USAID
FROM THE AMERICAN PEOPLE

CLIMATE CHANGE IN MALI:

KEY ISSUES IN WATER RESOURCES

NOVEMBER 2013

This report is made possible by the support of the American people through the U.S. Agency for International Development (USAID). The contents are the sole responsibility of Tetra Tech ARD and do not necessarily reflect the views of USAID or the U.S. Government.

ARCC

African and Latin American
Resilience to Climate Change Project

This report was prepared by Hammond Murray-Rust, independent consultant, through a subcontract to Tetra Tech ARD.

This publication was produced for the United States Agency for International Development by Tetra Tech ARD, through a Task Order under the Prosperity, Livelihoods, and Conserving Ecosystems (PLACE) Indefinite Quantity Contract Core Task Order (USAID Contract No. AID-EPP-I-00-06-00008, Order Number AID-OAA-TO-11-00064).

Tetra Tech ARD Contacts:

Patricia Caffrey
Chief of Party
African and Latin American Resilience to Climate Change (ARCC)
Burlington, Vermont
Tel.: 802.658.3890
Patricia.Caffrey@tetratech.com

Anna Farmer
Project Manager
Burlington, Vermont
Tel.: 802.658.3890
Anna.Farmer@tetratech.com

CLIMATE CHANGE IN MALI:

KEY ISSUES IN WATER RESOURCES

AFRICAN AND LATIN AMERICAN RESILIENCE TO CLIMATE CHANGE (ARCC)

NOVEMBER 2013

TABLE OF CONTENTS

ACRONYMS AND ABBREVIATIONS

AFD	*Agence Francaise du Developpement*
AfDB	African Development Bank,
AGRHYMET	*Agriculture, Hydrologie et Meterologie Centre de Recherche*
ARCC	USAID African and Latin American Resilience to Climate Change
BPD	Building Partnerships for Development
CGE	*Commission Gestion des Eaux de Selingue*
CGIAR	Consultative Group for International Agricultural Research
DANIDA	Danish International Development Agency
DNH	*Direction Nationale de l'Hydraulique*
DRI	Desert Research Institute
EDM	*Energie du Mali*
EIB	European Investment Bank
EU	European Union
FAO	Food and Agriculture Organization
FEWSNET	Famine Early Warning System Network
HDI	Human Development Index
ICRISAT	International Center for Research in the Semi-Arid Tropics
IWRM	Integrated Water Resources Management
ILRI	International Livestock Research Institute
KfW	German Development Bank
MCC	Millennium Challenge Corporation
MDG	Millennium Development Goals
MEA	*Ministère de l'Environnement et d l'Assainissement*
MEE	*Ministère de l'Energie et de l'Eau*
MUS	Multiple Use Systems
NBA	Niger Basin Authority
NGO	Nongovernmental Organization

OMVS	*Organisation du la Mise en Valeur du Fleuve Senegal*
ON	*Office du Niger*
O&M	Operation and Maintenance
PAGIRE	*Plan d'Action pour la Gestion Intégrée des Ressources en Eau*
PNPBBF	*Programme National de Petits Barrages et Bas – Fonds*
PPP	Public Private Partnership
SIGIRE	*Systeme d'Information pour la Gestion Intégrée des Ressources en Eau*
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
WARDA	Africa Rice Center (formerly West Africa Rice Development Association)
WA-WASH	West Africa – Water, Sanitation and Hygiene
WAWI	West Africa Water Initiative
WRI	World Resources Institute
WSS	Water Supply and Sanitation

ABOUT THIS SERIES

THE STUDIES ON CLIMATE CHANGE VULNERABILITY AND ADAPTATION IN WEST AFRICA

This document is part of a series of studies produced by the African and Latin American Resilience to Climate Change (ARCC) project that address adaptation to climate change in West Africa. Within the ARCC West Africa studies, this document falls in the subseries Climate Change in Mali. ARCC has also produced subseries on Climate Change and Water Resources in West Africa, Agricultural Adaptation to Climate Change in the Sahel, and Climate Change and Conflict in West Africa.

THE SUBSERIES ON ADAPTATION TO CLIMATE CHANGE IN MALI

Upon the request of the United States Agency for International Development (USAID), ARCC undertook the Mali series of studies to increase understanding of the potential impacts of climate change in rural Mali and to identify means to support adaptation to these impacts. Other documents in the Climate Change in Mali series include: Expected Impacts on Pests and Diseases Afflicting Livestock, Expected Impacts on Pests and Diseases Afflicting Selected Crops, Impact Modeling of Selected Agricultural Adaptive Practices, Climate Vulnerability Mapping, Organizational Survey and Focus Groups of Adaptive Practices, and An Institutional Analysis of l'Agence de l'Environnement et du Développement Durable (AEDD) and l'Agence Nationale de la Météorologie (Mali-Météo). In the Climate Change and Water Resources in West Africa subseries, two additional documents also address themes relevant to water resources in Mali: Transboundary River Basins, and An Assessment of Groundwater Management.

KEY ISSUES

Mali's relatively abundant water resources are concentrated along the Niger and Senegal Rivers, and in the inland delta in the center of the country. Almost all major urban centers are sited along these rivers and will continue to have adequate access to river water and associated groundwater resources as long as there is sufficient capital to provide water treatment and distribution infrastructure.

Areas away from the rivers face significant water stress, with stress increasing northwards as rainfall is progressively lower. These areas are the most susceptible to predicted climate change: lower rainfall, higher temperatures, and increased variability affect agricultural production and the reliability of both surface and groundwater resources.

At the national level, Mali's primary responses to the threat of climate change have been assuring food security through large-scale irrigation system development near the inland delta, and improving rural water supply by exploiting groundwater. While successful to date, these approaches do not significantly impact on vulnerability of rural populations away from the main rivers.

National level responses to climate change have not been matched by significant development of Integrated Water Resources Management (IWRM) at Commune level or establishment of village level IWRM plans. Despite decentralization to Commune level, support services at Commune level mirror central government structures, and interventions at village level almost always focus on a single use — water supply, *or* agriculture, *or* livestock — rather than developing an integrated approach.

Commune level cadres have little or no access to effective tools and information to help them develop more resilient IWRM plans. They have few guidelines about how to develop IWRM plans, they receive little information about predicted changes for short-term adjustments, and they have no effective planning approach that enables them to make efficient use of limited financial and manpower resources.

Effective IWRM, as exemplified by the Multiple Use Services approach, functions at multiple levels: household strategies for improved resilience to climate change through behavior change in agriculture and water-related hygiene; village strategies for participatory development of IWRM strategies; and support to service providers at the commune level.

USAID can support a program of greater resilience to impacts of climate change by developing and implementing an IRWM program that operates at these three levels, and strengthens local capacity to manage land and water resources more effectively under conditions of increased variability of rainfall and temperature.

EXECUTIVE SUMMARY

This desk study examines the extent to which water resources and the management of water supply and demand are impacted by climate change in Mali. The Mali National Plan placed high priority on food self-sufficiency and achievement of Millennium Development Goals for water supply and sanitation. Great strides have been made in accomplishing both of these objectives – the first through expansion of irrigation in areas on the fringes of the Niger delta, and the other through huge investments in rural water supply primarily based on groundwater development.

At one level, Mali is water rich: renewable water resources of over 7.5 km^3/year are much higher than the water poverty level of 1.7 k m^3/year. However much of this surplus is concentrated in the Niger River and flows towards the inner delta in the central, drier and less populated part of the country. Irrigation remains the single largest use of water, with all domestic and industrial water supply only about one-tenth of agricultural use. Further, Mali is required to allow water to pass downstream to Niger and Nigeria, and during the dry season this becomes a significant factor.

Institutional arrangements are slowly changing to meet the new challenges brought about by better understanding of climate change. There are increasing numbers of cross-disciplinary consultative bodies that include both government and civil society, but the normal management capacity of agencies responsible for water management is still in transition from capital investment to actual management of water resources.

Several exacerbating factors exist in Mali that can further increase risk. Population increase, poverty, and land degradation all place pressure on land and water resources. Water quality decreases in the Niger downstream of large cities, an effect felt more acutely in the dry season, when flows are lower. Technology also brings added risk, both in the increase in the number of pumps used for tapping groundwater and in the construction and management of reservoirs on major rivers and their tributaries. However, the large scale expansion of the irrigated areas near the Niger Delta is increasing potential demand for dry season water. This shift will require a more sophisticated approach to planning for the area that can be safely irrigated each year, particularly if there is greater variation in dry season discharges due to climate change. The Niger and Senegal Rivers remain the main focus of population growth: eight of Mali's largest ten cities and towns lie on the banks of these two rivers. The biggest threats lie downstream of these well-watered areas, and in rural areas away from the rivers. Water stress in areas away from the main rivers varies greatly both spatially and temporally, requiring greater management responsiveness.

Meeting the objectives of the National Plan has exposed Mali to increased risk – especially under the scenario of significant climate change in the future. Irrigation expansion targets mean that dry season demand for water will likely exceed available supply in years of low rainfall. The hydrology of the Niger River reflects rainfall patterns; so extended drought, even over two successive years, will mean less irrigation is possible during these downturns in the rainfall pattern. Groundwater expansion for drinking water and sanitation needs runs a risk of lowering groundwater supply, particularly if rainfall is low and recharge of aquifers is below normal. However, there are very few studies of groundwater modeling to date that can assess the degree of risk to rural communities.

The degree of sensitivity to these risks is examined in both biophysical and socioeconomic perspectives. The biophysical risks are largely related to the impact of changed water management on the hydrology and ecology of the inland delta. Supporting over one million people, the inner Niger Delta relies on annual floods to restore grazing land, facilitate fish production, and produce flooded rice. In addition, the inner delta is a highly valued wetland that provides a unique habitat for animals and birds.

National policies reacting to potential climate change include an increase in the role of irrigated agriculture and the pressure to focus on staple food production in the Niger Delta to achieve national food self-sufficiency. This will come at the expense of small-scale irrigation in rural areas more vulnerable to both short-term and long-term droughts, decreases in fisheries and grazing lands in the delta, and increased pressure on water and land resources in rural areas away from the main rivers. Hydropower generation has not, to date, had major impacts on downstream economic activities, but new dam construction has the potential to greatly impact downstream ecological conditions in the Niger delta.

Malian institutions at the national level have shown considerable willingness to become involved in the debate over the impact of climate change, but have not translated this into significant changes in the way they manage their institutions. They remain underfunded and with gaps in their adaptive capacity. At regional, district, and community levels, capacity to adapt to climate change remains weak, yet there is a pressing need for development of integrated water management programs at lower levels in the government hierarchy, with greater involvement of community members in water resources planning and management.

With a predominantly technocratic set-up and mandate, the institutions are good at designing and constructing new water management infrastructure, but are less well equipped to cope with the complexities of management once demand begins to reach or exceed supply. Further, as new political objectives become important, such as equitable access to resources, environmental protection, and food security, it is easier to create new institutions than to change the behavior of existing organizations because existing institutions are reluctant to cede any of their existing power to other bodies.

Building on past experiences and on current goals for the Agency, areas where USAID may have a comparative advantage include support for additional research into groundwater and surface water availability at regional, district, and community level; assessment of the resiliency of different water sources under drought conditions; support for information dissemination to, and planning capacity at, regional, district and, community levels involving a range of government agencies, NGOs, and where possible, the private sector; development and pilot testing of Integrated Water Resource Management (IWRM) at district and community levels that allows all water sources and uses to be integrated into a holistic plan that includes supply, sanitation, food security, livestock, and watershed protection; and continued support for better governance in the water sector at all levels, and especially at lower levels in the administrative hierarchy.

1.0 INTRODUCTION

This paper is part of a series of assessments addressing the current state of climate change vulnerability in West Africa. Some of these assessments have a regional focus, while a few of them focus specifically on different aspects of vulnerability to climate change in Mali. The specific focus of this paper is to summarize existing knowledge concerning the impacts of climate change on water resources in Mali, with an overall purpose of guiding future USAID investments in the water sector that will reduce vulnerability into the future.

In examining Mali's water resources and exploitation, there is an inherent contradiction between surplus and deficit. At the national level, Mali is not considered a water-short country; estimates of renewable water resources range between 3,500 and 7,000 m^3/person, far above the 1,700m^3/person threshold of water poverty (USAID, 2010a). But these water resources are concentrated on the Niger River, the Senegal River, and the inland delta of northeastern Mali; and there are widespread areas away from the rivers where renewable resources are at or below the threshold of water poverty.

Despite this abundance of water, Mali has experienced more than its fair share of drought-related catastrophes over the past half century, including the prolonged drought of the 1980s and early 1990s (*La Grande Secheresse*), in which millions of people and animals perished. The droughts, resulting from a combination of long-term decline in rainfall superimposed upon a natural cyclical pattern of wet and dry periods, forced Mali and its donors to search for strategies to reduce vulnerability to climate change.

These strategies have focused on two main thrusts: continued exploitation of the Niger River and its main tributaries that bring water from the mountains of Guinea and southwestern Mali to the much drier and more vulnerable northeast of Mali, and agricultural programs aimed at providing more stable and drought resistance crops and varieties to the larger areas of the country outside the direct influence of the major rivers. Most studies that examine the potential impacts of climate change, and especially drought, have focused on the impact on rain-fed crops. This includes most of the efforts of the Ministry of Agriculture, the Food and Agriculture Organization of the United Nations (FAO), and the research of various Consultative Group on International Agricultural Research (CGIAR) centers including the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Livestock Research Institute (ILRI), and the West Africa Rice Development Association (WARDA) (Pedercini et al, 2012; Ramirez-Villegas et al., 2013).

This dichotomy between the "haves" and "have-nots", in terms of water resources in Mali is central to understanding current and proposed efforts to limit Mali's exposure to climate change and try to ensure that there is no return to the terrible conditions experienced some twenty five year ago. In Mali, the "haves" are those close to the Niger and Senegal Rivers, while the "have-nots" are those away from their direct influence. Furthermore, the "have-nots" become even more water poor as one moves towards the north due to lower annual rainfall.

1.1 PURPOSE OF THIS PAPER

This paper examines current water resource exploitation and management in Mali in the context of vulnerability to climate change. It has four main objectives:

1.1.1 Present the current state of knowledge on the impacts of climate change on water resources

Current research on the impacts of climate change includes both hydrologic and agricultural assessments as part of both country-specific and regional concern for the Sahel as a whole. This research focuses primarily on possible hydrologic changes in the two main river basins, Niger and Senegal, with a great deal of emphasis on the potential impacts of changes in river discharges on the ecology and economy of the Niger delta. Much less is known of potential hydrologic impacts on areas away from the Niger and Senegal Rivers.

Agricultural research has focused largely on staple crops (rice, sorghum, millet, and maize) and the impact of changes in rainfall and temperature on maximum and sustainable yields. Thus research has been paralleled by crop breeding programs to develop more drought-resistant varieties suited to the different agro-ecological zones of the Sahel.

From the perspective of water resources, the greatest area of uncertainty concerns the susceptibility of those large areas of Mali that are away from the main rivers but that support much of the agricultural population of the country. Relying on wet season surplus, especially in *bas-fonds* (shallow inland valleys with high water tables), seasonal ponds and streams, and shallow groundwater tapped largely using manual pumps, the population remains vulnerable to both long-term and short-term fluctuations in water availability. These areas suffered the most during past droughts and they remain vulnerable.

1.1.2 Identify knowledge gaps for future research

Research priorities fall into two broad categories: better understanding of the hydrologic impacts in areas primarily dependent on ephemeral surface water sources and shallow groundwater, and better understanding of the governance and institutional setting for water resources exploitation and sustainable management.

There have been many initiatives that have addressed parts of these two broad areas, but they have neither been comprehensive nor brought into the main stream of conventional wisdom concerning water resources and their management. The reasons for this are many, but significant contributing factors have been national concentration on achieving food security through large-scale irrigation, meeting Millennium Development Goals (MDG) targets for water and sanitation while sidelining the need for Integrated Water Resources Management (IWRM) at community level, and the natural tendency for centralized government to resist change.

1.1.3 Assess the mandate and capacity of water authorities to manage climate change

Mali, like most countries in the region, has gone through institutional adaptations to meet immediate development needs. Water authorities were initially established to exploit and develop major water resources; and because water resources availability exceeded potential demand, the institutional setting focused more on administration than on management. With a predominantly technocratic set-up and mandate, the institutions are good at designing and constructing new water management infrastructure, but are less well equipped to cope with the complexities of management once demand begins to approximate supply. Further, as new political objectives become important, such as equitable access to resources, environmental protection, and food security, it is easier to create new institutions rather than change the behavior of existing organizations because existing institutions are reluctant to cede any of their existing power to other bodies. This creates a delicate situation where there are unclear mandates for making difficult decisions, and where institutional capacity to make changes is comparatively weak.

1.1.4 Identify opportunities for future action by USAID for continued support to Mali

USAID has provided support to Mali covering all sectors of interest, including agriculture, water and sanitation, and governance. Within the water sector, USAID has not been a major supporter of large-scale infrastructure development within the water sector (the European Union [EU], World Bank, and African Development Bank [AfDB] have been more willing to invest in new development, the MCC investment at Alatona being something of an anomaly in U.S. support strategies to Mali). USAID has focused more on the Water Supply and Sanitation sector (WSS) sector as part of the MDG program, often in partnership with nongovernmental organizations (NGOs) such as the United Nations Children's Fund (UNICEF), World Vision, and WaterAid. It has maintained a strong interest in issues of governance within the water sector and has supported research within the water sector.

With increasing concern over long-term strategies to address Mali's potential vulnerability to climate change, there is an opportunity for USAID to address some key areas that are not included in other donor support programs.

1.2 DOCUMENT ORGANIZATION AND ANALYTIC FRAMEWORK

This paper starts in Section 2 with an overview of water resources in Mali, their distribution and exploitation, the institutional setting within which water resources are exploited and managed, and a discussion of exacerbating factors that may compound or mitigate the effects of climate change.

Following this context setting section, the majority of the paper focuses on three aspects of climate change in the water sector. **Exposure of water resources to impacts of climate change (Section 3)** looks at the potential impact of changes in rainfall and temperature on both surface and groundwater resources; differential impacts of climatic variability and climate change in determining appropriate response strategies; and comparing the impacts of climate change to impacts of exacerbating factors such as population growth, poverty, natural resources degradation, and technological developments.

Sensitivity of biophysical and socioeconomic factors to climate change (Sections 4 and 5) follows**.** Biophysical sensitivity to the impact of climate change is addressed in Section 4. Impacts on the main rivers have been a major focus both nationally and internationally for several years, but much less is understood about biophysical impacts away from the main rivers. Areas of particular concern are ecosystems, fishing, and natural resources management.

The socio-economic sensitivity to climate change is discussed in Section 5. Impacts include direct benefits from water exploitation at both national and local levels (irrigated agriculture, fishing and livestock), non-consumptive use (hydropower), and the consequences of water use patterns on conflict, migration, and resettlement.

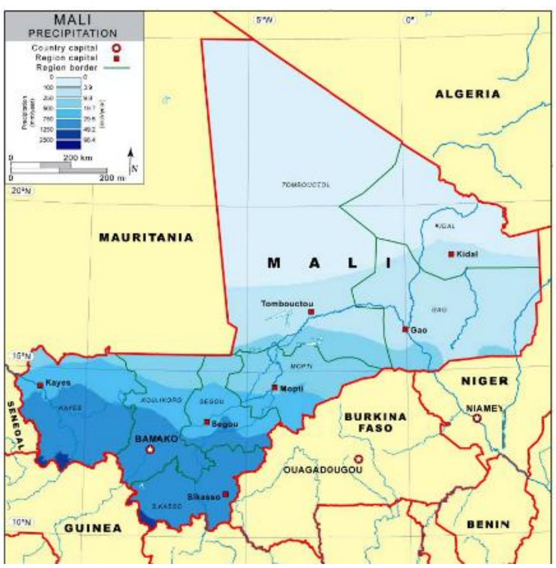
Adaptive capacity of water sector institutions (Section 6) discusses the institutional setting for water resources planning, exploitation and management. However well meaning, investments in infrastructure and research will not result in sustainable water resources unless there is commensurate institutional will and capacity. This report looks at current capacity to manage water resources, and the adaptive capacity of the institutions involved to manage for climate change.

