Addressing Climate Vulnerability of Africa's Infrastructure

Stock-Taking Exercise: Overview of Existing Analytical Work

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Executive Summary

Africa's economic growth requires a rapid upgrading of the region's infrastructures, which are at present inadequate, both in terms of physical stock and quality of service. Much of this investment will support the construction of long-lived infrastructure (e.g. dams, roads, power stations, etc.), which will thus need to be capable of delivering services both under current and future climate. There is ample literature focusing on infrastructure development in Africa, both at its current level and future needs, with the Africa Infrastructure Country Diagnostic (AICD) as one of the most recent efforts of delivery a repository of analysis and knowledge on Africa's infrastructure.

Nonetheless, relatively little is known on how climate change may affect the desirable design, location, timing, and composition of the stock of infrastructure that will need to be built in the short to medium term. Although various studies looked at the implications of climate change for infrastructure development, there are a number of serious shortcomings of earlier approaches, most notably consistency of methodologies making inter-comparison of results very difficult.

A rapid stock-taking exercise that maps out a first extent of existing work on infrastructure and climate change in Africa was carried out during Mar-Apr 2012. The exercise documents and summarizes on-going activities (investment plans, programmes, projects, mode etc.), relevant models and data-sets related to the energy, water and roads sectors. Seven major river basins were chosen as 'study areas' in order to get a general overview of Sub-Saharan Africa's varied climates, geography etc. They consist of Congo, Nile, Niger, Orange, Senegal, Volta, and Zambezi. As this was a rapid stock-taking exercise it is by no means exhaustive. Instead, it is intended to provide an understanding of the actors, on-going activities and available models and datasets upon which the new work will build and developing a conceptual framework for the subsequent analysis. The study results were presented in a report and a database.

The stock-taking exercise clearly revealed that there is a notable lack of climate change adaptation in Africa's infrastructure development plans. This lack of climate change adaptation can also be seen in Program for Infrastructure Development in Africa (PIDA) report. This is possibly due in part to the recommendations of the by organizations such as the African Development Fund (ADF) whose study on climate change adaptation costs found that "Africa's immediate adaptation priority is to improve its current adaptive capacity, much of which will be operationally indistinguishable from – and needs to be fully integrated with – traditional development activities".

The results of the stock-taking exercise for the five components included can be summarized as:

- **Relevant institutions**. A total of 62 institutions have been identified with an interest in infrastructure and climate change in Africa. In total 99 contacts working in these institutions has been identified and information from these sources was combined with internet information, literature and other knowledge available.
- **Existing analytical work**. Relevant reports, internet pages and literature that have been produced in the context of infrastructure and climate change were collected. It appeared that the amount of analytical work was quite substantial, although at a wide

range of level of detail. In general work varied from a more research oriented approach with limited or no stakeholders' involvement to large-scale studies involving stakeholders at all levels. In general focus has been on the latter. A wide range of analytical work of climate change and infrastructure has been found and can be more or less divided into: (i) global analysis, (ii) Africa wide reports, and (iii) regional/basin reports.

- **Relevant modeling tools**. The modeling tools have been divided into two sections: modeling systems (model frameworks that can be used to build an actual model for a certain region) and modeling implementations (actual models ready to be used). The modeling implementations have been grouped into the seven basins. Overall many modeling systems exist, but the number of modeling implementations varies substantially per basin (see basin summaries below).
- **Datasets**. In general sufficient global datasets are available to undertake further analysis. The advent of remote sensing and the internet have boosted the amount and detail of available data. A weak point remains flow data records and operational data on reservoir management. All other data, such as topography, climate, soils, and landuse are in general available at a reasonable level of detail for basin scale analysis.
- **Infrastructure investment plans.** A quite substantial and variety of relevant infrastructure investment projects that are planned for Africa were identified. A total of 300 investment projects related to hydro-power schemes, agriculture/irrigation, transport, overall water resources and water supply projects were identified. These projects were grouped by basin/country and as much as possible project status, budget and investor/donor were indicated. The Program for Infrastructure Development in Africa (PIDA) has flagged a subset of those: transport (24), energy (including pipelines and gridlines) (15), transboundary water resources (9), and ICT (3). Agriculture/ irrigation were not included and also climate change was not considered in the PIDA study.

Table. Investment plans per sector (details can be found in the database)

Sector	Count	US$ (billion)
Energy	28	12
Irrigation	19	2.1
Transport	163	14.5
Water	66	6.7
Water Supply	17	2.4
Miscellaneous	7	0.2
Total	***300***	***37.9***

The results of the stock-taking exercise can be summarized by basin as follows:

- **Congo**. For the Congo a total of 12 large investment plans were identified at a value of 2.1 billion US$. In terms of modeling limited existing approaches were found and also in terms of data limited information has been found.
- **Niger**. A total of 19 investment plans were found with a value of 3.5 billion US$. A basin-wide model is available based on the MIKE-BASIN modeling framework.
- **Nile**. The Nile basin has through its NBI very strong planning and evaluation capacity. A total of 192 investment plans were identified with a total value of over 16 billion US$. The Nile has an excellent modeling system available based on MIKE-BASIN. Also a good database is developed for the Nile.

- **Orange**. For the Orange basin a limited amount of investment plans were identified (4) with a value of 1.1 billion US$ in total. A modeling system is in place based on South-African WRSM2000 model which is used by the Orange River Basin Commission (ORASECOM).
- **Senegal**. 13 Investment plans with a total value of 2.4 billion US$ were found for the Senegal. Limited models have been identified for the Senegal and a up-to-date water resources planning model is most likely missing.
- **Volta**. Investment plans at a total value of 1.0 billion US$ were identified distributed over 12 projects. Many modeling efforts of the Volta have been undertaken and a MIKE-BASIN model is in place at the Volta River Basin Commission.
- **Zambezi**. A substantial amount of 47 investment plans with a total value of 11.1 billion US$ were found for the Zambezi. Various models are in place for the Zambezi and are ready to be used for impact assessment.

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1 Relevance

Africa is currently experiencing a decade of solid economic growth with an annual average of 5% from 2001 to 2005 accelerating to 6% for 2006 and 2008. Thanks to this growth, progress on the Millennium Development Goals (MGDs) has been sufficiently rapid that many countries are likely to reach most of the goals, if not by 2015 then soon thereafter. But the key ingredient required for Africa's attainment of its development aspiration is the rapid upgrading of the region's infrastructures, which are at present inadequate to support sustained growth in the years and decades to come.

The lack of infrastructure in Africa is widely recognized. The road access rate is only 34%, compared with 50% in other parts of the developing world, and transport costs are higher by up to 100%. Only 30% of the population has access to electricity, compared to 70–90% in other parts of the developing world. Water resources are underused. Current levels of water withdrawal are low, with only 3.8% of water resources developed for water supply, irrigation and hydropower use, and with only about 18% of the continent's irrigation potential being exploited (PIDA, 2011).

The World Bank estimates that $US 93 billion annually is needed to improve Africa's infrastructure; nearly half of it on power supply. The required investment will be much greater for new infrastructure that is (i) low carbon, (ii) climate proofed, and (iii) developmentally-sound and sustainable. Climate change is expected to affect the desirable design, location, timing and composition of the stock of infrastructure that will need to be built in the short to medium term:

- As extreme events become more frequent, the cost of meeting a given reliability standard can be expected to increase;
- Climate change could be expected to alter the optimal standard to which infrastructure should be built;
- Climate change can be expected to alter the pattern of demand for infrastructure;
- Climate change could be expected to affect the optimal choice of infrastructure technologies.

Since infrastructure basically increases the inter-connectedness of places, it provides a natural way of diversifying climate risk across countries and regions. Yet, because the future climate that will actually occur will remain largely uncertain in the foreseeable future, the challenge is to develop decision making frameworks capable of leading to investment decisions that are "desirable" under a wide range of possible climate outcomes.

This report provides part of the foundation for the development of these frameworks. It is the result of a rapid stock-taking exercise that maps out the full extent of existing work on infrastructure and climate change in Africa. It documents and summarizes on-going activities (investment plans, programmes, projects etc.), relevant models and data-sets related to the energy, water and roads sectors. Seven major river basins were chosen as 'study areas' in order to get a general overview of Sub-Saharan Africa's varied climates, geography etc. They consist of (Figure 1)

