W. D., and A. Bencherifa. 2000. An Assessment of the Drought Hazard in Morocco, ed. D. A. Wilhite, vol. 1. New York, Routledge, pp. 279-286.

Tadla Resource Management (TRM) final report, 1999. USAID Morocco

Tanji, A and M. Karrou. 1992. Water use and water use efficiency of weeds and wheat in semi-arid Morocco. Al Awamia 78:29-43.

Zerouali A. and M. Chtioui. 2007. Ressources en eau du bassin de l'Oum er-Rbia: Quelle gestion adopter face aux changements climatiques? Europe-INBO 2007 ; 8-10 november 2007, Roma, Italy.

Niger Case Study references

Andersen, I., Dione, O., Jarosewich-Holder, M., Olivry, J. 2005. The Niger River Basin, A Vision for Sustainable Management. Edited by K.G. Golitzen. Washington D.C.; The World Bank.

Barry, Boubacar, Sidy Mouhamed Seck, and Jean-Marie Fritsch. 2003. *Niger River Basin Mission Report*. CPWF Working Paper. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds., 2008: Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp.

BRL, and DHI. 2007. *Etudes Sur L'élaboration Du Plan d'Action De Développement Durable (PADD) Du Bassin Du Niger: Phase 1: Bilan Diagnostic*. NIGER BASIN AUTHORITY (NBA).

Brooks, N. 2004. *Drought in the African Sahel: Long Term Perspectives and Future Prospects*. Working Paper. Tyndall Centre for Climate Change Research.

Brown, C., and J. Hansen. 2008. “Agricultural Water Management and Climate Risk.” *IRI: The International Research Institute for Climate and Society*.

COERTJENS, DRIES. 2011. “The Impact of Changing Flow Regimes on Human Health and Livelihood in the Inner Niger Delta (IND), Mali”. Universiteit Antwerpen Instituut voor Milieu & Duurzame Ontwikkeling Master in de Milieuwetenschap.

Cotula, L., and S. Cissé. 2006. “Changes in Customary Resource Tenure Systems in the Inner Niger Delta, Mali.” *J. Legal Pluralism & Unofficial L.* 52: 1.

DIXON, Sam, and Julius HOLT. 2010. *Zones Et Profils De Moyens D’existence Au Mali*. Special FEWS NET. Réseau du Système d’Alerte FEWS NET, USAID, FEG Consulting.

Gallais, J. 1967. “Le Delta Intérieur Du Niger Et Ses Bordures: Étude Morphologique”. Paris, France: Editions du CNRS.

Hassane, A., S. Hamadou, M. Kuper, and A. (ed.) Kuper. 2002. *Les Disponibilites En Eau Du Fleuve Niger : Enjeux Et Perspectives Pour Les Amenagements Hydro - Agricoles. Le Cas Du Niger*. Bamako: INSAH. http://publications.cirad.fr/une_notice.php?dk=517500.

Mainuddin, M., J. Eastham, and M. Kirby. 2010. *Water-use Accounts in CPWF Basins: Simple Water-use Accounting of the Niger Basin*. CPWF Working Paper. Niger Basin Focal Project Series. Colombo, Sri Lanka: The CGIAR Challenge Program on Water and Food.

Marie, J., Pierre Morand, and H. N’Djim, eds. 2007. *The Niger River’s Future : Synthesis and Recommendations, Analytical Chapters*. Expertise Collégiale. IRD ; IER. http://www.documentation.ird.fr/hor/fdi:010041819.

Moorehead, R. 1997. “Structural Chaos: Community and State Management of Common Property in Mali”. IIED Home International Institute for Environment and Development.

Niger Basin Authority and World Wildlife Fund, Niger River Basin Atlas , Niamey, 2007

Picouet, C. 1999. “Géodynamique D’un Hydrosystème Tropical Peu Anthropisé: Le Bassin Supérieur Du Niger Et Son Delta Intérieur”. Académie de Montpellier.

UNEP, Africa Water Atlas, 2011 http://www.unep.org/publications/contents/pub_details_search.asp?ID=4165

Royal Haskoning, Altenburg & Wymenga, and Wetlands International. 2011. “2011 : Crise De L’eau Dans Le Delta Intérieur Du Niger Causes, Conséquences, Solutions” December, Mopti and Bamako.

Zwarts, L., P. van Beukering, B. Kone, and E. Wymenga. 2005. *The Niger, a Lifeline, Effective Water Management in the Upper Niger Basin*. RIZA IVM / WISO / A&W. http://www.altwym.nl/uploads/file/133Executive%20summary%20-%20The%20Niger,%20a%20lifeline.pdf.