2.0 WATER RESOURCES AND MANAGEMENT

In overall terms Mali is not a water-poor country. Estimates of per capita water availability at national level range from 3,500 to 7,000 m3/per annum, roughly two to four times the amount that is deemed necessary to provide drinking water, sanitation services, and food production without water stress (WRI, 2012). However, the distribution of these water resources in Mali means that while some areas have water surplus, there are large areas where water is close to or below the critical 1000m3/per capita level: these areas are the most vulnerable to changes in rainfall and temperature.

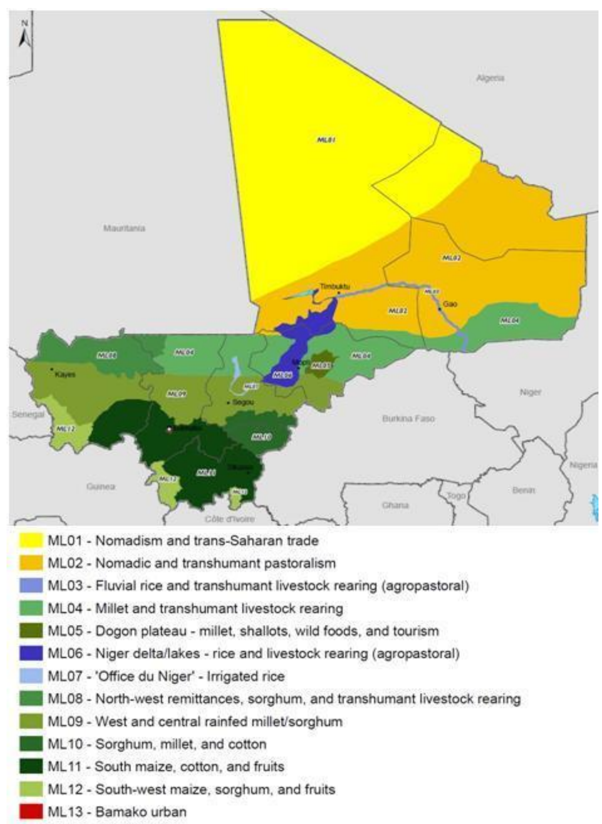
The two primary reasons for this disparity in water availability are the spatial variations in climate from southwest to northeast, and the transfer of surface water along the Niger River and its main tributaries from wet to dry parts of the country. Figure 1 demonstrates this dramatically: the average annual isohyets show a gradual reduction in rainfall moving northwards, from over 1000 mm/year in the southwest to below 300 mm/year for most of the northern half of the country. Superimposed on this, the Niger River provides a huge influx of water into drier parts of the country in the inland delta north and east of Segou.

FIGURE 1. RAINFALL MAP OF MALI



Source: World Trade Press, 2013

FIGURE 2. LIVELIHOOD ZONES IN MALI



Source: USAID/FEWSNET, 2010

Figure 2 shows that Livelihood Zones in Mali mirror rainfall distribution. However, while it is convenient to divide Mali into a series of zones that reflect this southwest to northeast trend in rainfall and temperature, the boundaries between zones are arbitrary and, more importantly, vary from year to year. Climatic data for both rainfall and temperature show a natural year-to-year variation that adds considerable uncertainty to farmer decision-making.

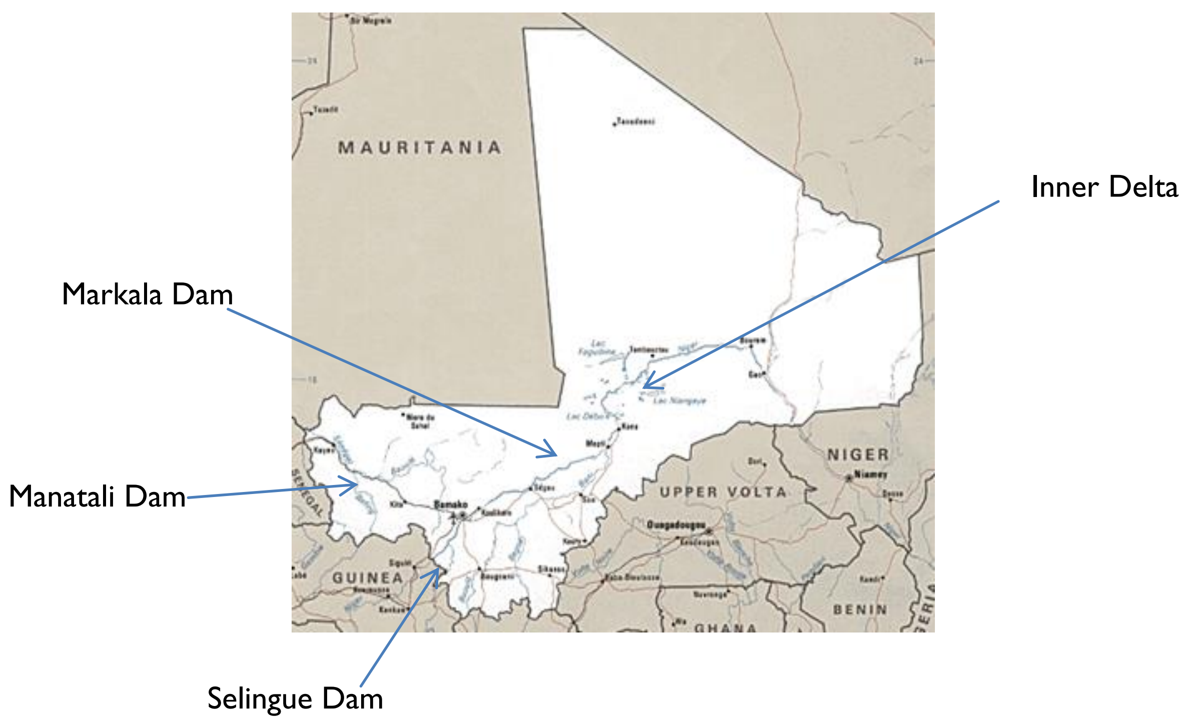
Any analysis of water resources in Mali needs to clearly separate areas that benefit from the Niger River (and to a lesser extent, the Senegal river) from those that do not, and in essence any vulnerability analysis has to fall into two distinct parts: those parts where management of water resources is essentially a local activity depending on a combination of smaller surface water bodies and groundwater, and those areas where water management occurs at national level and involves major water transfers that can be superimposed on local water resources.

This distinction between local and national water management is reflected not only in the nature of past and planned investments, but also in the way in which management structures have been established.

2.1 WATER RESOURCES IN MALI

2.1.1 Surface Water Resources

FIGURE 3. MAIN WATER CONTROL STRUCTURES IN MALI



Source: Alendrai Digital Library, University of California, Santa Barbara

Mali is dominated by two large rivers. Rising in the mountains of Guinea and southern Mali (the Fouta Djallon), the Niger River and its tributaries flow northeastwards into the semi-arid and arid parts of the country. North of Mopti it flows into the inland delta, one of the most important inland deltas in the world with rich wetlands that support wildlife, fisheries, livestock and floating rice. Near Timbuktu it turns eastwards towards Gao before turning again to flow southeastwards into Niger and Nigeria. About 50 percent of Mali lies in the basin of the Niger River. A further 10 percent of the country lies in the Senegal River basin, which flows northwestwards from the mountains before entering Senegal and Mauritania. See Figure 3. However, being located in one of these river basins is no guarantee of year-round access to reliable water supply: only riparian communities have such benefits.

At present there are two dams with significant storage capacity (Selingue on a tributary of the Niger, and Manantali on the Senegal River). In addition, there is a diversion dam at Markala that serves the irrigated lands of the Office du Niger north of the Niger River.

Upper catchment areas upstream of the Niger Delta

In those areas where there is no access to water from the Niger and its main tributaries, the influence of both short-term and long-term changes in both rainfall and temperature are felt immediately. Annual surface water rivers and impoundments will all be affected as soon as rainfall decreases, as will shallow groundwater. Water management strategies in these areas require specific actions that can make the best use of these water resources without expectation of any supplemental supplies.

Water management consists of a set of different activities, the importance of which varies according to local topography and hydrology. In many areas there are opportunities to use the "*bas-fonds*" (shallow inland valleys that flood seasonally) for rice cultivation. In some locations, small infrastructure has been added to allow partial control of water levels using small retention dams, and improved drainage to promote better crop growth.

Away from *bas-fonds*, water management is largely confined to on-farm management of water using terracing, ridges, and other land shaping techniques to minimize run-off from fields and encourage infiltration, and accessing shallow groundwater. In a relatively limited number of locales, shallow depressions that fill up in the rainy season can be used for agriculture, and in some locations small barrages that impound water into the dry season help facilitate livestock rearing and very small scale irrigation.

Groundwater use of agriculture is limited. Hand dug wells are primarily used for domestic and livestock water supplies because volumes of water required for agriculture are too great for manual lifting. Modern tube wells are primarily installed for domestic water supply and do not significantly change agricultural patterns. Where communities or individuals can afford motor pumps the use of groundwater for higher value crops is slowly coming into its own, but is still relatively uncommon.

The hydrology of surface water depressions, *bas-fonds,* and shallow groundwater is directly linked to annual rainfall: years of poor rainfall mean that there is simply less water available. They do not provide much of a buffer from year-to-year, and because the climatic changes are regional there is little local surplus available from neighboring areas.

Water management in these areas that are not close to the main rivers needs to include both individual and collective management. Individual families can make some improvements in agricultural production through adoption of improved on-farm technologies, including both adoption of improved plant varieties and use of water harvesting and soil water retention techniques. At the village level there are opportunities for collective management of both land and water resources: improved management of forests, grazing lands, surface water resources, and groundwater benefit all members of the community. Intervention programs have to include both levels of management to provide the greatest level of security possible.

Water resource use in the larger river valleys

Along the Niger River, the Senegal River, and their tributaries, the situation is very different because river flows last longer into the dry season, and there are opportunities to divert water from rivers into nearby agricultural land. While rainfall peaks in August, river flows tend to peak in October. This means that wherever there is an opportunity to divert water out of the rivers, water for irrigation is available much longer into the dry season.

However, although the Niger Basin covers roughly 50 percent of Mali, with the Senegal River draining an additional 11 percent of the country, the actual areas that can directly benefit from these surface flows are limited by topography and technology. For much of their length both the Niger and Senegal Rivers are incised into the landscape with relatively narrow and intermittent flood plains. Water management occurs in three distinct environments:

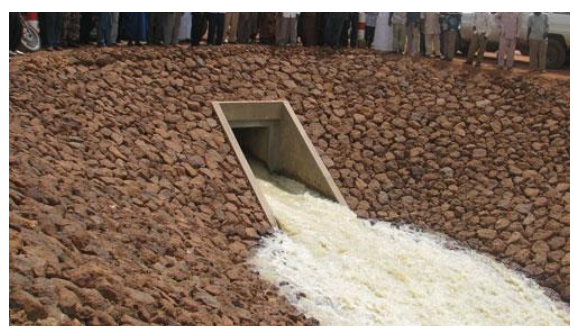
1. Small community managed systems (*Irrigation de proximite*) relying on run-of-the-river diversions that irrigate relatively restricted areas and require frequent maintenance to keep diversion weirs and channels functioning. These small areas may include extensive vegetable gardens near larger markets. They are often associated with recession irrigation, extending down into the floodplain as river water levels drop, or with handwatering of higher value crops. Small motor pumps are increasingly used to lift water onto higher areas. Pump irrigation by private farmers between Timbuktu and the Niger border has been very successful, and has led to the involvement of private sector pump repairers.

2. Larger technical irrigation systems using improved diversion structures and more sophisticated canals and distribution systems (the irrigation areas north of Selingue Dam are a good example of this). These irrigation perimeters generally include some role of central or local government in operating diversion structures and maintaining larger canals.

3. Government operated pump systems for irrigation have been established in several locations along the Niger River downstream of Mopti. These systems, ranging in size from a few hectares to 300 hectares, are geared toward the production of rice, and are essential to food security in these more remote areas.

4. Diversion of water during high flood of the Niger into low-lying areas and restriction of drainage back into the Niger River to allow flooding of rice (the Riz du Segou and Riz de Mopti systems). None of these water extractions significantly affect the hydrology of the Niger or the Senegal Rivers – the volumes extracted are small compared to the overall river discharge, and any excess diversions return back to the river.

IMAGE 1. WATER FLOWING FOR THE FIRST TIME INTO THE ALATONA PERIMETER



Source: U.S. Embassy, Mali, 2010

5. There is little opportunity to expand these diversions because it is simply uneconomic to lift water from the floodplain up to potentially productive higher land on either side of the main rivers. There are some opportunities for increasing the irrigated area but require additional government investment because they are technically and financially beyond the capacity of local communities.

The Niger Delta

In 1947 the *Office du Niger* (ON) inaugurated Markala Dam (See Photo 1). This is more of a large diversion structure than a true reservoir, consisting of the long embankment crossing the Niger to maintain water levels high enough to divert water into the downstream canal system. The potentially irrigable area downstream of Markala Dam is about 960,000 ha.[1] The actually irrigated area is far less, both because of the hydraulic capacity of the intake structure at Markala, and because of the capacity of the downstream canals; for many years, up until about 1985, the area actually irrigated was only 35,000 ha but has recently been expanded to about 75,000 ha (*Ministere de l'Agriculture,* 2009). This difference between potential and actual irrigated area has been a critical factor in how Mali has approached investment and management of its water resources.

Except in the most catastrophic drought years, the natural discharge of the Niger River at Markala, augmented by dry season releases, means that the feeder canal at Markala can be run at or close to full design discharge. With this level of water availability, and with significant improvements in water management and cultivation techniques, *Office du Niger* produces about 40 percent of Malian rice production, and the country has reached 80 to 90 percent rice self-sufficiency.

The *Office du Niger* operates a fully technical system with a hierarchical set of canals that channel water into individual irrigation sections. Water use is by tenant farmers as the *Office du Niger* owns the rights to land ownership (with the exception of land included in the MCC expansion at Alatona).

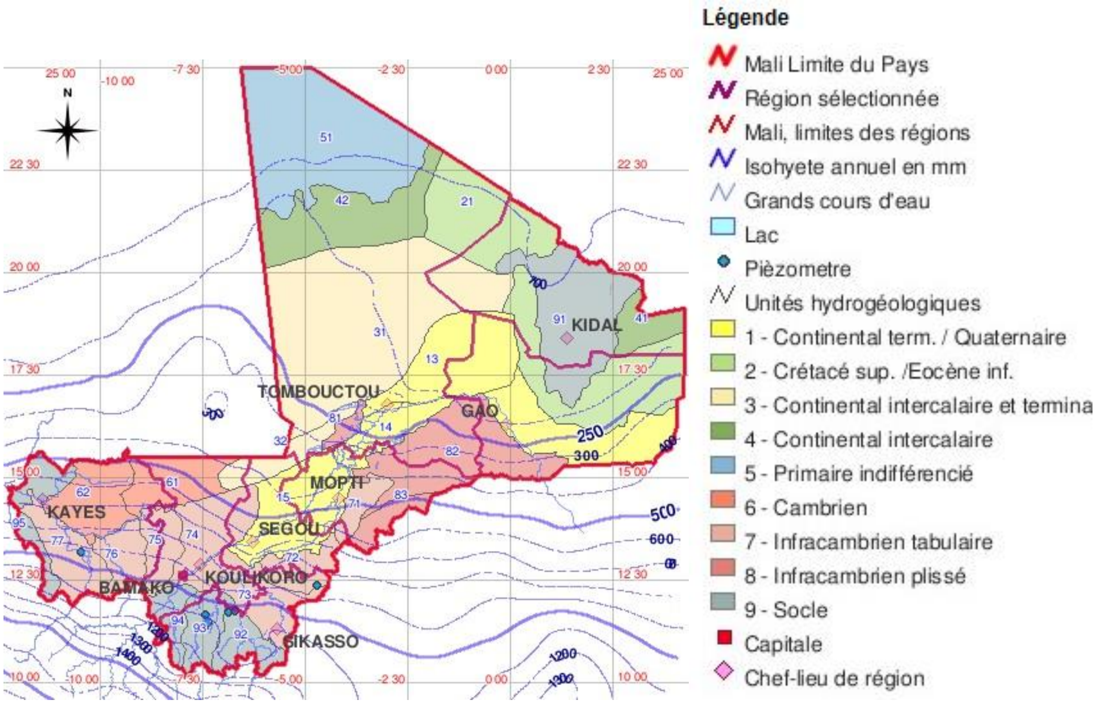
Large ongoing and planned expansions of the irrigated area, however, means that there are substantial questions about how reliable water supplies would be in not only the most extreme drought years, but also in years of below average discharge. These expansions raise issues of vulnerability that are discussed below.

2.1.2 Groundwater Resources

Mali has extensive groundwater resources, estimated at 20m km^3 (Aquastat, 2013). This includes both shallow groundwater that is recharged annually by rainfall, and extensive areas of fossil groundwater in northern parts of the country. There is a clear division between the basement complexes of the southern half of the country (units 7, 8, and 9 in Figure 4) and the younger sedimentary rocks along the Niger River and in parts of the northern areas. The basement complexes have limited access to groundwater, with most available water found in fracture zones within these areas. The sedimentary rocks have more extensive groundwater, including fossil groundwater in the northern areas.

[1] Potentially irrigable area is the area that could be irrigated if water was freely available and there were no constraints in the conveyance system.

FIGURE 4. HYDROGEOLOGIC MAP OF MALI.



Source: SIGIRE Project, DNH 2011

Groundwater use also shows a clear division between larger and smaller wells. Larger extractions rely on deep wells sunk using mechanical drilling rigs. Many of the larger urban areas use groundwater for domestic water supply because it is more reliable and of better quality than most surface sources. Similarly, industrial concerns also rely heavily on groundwater. There are few significant agricultural uses of groundwater using high discharge wells. Extractions from large wells are comparatively easy to monitor, because deep wells require government permits, and their pattern of usage is fairly predictable.

Small-scale groundwater extractions support a range of activities in rural communities, for drinking water, small-scale irrigation and livestock. In the past these small extractions have relied on hand-dug wells fitted only with buckets, but over the last few decades rural communities are increasingly using hand pumps that can meet domestic needs, and there are increasing numbers of motor and solar pumps that can provide water for domestic, livestock, and irrigation use. Some communities have adopted treadle pumps that lift shallow groundwater a couple of meters, but total numbers remain small. Irrigation using these technologies remains small-scale so that overall extractions are still modest.

Monitoring of both the number of shallow wells and their rates of extraction is rudimentary. Many are installed through private sector organizations, including NGOs. There are only approximations of the total number of improved wells; many community based programs do not keep effective records of the number of wells installed, nor are there reliable records of the number of wells actually functioning.

2.1.3 Water Availability, Supply, Balance, and Stress

Addressing issues of water balance and water stress requires the understanding of differences both spatially and temporally in Mali. Water balance looks at the ratio of water supply (rainfall, river water, and groundwater) to demand for water for agriculture, livestock, and drinking. When supply exceeds demand the system is not stressed, but when water demand exceeds supply, water stress occurs. A broad view of climatic conditions at national level focuses on the south-north trends of decreasing rainfall and increasing temperatures. In the wettest areas, typified by Sikasso Region, annual rainfall of over 1400 mm nearly meets annual evapotranspiration of 1750 mm, and there is a growing season of about five months when rainfall meets or exceeds evapotranspiration. By contrast, annual rainfall in the Niger delta is less than 500 mm while evapotranspiration is over 2000 mm, and there are only about two months a year when rainfall exceeds evapotranspiration. These climatic conditions show that on an annual basis all locations are stressed for several months a year. In the southern highlands the dry season extends from November to May, but in the north it may be from September through June.

Short-term stress during the growing season has a major impact of crop growth and food production. While no part of the country is free from the risk of short-term stress, drier areas in the center and north of Mali are far more susceptible to fluctuations in the monsoon rainfall: the start of rainfall is more variable (from May in the south to July in the north), total reliable rainfall is reduced, and the impact of dry periods during the rainy season far more pronounced as one moves from south to north.

Irrigation is the primary mechanism to overcome stress periods, but in practice most crops are either fully irrigated or fully rain fed, and there is relatively little supplemental irrigation that compensates for shortfalls in rainfall. This is because once the investment has been made in a canal system for irrigation, water is generally available throughout the growing season, and rice becomes a popular crop that can withstand over-irrigation. Small-scale irrigation focuses more on vegetables or other high value crops that are more sensitive to stress. There is little irrigation of dry land grain crops as this is normally uneconomic.