- Congo
- Nile

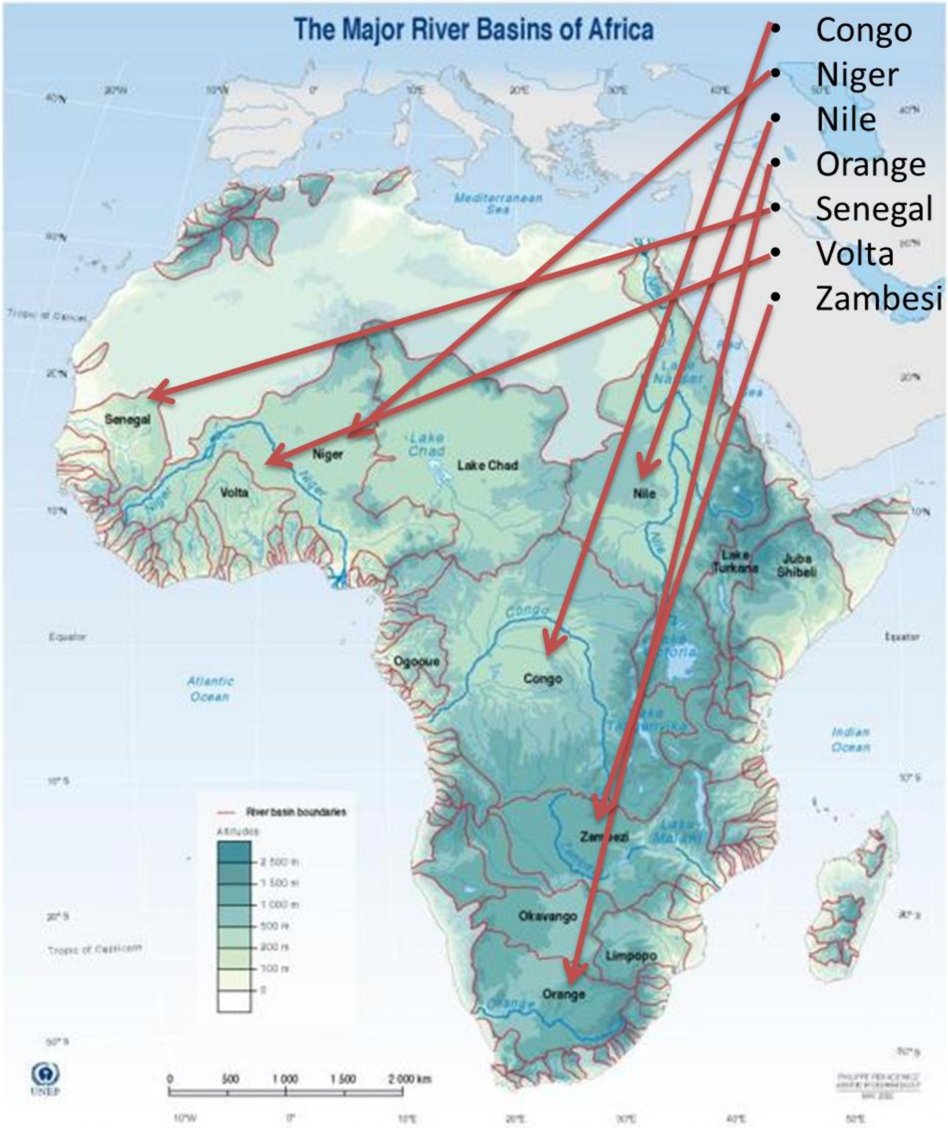
- Niger
- Orange
- Senegal
- Volta
- Zambezi

As this is a rapid stock-taking exercise it is by no means exhaustive. Instead, it is intended to provide an understanding of the actors, on-going activities and available models and datasets upon which the new work will build and developing a conceptual framework for the subsequent analysis.

The report is accompanied by an excel file which consists of a database of (i) contacts from relevant institutions, (ii) tabulated meta-data of identified models, (iii) tabulated meta-data of datasets and (iv) tabulated investment projects and their principal features. It is also accompanied by an (v) electronic archive containing all collected reports, models, databases and project documents. The report consists of five sections and finishes with conclusions made from the exercise. The sections are as follows:

- Relevant Institutions – Describes the Contacts data base that accompanies this report
- Existing Analytical Work/Report – This is an annotated bibliography of projects and studies relevant to Africa’s infrastructure development and/or climate change.
- Models –Describes the models data base that accompanies this report.
- Datasets- Describes the dataset data base that accompanies this report.
- Investment Plans - Describes the investment plans data base that accompanies this report.
- Conclusions – Conclusions reached from this exercise.

This report and the attached database are interlinked and should therefore be not considered as stand-alone products.



Source: Aaron T. Wolf et al., 1999; Revenga et al., *Watersheds of the World*, World Resources Institute (WRI), Washington DC, 1998; Philippe Rekacewicz, *Atlas de poche*, Livre de poche, Librairie générale française, Paris, 1996 (revised in 2001).

Figure 1. The seven river basins selected as focus areas.

2 Introduction

2.1 State-of-the-Art

A key ingredient required for sustaining Africa's economic growth is the rapid upgrading of the region's infrastructures, which are at present inadequate, both in terms of physical stock and quality of service.[1] Some US$ 93 billion per year for the next decade will need to be invested if Africa is to fill the infrastructure gap.[2] Much of this investment will support the construction of long-lived infrastructure (e.g. dams, roads, power stations, etc), which will thus need to be capable of delivering services both under current and future climate.

There is ample literature focusing on infrastructure development in Africa, both at its current level and future needs. For example, the Africa Infrastructure Country Diagnostic (AICD) is a compressive repository of analysis and knowledge on Africa's infrastructure covering the power, transport, irrigation, water and sanitation, and information and communication technology (ICT) sectors. It provides an integrated analysis of the challenges they face and includes findings based on extensive fieldwork across Africa.[3] Findings of the AICD effort include:

- Power is by far Africa's largest infrastructure challenge, with 30 countries facing regular power shortages and many paying high premiums for emergency power.
- Africa's infrastructure networks increasingly lag behind those of other developing countries and are characterized by missing regional links and stagnant household access rates.
- Africa's infrastructure services are twice as expensive as elsewhere, reflecting both dis-economies of scale in production and high profit margins caused by lack of competition.
- The infrastructure challenge varies greatly by country type—fragile states face an impossible burden and resource-rich countries lag despite their wealth.
- A large share of Africa's infrastructure is domestically financed, with the central government budget being the main driver of infrastructure investment.

Nonetheless, relatively little is known on how climate change may affect the desirable design, location, timing, and composition of the stock of infrastructure that will need to be built in the short to medium term. In particular, while there is widespread scientific consensus that the climate of the next few decades could be significantly different from today's climate, and the current trajectory of increasing temperatures is likely to accelerate over the next several decades, there remains large uncertainty on whether dryer or wetter conditions will prevail in Africa's various sub-regions and countries.

[1] Africa is currently experiencing a decade of economic growth with an annual average of 5% growth from 2001 to 2005 accelerating to 6% for 2006 to 2008. Analysis by *the Economist*, January 2011, also finds that over the ten years to 2010, six of the world's ten fastest-growing economies were in sub-Saharan Africa

[2] The gap is defined as the distance between the current quantity and quality of infrastructure, and a set of sector-specific targets that if achieved would enable Africa to catch-up with the rest of the developing world. These include for example: the MDG targets for water; connectivity between all key economic nodes (cities, ports, borders, secondary towns, agriculturally productive areas); supply-demand balance for power and make steady progress on electrification; universal access to a GSM voice signal and WIMAX telecenters

[3] Africa's Infrastructure: A Time for Transformation. Edited by Vivien Foster and Cecilia Briceno-Garmendia. 2010. Co-published by Agence Française de Développement and the World Bank. Available at: http://www.infrastructureafrica.org/aicd/library/doc/552/africa%E2%80%99s-infrastructure-time-transformation

The condition of a changing climate over the next decades matters in a number of different ways for infrastructure development. In addition to important implications on the cost, design standards, and location of infrastructure projects, the optimal composition of investment across the various forms of infrastructure is also likely to be affected. For instance, by inducing changes in the pattern of human activities, climate change can be expected to alter the pattern of demand for infrastructure. If climate change increases the occurrence of extreme events – including droughts and floods – this could be expected to have a significant impact on the costs or the efficiency of infrastructure provision.[1] Finally, since infrastructure basically increases the inter-connectedness of places, it provides a natural way of diversifying climate risk. For example, increasing the density of rural roads provides a way of diversifying heightened agricultural production risk due to climate variability, by allowing food to be moved from areas with higher rainfall to those with lower rainfall in any given year.

In recent years, there has been some overlap in studies looking at the implications of climate change for infrastructure development (see below). However, there are a number of shortcomings of earlier approaches, most notably consistency of approach in terms of climate scenario development and cross-sectoral linkages, which provide the rationale for the analysis proposed here. Looking at on-going activities (e.g., investment plans, programs, projects etc.), as well as relevant models and data-sets related to the energy, water and roads sectors, there is limited existing work on infrastructure and climate change in Africa. Looking across reports in this stocktaking report, there is a notable lack of climate change adaptation in Africa's infrastructure development plans.

In particular, previous work has either covered a certain subset of sectors throughout Africa (but leaving out important infrastructure such as power); or provided a more complete coverage of subsectors but for a few countries only. Most of the existing analysis has not fully addressed the variation across space of climate uncertainty (the distribution of projections across climate models for the world, or for Africa as a whole is typically different from the distribution of projections for individual countries or sub-national territorial units such as river basins); or it did not treat with the same emphasis both the change in averages as well as the effects on extremes (e.g. flood, droughts).

In addition, while explored for some of the World Bank's Economics of Adaptation to Climate Change (EACC) country case studies, the linkages between investments in water capture, and downstream projects in irrigation and hydropower has not yet been fully explored; nor has the issue of optimal combination of hydropower and thermal power generation in interconnected systems under an uncertain climate been fully analyzed. Similarly, the benefits of multipurpose development such as storage dams for managing risk and enhancing the beneficial uses taking into account the climate change effects are not well studied.

Finally, few if any of the previous studies have explicitly addressed the issue of how to use the results of a climate modeling exercise to inform investment decisions in conditions of deep uncertainty about climate models. In several cases, the assumption of "perfect foresight" has been implicitly employed, entailing the ability of decision makers to predict whether a "dry" or a "wet" climate future would materialize, and thus to determine the suited adaptation response

[1] The costs of infrastructure development are based on reliability standards and the ability to withstand extreme events.

accordingly. Since the climate that will actually occur will remain largely uncertain in the foreseeable future, the challenge is to develop decision making frameworks capable of leading to decisions that are "desirable" under a wide range of possible climate outcomes

A better understanding of the range of climate impacts on infrastructure development, and of the approach to deal with climate uncertainty, is thus necessary in order to inform future investment decisions and to avoid locking Africa in a pattern of climate-vulnerable development that will be very costly, or in some cases impossible, to undo in the future. These considerations have prompted the present document's proposal to add an explicit climate dimension to the knowledge platform developed in the context of the African Infrastructure Country Diagnostic (AICD). This will be the first comprehensive effort to link climate change and infrastructure with a consistent methodology across multiple sectors and spaces of climate uncertainty.