Zwarts, Leo. 2010. *Will the Inner Niger Delta Shrivel up Due to Climate Change and Water Use Upstream ?* Altenburg & Wymenga ecologisch onderzoek. http://www.altwym.nl/uploads/file/389_1294301369.pdf.

19. APPENDICES

19.1 APPENDIX A: DATASETS AVAILABLE

19.1.1 Meteorological data

NILE BASIN

Title	Data_format	Spatial_coverage	Spatial_scale or Spatial_resolution	Reference_date(s)_period(s)	Updating_frequency	Storage_format	Georeference_system	Base_Unit	Conditions_access_use
Rainfall	Raster	Continental	0.2 decimal degrees	June 1992 to present	daily	time series database files	WGS-84, Lat-Long	mm	Depending on license agreement

NIGER BASIN

Title	Data_format	Spatial_coverage	Spatial_scale or Spatial_resolution	Reference_date(s)_period(s)	Updating_frequency	Storage_format	Georeference_system	Base_Unit	Conditions_access_use
Temperature, Precipitation (rainfall & snow), radiation, wind speed and more...	NetCDF	Global, only land coverage	0.5x0.5 decimal degrees	January 1901 to December 2001	Daily	NetCDF	WGS-84, Lat-Long		Product is not yet released, but it will probably be made available during the duration of DEWFORA
Rainfall grid IRD-HSM	txt	latitude from 2°S to 18°N, longitude from 18°W to 17°E	0.5x0.5 decimal degrees	1940-1999	Monthly	txt	WGS-84, Lat-Long		Free access
Daily rainfall stations	points	20 stations in the Niger Basin	-	2000-2010	Daily	excel	WGS-84, Lat-Long		Free of use
Daily rainfall stations	excel	65 stations around the Bani catchment	7.75°N/9.25°W è 14.75°N/3.25°W – degrés décimaux	1950 à 2006		excel	WGS-84, Lat-Long		Free of use

Geological strate, Vegetation Class and Water Holding Capacity	Arcview Shape and xml	Niger river subbasin	0.5x0.5 decimal degrees	-	-	Arcview Shape and xml	WGS-84, Lat-Long		Free access
Landsat satellite picture	.aux .ecw	Inner Niger Delta	-	from 1984-08-06 to 2003-02-08	26 satellitte picture available	.aux .ecw			Free of use
Hydro station	Vector points	Global	-	-	Monthly	htm	WGS-84, Lat-Long		Free of use
Water level and discharge data collection	Vector points	Niger basin	-	-	-	csv	WGS-84, Lat-Long		Free of use
Water level	Vector points	3 stations		1922-2010	Daily	excel	WGS-84, Lat-Long		Free of use
Discharge	Vector points	3 stations in Niger river		1943-2010	Daily	excel	WGS-84, Lat-Long		Free of use
Discharge	Vector points	7 stations in Niger river		1970-2000	Monthly	excel or word	WGS-84, Lat-Long		Free of use
Discharge	Vector points	1 station in Niger river		1937-2000	Daily	excel	WGS-84, Lat-Long		Free of use
Water uptake Markala dam	Vector points	1 station in Niger river		1982-2007	Monthly	excel	WGS-84, Lat-Long		Free of use
Discharge	Vector points	3 stations in Niger river		2000-2008	Daily	excel	WGS-84, Lat-Long		Free of use

Oum Er-Rbia BASIN									
Title	**Data_format**	**Spatial_coverage**	**Spatial_scale or Spatial_resolution**	**Reference_date(s)_period(s)**	**Updating_frequency**	**Storage_format**	**Georeference_system**	**Base_Unit**	**Conditions_access_use**
Rainfall	excel	Ouled Gnaou station: Alt: 450m, lat: 32,3°, Long: 6,3°		1963 to present	daily	excel	WGS-84, Lat-Long	mm	data provided to IAV partner under collaboration agreement

Temperature, global radiation, wind speed, relative humidity	excel	Ouled Gnaou station: Alt: 450m, lat: 32,3°, Long: 6,3°		1996 to present	daily	excel	WGS-84, Lat-Long		data provided to IAV partner under collaboration agreement
Temperature, global radiation, wind speed, relative humidity	excel or word	2 Stations in the Tadla-Azilal region		2004 to present and 2010 to present	dailly	excel or word	WGS-84, Lat-Long		data provided to IAV partner under collaboration agreement
Rainfall	excel	Oum er-Rbia basin, 25 stations		differs between stations, longest period: 1935-2007	daily	excel	WGS-84, Lat-Long	mm	data provided to IAV partner under collaboration agreement
Rainfall	excel	Oum er-Rbia basin, 32 stations		differs between stations, longest period: 1935-2007	daily	excel	WGS-84, Lat-Long	mm	data provided to IAV partner under collaboration agreement
annual Hydrological situation	pdf	Oum er-Rbia basin		September 2007-August 2008; September 2008-February 2009		pdf	WGS-84, Lat-Long		free, available on line at the ABHOER website
Dams situation	pdf	oum er-Rbia basin		March 2010		pdf	WGS-84, Lat-Long		free, available on line at the ABHOER website