2.1.4 Main Water Demands: Household, Agriculture/Irrigation, Hydropower Generation

FAO Aquastat reported estimated water resources and water use by sector for 2000 (See Table 1) for Africa, and indicated that irrigation withdrawals predominate. Although these data are several years out of date, they demonstrate that actual withdrawals are only a fraction of total available water. However, the figure for domestic water supply only includes officially monitored municipal water and does not include the 65 percent of the Malian population served by wells and other sources. Including rural water supply into these figures may double the total water withdrawals for drinking water, but they are still overshadowed by withdrawals for irrigation.

TABLE 1. ESTIMATED WATER WITHDRAWALS BY SECTOR, 2000

Total Renewable Water Resources	$100x10^9m^3$ per annum
Actual withdrawals	$6.5x10^9m^3$ per annum
Irrigation	$5.9x10^9m^3$ per annum
Urban Drinking Water	$0.6 x10^9m^3$ per annum
Industry	$0.1x10^9m^3$ per annum

Source: FAO Aquastat, 2013

Domestic water supplies

Trends in the main water demands show that demand is increasing in all sectors. By itself population growth requires an increase of at least 3 percent a year, while investments in improved water supply and easier accessibility through the use of hand and motor pumps means actual water consumption increases (handwells are often designed to meet a daily water requirement of 20-30 l/day, while a piped source needs to allow for water use in excess of 100l/day). These differences in water use are accentuated as more people move to towns and cities where there is much greater access to piped water supplies.

As migration to cities increases at roughly 6 percent a year in Mali, and because urban water users use more water per capita than their rural counterparts, we can expect a significant increase in total withdrawals for municipal water supply, but irrigation water withdrawals will still dominate water use patterns. Urban water supplies, primarily derived from wells sunk into riverine areas, are not under threat from overall lack of water supply in the foreseeable future, although it requires significant capital investment to sink more wells and expand the existing water distribution networks. Peri-urban areas in all cities experience lack of adequate water supply, but this is largely for reasons of lack of capital to keep up with the demands of rapidly expanding urban communities.

Industrial water use

This is a very small fraction of water withdrawals in Mali. Industrial concerns in cities and towns are generally small-scale and rely on their own tubewells for water supply rather than the *Energie du Mali* (EDM) water networks. Because most industries are located along major rivers there is sufficient groundwater available if industries are willing to continue to invest in well drilling.

The mining industry presents a different set of problems because of the issue of water quality and impact on both surface and groundwater resources. No comprehensive assessment of the impact of mining on Malian water resources is available.

Irrigation

Demand for irrigation water is controlled to a large extent by available technology. Surface irrigation from diversion dams along the main rivers is limited by the capacity of installed canals and the ability to control river water levels to obtain maximum canal discharges. Plans for expanding irrigation, particularly in the Niger delta, require increased diversions for irrigation water. In the wet season there is normally adequate water to meet planned demand, but in the dry season there are severe risks of insufficient water.

Irrigation diversions in the upper catchments, along major rivers, and upstream of Markala Dam on the Niger drain back to the river so that excess water is made available for downstream use. At Markala, however, diversions in excess of needs will recharge groundwater or evaporate, and do not contribute directly to downstream flows in the Niger River.

With major expansions planned for irrigation downstream from Markala, irrigation water use will in that area will probably expand faster than all other uses combined.

Hydropower generation

Hydropower generation requires surface water, but unlike domestic and industrial use, hydropower generation is non-consumptive: after passing through turbines, water goes back immediately into the river. Run-of-the-river power generation, which merely diverts water from a river through turbines, has no impact on water resources; the small 5.2 Mw run-of-the-river plant at Sotuba falls into this category.

Reservoirs that have significant storage capacity provide the only opportunity to modify natural river discharges, and facilitate downstream water management for productive purposes.

In Mali there are only two large reservoirs and dams: Manantali on the Bafing branch of the Senegal River and Selingue on the Sankarani tributary of the Niger. Both these dams are multi-purpose, providing flood control, hydropower generation, and irrigation water.

Mali benefits from Manantali Dam primarily for power generation: Mali obtains about 55 percent of the total power generated, accounting for as much as 90 percent of the power generated in Mali. As a water resource, however, Manantali is peripheral to Mali: only 3000 ha downstream of the dam are irrigated, with virtually all of the expected irrigation benefits being for Senegal and Mauritania. It should be noted that actual benefits in both of those countries have been well below expectations (EIB, 2009).

Selingue Dam, however, is of great importance to water resources management in Mali. The capacity of the reservoir is such that there is very little, if any, year-to-year storage: the reservoir fills up to capacity in virtually every rainy season, and then is managed so that water is released downstream throughout the dry season. The releases are made so that electricity can be generated throughout the dry season, when demand is at its highest, and to augment the natural flow of the Niger River at Markala to allow *Office du Niger* to continue to irrigate as much as possible. For the most part, the reservoir is able to accommodate potentially conflicting demands for power and irrigation without major difficulty. The operating rules try to maintain a minimum generation of 9 Mw and keep overall generation fairly stable so as to maintain steady discharge in the river downstream: maximizing power generation when the reservoir is full would only increase overall power by about 5 percent but would mean serious reductions in discharge in the main dry season, when demand for irrigation water by *Office du Niger* is high (Kuper et al., 2003).

2.2 INSTITUTIONAL ARRANGEMENTS AND EXTERNAL SUPPORT

2.2.1 Water Authorities

At national level the ultimate authority for water resource exploitation and management is the *Direction Nationale de l'Hydraulique* (DNH) that is part of the Ministry of Energy and Water (MEE). DNH's responsibilities include inventory and evaluation of potential water resources development within the framework of the National Plan; oversight of studies for, and supervision of the construction of, hydraulic works and their subsequent proper operation and management; evaluation of development projects in the water sector; and participation in sub-regional bodies and initiatives to manage water resources (i.e., Niger Basin Authority or NBA, and *Organization pour la Mise en Valeur du Fleuve Senegal*, or OMVS). In addition DNH supervises and coordinates the work of regional and sub-regional offices that provide water services; maintains a documentation and information center; and runs the Water Quality Laboratory. DNH has five divisions (rural water, urban water, construction of hydraulic works, database resources, and standards and regulations).

DNH is responsible for the preparation and implementation of water management policies under the *Plan d'Action pour GestionIntegree des Ressources en Eaux* (PAGIRE). This document is the primary vehicle for translating goals of the National Plan into water management strategies. A summary of the current state of PAGIRE was recorded by Coulibaly (2011).

DNH chairs the important *Commission Gestion des Eaux* (CGE) that coordinates releases from Selingue Dam with *Energie du Mali*, *Office du Niger*, Niger Basin Authority, riverine municipalities, and other interested parties.

A great deal of decentralization has occurred in Mali, and this has impacted on DNH. There are nine Regional Directorates for Energy and Water who manage the day-to-day operations of DNH, and offices in each of the circles at sub-regional level. Applications for new water installations will normally be handled at District and Regional Directorate level. While DNH provides national level services, particularly for water resources development and planning, most other responsibilities are delegated to communes who have taken over management of local resources and interact with water users and their associations. This includes collection of any fees. The important water supply and sanitation sector is very much part of this decentralization program. While DNH has to issue well permits, and approve any drilling that may occur, much of the water supply in smaller towns and rural areas is handled by communes, while urban water supply is overseen by *Energie du Mali* (EDM), which manages urban water supplies in 18 larger urban centers. EDM operates as a private company within the authority of MEE.

Water user associations exist within communes and in rural areas, and may have operating and maintenance responsibilities for their water supply. Most programs that include installation of rural water infrastructure insist on establishment of water management committees responsible for O&M.

DNH is primarily concerned with domestic water supply and overall water resources management, and is not significantly involved in agricultural water management. All agricultural water use is handled through the Ministry of Agriculture and its semi-autonomous partner *Office du Niger*. Apart from *Office du Niger*, bodies subordinate to the Ministry of Agriculture manage the irrigation systems. Their rate of water extraction from rivers is permitted by DNH, beyond which they have little or no direct interaction with DNH. These systems include inundation systems of the *Riz du Segou* and *Riz du Mopti,* several smaller pump based systems between Mopti and Gao, and other irrigation systems on the major rivers and their upper tributaries. Outside of the formal irrigation systems, the Ministry of Agriculture provides largely crop-oriented support and has few of their cadre trained in water management.

One consequence of the current distribution of responsibilities is that in reality a program of integrated water management in rural areas covers several ministries and thus requires significant coordination for it to be effective. Nevertheless, experiences with IWRM interventions may serve as a model for Mali, such as Winrock's Multiple Use Services (MUS) that were successfully piloted under WAWI in Niger, and implemented on a wider scale in USAID programs in Tanzania and elsewhere. MUS is identified by USAID in its recent Water Strategy as a viable approach in IWRM (USAID, 2013).

Office du Niger is a semi-autonomous government agency charged with the development, operation, and management of the irrigated areas of the Niger Delta served by Markala Dam on the Niger River. It is nominally under the control of the Ministry of Agriculture, but has a great deal of independence for operations and investment purposes.

The Ministry of Environment and Sanitation (MEA) handles all matters related to sanitation and environmental protection at local level with relatively little interaction with DNH. In terms of water resources development MEA defers to MEE-DNH, but is included in the various inter-Ministerial committees that exist.

The Ministry of Environment and Sanitation has primary responsibility for ensuring that there is sufficient water for ecological purposes. It includes the Agency for Environment and Sustainable Development that includes programs to combat land degradation.

2.2.2 Water Resource Efforts Supported by Donors, UN, and Others

Mali has received long-term substantial support from donors in the water sector. Much of the focus has been on attempting to help Mali reach Millennium Development Goals (MDG) for water supply and sanitation. Leading bi-lateral donors have included SIDA, DANIDA, the Netherlands, Norwegian Aid, Belgian Technical Cooperation, Luxembourg, and to some extent USAID, although much of this has come more through collaboration with the private sector through Public Private Partnerships (PPPs). Multinational donors have included the World Bank and African Development Bank for a range of different water projects, including WSS in both rural and urban areas. International agencies in WSS have included UNICEF, UNDP, and FAO all of whom have supported programs in their areas of technical expertise. The WSS sector has also included large numbers of international NGOs, including but by no means limited to CARE, World Vision, and WaterAid, Support for DNH and its projects has come from a wide variety of sources: About 17 different organizations have provided support since the early 1970s, including World Bank, African Development Bank, the Islamic Development Bank, the European Development Fund, West African Development Bank, West African Monetary Union, the Kuwait Fund, French Development Agency, Canadian International Development Agency, German Development Bank (KfW) , German Technical Cooperation Agency (GIZ), and bilateral support from Japan, Belgium Italy, Demark, and the United Kingdom.

Germany provided substantial technical support for upgrading DNH's management capacity, funded jointly with the African Development Bank. This program (PAGIRE or *Plan d'Action de la gestionintégrée des ressources en eau*) inlcuded support for upgrading the SIGMA2 database, the creation of SIGIRE (*Systèmed'information de la gestion intégrée des ressources en eau*), and provided technical support to upgrade skills, both for national staff and for local staff in two pilot areas, Timbuktu and Kayes. The SIGMA2 database covers both surface and groundwater monitoring programs, and is intended to be the primary water resource information set that will link water agriculture and other demands for water into an integrated package. However, it is unclear to what extent these databases are fully integrated into everyday decision-making within DNH, and to what extent other agencies or NGOs can access information in these databases.

The Netherlands has also supported transnational water management activities, particularly between Guinea and Mali concerning the potential impacts of the Fomi Dam.

2.3 EXACERBATING FACTORS AFFECTING WATER RESOURCE MANAGEMENT

In addition to climatic factors, including both climate change and climate variability, several aspects of human behavior and management affect water resources in Mali. While there is relatively little data on the precise influence of these exacerbating factors, they need to be included when assessing potential for future water resource development and use.

2.3.1 Population Increase

Mali's population of approximately 16millioncontinues to grow at close to 3 percent per year, a trend that increased from about 1.2 percent in 1960 to a peak of about 3.1 percent in 2005 (World Bank Data Bank, 2013). This means that each year nearly half a million extra people require drinking water and food. When viewed at a national level this does not significantly affect the overall water availability per capita but, as indicated earlier, these national level statistics are grossly distorted by the discharge of the Niger River. Away from the river, water sources are less abundant and constrain growth in drier rural areas. This reinforces the concept of a clear split between the well-watered and poorly watered parts of the country.

Contrasting rural and urban growth rates emphasize the split. Projections from Mali's statistical service (DNSI) indicate that rural population increase between 1998 and 2024 would be about 1.2 percent per annum, while urban growth rates would exceed 5.1 percent. By 2024 urban populations would be nearly half the total population, up from 25 percent in 1994.

In terms of water supply and sanitation, this means that capital investment in water resources development in urban areas will continue to grow in an attempt keep up with the flood of people settling in peri-urban areas. However, of the 10 largest urban centers in Mali, seven are on the Niger River and one is on the Senegal River. The remaining two are in Sikasso District, which is in a relatively well-watered part of Mali. While proximity to rivers does not guarantee that there will be adequate water supply for inhabitants, it makes it a lot easier to plan and construct new facilities because rivers in or close to towns will recharge groundwater.

For smaller urban areas away from the main rivers, and for large tracts of rural areas, population increase requires development of far less reliable water sources. Installation of water supplies from deep wells is less cost-effective per capita than for larger urban installations, and the chances of drilling unproductive wells remains high in the fractured basement rocks.

2.3.2 Poverty

The UNDP Human Development Index places Mali 182nd out of 187 comparable countries with a score of 0.35. While the index has doubled since 1980, it remains far below the average for Sub-Saharan Africa (HDI of 0.475) and it has not shown any signs of increasing faster than the regional average. The HDI is a composite of indices for health, education and income so it reflects both direct poverty as well as associated measures of well-being.

From the perspective of water resources development, a low HDI implies that, for the most part, communities have neither the skill nor the capital to tap water resources other than by using the most basic methods. This means that they are limited to construction of hand-dug wells to tap groundwater, and to the use of streams and natural depressions for surface water sources.

Most water resource development in rural areas relies on funding external to the community, through government or private sector NGOs. Given the intensity of poverty in rural areas, the focus is primarily on water supply, followed by sanitation, with only a limited focus on agriculture and livestock or on watershed conservation.

2.3.3 Land Degradation

Population increase results in increasing pressure on land resources surrounding villages, as more land is required to produce adequate food for the community. The degradation includes more intensive use of fields in fallowing systems, increased clearance of forest resources for firewood and building, and increased pressure on grazing areas.

Data on long-term land degradation is based primarily on satellite image interpretation that looks at vegetation cover and its response to rainfall. Multi-year analysis helps to look at long-term trends of "greening" or "browning" that would be hidden by shorter term or annual vegetation response to rainfall.

This type of analysis (e.g., UNEP, 2012) shows that there are persistent browning trends, which indicate that recovery of vegetation after periods of poor rainfall is below what should be expected once rainfall returns to more normal levels. This suggests that during dry periods there has been systemic degradation of vegetation by drought and clearing, damaging the capacity of vegetation to regenerate to pre-drought levels.

Land degradation impacts directly on the hydrologic cycle. With less vegetation cover there is more flash flooding, greater soil erosion with accompanying loss of soil nutrients, less recharge of shallow groundwater, and reduction of soil organic matter. This results in poorer crop yields, poorer water productivity in agriculture, and increased depth to water in wells.

2.3.4 Technology

The final exacerbating factor is technology. In rural areas the lack of capital and expertise means that exploitation of water resources at community level is restricted to simple technologies that have very limited impact on groundwater or surface resources. Typically, dry season water is obtained through dug wells or surface ponding, with very low rates of extraction.

Dams

Mali has invested in two major dams, at Manantali on the Senegal River and Selingue on a tributary of the Niger. Dams have the capacity to mitigate the effects of both floods and drought, providing a more stable hydrologic regime that favors dry season irrigation.

While major dams have clear environmental and socio-economic risks, including displacement of populations, damage to downstream ecologies and agricultural lands, spread of water-borne diseases, flood augmentation when reservoirs are full, and the possibility of dam failure, they can greatly assist in reducing vulnerability to short-term rainfall deficits. Depending on the ratio of storage capacity to annual flood, they may have very limited benefits during periods of multi-year droughts; Selingue has virtually no year-to-year storage capacity, while Manantali has more.

The trade-off between wet season flood reduction and dry season flow augmentation is complex, and depends in large measure both on prioritization of hydropower versus irrigation, and the amount of water extracted for downstream use in the dry season. For Mali hydropower-irrigation tradeoffs are not large, but the percentage of dry season flow required for irrigation is becoming a serious issue.

Pumps

Modern technological innovations have changed this traditional pattern, both positively and negatively. Initially most technological innovations were restricted to drilling of tubewells fitted with either handpumps or, in a few cases, with motorpumps capable of lifting water from far greater depths. This level of investment requires specialized drilling rigs that can only be provided by government or larger NGOs. Almost all of these installations have been for drinking water, so the discharges involved are relatively small. On average a handpump is designed to provide domestic water for 400 people – at 25 l/day/person, this represents only 10 m^3 per day, a volume that has little immediate impact on groundwater levels (Lapworth et al., 2011).

Further, drilling rigs must be licensed by the central government, normally DNH, and permits are required for well installation. This nominally provides central government with some control over well spacing and overall groundwater extraction rates.

Other types of manually operated pumps have been promoted for irrigated agriculture, including treadle pumps and similar technologies; these are only suitable, however, for very small patches of high value crops, such as vegetables, because they require too much manual labor to meet water demands for larger areas. The same is true for irrigation using watering cans, common along riverine areas.

In principle, scaling up of manual lifting of water could impact on groundwater levels, but it does not seem to occur in practice because extraction rates are too low, and irrigated areas are small.

The advent of two new technologies has the capacity to change demand for water resources: small motorpumps and solar powered pumps. Small motor pumps that use gasoline, kerosene, or diesel enable farmers to tap both groundwater and surface water resources for irrigation. This enables farmers to transition from very small, irrigated patches such as private or community vegetable gardens to larger private irrigated enterprises for cash crops as well as vegetables. A one-hectare farm using 5 mm/day requires 50 m^3/day, five times the volume of an entire community's domestic water supply. Motor pumps not only pump more water; they can pump from greater depths, so that they have the capacity to impact overall water tables and thus impact on adjacent shallower wells.

Solar pumping has more or less the same impact. Although there are big differences in investment costs and operating costs, between cheaper motorpumps with high operational costs, and expensive solar pumps with low operational costs, the hydrologic impacts are similar. Individually they have little impact on water resources, but scaling up may have unexpected consequences.

While pumping helps mitigate the impacts of drought, two major issues require careful attention: the risk of groundwater depletion, and the capacity to operate and maintain pumps. Both require specific management skills, including monitoring and feedback systems for groundwater sustainability, and sustainable financing and technical services for pumps.

Information

A final exacerbating factor is the lack of good information to help quantify the magnitude of present and predicted water shortages, and therefore take informed steps to mitigate and alleviate the impact of climate change.

Early warning systems such as FEWSNET help by collating information on rainfall other climate data at a regional level, allowing countries access to important information outside their immediate data collection program. Similarly, there are protocols for communicating hydrologic information within the overall frameworks of the OMVS and NBA. However, these data tend to remain at national level and do not readily translate into useful materials for managers at lower levels in the administrative hierarchy.

The extent to which information on hydrologic conditions passes down to district, commune, or community level is unclear, but it does not seem to be very effective. As a result, much of the response to drought is reactive rather than proactive, so that impacts of at least short-term deviations from normal levels are poorly integrated into local level planning of water resources use.