2.2 Recent Studies addressing the overlap between climate change and infrastructure

A first order estimate of the impact of climate change on the costs of infrastructure development was undertaken on a global and regional level as part of the Economics of Adaptation to Climate Change (World Bank, 2010). According to this estimate, a large portion of the global annual undiscounted costs of infrastructure adaptation (US $13-28 billion over the period 2010-2050) can be attributed to Sub-Saharan Africa. These estimates were calculated econometrically and aimed to capture both the price/cost effects of adaptation (higher costs for a given infrastructure platform) and the quantity effects of adaptation (higher or lower costs from changes in the requisite infrastructure platform due to shifts in demand).[1]

Disaggregating the estimates, the price/cost effects of infrastructure adaptation in Sub-Saharan Africa amount to US$1-3 billion per year over the period 2010-50 depending on whether the driest or wettest models are used.[2] This amounts to no more than 1-2 percent of the infrastructure baseline costs for Sub-Saharan Africa estimated at US$130 billion per annum. Conversely, negative quantity effects were estimated, meaning that demand shifts resulting from climate change would reduce the amount of infrastructure required. The estimated demand shifts range from negative US$2-3 billion per year over the period 2010-50. When jointly considered, both effects amount to a net impact of positive US$1 billion to negative US$2 billion annually.

A recent study uses a micro-economic dose-response approach to estimate the price/cost effect of climate change on road infrastructure across Africa (Chinowsky et al. 2011). The study finds a cost premium of US$2.3 billion annually through the year 2100, a mark-up of about 24 percent over road spending needs estimated by the AICD. However, the methodology only considers

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[1] The estimate of the price/cost effect is based on stressor-response relationships between infrastructure development and maintenance costs and a range of climate stressors. The estimate of the quantity effect is based on coefficients from a cross-country panel data model that estimates demand for various kinds of infrastructure based on a range of economic and geographic controls.

[2] The price/cost premium is almost entirely associated with urban and road infrastructure. No material effects were found for ICT, health, power, water and sanitation infrastructure or any other transport infrastructure and the study excludes water resource and irrigation infrastructure.

the road agency costs of climate change without incorporating impacts on road users and the economy more broadly. It also focuses on changes in average temperature and precipitation, without taking into account the increased frequency of extreme events.

Studies have also been done at the country level. Ethiopia and Mozambique (World Bank 2010a) were considered in a more detailed look at the cost of adapting road networks (either through changed design standard or increased maintenance) over the period 2010-50. In Mozambique, the price/cost effect is estimated at around US$50 million annually, while in Ethiopia the estimated ranged between US $70-200 million. In both cases, that represents a premium ranging from 20 to 70 percent above AICD estimates of road spending needs for the country. In each scenario, the costs of adaptation are justified in terms of the savings in road user costs and there is no case for retrofitting as adaptation can best take place on a rolling basis (as existing infrastructure is replaced). The costs of adaptation are primarily associated with the need for increased maintenance activities.

Another study looked at the vulnerability of urban infrastructure and agricultural land in coastal areas to anticipated sea level rise and storm surges (Dasgupta et al. 2009), estimating an overall GDP loss of US$1.8 billion for Sub-Saharan Africa from an additional 1 in a 100 year storm surge. Finally, the World Bank's Africa Region has been undertaking work on the hydrological impact of climate change at the river basin level, looking specifically at the downstream implications for water use in hydro-power and irrigation (World Bank 2011a and 2011b). In the context of the Niger, Zambezi, and Nile, researchers find that the impacts of climate change can be quite substantial for some sub-basins and uses, particularly by the latter half of the century.

Sources:

Chinowsky, Paul, Amy Schweikert, Niko Strzepek, Kyle Manahan, Kenneth Strzepek, and C. Adam Schlosser . *Adaptation Advantage to Climate Change Impacts on Road Infrastructure in Africa through 2100*. UNU-WIDER working paper 25, available online at http://www.wider.unu.edu/publications/working-papers/2011/en_GB/wp2011-025/

Dasgupta, S., Laplante, B., Murry, S. and Wheeler, D., 2009. Sea-Level Rise and Storm Surges: A Comparative Analysis of Impacts of in Developing Countries. World Bank, Policy Research Working Paper 4901, April, World Bank, Washington.

Lempert, Robert J. and David G. Groves, 2010. "Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west." *Technological Forecasting & Social Change* 77:960–974.*The Economist* January 2011. See also http://www.economist.com/blogs/dailychart/2011/01/daily_chart

World Bank 2010a, *The Economics of Adaptation to Climate Change*, on-line at: http://climatechange.worldbank.org/content/economics-adaptation-climate-change-study-homepage

World Bank, 2010b *Africa's Infrastructure: A Time for Transformation*, World Bank, Washington, DC, available at http://www.infrastructureafrica.org/,

World Bank, 2011a *Zambezi Basin Multi-Sector Investment Opportunities*, World Bank, Washington DC

World Bank, 2011b *Niger Basin Strategic Development Action Plan*, World Bank, Washington DC

3 Relevant Institutions

This report provides a database in the form of an Excel spread sheet of contacts at institutions with an interest in infrastructure and climate change in Africa. This directory of institutions is categorized as follows:

- Regional Economic Communities
- River Basin Organizations
- Power Pools
- Multilateral Development Banks
- Donor Agencies
- Research Institutes

The Contacts spreadsheet contains 13 fields. These are described below:

Field Name	**Description**
Name	This field contains the name of institute/organization as listed above
Ministry/Division/ Dept.	Contains the name of the Ministry/Division/Department of the institute/organization that was contacted
Contact	Name and position of person contacted
Phone	Phone number of contact
Email	Email address of contact
Website	Website URL of institute/organisation
Project	Project that is undertaken by contact (if any)
Project sector	Sector (roads, energy, water) of the project
Report	Relevant reports that produced by the contact (contained in chapter 3)
Models	Models developed by the contact
Data sets	Data sets compiled by the contact
Investment Projects	Investment project undertaken by the contact

In total 99 contacts in 62 institutions were identified through existing contact and networks, publications and their respective websites. The quantity and quality of information contained in institution websites varied widely. Many of the African websites were not complete and were peppered with broken links and incomplete pages.

Much of the data compiled for this report was acquired from these institutions either through their websites or through personal contact through email and/or teleconference. Every contact with an email address (89) was initially sent email describing the project and requesting data. This email can be found in appendix I. Out of these 89 requests only 10 responded directly. Additional contacts by email and/or telephone resulted in the information in the database. Those that proved to be very helpful were from the donor agencies DFID, JICA, AfD (Ghana Office) and KfW and the Central African Development Bank. Research institutes referred often to their respective websites. Overall the response received should be considered as very modest.

4 Existing Analytical Work/Reports

4.1 Summary of Findings

The analytical reports identified during this stock-tacking exercise and summarized below, provide an overview of studies, programmes, projects and strategic plans that focus on climate change adaptation and development. This list comprises global reports that encompass the latest studies on development adaptation to climate change; pan-African reports that cover climate change and infrastructure on a continental level; and regional reports that focus on regional projects, investment strategies and resource management. The global reports are focused on water management adaptation guidelines and climate change policy guidelines.

The African continental and regional reports detail strategic development action plans, for example the PIDA report (2011), the Multi-Sector Investment Opportunities analysis report for the Zambezi River basin (2011) and major climate change reports e.g. the AfDB report on the 'Cost of Adaptation to Climate Change in Africa' (2011) and resource management related projects including the GLOWA Volta (2010) project.

During this study it was found that the quality and quantity of research and planning was not consistent throughout Africa. While some regions (e.g. SADC) could provide extensive information about infrastructure development including climate change adaptation strategies, this kind of information was very difficult if not impossible to come by in other regions e.g. Senegal River Basin. Nevertheless, this bibliography provides an extensive overview of climate change and infrastructure development studies and strategies in Africa.

4.2 Global Reports

4.2.1 Integrating Climate Change Adaptation into Development Co-operation: Policy Guidance. OECD, 2009

The Policy Guidance provides information and advice to policy makers and practitioners in development co-operation agencies on how to mainstream climate change into development. This Guidance uses a mainstreaming approach, starting from the methods and viewpoints of development cooperation. It is ordered according to spatial and governance scales. The objectives of the Guidance are to:

- Promote understanding of implications of climate change on development practices and the associated need to mainstream climate adaptation in development co-operation agencies and partner countries.
- Identify appropriate approaches for integrating climate adaptation into development policies at national, sectoral and project levels and in urban and rural contexts
- Identify practical ways for donors to support developing country partners in their efforts to reduce their vulnerability to climate variability and climate change.

The first part of the guidance introduces human-induced climate change and puts it within the context of weather and natural climate variability, followed by a discussion of the implications of climate change on key sectors and regions. It introduces the concepts of adaptation and mitigation, and outlines a generic approach for integrating adaptation to climate change within development policies, plans and projects.

The second part takes a partner country perspective and discusses in detail how to assess and address climate risks and opportunities, and how to integrate adaptation responses within development at key decision making levels: national, sectoral and project. For each of these levels, the policy guidance first provides an introduction to the level and its relevance to climate change adaptation. Next the decision making architecture is outlined and entry points and interventions are identified for integrating adaptation considerations within existing processes.

The third part examines the specific challenges and opportunities arising from climate change in urban and rural contexts and discusses how to incorporate adaptation considerations within government- and community-level processes at the local level. Entry points have been identified to facilitate the integration of climate change adaptation into local development planning processes.