Groundwater depth and chemical quality	excel or word	Tadla perimeter , 100 wells		1996 to present	every 2 months for ground water depth and twice a yera for ionical balance	excel or world	WGS-84, Lat-Long		data provided to IAV partner under collaboration agreement
Reservoir levels	excel	Oum er - Rbia basin, 6 dams		differs between dams, longest period: 1974-2007, shorter period: 2001-2007	monthly	excel	WGS-84, Lat-Long	Mm3	data provided to IAV partner under collaboration agreement
Average daily flows of Oum er-Rbia river and its main tributaries	excel	Oum er - Rbia basin, 15 streams, 22 stations		1980-81 to 2006-2007	daily	excel	WGS-84, Lat-Long	m3/s	data provided to IAV partner under collaboration agreement
Aquifers level and groun water quality	excel	Oum er-Rbia basin, 219 piezometers across the basin		to be precised later	to be precised later	excel	WGS-84, Lat-Long		data provided to IAV partner under collaboration agreement
Crops hectarages and yields, Livestock evolution and herds composition	excel, paper or word	Tadla perimeter ,		from 2000 to present	every agricultural campaign	excel, paper or word	WGS-84, Lat-Long		data provided to IAV partner under collaboration agreement
Crops hectarages and yields, Livestock evolution and herds composition	excel, paper or word	Doukkala perimeter		from 2000 to present	every agricultural campaign	excel, paper or word	WGS-84, Lat-Long		data provided to IAV partner under collaboration agreement

Crops hectarages and yields, Livestock evolution and herds composition	excel, paper or word	Tadla-Azilal region		from 2000 to present	every agricultural campaign	excel, paper or word	WGS-84, Lat-Long		data provided to IAV partner under collaboration agreement
Crops hectarages and yields, Livestock evolution and herds composition	excel, paper or word	Doukkala-Abda region		from 2000 to present	every agricultural campaign	excel, paper or word	WGS-84, Lat-Long		data provided to IAV partner under collaboration agreement

Limpopo Basin									
Title	**Data_format**	**Spatial_coverage**	**Spatial_scale or Spatial_resolution**	**Reference_date(s)_period (s)**	**Updating_frequency**	**Storage_format**	**Georeference_system**	**Base_Unit**	**Conditions_access_use**
Standardized Precipitation Index (SPI)		South Africa	Depends on the availability of rainfall stations	2006 -to present	Monthly	MSWord and pdf	WGS-84, Lat-Long	Non dimensional	Available on demand; Free and full
Rainfall	Station data	South Africa		1846 to present	Daily	SQL database		mm	Depends on commercial use of data

19.1.2 Data/information on sources of food and livelihood

The Proceedings of the 2007 Meeting on SADC Agricultural Information Management System (AIMS) highlighted important sources of data that could assist in drought early warning in the region. The data include rainfall, temperature, crop regions, land use, soils, population, and agriculture production, to cite a few (SADC AIMS, 2007).

Some global data can be obtained from the following websites:

- http://www.diva-gis.org for downloading country level data for any country in the world: administrative boundaries, roads, railroads, altitude, land cover, population density. The website also provides links to other data sources.
- http://www.limpoporak.org

- http://www.edenextdata.com/?q=content/global-gis-datasets-links-0 is a portal of data sources links
- GeoNet Names Server of National Geospatial Intelligence Agency http://earth-info.nga.mil/gns/html/namefiles.htm
- http://www.maplibrary.org/stacks/Africa/index.php
- https://services.google.com/fb/forms/mapmakerdatadownload/
- http://www.fao.org/nr/land/databasesinformation-systems/en/ for information and links on land resources
- http://www.fao.org/ag/agl/agll/wrb/soilres.stm#down for data on soil types
- http://www.fao.org/geonetwork/srv/en/metadata.show?id=37139&currTab=simple for data on land uses of the World

Land use

Some land use data for Zimbabwe is available. However, the period of production of the data needs to be validated against the current situation.

Land Cover

Global land cover data exists on the website of JRC on the following link: http://bioval.jrc.ec.europa.eu/products/glc2000/products.php