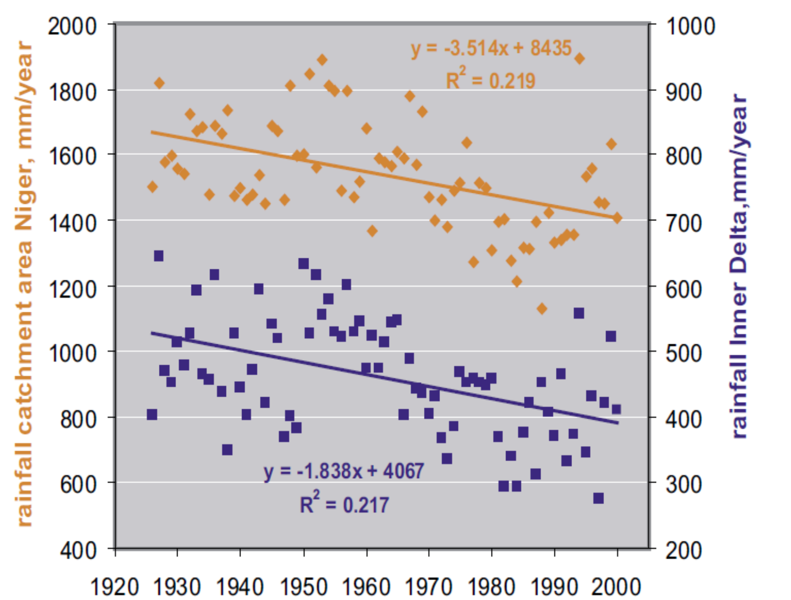
3.0 EXPOSURE TO CLIMATE CHANGE

Any analysis of vulnerability of water resources to climate change requires an assessment of past and predicted climate changes, the extent to which deviations from the norm are long-term or cyclical, and the impact of non-hydrological factors on supply and demand within the hydrologic cycle. Vulnerability profiles (e.g., Simonsson, 2005) stress the importance of certain uses of water, particularly for water supply and sanitation, but do not address wider issues of IWRM that integrate issues of agriculture, livestock, and natural resources management with those of health and sanitation.

3.1 ASSESSMENT OF IMPACT OF CLIMATIC FACTORS ON WATER RESOURCES

Rainfall trends in Mali show a consistent long-term decline over the past several decades. Figure 5 shows that both in the upper catchments (brown) and in the Inner Delta to the northeast (blue), rainfall has been consistently lower from 1920 onwards. Although this decline can be expressed as a steady decline, in reality there is considerable year-to-year variability and evidence of cyclical trends that resulted in significantly drier periods in the 1940s and in *La Grand Secheresse* of 1980 to 1995. Conversely, wetter periods, including the 1950s and 1970s when there were no droughts, may have led to optimistic assessments of rainfall and water resources.

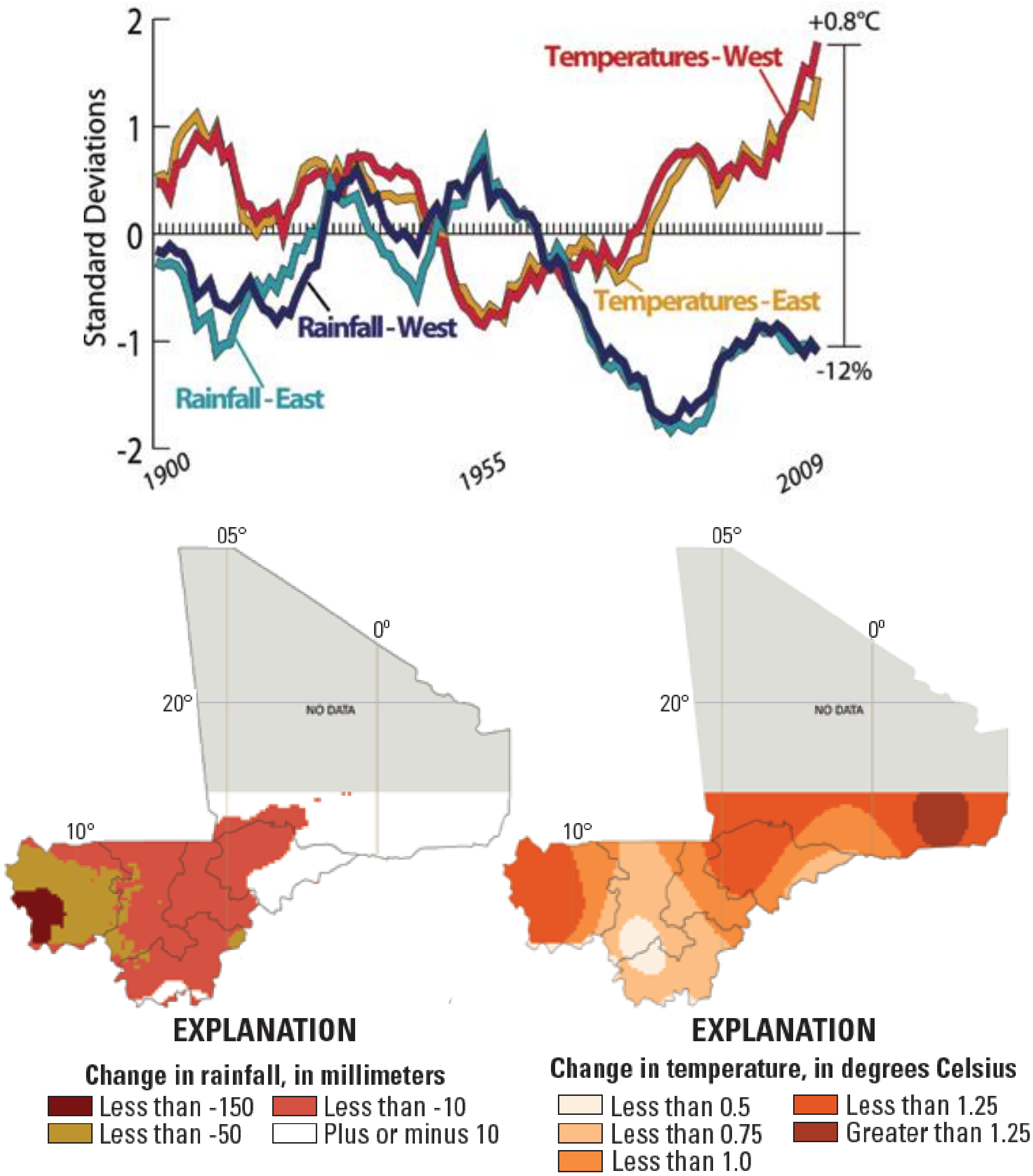
FIGURE 5. LONG-TERM TRENDS IN RAINFALL IN UPPER CATCHMENT AREAS AND INNER DELTA IN MALI



Source: Zwarts et al., 2005

Analysis undertaken by USAID's FEWSNET project show similar results (Figure 6). Rainfall has declined significantly since about 1960, while temperatures have increased significantly during the same time period. The data have been broken down to show the degree of spatial variation, with greater decreases in rainfall in the western uplands, and greater increases in temperature in eastern and northern areas.

FIGURE 6. TEMPORAL AND SPATIAL TRENDS IN RAINFALL AND TEMPERATURE, MALI, 1900-2009

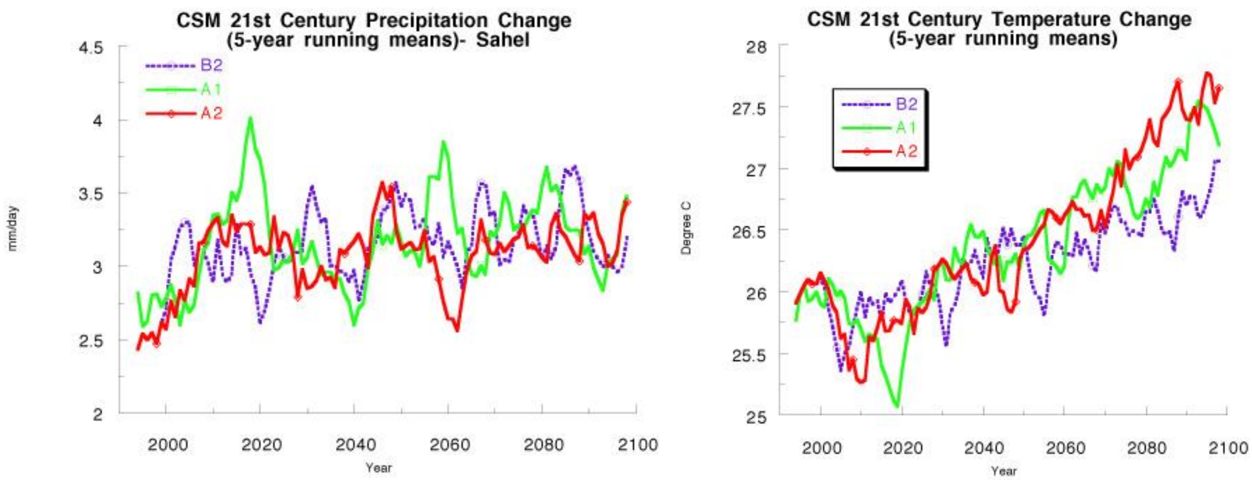


Source: Funk et al., 2010

Climate change models suggest that there will be different trends for rainfall and temperature in the 21st century. Precipitation in Mali is expected to increase slightly with a strengthening of the monsoon, but temperatures are anticipated to rise. From a hydrologic perspective, higher temperatures increase the rate of evaporation from water bodies and the ground surface. They may increase transpiration, but under certain conditions higher temperatures may inhibit transpiration from temperature sensitive plants if temperatures exceed certain thresholds and plants wilt because the transpiration mechanisms shut down.

One thing that is clear is that there continues to be considerable year-to-year variability with periods of below average rainfall that will have a direct impact on river and groundwater availability. Furthermore, not all parts of Mali are predicted to behave in the same fashion. Temperature increases are anticipated to be widespread, while rainfall may decrease in the wetter parts of the country and increase somewhat in the central zones (Figure 7).

FIGURE 7. PREDICTED RAINFALL AND TEMPERATURES IN MALI IN THE 21ST CENTURY



Source: Jenkins et al., 2004

The majority of existing studies that examine the impact of climatic change on water resources in Mali have focused on the hydrology of the Niger River and its major tributaries. The detailed hydrologic analysis, which goes back for many decades, reflects the importance of the river for providing domestic, industrial and irrigation water as well as its role in power generation. It has been supported by international initiatives that look at the hydrology of the entire Niger River basin to support the activities of the international Niger Basin Authority.

By contrast, there are far fewer studies of hydrology outside the Niger basin, and there is a paucity of information on groundwater and its behavior over the same time period. As a result, it is prudent to split the analysis of exposure to climate change into two parts: those areas within the direct hydrologic influence of the Niger and Senegal Rivers, and those areas that depend on more local sources of water.

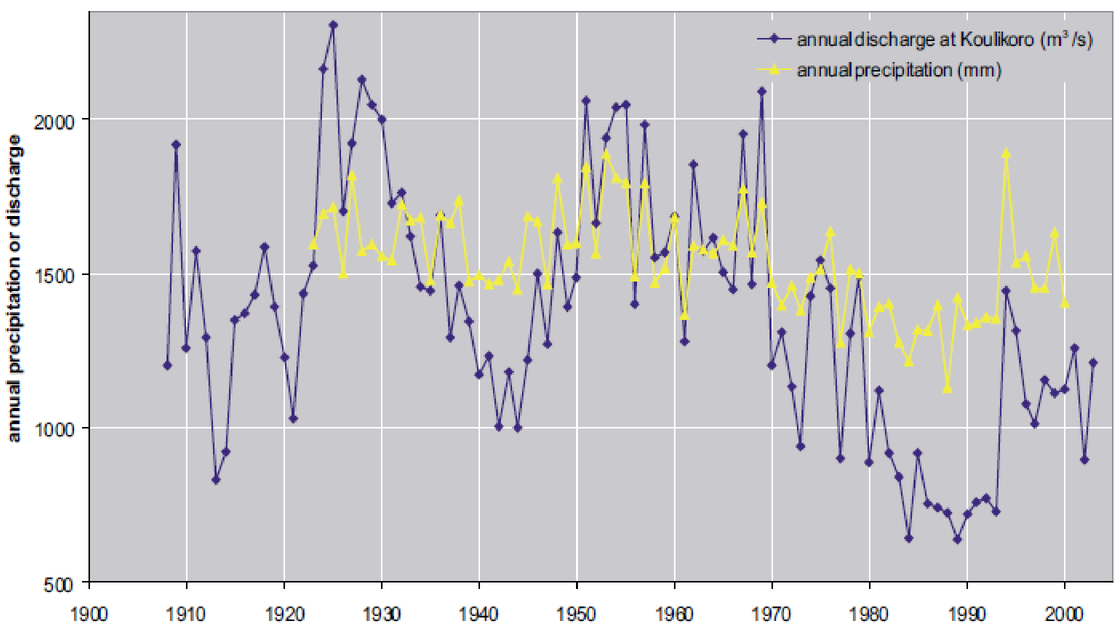
3.1.1 Climate and Hydrology of the Niger River

As indicated earlier, the discharge patterns and water extractions from the Niger River are well documented. There is a well-established river gauging network that provides accurate data throughout the Niger River basin, both within Mali and in other countries included in the basin. In Mali, this information is collected by DNH, and both used nationally, and shared with NBA according to the treaty protocols.

There are many studies of the hydrology of the Niger River in Mali. The most comprehensive documents have been produced by Dutch researchers, who have benefitted from Netherlands support for an exhaustive analysis of the upper basin of the Niger and modeling of the impact of climate change and human intervention on potential impacts from ecological and socioeconomic perspectives (Zwarts, 2005; Zwarts, 2006).

Long-term discharge data at Koulikoro show a close relationship with annual rainfall averaged over seven stations in the upper catchment. Periods of good rainfall (when rainfall exceeds 1600 mm) result in average annual discharges in excess of 1700 m^3/sec at Koulikoro (Figure 8). However, as soon as average rainfall in the upper catchment drops below 1500 mm/year, the effect on total river discharge is dramatic: the data from the 1940s indicate the high sensitivity of the river to multi-year reductions in rainfall, and also note the cumulative effect of persistent low rainfall. Six years of rainfall of approximately 1500 mm led to river discharges declining from 1500 m^3/sec to 1000 m^3/sec. In the 1980s and 1990s, when rainfall was only about 1300 mm in the upper catchment, average annual river discharges fell to about 700 m^3/sec. In other words, a 25 percent decline in annual rainfall results in a decline of over 50 percent in annual discharge; and the longer the intensity of the dry spell, the more river levels fall. This is a consequence of widespread lowering of the groundwater table due to poor recharge, reducing the rate of replenishment of surface waters from groundwater.

FIGURE 8. LONG-TERM RAINFALL AND DISCHARGES IN NIGER RIVER AT KOULIKORO



Source: Zwarts, 2005

Despite these hydrologic relationships there currently appears to be little risk of water stress for water resource users along the Niger River until the major diversion structure at Markala. Irrigation along the river does not consume a great deal of water (the two largest schemes are 1,350 ha just below Selingue Dam and 3,500 at Banguineda, just downstream from Bamako), and extractions for domestic and industrial use are small compared to overall river flows (see Figure 9 on the following page).

Exposure to declining discharges in the Niger River at and below Markala Dam, however, is very much higher due to the volume of water required for irrigation by the Office du Niger. Markala Dam has no effective storage capacity: it keeps river levels sufficiently high to allow the feeder canal to run at or close to design levels. Data from *Office du Niger* indicate that with infrastructure in place until the mid-2000's it was possible to operate the feeder canal at desired levels largely irrespective of upstream changes in climate and hydrology. The detailed analysis of Zwarts et al (2005) indicates that the operation of Selingue Dam is critical to maintaining adequate water supply at Markala.

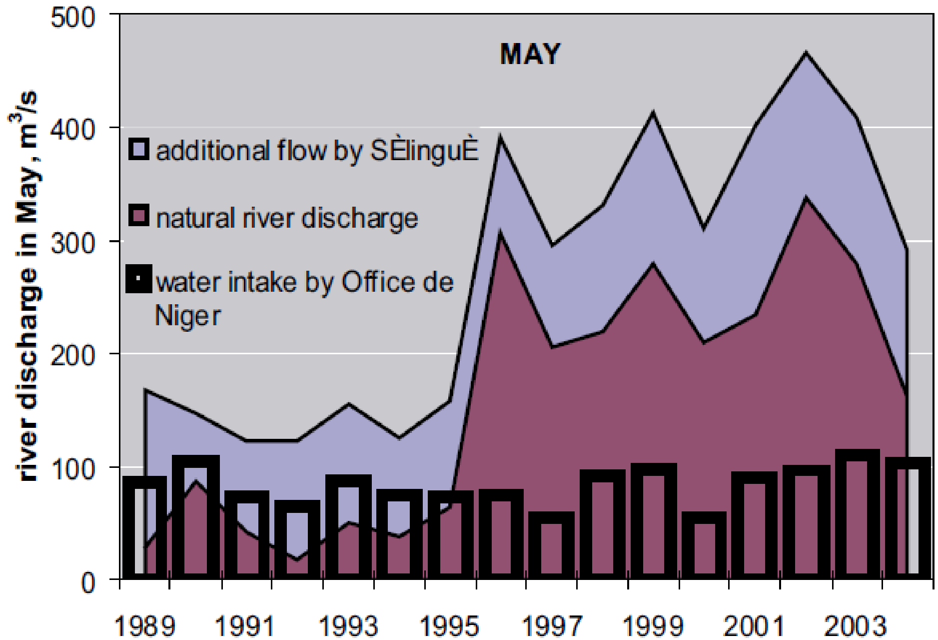
Since the Selingue Dam started operating in 1982, discharge at Koulikoro has never fallen below 113 m^3/sec, far above the minimum requirement for maintaining downstream ecological flows. Prior to operation, discharges at Koulikoro fell below 50 m^3/sec roughly one year in four (Zwarts, 2005). But with release of water from the reservoir throughout the dry season, it is possible to augment the flows of the Niger River to meet demand for water from all uses throughout the dry season.

Analysis of supply and demand at Markala for the month of May (the driest month, and the one immediately prior to the onset of rains and increases in natural river discharge) shows that if Selingue Dam did not exist, *Office du Niger* would not have been able to meet its planned discharges into the feeder canal. The data show that even throughout *La Grande Secheresse* of 1989 to 1995 *Office du Niger* could divert sufficient water to meet its targets, and that those targets were not significantly different from those established when water was far more abundant in the period after 1995. If there were no changes in the irrigated area served by Markala, then there would be little cause for long-term concern about overall water availability in the Inner Delta and below. However, there have been several increases in irrigated area in recent years that require additional extractions from the Niger at Markala, including US investment of 5,000 hectares at Alatona though the Millennium Challenge Corporation (MCC), Libyan investment in the Malian rice growing system of 100,000 hectares, and Chinese investment for 50,000 ha of sugar cultivation. Were these areas all to come into full production, they would increase the total irrigated area from about 90,000 ha to over 200,000 ha, requiring more than double the amount of water to be diverted from the Niger River at or near Markala. While this increased demand can be met during the period of higher river discharges, it is clear that there would be inadequate years, and Kuper et al. (2003) believe it is impossible to reliably irrigate additional areas without more dams upstream.

One response to the possibility of water shortfalls is to plan the construction of new dams on the upper Niger and its tributaries. Plans exist for a major dam to be constructed in Guinea (still to be finally approved and financed) at Fomi, and two smaller dams in Mali on the Bani River. While the Mali dams would not contribute much storage and would not affect the hydrology of the Niger at Markala, they would provide some water to meet downstream minimum flows into Niger and permit somewhat greater extractions at Markala.

The data on extractions by Office du Niger in Figure 8 represent the requirement for extractions sufficient to irrigate between 35,000 and 50,000 ha. If the irrigable area increases to 200,000 ha, then the required extractions would rise from the approximately 100 m^3/sec level to as much as 250-400 m^3/sec, which would not be available in every year because of the need to maintain at least 40 m^3/sec in flows to downstream riparian countries.