At the different decision making levels, the role of donors in the integration process is discussed and some priorities outlined to foster greater integration of adaptation considerations.

4.2.2 Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC, 2008

This technical paper explores the relationships between climate change and freshwater, as set out in IPCC Assessment and Special Reports. Its objectives are to improve our understanding of links between climate change/adaptation/mitigation and water related issues and to inform policymakers and stakeholders about the implications of climate change for water resources and climate change response options. The paper is based on a climate-driven, technical approach.

Observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide ranging consequences for human societies and ecosystems. Climate model simulations for the 21st century project that:

- precipitation increases in high latitudes and parts of the tropics, and decreases in some subtropical and lower mid-latitude regions
- annual average river runoff and water availability increase at high latitudes and in some wet tropical areas, and decrease over some dry regions at mid-latitudes and in the dry tropic
- increased precipitation intensity and variability increase the risks of flooding and drought in many areas
- water supplies stored in glaciers and snow cover decline
- higher water temperatures and changes in extremes affect water quality.

Globally, the negative impacts of future climate change on freshwater systems are expected to outweigh the benefits. Changes in water quantity and quality are expected to affect food availability, stability, access and utilization. Climate change affects the function and operation of existing water infrastructure as well as water management practices. Current water management practices may not be robust enough to cope with the impacts of climate change. Adaptation options designed to ensure water supply during average and drought conditions require integrated demand-side as well as supply-side strategies.

Mitigation measures can reduce the magnitude of impacts of global warming on water resources, in turn reducing adaptation needs. Water resources management clearly impacts on many other policy areas, Several gaps in knowledge exist in terms of observations and research needs related to climate change and water.

This IPCC Technical Paper provides numerous facts and figures on projected changes in the hydrological cycle and adaptation strategies at regional scale for the Water Guidance.

4.2.3 Guidance on Water and Adaptation to Climate Change, UNECE, 2009

This UNECE Guidance aims to spur climate change adaptation that takes into account the transboundary dimension of water management. Based on the concept of IWRM (Integrated Water Resources Management), it provides advice to decision makers and water managers on how to assess impacts of climate change on water quantity and quality, how to perform risk assessment, how to gauge vulnerability, and how to design and implement appropriate adaptation strategies. The Guidance uses a climate-driven, technical approach with the water sector as starting point.

The UNECE guidance is set up along the steps of (i) establishing the policy, legal and institutional framework, (ii) understanding the vulnerability of society, (iii) develop, finance and implement an adaptation strategy, (iv) evaluation. The main results for each step are:

I. Adaptation should build upon water management measures which are already available and implemented. Policies should be developed within the context of IWRM, integrated coastal zone management and integrated flood management, with effective transboundary cooperation ensured at all relevant stages of decision-making, planning and implementation. Adaptation should also include a disaster risk reduction strategy, grounded in local knowledge and communicated broadly. Spatial planning is an important basis on which to develop policies that take into account all sectors.
II. Adaptation to climate change requires a multi stakeholder approach to identify data needs according to the principles of IWRM. Data collection should cover all aspects of the hydrological cycle and explicit information on water uses. Scenarios and models are tools that help to incorporate uncertainty on future events into planning. Riparian countries should develop common scenarios and models to develop a joint understanding; common scenario development also permits a more rational use of the limited financial resources available.
III. Adaptation strategies and measures should be based on the results of vulnerability assessments as well as on development objectives, stakeholder considerations and

available resources. To adopt a cross-sectoral approach when formulating and evaluating options, strategic environmental assessment (SEA) is a useful tool. In financing, the private sector typically engages in adaption in cases where it can directly benefit from its investments. Insurance and re-insurance also have an important role to play in adaptation to climate change.

IV. Evalution is needed to determine relevance, efficiency, effectiveness and impact of the adaptation strategies in light of their objectives, carried out during implementation, at completion and some years after. Learning by doing is very important (pilot projects).

4.2.4 Vision 2030: The Resilience of Water Supply and Sanitation in the Face of Climate Change, WHO / DFID, 2009

The Vision 2030 report focuses on how climate change will affect the drinking-water and sanitation situation. It aims to help policy makers, planners, operators and communities to improve the resilience of their water and sanitation services. The Vision 2030 presents the results of a technology projection study, providing projections of access to drinking water and sanitation in both urban and rural areas for 2020. Water supply and sanitation technologies are categorized according to their resilience to climate change.

Conclusions are that achieving resilience will have significant policy implications if ongoing and future investments are not to be wasted. Integrated water management provides an approach to assessing and negotiating agreement among competing demands, so there is an urgent need to reflect drinking-water and sanitation in IWRM policy and practice. The Vision 2030 also indicates the impact on achieving the Millenium Development Goals (MDG 7 target: halve the proportion of the population without sustainable access to safe drinking water and basic sanitation by 2015).

4.2.5 How to Integrate Climate Change Adaptation into National-Level Policy and Planning in the Water Sector: A Practical Guide for Developing Country Governments, Tearfund, 2010

The Guide has been produced for use by developing country governments, in particular least developed countries, small island developing states and countries in Africa affected by drought, desertification and floods. It is also for donor institutions wishing to support the integration of adaptation through development cooperation, as well as for civil society organizations. It aims to be practical, pragmatic and based on existing knowledge, skills, capacity and observed climate change impacts and risks. The Guide uses a mainstreaming approach focused on vulnerable countries and geographical areas at national governance scale.

The Guide is divided into four tasks, each with a set of sub-tasks. A sequence of steps is given to help the user accomplish each sub-task, as well as indicating crucial stakeholders and the potential role of donors. Throughout the guide, examples and case studies are included. The four main tasks are:

- Establish an understanding of climate change risk and key actors.

- Strengthen national policy frameworks.
- Develop and implement a climate-resilient action plan for the water sector.
- Track performance, adjust to changes and make improvements.

4.2.6 Managing the Water Buffer, for development and climate change adaptation: Groundwater recharge, retention, reuse and rainwater storage, Frank van Steenbergen & Albert Tuinhof, 2009

This publication focuses on managing buffer functions as part of basin management and climate change adaptation. The buffer function in a region, through groundwater storage and rainwater harvesting, may be used to deal with the larger variability in peaks and lows that are expected to come with climate change. The outlined 3R approach (recharge, retention, re-use) is applicable in both arid and humid areas and may generate benefits for water security, development and sustainability of livelihood. The publication uses a technical, climate-driven approach at different scales.

In the document, 19 cases are presented of existing 3R applications from different locations and at different spatial scales. It is concluded that optimal use of water resources through recharge, retention and reuse provides options for coping with climate variability and 3R techniques should increasingly be incorporated into planning, design and operational concepts, since they will create resilience against the vagaries of climate change.

4.2.7 Adapting to Coastal Climate Change: A Guidebook for Development Planners, USAID, 2009

This Guidebook provides a detailed treatment of climate concerns in coastal areas based upon a mainstreaming approach. It proposes a five-step vulnerability and adaptation approach consisting of: (i) assess vulnerability, (ii) select course of action, (iii) mainstream coastal adaptation, (iv) implement adaptation and (v) evaluate for adaptive management.

Climate change will impact the health, function and productivity of coastal ecosystems, thus impacting the health and welfare of coastal communities and the billions of people that depend on these natural resources. Coastal areas most vulnerable to climate change are low-lying islands, coastal areas and deltas; countries subjected to hurricanes and typhoons; and less developed countries.

Planned adaptation aims to address the full range of coastal climate change hazards in ways that meet social objectives. The guidebook includes practitioner briefs on 17 coastal adaptation measures and strategies. Adaptation responses will often include bundles of adaptation measures and require additional consideration in evaluating multiple measures.

Climate change adaptation on the coast must be mainstreamed into coastal policy at all levels. Guidelines and policies for mainstreaming climate concerns and adaptation responses into capital investment plans and project cycles are recommended. A two-track approach combining local level, community-based adaptation with national level enabling policy, finance and legal frameworks is an effective approach to adaptation implementation.

4.2.8 IWRM and SEA Joining Forces for Climate Proofing. CPWC, 2009.

The paper summarizes recent food production and food security trends and provides an overview of how climate change, through impacts on global hydrology, could impact food production and consequently food security in some key farming systems. However, as climate change is but one of many drivers of agriculture, climate change impacts need to be appreciated in relation to specific farming systems in order to identify appropriate adaptation measures. The paper highlights key drivers and presents possible responses, emphasizing that the scope of policy response will need to be broad if water institutions are to be effective in coping with climate change.

The mechanisms of IWRM and SEA are discussed. It is concluded that both instruments have a complementary scope of work, and there is a clear opportunity to further elaborate the added value of bringing IWRM and SEA together when discussing the implementation of climate change adaptation.

4.2.9 A Stitch in Time: Lessons for Climate Change Adaptation from the AIACC Project. AIACC Working Paper No. 48. Leary et al., 2007.

The international AIACC project (Assessments of Impacts and Adaptations to Climate Change) seeks to enhance capabilities in developing countries for responding to climate change by building scientific and technical capacity, advancing scientific knowledge, and linking scientific and policy communities. In this paper, results for part of the project focusing on examining adaptation strategies are presented. These are based on case studies from a wide variety of regions, including assessments of agriculture, rural livelihoods, food security, water resources, coastal zones, human health and biodiversity conservation.

The general recommendations are: (1) adapt now, (2) create conditions to enable adaptation, (3) integrate adaptation with development, (4) increase awareness and knowledge, (5) strengthen institutions, (6) protect natural resources, (7) provide financial assistance, (8) involve those at risk, and (9) use place-specific strategies.

4.2.10 Climate change adaptation in the water sector. London, Earthscan. Ludwig, F. et al., 2009.

The main purpose of this book is to inform water managers and decision makers about climate change, its impacts and how to adapt to these changes. It provides a compendium of specific strategies to show advanced students and professionals in the water sector how to adapt to climate change and variability, thus enabling them to feel comfortable in using climate data in decision support and in managing water resources.

The first part of the book describes theoretical and methodological aspects of the climate system, and what options are available for climate change adaptation in the water sector. The second part contains specific case studies drawn from a wide range of contrasting countries.

4.2.11 Inventory and assessment of methods and tools for supporting the development and implementation of adaptation plans addressing climate change impacts on water management. Wageningen UR; Ludwig, F. & R. Swart, 2010.

This report summarizes an inventory of methods and tools for assessing climate change impacts, vulnerability and adaptation options in the water sector, from a Dutch perspective. The main conclusions are that many tools assisting in climate change adaptation are available but most of them with limited applicability. In the Netherlands, all steps of the adaptation development cycle are covered in principle, but not in practice. Existing Dutch capacity has to be further mobilized for international applications; integration and packaging of existing knowledge may provide better opportunities for international application rather than developing new tools. Foreign methods and tools can provide very useful new insights and inspiration for strengthening Dutch approaches.

4.2.12 World Meteorological Organisation: Comprehensive Review of the World Hydrological Cycle Observing System (WHYCOS) 2011. Dr. Paul J. Pilon, Mr. Kidane Asefa, Dr. Geert Rhebegen and Mr. Serge Pieyns

The World Meteorological Organization (WMO) launched the World Hydrological Cycle Observing System (WHYCOS) concept in 1993 in order to address the need for monitoring systems, data archives, resource assessment and management, and pollution monitoring, protection and control.

WHYCOS was initially developed as a global programme with the objective of establishing approximately 1000 stations on the major rivers of the world, measuring up to 15 variables, such as flow, sediment, water chemistry and nearby meteorological variables. It had two main objectives: one of support to strengthen cooperative links among participating countries having common hydrological problems and an operational objective to help achieve on-the-ground implementation at regional and international river basin levels through regional HYCOS components.

This report describes the current problems of WHYCOS and lays out a number of recommendations to improve the effectiveness of the program, including increasing the awareness of the WMO Integrated Global Observations System (WIGOS) and WMO Information System (WIS) among the HYCOS regional components.

The report also provides a Gantt chart showing the different HYCOS components (including African HYCOS projects in SADC, Volta, Niger, IGAD, Senegal, Congo and Nile HYCOS) and their status with respect to the project stages as defined in WMO.

4.3 Africa-Wide Reports

4.3.1 The Cost of Adaptation to Climate Change in Africa. African Development Fund, Vivid Economics, 2011

This paper provides a synopsis of the potential impacts of climate change on Africa and draws out implications for the resources the Continent may require enabling it to adapt to climate change.

The paper summarizes the recent literature on climate impacts and adaptation - although some new modeling results are also provided from the Regional Integrated model of Climate and the Economy (RICE) model and the Climate Framework for Uncertainty, Negotiation and Distribution (FUND). On this basis, the paper presents evidence on the impacts of climate change in Africa and the cost of adaptation to these changes and identifies priority investment areas. The paper concludes that adaptation costs in Africa are likely to be in the region of US$ 20-30 billion per annum over the next 10 to 20 years. Africa's immediate adaptation priority is to improve its current adaptive capacity, much of which will be operationally indistinguishable from – and needs to be fully integrated with – traditional development activities. Africa also has a large infrastructure deficit and will want to catch up over the coming decades. The design and location of this infrastructure which will have a lifetime of decades, needs to account for changes in the climate.

4.3.2 Strategies for Adapting to Climate Change in Rural Sub-Saharan Africa: A Review of Data Sources, Poverty Reduction Strategy Programs (PRSPs) and National Adaptation Plans for Agriculture (NAPAs) in ASARECA Member Countries. IFPRI Environment and Production Technology Division, 2010

This report profiles the available climate change–related datasets, as well as details about their accessibility and procurement, in the 10 Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) member countries. In addition, the report assesses the incorporation of climate change adaptation strategies in national development plans and discusses the country positions in the current UNFCCC negotiations in eastern and central Africa.

An interesting finding from this study was that all ASARECA member countries had incorporated climate change adaptation strategies in their national development plans. These strategies are broad and cover virtually all sectors of the economy. In addition, most ASARECA member countries report that they are implementing some, if not all, of the specified climate change adaption strategies.

This study recommends that the ASARECA member countries be assisted both financially and technically to build the capacity needed to adopt the climate change adaptation policies specified in their development plans.

4.3.3 Climate Risk Management through Sustainable Land Management in Sub-Saharan Africa. Environment and Production Technology Division, IFPRI, 2011

The overall objective of this study was to generate practical, context-specific recommendations of sustainable land and water management (SLWM) approaches and practices that are suited to improve food security and economic prospects while reducing climate-related risks and greenhouse gas emissions. This study was conducted to examine the impact of government policies on adaptation to climate change.

Kenya and Uganda in East Africa and Niger and Nigeria in West Africa were used as case studies. Each of the four case study countries offers success stories that enhance adaptation strategies. In all the countries we see the influence of policies that have influenced adoption of SLWM and response to climate change in general, policies that show promise for scaling up. Some SLWM practices may require special attention. Specifically, irrigation is touted as an essential ingredient for increased productivity and for climate change adaptation in Africa by numerous organizations as it faces many of the same challenges as other SLWM practices but also brings in the element of the need for capital investment (in water storage or distribution) and more effective adaptation to climate change.

4.3.4 Review of the AU/NEPAD African Action Plan: Strategic Overview and Revised Plan, 2010 – 2015. CPCS Transcom Limited, 2009

The AU/NEPAD African Action Plan 2010-2015 is a statement of Africa's priorities for investment in regional and continental integration. Covering a wide range of sectors, the Plan showcases priority programmes and projects for which investment is being sought during the period 2010-2015. It highlights the opportunities, challenges and objectives of programming to advance the goals of regional and continental integration in Africa, led by the African Union (AU) and eight Regional Economic Communities (RECs), under the banner of the New Partnership for Africa's Development (NEPAD).

4.3.5 Project Implementation Review for the NEPAD Infrastructure Short Term Action Plan (STAP). African Development Bank, 2010.

The New Partnership for Africa's Development (NEPAD) had launched the Short-Term Action Plan (STAP) in 2002 to kick-start the process of developing regional infrastructure in Africa. STAP consisted of approximately 120 regional infrastructure projects spread across the continent, covering four sectors – Energy, ICT, Transport and Trans-boundary Water.

The third review reveals that the implementation progress of the STAP programme has been below expectations. In all, 103 STAP projects were reviewed; of these 16 projects reached completion. Approximately 70% of the STAP projects have progressed in some form or another.

The most glaring observation of the third review was that the majority of the RECs did not have up-to-date information on many of the STAP projects. This was mostly observed for capacity-building and facilitation projects. Most RECs were unsure of the progress made by such projects and had very little information to share on their progress.

The review revealed that all the implementing agencies viz. RECs, Regional Power Pools, River Basin Organizations etc. were facing capacity constraints (severe in some cases). The review recommends more assistance from NEPAD and AFDB is needed to improve institutional capacity (including climate change forecasting) to fast track projects and improved regular monitoring of the performance/contractual obligations of PPPs regarding regional infrastructure projects.

4.3.6 Study on Programme for Infrastructure Development in Africa (PIDA). SOFRECO, NEPAD, AfDB, 2011

Designed to support implementation of the African Union Abuja Treaty and the creation of the African Economic Community, PIDA is a joint initiative of the African Union Commission (AUC), the New Partnership for Africa's Development Planning and Coordination Agency (NPCA), and the African Development Bank (AfDB). The overarching objective of PIDA is to support delivery of the African Union Abuja Treaty and the creation of the African Economic Community by facilitating regional integration in Africa through improved regional and continental infrastructure.

The PIDA Study assembled and reviewed a panel of case studies of the efficiency of current regional infrastructure in each sector (transport, energy, ICT and trans-boundary water resources management (TWRM)), as well as regional projects and programs under preparation or under construction(all case studies are listed in the main reports annexes). On the basis of GDP projections, the Study determined each sector's demand for services through 2040 (or 2018 in the case of ICT), making it possible to assess the likely size of the gap between demand and supply at each step of the way.

The review revealed that the lack of alignment with national and regional priorities and financial problems were the principal drags on efficiency. Raising finance and reaching financial closure are complicated for regional projects (even those undertaken in the public sector with grant financing) because of the number of actors involved.

The study produced three outputs:

- A strategic framework for the development of regional and continental infrastructure across the four target sectors based on long-term social and economic development visions, strategic objectives, and sector policies;
- An infrastructure development programme that articulates short- (2020), medium- (2030), and long-term (2040) priorities for meeting identified infrastructure gaps; and
- An implementation strategy and processes for the Priority Action Plan (PAP), 2012–20.

4.3.7 African Development Bank Group Agriculture Sector Strategy 2010-2014, 2010. Agriculture and Agro-Industry Department And Operational Resources And Policies Department

The African Development Bank's (AfDB) Agricultural Sector Strategy (AgSS) for 2010-2014 is shaped by a series of consideration and consultations with country officials and external public and private stakeholders in Africa. The AgSS seeks to position the Bank to effectively contribute to a broader development of greater agricultural productivity, food security and poverty reduction while promoting the conservation of the natural resource base. Two mutually reinforcing pillars underpin the AgSS: agricultural infrastructure and renewable natural resource management. In both of these areas, the Bank has demonstrated considerable competence and comparative advantage. These interventions will among others, focus on agriculture water storage and management to overcome the low, unreliable rainfall during the cropping season, and in situ rainwater management, water harvesting or run-off harvesting, and water management for crop growth in wetlands. With respect to renewable natural resources (land, water, forests), the interventions will ensure the sustainability and resilience of agricultural infrastructure investments to climate variability and protect the natural resource base. The Bank's indicative pipeline of projects and programs amount to UA 3.4 billion (5.33 USD billion) for the period 2010-2014.The AgSS Action Plan describes the operational focus, core activities, financing, and monitoring and evaluation in 2010-2014.