FIGURE 9. RIVER DISCHARGE AND IRRIGATION EXTRACTIONS AT MAKALA DIVERSION, 1980-2003

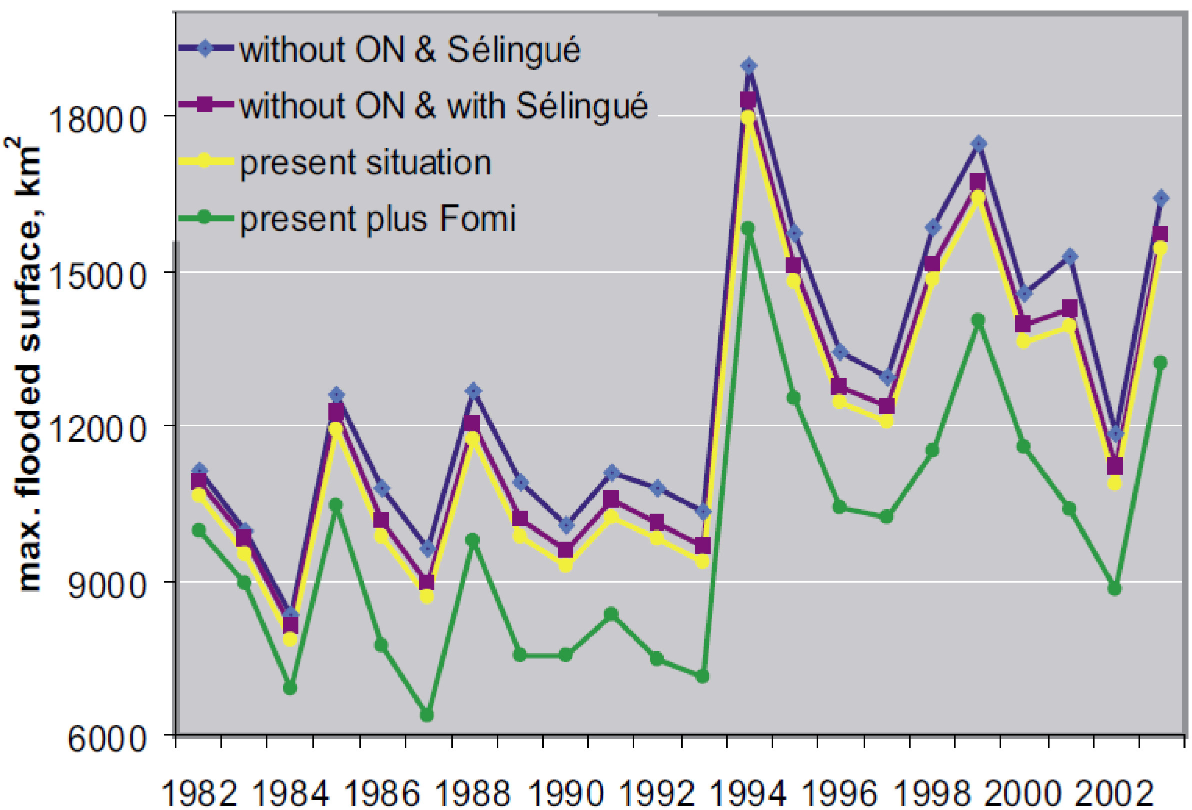


Source: Zwarts et al., 2005

Once constructed, the Fomi Dam would have enough storage to impact peak flows on the Niger River. Unlike Selingue, which has no effective year-to-year storage, Fomi Dam could reduce peak flows and this would result in significant reductions in inundation of the inner delta during the flood season. This has a direct and high impact on the populations not served by *Office du Niger*, their grazing lands and wetlands, and on the biodiversity of the whole delta area. The ecological, economic, and social impacts are addressed in sections 4 and 5 below.

Changes in the area and intensity of flooding of the inland delta, which is an integral part of the hydrology and ecology of the entire Niger Basin, are the most contentious part of the overall water management of the Niger River. Although the Niger loses some 20 percent of its total discharge in the delta, the flooded area not only acts as a sponge and mitigates downstream effects of flood peaks, but also allows for grazing, fishing, and other economic activities. The construction of Markala Dam reduced some of the inundation by diverting water away from the main portion of the inland delta. In response to the impacts of these extractions on the downstream hydrology, Mali has agreed to deliver a minimum discharge along the Niger to maintain sufficient water to meet the basic demands of the delta and serve downstream users in Niger and Nigeria. However, the area subject to annual flooding has already decreased following the construction of Markala and Selingue Dams, and construction of additional upstream storage that would attenuate flood peaks would further exacerbate the situation (see Figure 10).

FIGURE 10. IMPACT OF UPSTREAM STORAGE ON AREA OF ANNUAL FLOODING IN THE INNER NIGER DELTA



Source: Zwarts et al., 2005

Overall, therefore, it is possible to conclude that in areas upstream of Markala there are few risks of exposure to water stress in periods of below average rainfall. Below Markala, however, risks to ecology and socio-economic conditions are very high (see Section 4 and 5 below).

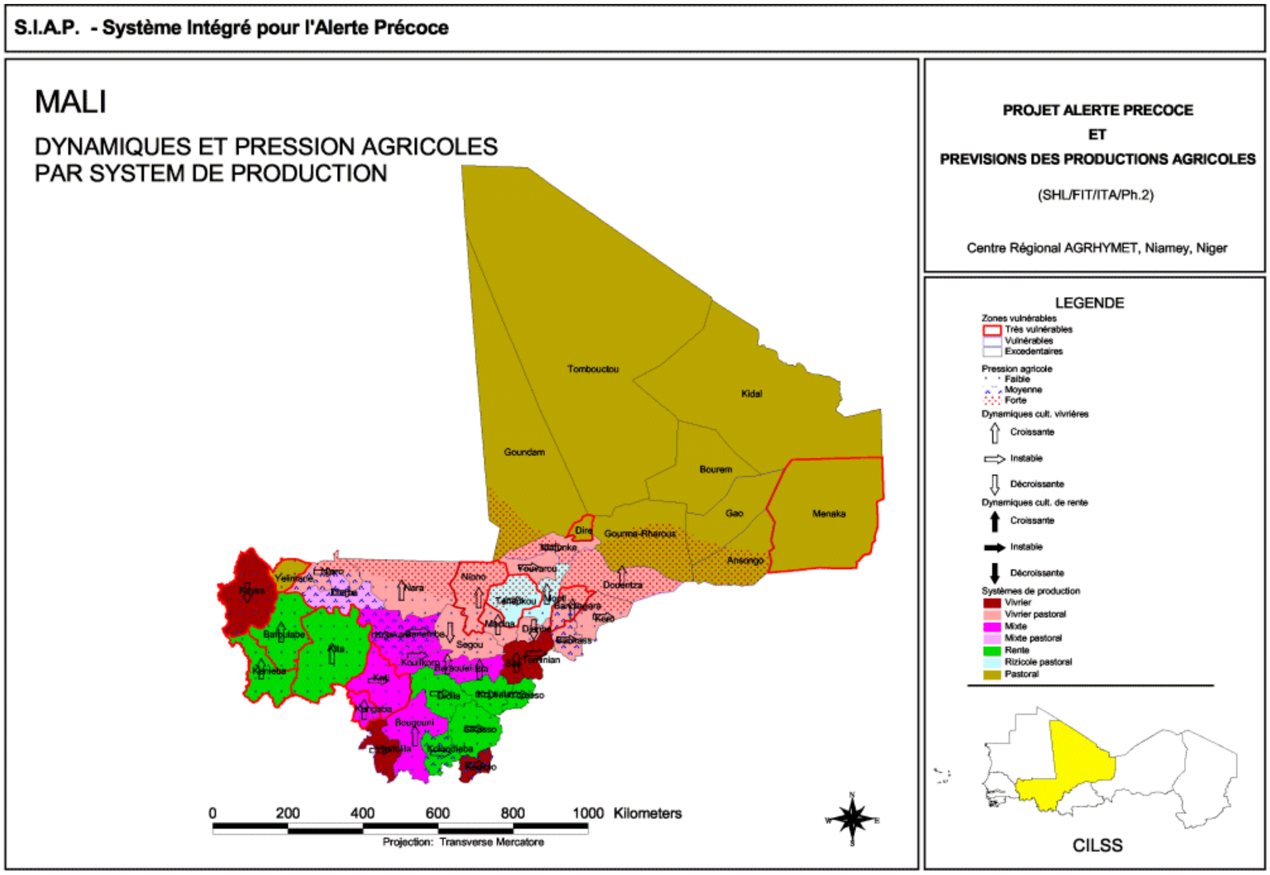
3.1.2 Outside the Niger River

Assessing exposure in terms of water resources in areas outside the Niger River is largely uncharted territory. There are some scattered pieces of information, but more systematic studies are needed to examine the impact of both short-term and long-term declines in rainfall.

Rural areas that rely heavily on shallow groundwater and surface water sources such as streams and ponds are particularly exposed to changes in rainfall. Unlike areas served by the Niger River, there is little buffer capacity in those water sources, and populations can feel the effects of reduced rainfall and increased demand within a single dry season. If dry spells stretch over several successive seasons then the effects may be catastrophic.

The degree of exposure is related both to hydrology and the capacity to access groundwater. A few data sources demonstrate these relationships.

FIGURE 11. DYNAMICS AND STRESS IN AGRICULTURAL ZONES OF MALI



Source: AGRHYMET

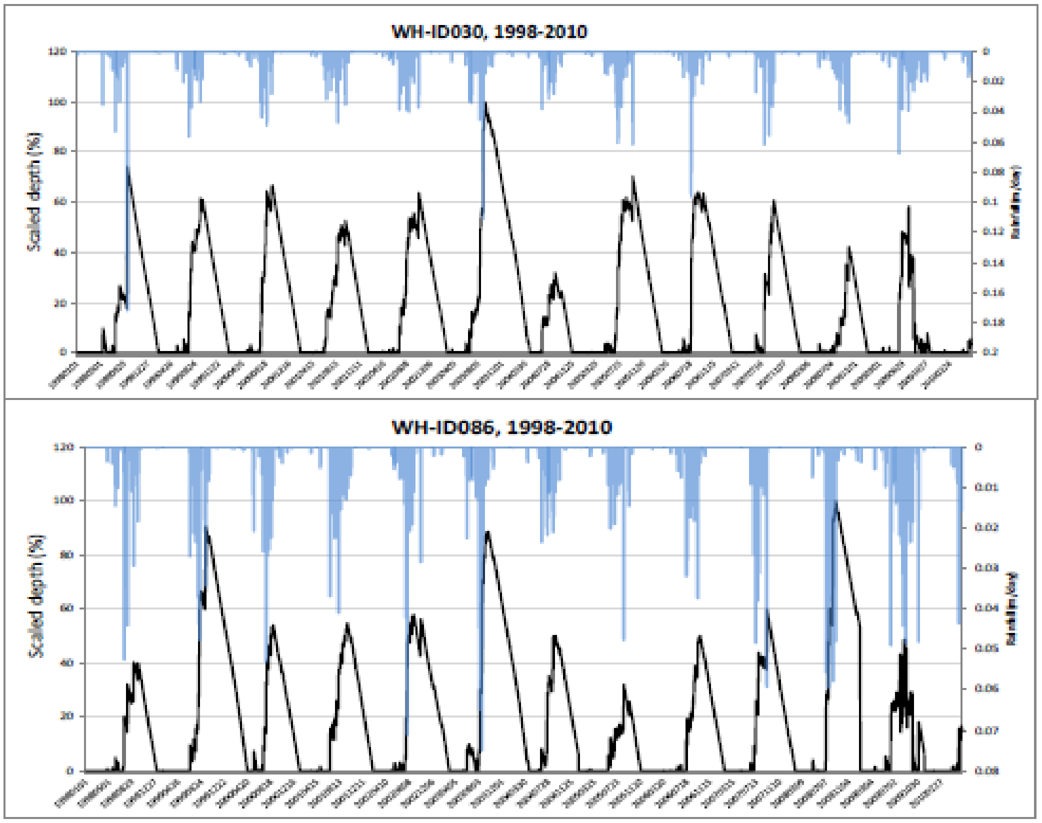
Most impact studies are based on agricultural data rather than on assessment of water resources. The focus of many of these studies is on rain-fed cropping patterns, and does not include the contribution of any irrigation systems in each zone.

For example, AGRHYMET data show increasing stress (see red outlined zones on map, Figure 11) on agricultural lands from south to north, mirroring the normal rainfall patterns. Based on rainfall alone the increasing stress does not show the potential impacts of irrigation and groundwater use, but stress on agricultural systems is increasing in almost all parts of the country: only Segou, San and Djenne show reductions in stress, and these are all areas close to the Niger River.

The African Monsoon Multi-disciplinary Analysis (AMMA) has a long-established observatory site in Gourma, Mali, that looks at relationships between rainfall, vegetation and hydrology, and has produced many scholarly papers on this topic (see Frappart et al., 2009, and Mougin, 2009, for an exhaustive list of these publications).

A handful of studies look directly at water resource data. The USAID Mali Livestock, Pastoralist and Poultry Initiative (MLPPI) included a component on modeling the amount of water in ponds used for livestock in the Bani area as a first step to assessing the extent to which pond water levels and surface area changed with rainfall.

FIGURE 12. HYDROGRAPHS FOR TWO WATERHOLES IN BANI DISTRICT, 1998-2010

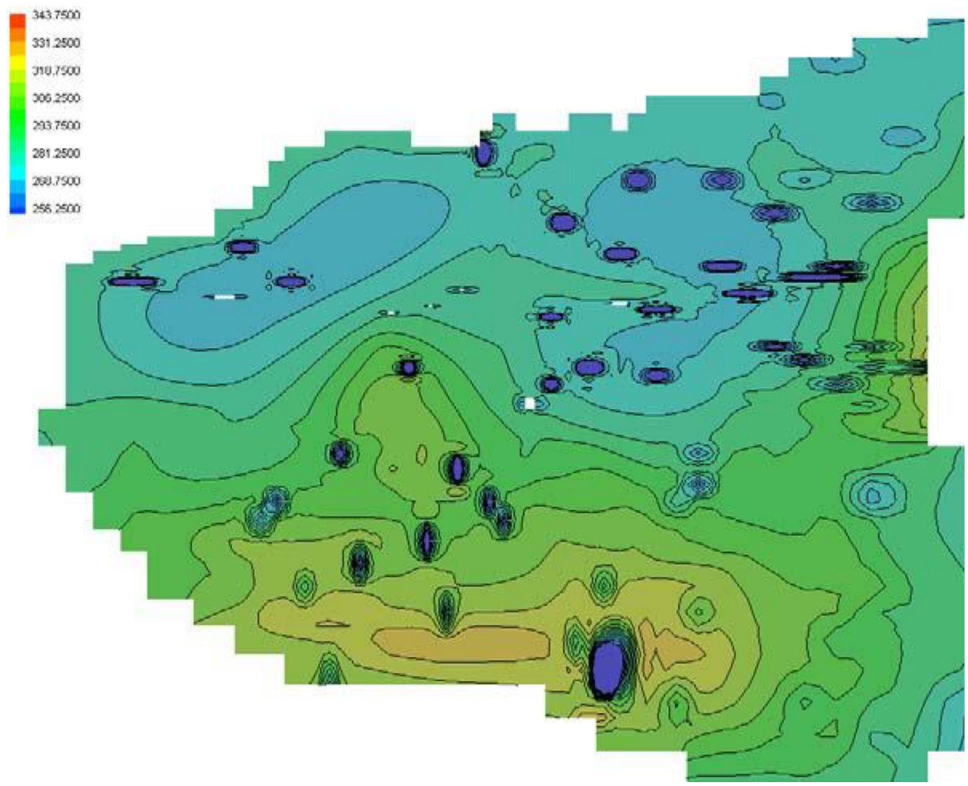


Source: MLPPI Annual Report 2012

The MLPPI data suggest that under current rainfall conditions, water levels in the two waterholes increase during the rainy season and dry out during each dry season. The length of the dry period is related to total rainfall in the dry season, so that livestock are far more vulnerable to drought years of low rainfall.

Also in Bani, DRI undertook detailed hydrologic investigations over a couple of years in the Bani region (Lutz, 2011) within the framework of the Rural Water Supply project supported in part by USAID. They show that in an area where only handpumps are used to tap groundwater, wet season recharge more or less restores groundwater levels before the ensuing dry season. Under current conditions, and assuming that water consumption is 90 l/person/day to cover drinking, sanitation, and small amounts of vegetable gardening, the total water demand is less than 1 percent of total annual precipitation. However, if mechanical pumping were introduced for domestic water supply in larger communities, for some industry and for agriculture, then demand reaches or exceeds 3 percent of total annual precipitation and this may not be sustainable. More information is required on aquifer recharge rates from both rainfall and lateral flow from rivers, plus knowledge of aquifer transmissivity (rate of flow of water through the aquifer) in order to determine and sustain extraction rates. Little information is available on these key pieces of information (see Figures 12 and 13).

FIGURE 13. PREDICTED WATER TABLES IN BANI DISTRICT, MALI IN 2040



Source: Lutz et al, 2011

Other modeling studies include some assessment of possible groundwater changes in response to climate change in highland areas of Mali (Bokar, 2012), detailed modeling in the Bani river area (Henry 2011), and modeling of groundwater recharge near Timbuktu (Jacks, 2013). None of these studies come up with conclusive evidence of the probable impact of climate change on either groundwater fluctuations or the relationship between rainfall, groundwater extraction, and sustainability of water resources. Shonsey (2009) shows that it is possible to come up with estimates of water availability at community level, even with relatively few resources. Lapworth et al. (2011) show the value of rapid appraisal techniques for assessing groundwater opportunities.

The lack of detailed studies such as those undertaken in the MLLPI and DRI projects makes it difficult either to assess the overall vulnerability of rain-fed areas to climate change, or to devise effective management solutions that can be implemented at community level. But it is precisely this type of information that is required for development of effective IWRM plans at district and community levels.

3.2 DISTINGUISHING CLIMATIC VARIABILITY FROM CLIMATE CHANGE

The importance of distinguishing climatic change from climatic vulnerability is seen in assessing the degree of short-term versus long-term exposure. A resilient system can weather short-term deviations in water availability and thus is primarily susceptible to long-term change. The areas the Niger River serves fall into this category: river levels do not drop dramatically with a single year of below average rainfall because of the buffering effect of groundwater recharge; however, once those groundwater resources fall over a period of a few years, then the entire system becomes highly exposed to risk.

Non-resilient systems with high exposure to risk are those where there is little buffering effect. The most susceptible locations are those that rely solely on surface water sources; the huge increase in shallow tubewells means that there are fewer and fewer areas in Mali that face very high levels of risk during shorter periods of drought within a single year. However, shallow groundwater is likely to show declining trends with only a year or two of declining rainfall and increasing temperature, so water supply systems based on shallow groundwater still face high risk in periods of prolonged drought. The effects may be localized, depending on the aquifer and the rate of extraction, but the impact on particular communities may be severe.

3.3 IMPACT OF EXACERBATING FACTORS

From the previous two sections it is clear that separating out the impacts of climatic change, climatic variability, and the four main exacerbating factors is very difficult, if not impossible.

The first three exacerbating factors (population growth, poverty and degradation) are interwoven and it is difficult if not impossible to separate out their individual impacts. It is clear from several studies that in periods of below average rainfall one consequence of population growth is to degrade land and vegetation resources through a combination of overgrazing, deforestation, reduction in soil carbon and nitrogen resources, and reduction in fallowing time. Poverty compounds these problems because communities do not have the resources or skills to adopt other soil, water and vegetation management practices that would be more sustainable.

Many of the reports dealing with impacts of climate change restrict themselves almost exclusively to rain-fed agriculture and interconnected issues of soils, land degradation, inputs, and other aspects of the production system (e.g., Adepetu, 2007; Ng'ang'a et al., 2013; Traore, 2011). This makes it difficult to know the extent to which opportunities for more resilient production systems based on IWRM might function.

So far, technological innovations that access additional water resources have focused on major investments in dams and new irrigation schemes, or on provision of improved water supplies for drinking and sanitation; neither investment contributes to improved food security at community level by widening access to water resources.

Manual pumping for domestic water supply does not appear to have led to significant declines in water table levels, and most shallow aquifers appear to recharge within a month or two of the onset of the rainy season. The larger potential threat comes from development of pump-based irrigation that has the potential to draw down groundwater levels if adopted on a significant scale.

Over the past decade or so there have been greater efforts to promote commercially oriented, small-scale irrigation through manual or small-motor pumps. Initiatives have included the treadle pumps promoted by Winrock, and the hand-powered force pumps ("moneymaker pumps") marketed by Quickstart. Both programs resulted in significant adoption of these pump systems by involving the private sector in pump manufacturing, sales, and after-sales service.

Farmer preference, however, is for motor pumps to exploit hand dug wells and surface water resources. To date there is no evidence of long-term water table decline but the adoption rate of pumps remains low because communities are too poor to purchase them in large quantities. However, efforts to improve nutrition and income through expansion of irrigated agriculture are not risk-free with respect to sustainability of groundwater resources.

Information technology has not yet made a significant impact at the community level. However, the potential for IWRM in rural communities appears high. It requires information on the number of different water sources available, their water yields, and their sustainability in the dry season and in periods of drought.