4.3.8 Climate Change and Infrastructure Development : 7th African Development Forum: Acting on Climate Change for Sustainable Development in Africa. Issues paper #8, 2010

This report, compiled by the AU, ADB and ECA, is a short overview on how climate change will affect future development of Africa's infrastructure. It lists general considerations for climate-proofed infrastructure and summarizes sectoral considerations in building resiliency into infrastructure systems including different energy sectors, water and sanitation and transport.

4.3.9 Improved Drought Early Warning And Forecasting To Strengthen Preparedness And Adaptation To Droughts In Africa (DEWFORA).

Inventory Of Drought Monitoring And Forecasting Systems In Africa, 2011

This document provides an inventory of drought monitoring and forecasting systems which cover Africa. The inventory considers systems, networks/ institutions and projects and captures the information on a list, factsheets and detailed descriptions. The list can be considered a census. It can be divided into groups by coverage as follows:
(i) Global which also cover Africa,
(ii) European which also covers the whole of the African continent,
(iii) European which also covers Northern Africa
(iv) Regional namely Northern Africa, Eastern Africa, Southern Africa and Western Africa as focus areas, and;
(v) National which covers individual countries in Africa.

The factsheets provide a summary of key information on each system/network/institution or project obtained from further based interrogation. The detailed descriptions provide information on the status of each system/network/institution or project.
A list of modelling and local knowledge systems applied to provide drought early warning in Africa is also provided in this document.

4.3.10 2nd GEOSS African Water Cycle Symposium White paper on GEO Capacity Building and Water Resources in Africa - The African Water Cycle Coordination Initiative (AFWCCI). Addis Ababa, 23-25 February 2011

The Global Earth Observation System of Systems (GEOSS) is a coordinating and integrating network of Earth observing and information systems, contributed on a voluntary basis by Members and Participating Organizations of the intergovernmental Group on Earth Observations (GEO) (African members include Benin, Burkina Faso, Cameroon, Chad, Ghana, Ivory Coast, Somalia, Togo, Tunisia, Volta Basin and Zambia). GEOSS implementation aims to achieve comprehensive, coordinated and sustained observations of the Earth system in order to improve monitoring of the state of the Earth, increase understanding of Earth processes, and enhance prediction of the behaviour of the Earth system.

The GEO framework is being used to coordinate international capacity building efforts to support the development of sustainable African Water Observation Systems, making the best use of Earth observations and products to improve the collection of water information.

This symposium report details the capacity building needs for African water resources including the effect of climate change on these needs. The specific information and decision support requirements for water resource management, remote sensing, data products, infrastructure and services are listed. Additionally, the capacities of international and African water resource management and monitoring institutions and infrastructure are listed and described along with new opportunities and recommendations for each sector.

4.4 Regional Reports

4.4.1 Eastern Africa Power Pool: Regional Power System Master Plan and Grid Code Study: Final Master Plan Report

This document, the Final Master Plan Report, identifies regional power generation and interconnection projects in the power systems of EAPP and EAC member countries in the short to long term. Current member states are Rwanda, Burundi, Democratic Republic of Congo, Tanzania, Kenya, Ethiopia, Sudan, Egypt and Libya, while potential members are Somalia, Eritrea, Djibouti, Uganda and South Sudan. The East African Community EAC and EAPP identify the horizon year to be 2038, extending national plans that do not extend to that year. The existing power interconnection projects include:

- DRC, Burundi, and Rwanda interconnected from a jointly developed hydro power station Ruzizi II, (capacity 45 MW) operated by a joint utility [SOCIETE D'ELECTRICITE DES PAYS DES GRAND LACS (SINELAC)];
- Cross-border electrification between Uganda and Rwanda, Tanzania and Uganda, and Kenya and Tanzania;
- Kenya – Uganda interconnection; and
- Egyptian power system interconnection through Libya to other Maghreb countries and Southern Europe; and through Jordan to Eastern Mediterranean.

The table is provided in Excel sheet format and provides a list of ongoing power connection systems. The Master Plan will be outlined in terms of the WBS (Work Breakdown Structure) documents supplemental to the executive summary. They are:

1. Demand Forecast (WBS 1100)
2. Generation supply study and planning criteria (WBS 1200)
3. Supply-demand analysis and project identification (WBS 1300)
4. Transmission network study (WBS 1400)
5. Interconnection studies (WBS 1500)
6. Detailed system studies for each country (WBS 2100)
7. Environmental impacts (WBS 2200)
8. Cost estimates (WBS 2300)
9. Financial economic analysis and risk-assessment (WBS 2500)
10. Investment plan for the identified interconnection projects (WBS 2600)
11. Analysis of institutional and tariff aspects (WBS 2700)
12. Project funding (WBS 2800)
13. Regional market operations center location (WBS 2900)
14. Final interconnection code report (WBS 3300)

4.4.1.1 Demand Forecast

Demand forecasts were modeled using a combination of intuitive, extrapolation, end-user and econometric analysis of demand. In order to do that, from each member state, data was collected on:

- Previous demand forecasts
- Historical electrical data (hourly load data, loss data, peak demand, generation, sales data, etc)

- Historical demographic and economic data (population and GDP)
- Economic and demographic forecast data
- Any background information leading to topic such as electrification, loss reduction, etc
- Gaps in this data were identified

The study resulting in this report independently performed demand forecasts and compared it to existing national demand forecasts. Below are lists of demand forecasts previously modelled for each of the countries under study:

Country	Study	Year	Comments
Burundi	Nile Equatorial Lakes Subsidiary Action Program (NELSAP)	2008	Study extended from 2025
Djibouti	Least Cost Electricity Master Plan (LCEMP)	2009	Study covers up to 2038
East DRC	NELSAP	2007	Study extended from 2020; Data in this region is limited and unreliable
Egypt	Egyptian Electric Holding Company, EEHS	2007	Using econometric based computer package, E-views. Extended from 2026
Ethiopia	Highlights on Power Sector Development Program; Ethiopia Electric Power Corporation, EEPCO	2008	Moderate I forecast model; extended from 2030
Kenya	Least Cost Power Development Plan, by Ministry of Energy	2008	Model for Analysis of Energy Demand; extended from 2030
	Least Cost Power Development Plan, by Ministry of Energy	2009	E-views model; extended from 2030
Rwanda	NELSAP		Study extended from 2025
Sudan	Long Term Power System Planning Study LTPSP	2005	Extended study from 2030
Tanzania	Power System Master Plan	2007/ 2009	Extended from 2033
Uganda	Power Sector Investment Plan	2008	RALF model; study covers up to 2038

For each of the countries above, a base, low and high national demand forecast was produced, and results are given in the form of GWh, MW and percentage (%) load factor starting at the year in which the country forecast was conducted (2005, 2007, 2008 or 2009) and extending to 2038.

4.4.1.2 Generation Supply Study and Planning Criteria

The objectives of this WBS are:

1. Update the available data on generation supply for each country, including the existing facilities, rehabilitation projects, ongoing plant construction, supply import and export, and any other stations that may be developed during the planning period (2013 to 2038)
2. Establish a list of existing and potential energy sources suitable to meet the demand of the combined systems, including at least hydroelectric, thermal and geothermal sources
3. For each candidate plant, list information on capital costs (including environmental mitigation costs), operation and maintenance costs and earliest in service date
4. For hydroelectric options, rank projects in accordance with attractiveness including cost

5. Explain the generation planning criteria such as reliability criteria, outage rates and service lives
6. Provide a hydrology database for all the hydro sites used in the study
7. Update the hydro energy capability of all the hydro plants considered in the study

Existing power interconnection systems include:

- DRC, Burundi, and Rwanda interconnected from a jointly developed hydro power station Ruzizi II (capacity 45 MW) operated by a joint utility Societe d'Electricite des Pays des Grand Lacs (SINELAC);
- Cross-border electrification between Uganda and Rwanda, Tanzania and Uganda, and Kenya and Tanzania;
- Kenya – Uganda interconnection; and
- Egyptian power system interconnection through Libya to other Mahgreb countries and Southern Europe; and through Jordan to Eastern Mediterranean.

Ongoing Projects in the region

- Ethiopia-Kenya 500 KV DC: Commissioning 2013
- Ethiopia-Sudan 220/230 KV: commissioning end of 2010
- Ethiopia-Djibouti 283KM of 230 KV: commissioning by 2011
- Ethiopia-Sudan and Sudan-Egypt 500 kV HVDC: feasibility study report has been prepared. Financing is being sought
- Kenya–Tanzania 400 KV / NELSAP: commissioning 2015
- Kenya-Uganda 220 KV / NELSAP: commissioning 2014
- Uganda–Rwanda 220 KV / NELSAP: commissioning 2014
- Rwanda-Burundi 220 KV / NELSAP: commissioning 2014
- Burundi-DRC 220 KV / NELSAP: commissioning 2014
- RUSUMO Falls Project 60 MW: commissioning 2016. RUSUMO will link West Tanzania, Burundi and Rwanda at 220kV
- Tanzania–Kenya-Zambia interconnection
- DRC–Zambia 220kV interconnection

The study identified new power options in order to conduct an analysis of potential power in each country. In order to do that, the following data were harmonized:

- Capital costs, adjusted for inflation based on
- Mitigation costs were included based on estimates from existing reports on potential power plants; when no estimate was given, a 5% of the project cost was added
- Project lead times to on-power were taken from reports or estimated based on planning criteria and plant sizes
- Fixed and variable operation and maintenance costs were based on international experience
- Technical characteristics were obtained from existing reports or from country electric utilities for existing plants
- Performance characteristics were obtained from existing reports, country utilities and based on international experience
- Information on trans-border imports and exports were obtained from country utilities, or EAPP

- Hydro generation capabilities were obtained from country reports where it is available, or otherwise estimated
- Other renewable energy was also included in the dataset

The remainder of this section will outline conceptual characteristics of the model used to calculate generation, while a detailed coverage of the data used for the calculations and the types of data available through this report is provided in our accompanying excel sheet.

Conceptual Features:

- Economic Criteria
    - Objective function given by
      Min [Net Present Value (Investment costs + O&M costs + Fuel Costs + Un-served energy cost + Externalities)]
        - All costs apply to the planning period, 2013-2038
    - Reference year and study horizon: all terms expressed in terms of mid 2009 costs and no further escalation is applied
    - Discount rates and escalation: A real discount rate of 10%, that excludes inflation, will be used
    - Cost of un-served energy: depends on the perceived cost of outages to consumers; it is taken to be $1.10/kWh
    - Shadow pricing: shadow pricing is not used as there is no restriction on currency trading
- Generation Planning
    - System reliability criteria:
        - For hydro-dominated plans, the installed capacity normally exceeds load by 20-30%
        - Based on 35 years of monthly flow data, it was established that the probability of a deficit must be less than 100%; and the probability that in any given month the deficit is greater than 2% of the energy demand must be less than 5%
    - Reserve margins
    - Outage rates and maintenance schedules: the document provides scheduled maintenance (weeks in a year), forced outages (% of time) and availability factors (%) for different fuel types
    - O&M costs and other owner costs for the region: details provided in excel sheet
    - Service lives: documentation provides international standards for service lives of plants by fuel type

4.4.1.3 Supply-Demand Analysis

The objectives of this study are to:

- Set-up a regional database of existing, committed and candidate generation and interconnection projects for the development of the regional plans for the EAPP/EAC
- Set-up the models for advanced generation planning simulation and planning tools: SDDP & OPTGEN (see below)
- To develop a supply-demand balance for each country based on the national expansion plans

- To identify significant potential surpluses of indigenous generation as an indicator of potential interconnection opportunities
- Develop regional master plans with different degrees of planning and operational coordination among the pool members

It is important to note that two types of scenarios were developed for this analysis:

a) NGP_RIP: national generation plans derived for the study were not changed, however, regional planning is conducted for interconnection projects where opportunities arose
b) RGP_RIP: the generation plan of each system is optimized on a regional level in coordination with generation plans of other systems and with a regional interconnection plan

The analysis involves choosing selective variables from the supply and demand sections. OPTGEN, a supply-demand analysis model is used for the analysis, and SDDP, a probabilistic multi-area hydro-thermal production costing model. These two models are then used to develop a regional plan:

1) Adjustment of national plans
    a. Revise (if necessary) national plan using OPTGEN, based on revised demand forecast, common generation reliability criteria, update of status of committed projects, self-sufficiency (building only for local demand)
    b. Evaluation of national surpluses (SDDP)
2) Regional Planning of Interconnections (NGP_RIP)
    a. First level of regional coordination
    b. New interconnections are built to maximize profitable exchanges of surpluses of national plans
    c. National generation master plans are not modified
    d. Analysis of net economic benefits
3) Regional Planning Interconnections and Large Generation Projects (RGP_RIP)
    a. Second level of regional coordination
    b. New interconnections are built to maximize profitable exchanges of surpluses of national plans
    c. National generation master plans are coordinated so that advancing or delaying a large generation project may provide additional regional benefits
    d. Analysis of net economic benefits
4) Risk Analysis
    a. Variables/policies that could have significant impact on the regional plan
    b. Limited participation of large importers (eg Egypt) in regional exchanges
    c. Increase of investment cost of interconnections projects (double the base cost)
    d. Analysis of impacts on net economic benefits

The results of this analysis are that a national plan is updated for each of the ten countries; these national plans present exploitable surpluses. These present a first level of regional coordination consisting of existing and selected interconnection plans, and a second level of regional coordination consisting of integrated interconnection plans, or the theoretical optimum for the region. The results of this analysis also include risks of including the Egyptian system, in particular, and to the entire interconnection system.

4.4.1.4 Transmission Network Study

The objectives of this section of the study were to develop a database of existing transmission network information for each country, so that it is possible to build a working load flow case for each country; and to build a collective transmission model for the year 2013 for use in the regional system studies.

This section mostly consists of data and models used to develop database of transmission network. A detailed review of the data and models used are included in the accompanying excel sheet.

4.4.1.5 Interconnection Studies

The objectives of this section of the study are to develop common planning criteria to enable cross border power exchanges and to identify the major interconnection projects and develop a phased interconnection plan for the ten countries involved in the project.

Input data involved in this study consists of existing, ongoing and committed projects, future projects as identified in the reference documents, and load forecast and generation plans for the study years.

The methodology for developing the common planning criteria was to review national master plans and reference documents, with the goal of harmonizing parameters related to the interconnected system, for example defining system voltage range, and equipment loading under normal contingency conditions, fault levels and stability criteria.

4.4.1.6 System Studies for Expansion Plan

The objectives of this section of the study are to evaluate the technical feasibility of the interconnection projects and to identify the necessary technical reinforcements required for the successful implementation of these interconnection projects.

In order to carry out this study, load flow analyses were performed for the case years 2013, 2018 and a qualitative assessment for the year 2038. For each case year, the necessary technical reinforcements were then identified.

The load flow analysis was performed for peak load conditions, where for each load flow study year case, the base case was checked for voltage range and line/transformer overloading under normal conditions (the transmission system is entirely available – no equipment is forced out of service); contingency analysis was then performed for each base case and the voltage range and line/transformer overloading are checked under “contingency operating condition (where one element of the transmission system – line or transformer – is forced out of service). From these analyses, system reinforcements were identified and recommended for each of the 10 countries.

4.4.1.7 *Environmental Impact Assessment*

As construction of transmission lines and other interconnection infrastructure could potentially affect the environment, and Environmental and Social Impacts Assessment (ESIA) was conducted for each interconnection project. It is assumed that for existing projects or projects whose funding has been secured, a full scale ESIA has already been conducted. Therefore, this section provides a generic guide to the potentially significant environmental risks and impacts.

1) Soil and geology: soil contamination, soil erosion and removal of vegetation
2) Water environment: water quality can be affected during the construction of transmission line infrastructure through sedimentation, contamination and changes in bank stability of nearby surface water
3) Air quality: increases in dust and air pollutants during construction
4) Ecology: removal of vegetation during construction and possibly along the extent of transmission lines
5) Noise: noise levels will rise during construction and operation of projects
6) Land use: acquisition of land for construction of project
7) Socio-economic factors: a positive impact of this is the provision of new employment opportunities; however, an influx of employees may place additional pressure on local services and resources
8) Health and safety: an influx of construction workers may potentially increase the risk of HIV/AIDS and other infections and diseases. Also, electrocution poses a safety risk for local communities
9) Cultural heritage: excavation of lands for building project sites may disturb lands of cultural and archaeological significance
10) Electromagnetic fields pose a threat to persons coming into contact with transmission lines

The study suggests monitoring and mitigation measures that can be taken for each of these circumstances

4.4.1.8 *Cost Estimates*

In this section, cost estimates are provided for the recommended projects. Cost estimates are calculated for the recommended projects based on Engineering, Procurement and Construction (EPC) costs, full project costs including Contingency and Interest During Construction (IDC) costs, and division of the project costs to identify amounts to be spent on local and foreign currency. HVAC interconnection costs were based on recent projects involving 500 kV, 765 kV, as well as the Gulf Corporation Council interconnections involving 400 kV and 220 kV. HVAC transmission costs were based on the Ethiopia-Kenya Interconnection Project (Fichtner, 2009) and the Nile Basin Initiative Project (EDF and Wilson Scott, 2008).

The accompanying excel sheet provides breakdown of cost estimates for hydro power plants and thermal power plants. In addition, the study provides estimates of EPC project costs for transmission, substation and convertors. Finally, the section provides project implementation schedules.

4.4.1.9 *Financial economic analysis and risk-assessment*

After evaluating the technical feasibility of the interconnection projects, and that they respond to existing supply and demand projections, this part of the study evaluates whether interconnection are economically and financially viable.