Some pilot programs have implemented such an approach. Multiple Use Systems (MUS), developed by Winrock in Mali and elsewhere, has shown that with such inventorying it is possible to develop a community-based water and land resources management plan that includes domestic water supply livestock needs, small scale irrigation for individuals and women's groups, forest and grazing land management, and roles and responsibilities for implementing the entire program.

This is in sharp contrast to single use development programs that do not account for all water resources within a community.

4.0 BIOPHYSICAL SENSITIVITY TO CLIMATE

4.1 WATER AVAILABILITY/SUPPLY AND SPATIAL VARIATION

While it is convenient to address the issue of biophysical sensitivity at the national level, it is important to understand that there are major variations in both physical conditions and their relative sensitivity to climate change within Mali. From a biophysical perspective, four broad types of hydrological conditions exist within Mali, each having its own set of characteristics and responses to water management interventions.

4.1.1 Upper Catchment areas of the Niger and Senegal Rivers

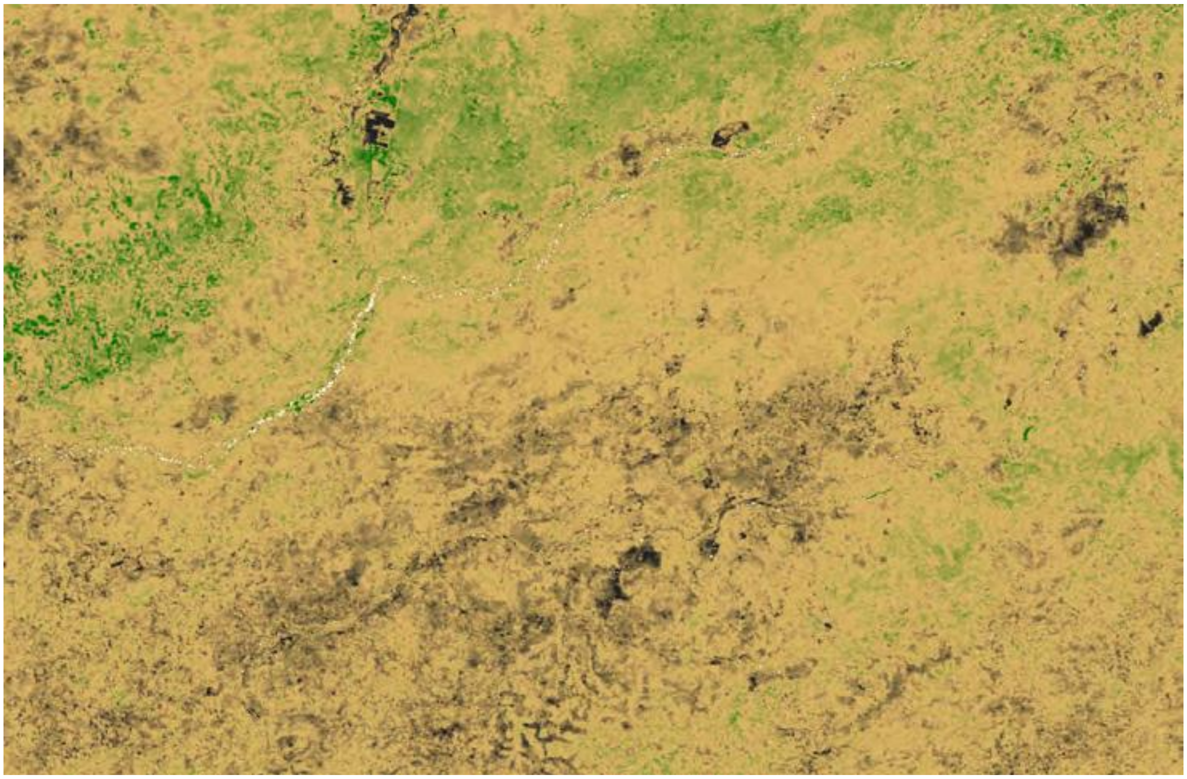
The upper catchment areas are generally well watered, and the majority of streams are perennial. Climate models seem to agree that in these areas there may be a reduction on annual rainfall and a modest increase in temperature that will have consequences both within the zone and for downstream water users.

Decreased rainfall in the upper catchments means that the total volume of flow is reduced, but overall rainfall and hydrology will likely meet local needs. Groundwater storage is limited due to the nature of the basement geology, and although at least one model study (Bokar et al., 2012) indicates a slight reduction in groundwater, it is unlikely to have significant local impact.

Impact on vegetation is likely to be more important because low rainfall and higher evapotranspiration means some diversity may be lost, compounded by continued clearing of forests. However, the overall impact of predicted climate change is not expected to be severe in the upper catchment areas.

Although land degradation is a serious threat to sustainability of rural communities, it is not inevitably irreversible. During periods of improved rainfall vegetation cover has a chance to recover, a trend that can be greatly assisted by community level water and land management programs. Trends are not consistent across the country. Figure 14 shows contrasting changes in Mali based on seven years of satellite imagery. To the south of the area depicted (south and east of Segou and Mopti) there are extensive areas of browning, indicating degradation of vegetation cover. But north of the Niger and in the inner delta, substantial recovery of vegetation occurred in the same time period.

FIGURE 14. TRENDS OF LAND DEGRADATION (BROWN) AND GREENING (GREEN) BETWEEN SEGOU, BLA, AND SAN, SEGOU DISTRICT, MALI, 2000-2006



Source: UNEP, 2012

4.1.2 Riverine Zones along the Niger and Senegal Rivers

Climate change in the upper catchments may result in reduced discharges in the main rivers, but at present it appears the impact on water supply will be limited. Within the Niger Basin, Selingue Dam will continue to provide managed dry season flows along the river down to Markala, and existing and proposed irrigation systems served directly by the river will remain largely unaffected.

If there are significant reductions in the maximum annual flood of the Niger River, then there may be fewer years when the lowland areas of Segou and Mopti are flooded, reducing rice cultivation in those areas. For the most part, though, rainfall predictions during the remainder of this century appear to predict adequate wet season flows.

There is therefore little concern for major impacts along the main rivers and their tributaries upstream of Markala and Manantali Dams unless new reservoirs are built that significantly alter the current flow patterns.

4.1.3 Lowland Areas outside the Influence of the Main Rivers

The impact of changes in the hydrology of lowland areas outside the influence of the Niger and Senegal Rivers is hard to predict. Rainfall models suggest a slight increase in rainfall in these areas, meaning that vegetation should trend more towards greening, but temperatures are also expected to rise, increasing evapotranspiration. Many of the areas with sandstone layers overlying the basement complexes have adequate aquifers, and modeling for these areas generally indicates there is adequate recharge in almost every year. Further, these aquifers are thick enough that water is available even following a year or two of drought.

However, these lowland areas are also more subject to degradation of soil and vegetation resources, and this may alter present rainfall-runoff relationships. Local surface water sources such as ponds and seasonal rivers will continue to support these areas.

There is no clear evidence of the impact of the anticipated climatic changes on the hydrologic resources of these lowland areas, particularly since there is no clear agreement on whether rainfall in this area will increase or decrease. The majority of impact assessment modeling in rain-fed areas has focused on rainfall-crop production interactions. Assessment of impacts on small scale irrigation or supplemental irrigation is rarely mentioned, nor is there any discussion of the potential impact of changes in groundwater level on the agricultural ecosystem. Conclusions can be summarized by saying rainfall increases will clearly be beneficial as there will be reduced stress on plants, more greening, and greater productivity of agriculture; decreases in rainfall will have the completely opposite effect. But in terms of how water resources will be affected by climate change in rain-fed areas, there is a paucity of reliable information.

4.1.4 The Niger Delta

The area most hydrologically vulnerable to climate change is the inland delta of the Niger. Even without human interference, the delta would be subject to negative consequences of upstream desiccation, with reduced flood peaks resulting in reduction in the area that is seasonally flooded. If flood peaks are reduced due to declining rainfall in the upper catchment area, then natural beneficial flooding would be significantly reduced.

The ecological sensitivity of the delta areas is made far greater, however, due to diversion of water for irrigation in the western portions of the delta, primarily from operation of the diversion dam at Markala. Mali has committed to providing a minimum flow of 40 m3/sec for downstream ecological purposes as part of its protocol under the NBA agreements, but it is always difficult to forego irrigation water, particularly when crops are already established. As the new irrigated areas develop, then there are substantial risks to the inner parts of the delta in terms of reduced annual flooding.

Djoudi et al., (2013) give one example of the vulnerability of natural water sources to climate change in the inner Delta area, where upstream water demand directly impacts on lake hydrology.

In terms of biodiversity, large-scale irrigation is a negative factor because not all species thrive under these artificial conditions. Cultivation of a restricted range of crops in both sugar and rice cultivation, reduces natural habitats for animals, birds, and plants. If there are substantial areas of natural wetlands in proximity to irrigated areas, however, there may be some synergistic effects. In the Niger Delta the combination of expanded irrigation and reduced annual flooding will reduce both the number of species and total populations. The inner delta is a Ramsar site (an internationally recognized wetland; signatories of the Ramsar Convention on Wetlands agree to protect these wetlands for the international public good), and thus Mali is obligated to preserve biodiversity within the area.

A key element of the inner delta is the presence of *bourgou*, floating grasses that thrive during the period of inundation in the wet season. In addition to its role is providing habitats for birds and animals, *bourgou* is a major source of food for livestock within the delta, and as *bourgou* areas shrink, livestock are moved to more sensitive areas on the fringes of the delta, or migrate southwards into agricultural lands.

4.2 FISH HABITATS: MIGRATION, RECRUITMENT, AND BREEDING

The inner Niger Delta has economically important fisheries. The total volume of catches is very closely related to the size of the annual flood in the preceding wet season: larger floods result in more fish. However, the volume of catches has been reduced over the past 20 to 30 years due to the use of nylon nets with smaller mesh size (Lae et al., 2004). It is believed that few fish live from one year to the next.

Selingue reservoir is a significant source of fish, particularly for Bamako due to good roads linking the two sites. Although catches are seasonal, with more production in the dry season, they appear to have reached some degree of stability, and there is little opportunity for expanding fishing. Upstream changes in rainfall-runoff relations are unlikely to have any impact on Selingue fisheries, as the reservoir rarely fails to fill up completely during the rainy season. Fish catches at Manantali are much lower and show significantly lower species variation (Lae et al., 2004).

Studies of fish production in the inner delta and in Selingue and Manantali reservoirs all indicate that current levels of fishing have indeed reached the maximum potential. It is unlikely that there will be significant improvements in the future because flooding in the inner delta will not reach its maximum extent if total discharge in the Niger decreases in response to upper catchment declines in water yields, or if irrigation extractions at Markala increase. Reservoir capacity is fixed and cannot expand to produce much more than at present.

If the flooded area continues to shrink, then fish catches will also fall. One estimate (Lae et al., 2004) is that operation of Selingue reservoir has reduced fish production by 6 percent by reducing the size of the annual flood, and any further dam construction upstream would have an even larger impact.

4.3 CONTRIBUTION OF EXACERBATING FACTORS

Insofar as the major biophysical risks are situated in the Inland Niger Delta, economic pressures for increased hydropower and irrigation are the key factor in exacerbating underlying climatic changes. Indeed, the very scale of proposed irrigation diversions for the Chinese and Libyan programs in the western part of the delta probably pose a far greater threat than natural changes in discharge consequent on climate change and variability.

Similarly, the operation of upstream dams to reduce the peak flood periods and extend flows in the dry season has a negative impact on *bougou* for grazing and on fisheries due to reductions in the flooded area.

Population change is also a contributing factor: during *La Grande Secheresse* there was significant in-migration into the Niger Delta, because the irrigated areas were perceived as a safe haven during the drought. Most of those coming to the delta came from surrounding lowland areas that had no reliable water. The increased population, together with natural population increase of tenants within the Office du Niger irrigation schemes, has led to subdivision of plots and more intensive cultivation practices, together with greater use of chemical inputs for fertilization, and pest and weed control. While this has had clear economic benefits in terms of overall rice production, it has affected water quality of drainage into other parts of the delta.

5.0 SOCIOECONOMIC SENSITIVITY TO CLIMATE

5.1 WATER DEMAND AND BALANCE

In terms of current water use practices, Mali remains relatively well endowed with water resources, both in the two major rivers and in shallow groundwater. None of the model projections seem to suggest significant reductions in groundwater, although the data are sparse at best, and modeling of river discharges is plagued with uncertainties over whether rainfall will increase or decrease.

With respect to year-to-year variations, the Niger and Senegal Rivers remain fairly resilient, as there is always surplus water in rivers in the wet season. The Niger, at least downstream as far as Markala, has sufficient flow to meet current demands for domestic and industrial water supply either through direct extractions or recharge of water along the main valleys.

The greatest uncertainty is in how much water is available for irrigation, particularly in the peak of the dry season. Although Kuper et al. (2003) indicate that additional and sustainable irrigation in the Niger Delta is not possible with current levels of reservoir storage and release, irrigation expansion has been proceeding apace.

Irrigation accounts for as much as 90 percent of all water used in Mali. Urban and industrial uses are so small in comparison that it is the level of investment in pumping and distribution infrastructure that restricts use in urban areas, not the overall level of supply. This situation is unlikely to change under the type of climatic changes predicted.

In rural areas groundwater based irrigation extractions in areas away from the main rivers remain at very low levels, but are perhaps more vulnerable to climatic change because they rely on shallow groundwater which is recharged close to communities that extract the water. In terms of value of production changes in small-scale irrigation consequent on climatic change may be small in financial terms, but may have important local impacts on communities who have come to rely on vegetables and cash crop production from irrigation.

The primary impact of climatic change is therefore restricted to agriculture and livestock, and impact in this area needs to be explored in more detail.

5.2 AGRICULTURAL PRACTICES THAT REQUIRE WATER

The only significant use of water in agriculture is for rice and sugar production. Although *Office du Niger* was originally established to grow cotton, rice has always been more successful. In recent years there have been efforts to diversify into vegetables, maize and other grains but by and large rice remains the preferred crop in irrigated areas.

The *bas fonds* are the other major areas producing rice, but with low productivity compared to technical irrigation. *Bas fond* rice cultivation relies primarily on local high groundwater tables and shallow flooding, and although efforts are made to manage water through small check structures (particularly through

Programme National d'Irrigation de Proximite), the cultivation practices and water management remain basic (*Ministere de l'Agriculture*, 2010).

The revitalization of the *Office du Niger* irrigation systems after 1982 has had a large impact on Malian food security, particularly with regard to rice cultivation. The rehabilitation of the old irrigation systems following the completion of Selingue Dam has not only increased the total irrigated area, but has also allowed introduction of more productive rice farming techniques.

During the rice campaign of 2009 Mali produced some 1.6 m tons of rice. Of this total, almost exactly half was grown in technical irrigation systems, with Office du Niger producing nearly 600,000 tons averaging about 6 tons per hectare. The other systems along the Niger (*RizSegou*, *RizMopti*, Selingue, Baguida, and small systems along the upper Niger) produced about 200,000 tons, and averaging roughly 2 tons per hectare. Open flooding of rice, primarily in the inner delta of the Niger contributed another 300,000 tons, with average yields of 1.2 tons per hectare (*Ministere d'Agriculture*, 2009).

These levels of production leave no doubt about the potential sensitivity of Mali to reductions in rice production as a result of water deficits, although most of the rice production occurs with wet season water diversions. It also emphasizes the pressure on *Office du Niger* to maximize water deliveries to the technical irrigation systems rather than release water to the inner delta to support low productivity rice production (along with all of the ecological benefits of the wetland areas).

In the event of a pronounced period of low rainfall it is not possible to adequately irrigate all of the existing and newly developed irrigation areas, and the impact on food security at national level is obvious. While the *Office du Niger* has made great efforts to improve water productivity in their rice-based systems, with water use falling from over 30 m^3 per kg to less than 8 m^3/kg, the basic issue for rice cultivation in the *Office du Niger* will continue to be meeting demand in periods of low flow. Any discharge reductions will merely intensify conflict between rice farmers, pastoralists, fishing communities, and ecologists.

Reduced flooding in the inner delta greatly affects the area of flooded rice. Although yields are low, the rice production systems there are critical to the survival of people living the inner delta. The maximum area cultivated under both inundated and floating rice may reach over 150,000 ha, but require plentiful water from flood stage in the Niger River. Typical production is estimated to be about 100,000 tons per year. It is estimated that reservoir operations at Selingue Dam have reduced rice production in the inner delta by 10 percent due to limiting the peak flood, while extractions for *Office du Niger* have reduced production by a further 5 percent. Further reductions in flow due to climate change will have additional negative impacts on rice production in the inner delta.

One clear sign of a lack of understanding of water balance and demand issues is a lack of attention to the productive value of water, particularly in relation to food production. Insofar as most of Mali has insufficient water but plenty of land, traditional measures of agricultural and irrigation performance such as area cultivated and yield per hectare do not say much about how well water is being used. Measures of water productivity ("crop per drop"), such as those developed by International Water Management Institute (IWMI), include assessing production in such terms as yield per unit of water or value per unit of water. As water is the primary limiting factor in most Malian production systems, water productivity needs to be in the forefront of investment and management strategies (Mulligan, 2012).

Information on water productivity provides the basis for long-term assessment of how effectively water resources are being used. But to date there is no evidence that this is being used as a practical management tool.

5.3 LIVESTOCK

Two distinctly different livestock systems exist in Mali. In most rural areas communities have livestock (cattle, sheep and goats) and have access to water sources that include local streams, shallow ponds and dug wells that can tap shallow groundwater. Grazing is local and uses uncultivated land and fallow fields in and around settlements. These livestock are vulnerable to prolonged drought because most water sources are not sufficiently resilient to last through extended dry periods. If climate change results in such dry periods, the economic impact on communities would be significant. During *La Grande Secheresse* animal populations, particularly in the northern half of Mali, were very severely affected, with losses of up to 60 percent of livestock dying from lack of food and water.

In the inner Niger Delta a far more complex situation exists. Traditionally cattle raising has been practiced in the grasslands and floating islands that are found in the shallow lakes and depressions. Total animal populations (cows, sheep, and goats) have traditionally been dependent on the area in the inner delta during the wet season, which is key to ensuring animal survival. Only after inner delta forage supplies have been exhausted do herders move their animals southwards into agricultural land to graze on crop residue.

If the rainy season is shorter than normal, there are two separate impacts: firstly, the amount of forage, especially *bourgou*, is limited and is finished earlier in the season with commensurate reduction in animal populations; and secondly, animals move into agricultural areas prior to harvest and come into conflict with cultivators.

Estimation of the negative impact of drought on animal populations is sketchy. In the worst of the 1980-1995 drought in the inner delta area animal populations fell by 32 percent. It is reported that herders took their cattle to Sikasso and Cote d'Ivoire to try to find enough forage.

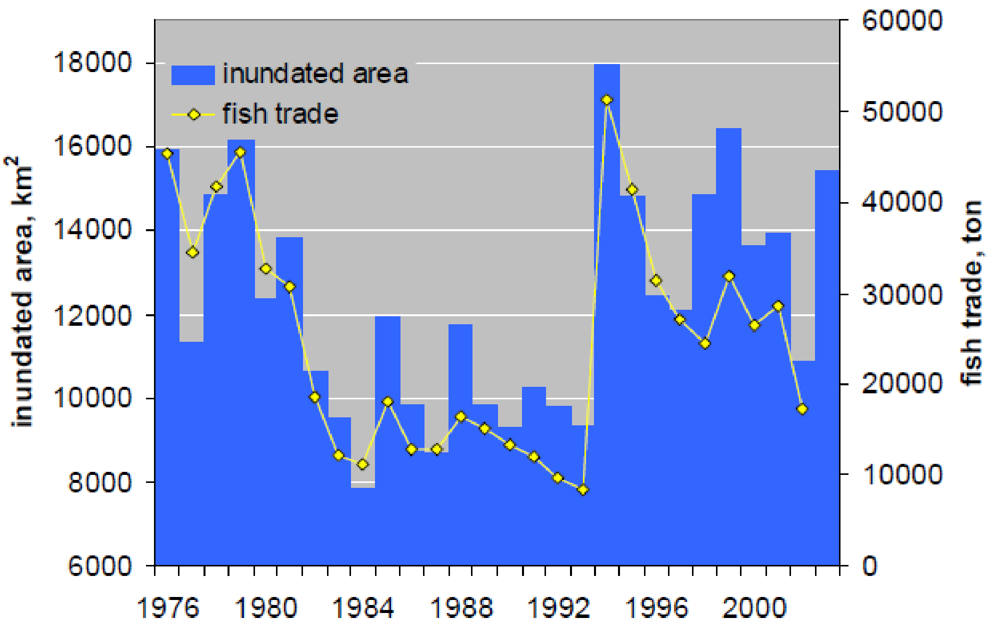
5.4 FISHING LIVELIHOODS: CATCHES

Upstream of Markala, including fisheries at Selingue, it appears that there is little room for expansion of fisheries. Fish caught are almost entirely less than one year old, indicating that the upper limit of catch has been reached. With reservoir operation and adequate river flows fishing in the main rivers and the reservoir are likely to remain fairly stable even if overall river discharge falls.

The same is not true for the inner delta (Figure 15). Fish populations are dependent on the amount of the annual flood, so that high floods enable larger and bigger fish populations as well as similar increases in the livestock and flooded rice sectors. Declining flood water levels in the past have had catastrophic impacts on the population living in the inner delta, and they remain highly vulnerable to reduced flooding if there is a combination of lower river discharges and increased diversions for irrigation into other parts of the delta.

Total production in the inner delta may exceed 100,000 tons in the wet season, and an additional 50,000 tons in the dry season. But both totals will fall if there is a decrease in the flooded area. These decreases are reflected in the actual trade of fish (both fresh and dried).

FIGURE 15. FISH POPULATION DEPENDENCE ON ANNUAL FLOODING



Source: Baker, 2009

5.5 HYDROPOWER GENERATION

Although climate models suggest a decline in upper catchment rainfall, it seems unlikely that there will be enough of a reduction of flow into Selingue reservoir to cause concern for economies and livelihoods dependent on the power. Currently the reservoir spills almost every year, and this means that it will almost always be full at the start of the dry season. A full reservoir allows for controlled releases along the Niger River as far downstream as Markala, and will not impact on hydropower generation at either Selingue or the smaller turn-of-the-river plant at Sotoma.

5.6 TRADITIONAL WATER CAPTURE OR STORAGE PRACTICES

In the areas outside the influence of the Niger and Senegal rivers the impact of climate change on traditional water sources will probably have a significant impact on their economies at community level. Communities generally have a combination of traditionally dug wells, tubewells for drinking water, and shallow ponds or ephemeral streams for livestock. Some communities have developed small-scale irrigation using groundwater or surface water. All these water sources are vulnerable to prolonged drought, either through falling water tables or desiccation of surface water resources.

During the 1980s millions of people moved from their communities because of the lack of water, failed crops, and increased destruction of natural forest habitats for grazing, firewood, and hunting. While some returned, the drought led to a net movement of people to areas benefiting from Niger River water.

Although the results of climate change modeling do not predict a prolonged drought of the same magnitude of 1980-1995, this does not mean it will not happen. Most communities, even with improved water sources for drinking, currently have no buffer against prolonged drought, and the level of irrigation is completely inadequate to compensate for loss of rain-fed crops.

5.7 HUMAN MOBILITY LINKED TO WATER

Climate change has already influenced major migrations in response to drought. The population of the areas irrigated by *Office du Niger*, which was able to continue irrigation despite lower discharges in the Niger, increased at least ten-fold during the Grande Secheresse between 1985 and 1992. Many migrants came from the inner delta area where the flooded area was only a quarter of its normal size, huge numbers of livestock perished due to lack of *bourgou*, fish catches were small, and floating rice production was extremely low.

But migrants have also come from areas away from the Niger, attracted by the opportunities offered by the perennial waters of the Niger. All of the towns along the Niger, from Bamako to Gao, experienced in-migration and, as stated earlier, many remained rather than returning to their villages once the drought came to an end. Some migrants even came from neighboring countries due to civil unrest as well as drought.

5.8 WATER-LINKED CONFLICT

Published information on water linked conflict is primarily related to major developments along the Niger River and downstream of Manantali Dam on the Senegal River. However most of the problems along the Senegal River have occurred in Senegal and Mauritania and are not addressed here. The nub of the conflict is the development of irrigation below Markala Dam that diverts water away from the inner delta of the Niger to irrigable lands to the western fringes of the delta.

Until the construction of Selingue Dam in 1982 and the parallel rehabilitation and revitalization of the *Office du Niger*, the flooding of the inner Niger followed natural events: wet season flooding for *bourgou*, fisheries and floating rice, followed by dry season transhumance into the fringes of the delta and lands to the south of Mopti. Before 1982, there was a steady but low-level conflict between pastoralists and sedentary farmers, particularly in dry years when livestock entered into cultivated areas before harvest. Traditional methods for dispute resolution developed over several hundred years to help manage these conflicts. Goulden and Few (2011) present a review of climate change, water, and conflict in the Niger basin. Because of the long distances covered by migrant pastoralists, water- and grazing- induced conflicts spread throughout wide areas away from the major rivers.

Following the construction of Selingue reservoir, however, much more water is now used for irrigation. The impacts of these changes are far more important than probable changes in discharge due to natural processes associated with climate change, and are addressed in the next section.

5.9 CONTRIBUTION OF EXACERBATING FACTORS

It is unfortunate for the inhabitants of the inner delta that the great drought came shortly after the completion of Selingue dam in 1982. The dam reduced peak flows, thereby restricting the flooded area and exacerbating the effect of the drought, and established priorities for irrigation diversions at the expense of traditional water users in the delta and below. At the national level, Mali benefited from increased rice production, which helped mitigate the effects of the drought and helped provide food for the growing urban population.

One consequence of prioritizing use of water for irrigation was the establishment of minimum flows along the Niger River below Markala to provide at least some water for domestic and irrigation uses down to Gao and into Niger. These minimum discharges form part of the agreements within the framework of the Niger Basin Authority.

The decision to dramatically increase irrigation using water from Markala Dam for major expansions in investments in new lands, funded in part by Libyan, Chinese, American and South African programs, has led to a major outcry from environmental and ecological NGOs and lobbyists. Wetlands International has been one of the main opponents of increased water extractions in the Niger River, and the debate will no doubt continue. These lobbyists have strongly opposed the development of the new irrigated areas, and have received support from many hydrologists who believe that these new lands cannot be properly irrigated in dry periods because the beneficial effects of Selingue Dam on dry season discharges have already been maximized.

If the proposed dam at Fomi is actually constructed, the impacts on the hydrology of the Niger will be far greater than changes in hydrology resulting from climate change. If Fomi is operated to generate hydropower and smooth out some of the flood peak of the Niger River and augment dry season discharges to support the new irrigation lands in fringes of the inner delta, then the annual flooding of the Niger delta will be dramatically reduced.

Lessons from the operation of Manantali Reservoir support these concerns: providing a more stable hydrologic regime also results in river bank erosion, loss of recession agriculture, spread of water-borne diseases, and soil degradation in agricultural lands.

Away from the Niger River, climate change will likely exacerbate the typical nexus of population growth, poverty, and land degradation if rainfall levels are lower than at present, but there is more optimism if rainfall levels actually increase. The uncertainty of the climate models to date leaves it unclear as to which scenario will prevail.

Technological developments that foster increased pumping of groundwater have the potential to improve livelihoods in these vulnerable areas, but again if rainfall levels decline leading to a consequent decline in groundwater levels, then the benefits of irrigation may be relatively short-lived.

6.0 ADAPTIVE CAPACITY

At the international level, Mali participates in both *Organization pour la Mise en Valeur du Fleuve Senegal* (OMVS) and Niger Basin Authority (NBA). The adaptive capacity of these organizations has been discussed elsewhere (El Vilaly, 2013) and is not repeated here.

6.1 EXISTING STRUCTURES

Section 2.2 lists the main organizations involved in different aspects of water management at the national, regional, commune, and community level. For the most part, decision-making with regard to both investment and sector level water resource allocations remains at national level. MEE, and particularly DNH, retains almost complete authority in matters regarding water. Most of the decentralization that has occurred within MEE, EDM, and DNH, has been for operational purposes rather than for strategic purposes.

In Mali all ministries and their various agencies and departments must fit into the National Plan. The Plan determines development targets and estimated budgets, and all new programs have to be seen to be consistent with the National Plan. This reflects the strong central control that still characterizes decision-making. There is relatively little opportunity for new initiatives to work their way up through the system.

Traditional weaknesses in the management of water resources have included inadequate and poorly maintained databases of hydrologic information (river gauging on the Niger is probably the best data set), weak monitoring and feedback systems to allow managers to assess impacts of their decisions, limited interaction between different ministries and agencies except through the establishment of large and rather unwieldy consultative bodies that have very limited implementation powers, and the natural tendency of individual ministries to keep control over their influence and their budgets. This has been the primary focus of efforts of the German government to improve water oriented databases and their management.

These comments are not intended as criticism. Indeed, the notes above reflect the natural evolution of government systems that were established and developed when central control and infrastructure development was required with commensurately less concern for making efficient use of existing resources, and limited financial and manpower resources were positioned away from the capital city.

6.2 ADAPTATION OF WATER AUTHORITIES TO MAINSTREAM IMPACTS OF CLIMATIC CHANGE

To date, it appears that water agencies have accepted that climate change will likely impact upon the availability and utilization of water resources in the future. There has been no shortage of involvement of government and civil authorities in discussions on the possible impacts of climate change on water resources, agriculture, and the environment. Many of the donor agencies and programs supporting the work of MEE and DNH are predicated on addressing the issues of climate change, and ensuring that Mali is better equipped to address such issues in the future.

The transition towards mainstreaming these concerns into new management systems is still ongoing. Over the past decade or so, positive steps to improve management capacity within DNH have included the establishment of a national action plan for water management (PAGIRA), support for upgrading the essential SIGMA2 database into something that can support both DNH and other agencies, and the establishment of SIGIRA as an integrated management system that links national and regional offices more effectively. The German government and the African Development Bank have been strong supporters of these efforts to improve the managerial capacity of MEE and DNH.

However, these steps are still largely in their infancy and it remains to be seen whether the new technology and information base will result in greater mainstreaming of climate change concerns into management plans. Many other well intentioned projects and programs have been adopted and implemented by Malian agencies but when project funding finishes there is inevitably a tendency for agency staff to return to "business as usual" until the next tranche of external funding is made available.

Another major factor in limiting the degree of mainstreaming of impacts of climate change within the water sector lies in the prioritization of two major pillars of the National Plan: food self-sufficiency and meeting MDG goals for sanitation and health.

The drive for food self-sufficiency was galvanized by the 1980-1995 drought, when Mali relied heavily on external food aid to survive. The concept of letting the majority of the waters of the Niger River go unused was anathema to almost everyone, and it led to high prioritization of major expansion of the irrigated lands served by Markala Dam. These investments, which included rehabilitation of the irrigation infrastructure of the Office de Niger and planning of major expansions with Chinese, South African, Libyan, and American assistance, were so important to meeting the goals of self-sufficiency that they easily overcame any opposition. Expansion of irrigation in the delta area dominates strategy within the Malian water sector even though there may be problems with insufficient water in the not too distant future. The strategy has been largely successful in terms of rice production, but has had negative environmental and social impacts that are still increasing.

Meeting MDG goals for potable water and sanitation has also pre-occupied the water sector in Mali. With donors and private NGOs willing to pour in large resources for drinking water and sanitation in rural areas, almost all new initiatives in these areas have been single purpose: wells, wells, and more wells. Although MDG goals will not be met, the increase in access to potable water is highly commendable.

An additional important topic, though one which is not commonly raised, is the sustainability of the large number of newly installed wells. While almost all water supply programs include the stipulation that community members must pay for water to defray operation and maintenance costs, actual rates of payment are low. They may help pay for minor repairs, but they do not cover replacement costs of the entire well and pump system. All mechanical systems have finite lifetimes, but there is no program in existence to replace wells and pumps that wear out. There is a substantial risk that if and when MDG goals are met, donor funding will dry up and there will be no funds for the required long-term replacement program.

What is lacking in these water-stressed rural areas is the implementation of a major program in IWRM at the community level. Installation of wells for drinking water took all of the resources of DNH staff in target areas and while the new water sources clearly have significant benefits to communities, these programs offer little towards food self-sufficiency at community level. Mainstreaming of IWRM, which includes not only water supply but also small-scale irrigation, livestock needs for water and pasture, water harvesting, forest protection and recovery programs in watershed areas has not occurred. Even the initial steps towards IWRM have been tentative.

IWRM in rural areas remains extremely weak. Much of the responsibility for water management at district and community level has been devolved to agencies or institutions that have little capacity to adapt to changing needs. Such devolution works well when resources are known and objectives fixed, but is poorly suited to more flexibility decision-making and alternative resource allocation patterns. One hallmark of Winrock's MUS approach is to involve the relevant decision-makers at the commune level as well as working directly with the communities and individual farmers in target areas. MUS was never implemented on a wide scale in Mali, but scaling up has worked successfully elsewhere (see http://www.musgroup.net for a range of examples). MUSgroup.net defines MUS as follows:

> "Rural and peri-urban people need water for drinking, cooking, washing, sanitation, watering animals, growing food and generating income. Multiple-use water services (MUS) take people's water needs as the starting point. By looking at all water needs and available water resources holistically, it is possible to make more cost-effective and sustainable investments that generate a broader range of health and livelihood benefits than is possible with single-use systems.
>
> Multiple-use water services meet people's domestic and productive needs while making the most efficient use of water resources—taking into account different water sources and their quality, quantity, reliability and distance from point of use. A MUS approach can be used to plan a new water service or to upgrade existing domestic or irrigation services."

But for the approach to be effective, it needs to be linked to support services, particularly for water resources development, agricultural production, and protection of forest and grazing resources. This responsibility in Mali lies at Commune level, and assistance also needs to be provided to Commune-level technicians on how to assist villages development NRM plans, provide the appropriate services that meet the identified needs of villages, and channel resources towards those communities that have agreed upon clear plans of action.

6.3 STRENGTHS AND WEAKNESS OF CURRENT ADAPTIVE CAPACITY

From the perspective of adaptive capacity in Mali, it is clear that there are both strengths and weaknesses that affect the capacity of agencies to respond effectively to the impacts of climate change. Official documents from government agencies have clearly internalized the concerns of climate change impacts on water and agriculture (e.g., MEE, 2006; MET, 2007). Indications of these strengths are seen in the following:

- high level of awareness of the possible impacts of climate change on water resources;
- willingness to participate in donor programs to help address these issues;
- willingness to accept long-term support from committed donors for capacity building and training, especially the Germans and Dutch;
- willingness to include institutional and governance elements as part of the overall program rather than restrict support only to technical issues;
- active participation in regional bodies including OMVS and NBA;
- willingness to establish participatory bodies involving both government and civil society to discuss options for different approaches to management of water and other resources; and
- clear mandate for DNH to oversee all aspects of development of the water sector.

Despite these strengths, there remain a series of weaknesses that have diluted the potential impact of different development and assistance programs. One widely reported weakness is that although planning and policy directives include understanding of impacts of climate change, the actual implementation of projects on the ground does not reflect these goals. The effectiveness of several projects fails to meet higher-level objectives (see, for example, AfDB, 2011 concerning agricultural water management projects, and the *Facilite Africaine de l'Eau* for the implementation of PAGIRE). While capacity may be sufficient at the national level, much of the implementation is carried out at regional or district level where there has been much less exposure to the interactions between project design and the complexities of impact of climate change at community level. These weaknesses include:

- low levels of non-project funding for mainstreaming activities, so that when project funding ceases there are limited resources to follow on the good work already accomplished;
- national priorities for food self-sufficiency through large-scale irrigation development in ON and meeting MDG goals for water supply and sanitation overshadow moves towards IWRM at district and community level, leaving rain-fed areas more exposed to impacts of climate change;
- piecemeal development of local level water resources, particularly for single purpose water projects (i.e., drinking water, livestock watering holes) without looking at overall opportunities and requirements for IWRM;
- dependency on donor funds and projects that have their own goals and objectives, but which do not readily mainstream into regular tasks of water sector agencies and personnel;
- stove-piping of government agencies with consultation between Ministries and Agencies at high levels but less collaboration in program design and implementation at lower levels;
- limited research capacity and mandates, and little funding available;
- despite good access at national level, there is limited access to and use of international resources and datasets at regional and district level (e.g., products of FEWSNET, CGIAR research);
- limited change in terms of governance with weak levels of accountability for management actions, and little scope for autonomous change; and
- poor understanding of the value of feedback systems that incorporate effective monitoring and evaluation, target setting, review of progress made towards multiple goals, and adjustment of plans and programs to respond to actual experiences.

7.0 CONCLUSIONS

7.1 OVERALL IMPACT OF CLIMATE CHANGE IN MALI

Mali is in the forefront of exposure to climate change. Although there is no clear agreement on rainfall trends, the consensus appears to support a reduction in rainfall in southern areas and a slight increase in central areas. There is also consensus that temperatures will continue to rise throughout the 21st century. These changes will not only affect programs for food self-sufficiency that are based on continued exploitation of the Niger River, but also food security in rural areas relying primarily on rainfall for staple crop production.

The overall impact of climate change in Mali is mitigated by the transfer of water from upper catchments into the drier zones of the country by the Niger River. The benefits of mass water transfers are substantial in both economic and strategic terms, and have been a major focus of investment in Mali over the past 20 years. These water transfers are still subject to the impact of declining rainfall resulting in lower than anticipated discharges in the dry season, but for the most part provide much more stability to Mali than was the case during *La Grande Secheresse.*

However, the benefits of these water transfers are not felt in much of the country. Away from the main rivers, farmers are still highly dependent on rain-fed agriculture, and are very exposed to short and long term deviations from normal rainfall and temperature regimes. Water supply programs have substantially benefited rain-fed areas, but the impacts of climate change on agriculture have not been mitigated to any great extent. These areas that are not served by the main rivers remain very vulnerable to both rainfall and temperature changes.

7.2 GEOGRAPHIC AND THEMATIC AREAS OF HIGHEST VULNERABILITY

The areas of greatest vulnerability in Mali are the rain-fed agricultural lands throughout the middle part of the country, and the inner Niger delta.

Rain-fed areas rely on shallow groundwater or ephemeral water sources during the dry season: in the event of a failure of monsoon rains and a protracted dry season, these water sources are inadequate to meet even basin requirements. While steps have been taken to provide a more robust agricultural base, and to increase access to drinking water, this has not been matched by parallel development of water resources to supplement rainfall. Irrigation in rain-fed areas remains at low levels, even where there is potential (i.e., *bas-fonds*), making very limited progress towards food security.

The inner delta issues are well understood but the primary features are those of prioritization of water allocation. The *Office du Niger* (ON) lands provide a large measure of food security from the national perspective, and the economic benefits appear to outweigh the production losses of the inner delta resulting from fisheries, livestock and uncontrolled rice irrigation. However, the social and environmental impacts of prioritization of ON lands have not been fully included in major water allocation decisions.

7.3 CURRENT ADAPTATION STRATEGIES

The primary adaptive strategy at national level has been to focus on investments in large-scale irrigation systems downstream of Markala Dam to meet national food needs. Investments since 1982 in both infrastructure and agricultural programs in the *Office du Niger* have greatly increased rice production so that Mali is now approaching rice self-sufficiency. Management strategies for the waters of the Niger have been adopted with the establishment of national bodies such as the *Commission Gestion des Eaux* CGE that coordinates the operation of Selingue and Markala Dams, but it is more of a reactive strategy than a long term plan for mitigation of the impacts of climate change. ON focuses on maximizing both the area and production of rice, sugar and others crops in the land served by Markala Dam, but it is unclear what their strategy would be if water at Markala was insufficient to meet their targets.

While this situation benefits urban dwellers and those able to afford food in periods of shortage, it does not provide much direct benefit to predominantly rain-fed farmers growing sorghum, millet, and maize.

7.4 ADAPTIVE CAPACITY OF WATER AUTHORITIES

The adaptive capacity of water authorities remains weak. Both DNH and ON are subject to normal political pressures and influences, their funding and leadership have not increased very much, and their ability to respond to feedback is limited by weak monitoring programs and inadequate databases. While some progress has been made in providing technical upgrades to these supporting systems, use of that information for developing more resilient water management programs is still not optimal.

With a predominantly technocratic set-up and mandate, the institutions are good at designing and constructing new water management infrastructure, but are less well equipped to cope with the complexities of management once demand begins to approximate supply. Further, as new political objectives become important, such as equity of access to resources, environmental protection, and food security, it is easier to create new institutions rather than change the behavior of existing organizations because existing institutions are reluctant to cede any of their existing power to other bodies.

7.5 GENERAL GAPS IN KNOWLEDGE THAT ARE PRIORITY AREAS FOR RESEARCH

Important gaps in knowledge that merit attention include the potential and limitations of IWRM at community level. Water developments in communities cannot focus on single uses such as drinking water or livestock because water sources are interdependent. Developing better methods for community level IWRM include agriculture, livestock, drinking water, and natural resource protection remains the single largest priority for water resources management in areas of rain-fed agriculture.

The limits to growth using combinations of surface and groundwater resources are also not well understood and merit more extensive investigation. Potential for systematic development of water for small-scale irrigation is poorly understood, and needs to move beyond the current ad-hoc approach to IWRM development.

Conspicuously absent from almost all of the literature and reports is a useful discussion of water productivity. Evaluations are still made almost exclusively on areas cultivated and yields per hectare. Yet water, not land is the in this part of the world. Measures of water productivity (kg/m^3 or value/m^3) are much more meaningful in water deficit environments such as Mali.

7.6 OPPORTUNITIES FOR INVESTMENT AND THE COMPARATIVE ADVANTAGE FOR USAID

There seem to be four areas where USAID can continue to provide effective support for water resources management with particular focus on improving capacity to respond to impacts of climate change. These activities lend themselves both to bilateral programs as well as PPP programs involving private sector entities. None of these areas involve major capital expenditures such as those provided by MCC, but focus more on capacity building, improved governance, and greater involvement of community groups in planning for the future. Indicative research questions for each of these four areas are presented in Annex B.

1. Integrated groundwater and surface water availability and resiliency: USAID has, through the Rural Water Supply Project and the West Africa Water Initiative (WAWI), supported research into groundwater conditions at the district level with DRI taking the lead. Such activities merit expansion into other areas, together with close cooperation with existing donor programs (primarily German technical support with German and AfDB financing) to help upgrade the data collection, monitoring and evaluation programs of DNH. Given the strong support other donors provide at the national level (DNH, *Ministere de l'Agriculture*, *Direction Nationale de la Meteorologie*, etc.), USAID should focus on regional and district level investigations, the establishment of water management planning at those levels, and scaling down from national to local levels.

2. Development of IWRM action plans at district and community level. Parallel to improved hydrogeological information is the opportunity to support Malian authorities at regional and district level to develop long-term IWRM. This requires evaluation of the informational needs of staff to develop plans, and mechanisms for improving the participation of community members in formulating alternative options. These actions will require careful coordination with other donor programs, with the aim at developing feedback systems than allow IWRM plans to be flexible enough to respond to observed field level conditions.

3. Field Implementation of IWRM at community level. Through prior experiences in several programs, USAID can continue to support districts and communities in development and implementation of IWRM programs. MUS is an excellent entry point, and Winrock's experience will prove invaluable. MUS, when linked with small-scale irrigation developments based either on groundwater or surface water resources in *bas-fonds*, can improve economic and food security at community level, allow greater involvement of women through group activities, and complement improvements in water supply and sanitation of other intervention programs. Ideally, IWRM should involve a cluster of villages so that common resources such as surface and groundwater sources, forests, grazing lands, and agricultural lands are not artificially segmented; and it should allow commune level officers from different ministries and departments to become engaged in the planning and implementation of the program.

4. Governance in the water sector. USAID has an opportunity to continue support for improved governance programs in the water sector. Building Partnerships for Development (BPD) undertook training programs in Mali and other countries in the region to develop more responsive management systems, with a focus on regional and district level issues. There is great potential for expanding this type of capacity building in the area of governance, and for ensuring that national level personnel are integrated into the programs.

8.0 SOURCES

Abrate, T, Hubert, P., & Sighomnou, D. (2010). A Study on the Hydrological Series of the Niger River at Koulikoro, Naimey and Lokoja Stations. Paper presented to International Workshop on Advances in Statistical Hydrology, May 23-25, 2001. Taormina, Italy.

Adepetu, A.A., and Berthe, A. (2007). Vulnerability of Rural Sahelian Households to Drought: Options for Adaptation. International START Secretariat, Washington DC, USA.

African Development Bank (2011). Agricultural Water Management Evaluation of the African Development Bank's Assistance in Ghana and Mali, 1990-2010. Tunis, Tunisia. 2010. 48 pp.

Aquastat (2013). Mali. FAO Information System for Water and Agriculture.

Baker, C. (2009). Vulnerability in wetland communities and the response of water management: case study of the inner Niger Delta. Stockholm Water Week 2009.

Bokar, H., Mariko, A., Bamba, F., Diallo, D., Kamagaté, B., Dao, A., Soumare, O., & Kassogue, P. (2012). Impact of Climate Variability on Groundwater Resources in Kolondieba Catchment Basin, Sudanese Climate Zone in Mali. *International Journal of Engineering Research and Applications, 2*(5), 1201-1210.

Coulibaly, D. (2011). Plan D'Action National de Gestion intrgee des Ressources en Eau (PAGIRE) du Mali et Etat de sa Mise en Oeuvre. Presentation to Partners for Water Meeting, Wageningen, the Netherlands, 3 Nov 2011.

Djoudi, H., Brockhaus, M., and Locatelli, B. (2013). Once there was a lake: vulnerability to environmental changes in northern Mali. *Regional Environmental Change 13*(3) 493-508.

EIB, 2009. La Barrage de Manantali: Evaluation ex poste, Rapport d Synthese. Jointly prepared by EIB, KfW and ADF in collaboration with OMVS. 69 pp.

Facilite Africaine de l'Eau. (2009) Appui la FAE a la Mise en Oeuvre de Plan d'Action de Gestion Integree des Ressources en Eau (PAGIRE) du Mali: Rapport d'Evaluation.

Frappart, F., Hiernaux, P., Guichard, F., Mougin, E., Kergoat, L., Arjounin, M. ... Lebel, T. (2009).Rainfall regime over the Sahelian climate gradient in the Gourma region, Mali. *Journal of Hydrology 375*, 1-26.

Funk, C., Rowland, J., Adoum, A., Eilerts, G., & White, L. (2012). A climate trend analysis of Mali: U.S. Geological Survey Fact Sheet 2012-3105. 4 p.

Goulden, M and Few, R. (2011). Climate Change, Water and conflict in the Niger River Basin. USAID/Washington DC. 70 pp.

Henry, C. M., Demon, H., Allen, D. M., & Kirste, D. (2011). Groundwater recharge and storage variability in southern Mali. Chapter 3 in Gurdak, J.J. (Ed.). Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations. London, UK: CRC Press.

Jacks, G. & Traoré, M. (2013).Mechanisms and Rates of Groundwater Recharge at Timbuktu. *Republic of Mali. Journal of Hydrologic Engineering,* 10.1061.

Jenkins, G., Gaye, A., Kamga, A., Adedoyin, A., Garba, A., & Sarr, A. (2004). GCM simulations for West Africa: Validation against observations and projections for future change. Presentation to the 2nd AIACC Regional Workshop for Africa & Indian Ocean Islands, March 24-27, 2004, Dakar, Senegal.

Kuper, M., Mullon, C., Poncet, Y., & Benga, E. (2003). Integrated modelling of the ecosystem of the Niger river inland delta in Mali. *Ecological modeling, 164* (2003) 83-102.

Lapworth, D. J., MacDonald, A. M., Bonsor, H., Tijani, M. N., & Calow, R.C. (2011). Preliminary results from a Water Economy and Livelihoods Survey (WELS) in Nigeria and Mali, sub-Saharan Africa: Investigating water security across a rainfall transect. British Geological Survey Open Report, OR/11/018. 74pp.

Lae, R., Williams, S., MalamMassou, A., Morand, P., & Mikolasek, O. (2004). Review of the present state of the environment, fish stocks and fisheries of the River Niger (West Africa) In: Proceedings of the Second International Symposium on the Management of Large Rivers for Fisheries. Vol. I; Sustaining livelihoods and biodiversity in the new millennium ; RAP Publication (FAO) , no. 2004/16; International Symposium on the Management of Large Rivers for Fisheries, 2, Phnom Penh (Cambodia), 11-14 Feb 2003 Welcomme, R.L. (ed.) Petr, T. (ed.) / FAO, Bangkok (Thailand). Regional Office for Asia and the Pacific; Mekong River Commission, Phnom Penh (Cambodia), 2004.

Lutz, A., Thomas, J. M., & Keita, M. (2011). Effects of Population Growth and Climate Variability on Sustainable Groundwater in Mali, West Africa. *Sustainability, 3*(1), 21-34.

MEE/DNH. (2006). Report National sur la Mise en Valuer des Ressources en Eau. Prepared for UN World Water Assessment Program. MEE/DNH, Bamako, Mali. 212 pp.

MET. (2007). Programme d'Action National d'Adaptation aux Changements Climatiques Ministere de l'Equipment et des Transports, Directionale Nationale de la Meterologie. 100 pp.

Ministere de l'Agriculture. (2009). Bilan de l'Initiative Riz de la Campagne Agricole 2008-2009. Bamako, Mali.

Ministere de l'Agriculture. (2010). Programme National de l'Irrigation de Proximite. Bamako, Mali.

MLPPI. (2013). Mali Livestock, Pastoralist, and Poultry Initiative - Phase 2. FY 2012 Annual Report. USAID Mali.

Mougin, E., Hiernaux, P., Kergoat, L., Grippa, M., de Rosnay, P., Timouk, F. ... Mazzega, P. (2009) The AMMA-CATCH Gourma observatory site in Mali: Relating climatic variations to changes in vegetation, surface hydrology, fluxes and natural resources. *Journal of Hydrology, 375*, 14-33.

Mulligan, M. (2012).Hydro-Literacy of Environmental Risks and pportunities for Foreign Direct Investment in Africa. Paper presented to the International conference on Food Security in Dry Lands, Doha, Qatar, Nov. 14-15, 2012.

Ng'ang'a, S. K., Diarra, L. Notenbaert, A. & Herrero, M. (2013).Coping strategies and vulnerability to climate change of households in Mali. CCAFS Working Paper no. 35. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Copenhagen, Denmark.

Pedercini, M., Kanamaru, H., & Derwisch, S. (2012). Potential impacts of climate change on food security in Mali. Natural Resources Management and Environment Department, FAO, Rome. 49 pp.

Ramirez-Villegas, J., Challinor, A. J., Thornton, P. K., & Jarvis, A. (2013). Implications of regional improvement in global climate models for agricultural impact research. *Environmental Research Letters, 8*(2) 024018.

Shonsey, C. W. (2009). Quantifying Available Water at the Village Level: A Case Study Horongo, Mali, West Africa. M.Sc. Thesis, Michigan Technical University. 70 pp.

Simonsson, L. (2005) Vulnerability Profile of Mali. Stockholm Environmental Institute. 37 pp.

Traore, S. B. (2011) Crop and Rangeland Monitoring in West Africa, the AGRHYMET experience. Presentation to 3rd. CRAM Workshop, Nairobi, Kenya, 26-30 September 2011.

UNEP. (2012). Sahel Atlas of Changing Landscapes: Tracing trends and variations in vegetation cover and soil condition. United Nations Environment Programme, Nairobi.

U.S. Embassy Mali. (2010). MCC Alatona Irrigation Project celebrates the first flow of water to the perimeter. Embassy of the United States, Bamako, Mali. Retrieved from http://mali.usembassy.gov/mcc_alatona.html.

USAID. (2009). Map of Livelihoods Zones: Mali. FEWSnet/USAID. Washington, D.C.

USAID. (2012a). Food Security Infographic as of July 1, 2012. USAID/Mali.

USAID. (2012b). Water and Sanitation Profile, Mali. USAID/Bamako, March 2010.

USAID. (2013). Water and Development Strategy 2013-2018. USAID, Washington D.C. 28pp.

World Bank. (2013). World Bank Data Bank. Retrieved from http://data.worldbank.org.

WRI. (2012). Annual Renewable Water Supply per person by River Basin. World Resources Institute, Washington, D.C.

Zwarts, L., van Beukering,P., Kone, B., & Wymenga, E. (Eds.) (2005). The Niger, a lifeline.Effective water management in the Upper Niger Basin. RIZA, Lelystad / Wetlands International, Sévaré / Institute for Environmental studies (IVM), Amsterdam / A&W ecological consultants, Veenwouden. Mali / the Netherlands.

Zwarts, L., van Beukering, P., Kone B., Wymenga, E., & Taylor, D. (2006).The Economic and Ecological Effects of Water Management Choices in the Upper Niger River: Development of Decision Support Methods. *Water Resources Development, 22*(1), 135–156.

ANNEX A. MAPPING OPPORTUNITIES

The following table gives an indicative list of mapping opportunities that will be of value to ARCC activities. It is not intended to be exhaustive, and will require integration with other elements of the ARCC program. However, much of the mapping contained in other studies are at fairly small scales and do not provide sufficient detailed information for on the ground management support.

TABLE A1. MAPPING OPPORTUNITIES

Mapping Opportunities	Possible partners
Develop integrated maps showing groundwater availability and surface water resources at district and community levels as a basic resource for IWRM planning and implementation	DNH, SIGIRE, GIZ, DRI District officials
Develop methodology for satellite-based maps of target communities wishing to implement IWRM	DNH, SIGIRE

ANNEX B. INDICATIVE RESEARCH PLAN

The proposed research activities listed below more or less follow the four areas identified as being priorities for possible future USAID investments within Mali in relation to support for water resource studies and programs aimed at mitigating impacts of climate change.

These activities are not intended to duplicate activities included in other programs, either of USAID or others, but to focus specifically on the issue of the impact of climate change on water resources as well as the ecological, socioeconomic, and other considerations of climate change.

The research questions are formulated to help answer three separate issues:

1. What types of information are required to develop a program of integrated water resources management (IWRM) at community level that can attenuate the impacts of climate change in terms of rainfall and temperature variations?
2. Who currently has such information, how do they access it, and what key pieces of information are currently not available to decision-makers and planners at different levels?
3. What administrative and other support services are required so that programs for IWRM can be effectively implemented by different line agencies, NGOs and the private sector within the context of devolved responsibilities for water management at lower levels?

Although the research questions are divided into four thematic groups, the intention is that these four thematic areas all contribute to the development of effective IWRM. By its very nature, IWRM is a multi-disciplinary approach which operates at three levels:

1. **household level**, where individuals or families changes to agricultural practices, hygiene and other behaviors that improve their overall income, health and capacity to cope with climate change;
2. **village or community level**, where members work together for joint management of their natural resources (drinking water, agricultural water, livestock water, forests, grazing lands, etc) that impact on all members of the community;
3. **commune level**, the lowest level of government support services, where clusters of villages can be brought together to enable them to receive the best possible level of external support.

Within each of the four thematic areas, research questions in bold represent those that merit priority as the basis for an IWRM focused program. Based on the answers to those questions, it should be possible to develop a program in target areas that will lead to more effective IWRM that has an in-built capacity to provide as much resiliency as possible under the scenarios of climate change that have been identified for Mali.

TABLE B1. GROUNDWATER AND SURFACE WATER

Research questions that merit further exploration	Options and methods to find answers
Are there detailed hydrogeological maps at national, regional and district level available for planning groundwater exploitation? **Are there existing studies of changes in groundwater levels in different hydrogeological zones?** **What are estimated safe yields in the different zones that could be used as a basis for expansion of small-scale irrigation in areas away from Niger and Senegal rivers??** Is there evidence of groundwater depletion in different parts of Mali? Does the existing SIGMA2 database permit replication of the detailed DRI study in the Bami subcatchment? What data are available on surface and groundwater interconnectivity? Are there detailed hydrologic studies of *bas*-fonds that examine how both surface and groundwater resources can be better managed? Are there evaluations available of the impacts of bas-fond development programs? Is there any evidence of the sustainability of wells and pumps in recent groundwater development programs aimed at meeting MDG goals for water supply and sanitation? Is there a long-term program for replacement of small-scale infrastructure to cope with normal wear and tear of mechanical parts, and normal well rehabilitation? Is there potential for small dam programs similar to those in Burkina Faso?	Meet DNH and SIGIRE program to look currently available data, including the two pilot programs in Timbuktu and Kayes Work with DRI to explore new research needs and opportunities Consult with Ministry of Agriculture and PNPBBF (*bas-fonds*) to review experiences of *bas-fonds* programs and their contribution to food security in areas away from Niger and Senegal rivers Develop proposed action plan for small-scale irrigation based on shallow groundwater and *bas-fonds*management Review with IWMI their experiences with benefits of small dam programs

TABLE B2. INFORMATION AND DATA MANAGEMENT

Research questions that merit further exploration	Options and methods to find answers
What information is required at national, regional and district levels to develop a sustainable surface and groundwater management plan? Does the SIGIRE program collect all of the information required for development of such a plan? If not, what additional data might be required? What are appropriate protocols for transfer of data with DNH and between different Ministries and agencies for the establishment of IWRM plans at commune and village cluster level? To what extent do current monitoring programs of water resources provide information that can be used to adjust management strategies in both short-term and long-term programs? Have data collection and monitoring programs been modified in respond to possible impacts of climate change? Are there any periodic reports of water resources conditions for either surface or groundwater conditions that can be used to help make adjustments to management of those resources?	Work with DNH at national, regional and district offices Review impact of SIGIRE project in pilot regions of Kayes and Timbuktu Propose pilot activities for development of detailed surface and groundwater management programs adapted to meet hydrogeological and agricultural conditions

TABLE B3. IWRM AND MUS (MULTIPLE USE SYSTEMS)

Research questions that merit further exploration	Options and methods to find answers
What have been recent experiences in MUS pilot programs in Mali (and elsewhere) that provide practical examples for program implementation **Have MUS activities and benefits lasted beyond project life length, and mainstreamed into current management plans?** **Is there evidence that existing small-scale irrigation programs have had impacts on food security at community level, or increased incomes to provide greater resilience in times of shortage?** Are there examples of effective IWRM plans (MUS or other) in Mali at regional, district or community level that merit replication? Do existing IWRM plans effectively involve all water uses, including drinking water, livestock, irrigation, water harvesting and natural resource protection? Are communities able to effectively participate and implement IWRM programs, and what are their limitations? Are there additional detailed studies on the distribution, hydrologic yield and sustainability of different water sources, both geographically and over multiple seasons What are experiences with different types of small-scale irrigation at community level, including information of type of water source and water lifting/pumping technologies (manual, motor pump, solar)? Have they had groundwater depletion issues? What have been the operation and maintenance experiences? Do community members, either individually or as part of women's groups, perceive economic and food security benefits from irrigation, and is there enthusiasm for expanding those programs?	Review experiences in field sites and with Winrock Intl. and MUS Group Discuss with agency and NGO staff in various districts to obtain their experiences (Kickstart, Winrock, World vVsion, etc) Link with MLPPI study on livestock water sources Link with PNPBBF to determine experiences of improved rice irrigation in *bas-fonds*

TABLE B4. GOVERNANCE

Research questions that merit further exploration	Options and methods to find answers
How effective is communication between different ministries and agencies involved in seeking sustainable use of water resources at commune level? What types of training and resource materials are required at commune level to enable development of effective IWRM plans? Have previous efforts of improved governance through training and in program implementation in the water sector (e.g., through WAWI and WA-WASH) been mainstreamed, or did progress fade away after the project ended? What steps need to be taken to develop internally sustainable planning and support service capacity? What are current strengths and weaknesses of governance systems in place at national, regional and district level? How effective is the consultative process in allowing community members to make substantive contributions to plans for increased use of their water resources? Are structures at community level for management of water supply programs suitable models for wider community IWRM activities?	Review experience with other donors involved in addressing governance issues (German, Dutch, etc.) Review experience with BPD and other partners in WAWI and WA-WASH Discuss progress of improved governance with MEE, DNH and other Ministries and agencies at national, regional, and district levels Propose additional governance training programs that will aim at improved mainstreaming of climate change Develop rapid appraisal techniques for community and district level IWRM planning

U.S. Agency for International Development
1300 Pennsylvania Avenue, NW
Washington, DC 20523
Tel: (202) 712-0000
Fax: (202) 216-3524
www.usaid.gov