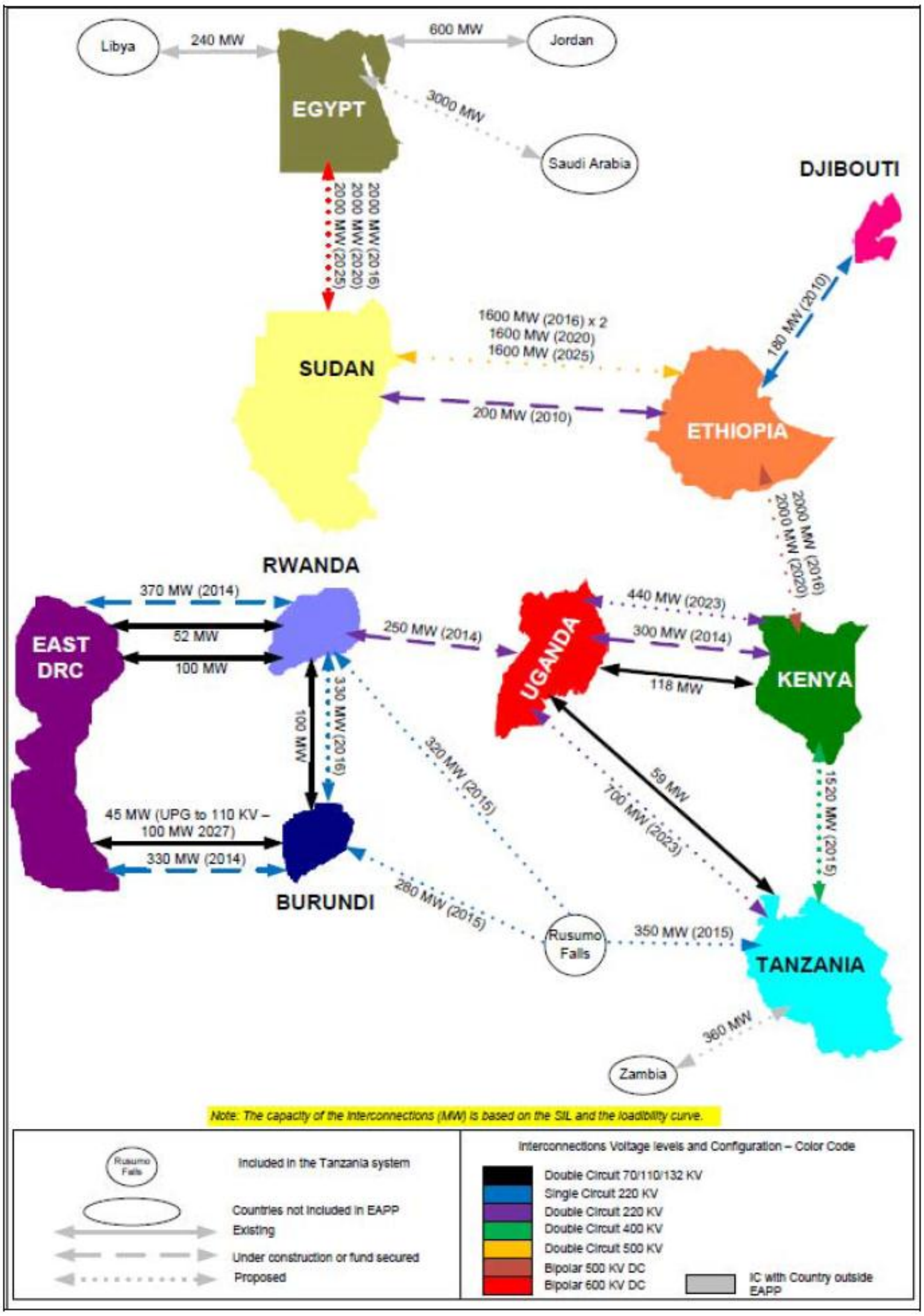
As was mentioned under the Supply-Demand Analysis section, two types of scenarios of interconnection were simulated:

a) NGP_RIP: national generation plans derived for the study were not changed, however, regional planning is conducted for interconnection projects where opportunities arose

b) RGP_RIP: the generation plan of each system is optimized on a regional level in coordination with generation plans of other systems and with a regional interconnection plan

Financial and risk analyses were conducted for the two above scenarios. The financial analysis shows that RGP_RIP provides the most net benefits to the system. However, due to the large political issues that could arise from each scenario, in addition to the technical and coordination complexities, it was determined that NGP_RIP is the more practical direction for interconnection projects. The figure shows interconnection projects under this scenario; they include existing, ongoing and proposed projects.

Project ID	From	to	Type	Length (kM)	Capacity (MW)	Year of Operation
P 1	*Tanzania*	*Kenya*	*400 kV-2 CKT*	*260*	*1,520*	*2015*
P 2	*Tanzania*	*Uganda*	*220 KV - 2 CKT*	*85*	*700*	*2023*
P 3	*Uganda*	*Kenya*	*220KV - 2 CKT*	*254*	*440*	*2023*
P 4	*Kenya*	*Ethiopia*	*500 kV-DC-bipole*	*1,120*	*2,000*	*2016*
P 5	*Ethiopia*	*Sudan*	*500 kV 2 CKT +2 CKT*	*2x570*	*2x1,600*	*2016*
P 6	*Sudan*	*Egypt*	*600 kV-DC-bipole*	*1,665*	*2,000*	*2016*
P 7	*Kenya*	*Ehtiopia*	*500 kV-DC-bipole*	*1,120*	*2,000*	*2020*
P 8	*Ethiopia*	*Sudan*	*500 kV-2 CKT*	*544*	*1,600*	*2020*
P 9	*Sudan*	*Egypt*	*600 kV-DC-bipole*	*1,665*	*2,000*	*2020*
P 10	*Ethiopia*	*Sudan*	*500 kV-2 CKT*	*544*	*1,600*	*2025*
P 11	*Sudan*	*Egypt*	*600 kV-DC-bipole*	*1,665*	*2,000*	*2025*
P 12	*Uganda*	*Tanzania & Kenya*	*2x 220 KV - 2 CKT*	*339*	*1,140*	*2023*



The economic viability of the system is the net contribution of the project to the country's socio-economic goals, and it is based on a cost benefit analysis. Costs of the system are based those given in section Cost Estimates (capital costs, costs of operation, including fixed and variable O&M, costs of energy transmitted, construction cash flows, losses and un-served energy), and benefits are derived as the difference of system operating costs for the scenarios with and without the project (derived from SDDP).

This section identifies economic benefits of the projects as being attributed to economies of scale, least cost generation, reduced cost of reserve and opportunity trades of surplus from excess capacity areas to areas with capacity deficit. Other benefits are:

- Hydro-hydro complementarities due to differences in river basins' hydrology over the years (reservoir capacity, and temporal/spatial distribution of runoff)
- Hydro-thermal complementarities due to the differences in opportunity costs of water and marginal costs of thermal power. Also, this allows for the system to respond and mitigate outages, exceptionally dry years or shortages of fuel
- Emergency assistance between systems
- Regional security of supply
- Reduced installed capacity due to reserve sharing

For the twelve interconnection projects, the following table shows potential savings:

Project ID		P 1	P 2	P 3	P 4	P 5	P 6	P 7	P8	P9	P10	P11	P12
Project name		Tan - Ken	Tan - Uga	Uga-Ken	Ken-Eth	Eth-Sud	Sud-Egy	Ken-Eth	Eth-Sud	Sud-Egy	Eth-Sud	Sud-Egy	Uga-Tan&Ken
No.	Year												
-4	2011												
-3	2012												
-2	2013	0	0	0	0	0	0	0	0	0	0	0	0
-1	2014	0	0	0	0	0	0	0	0	0	0	0	0
1	2015	7	0	0	0	0	0	0	0	0	0	0	0
2	2016	45	0	0	187	2,301	2,921	0	0	0	0	0	0
3	2017	126	0	0	400	1,525	2,264	0	0	0	0	0	0
4	2018	170	0	0	419	1,300	2,128	0	0	0	0	0	0
5	2019	117	0	0	388	1,147	1,900	0	0	0	0	0	0
6	2020	214	0	0	-13	520	528	21	197	592	0	0	0
7	2021	169	0	0	10	636	869	12	191	888	0	0	0
8	2022	173	0	0	35	876	1,810	32	189	1,821	0	0	0
9	2023	148	6	8	64	965	1,880	64	177	1,888	0	0	7
10	2024	149	5	1	60	634	1,953	57	96	1,954	0	0	7
11	2025	153	3	1	98	162	1,143	99	30	1,144	62	1,260	5
12	2026	202	2	3	126	202	1,252	125	35	1,255	41	1,269	4
13	2027	197	1	3	138	174	1,240	138	22	1,241	23	1,243	4
14	2028	186	0	-1	116	174	925	117	24	926	23	927	7
15	2029	133	3	-2	105	253	368	105	55	368	55	368	3
16	2030	101	2	0	90	252	327	89	53	327	54	329	3
17	2031	52	0	-1	90	470	377	90	172	377	172	375	3
18	2032	239	13	14	148	505	361	148	179	361	179	361	127
19	2033	215	12	20	140	480	371	140	182	371	182	370	125
20	2034	249	8	30	160	429	449	160	168	449	168	449	126
21	2035	255	9	26	151	422	443	151	161	443	161	443	111
22	2036	246	9	22	151	463	503	151	183	503	183	503	104
23	2037	145	9	3	128	395	492	128	174	492	174	492	87
24	2038	89	9	9	147	477	771	147	203	771	203	771	77
25	2039	176	6	9	128	347	644	128	117	645	120	654	56
26	2040	176	6	9	128	347	644	128	117	645	120	654	56
27	2041	176	6	9	128	347	644	128	117	645	120	654	56
28	2042	176	6	9	128	347	644	128	117	645	120	654	56
29	2043	176	6	9	128	347	644	128	117	645	120	654	56
30	2044	176	6	9	128	347	644	128	117	645	120	654	56
31	2045		6	9	128	347	644	128	117	645	120	654	56
32	2046		6	9				128	117	645	120	654	56
33	2047		6	9				128	117	645	120	654	56
34	2048		6	9				128	117	645	120	654	56
35	2049		6	9				128	117	645	120	654	56
36	2050		6	9							120	654	56
37	2051		6	9							120	654	56
38	2052		6	9							120	654	56
39	2053										120	654	
40	2054										120	654	
41	2055												

The economic cost-benefit analysis included calculation of the Economic Internal Rate of Return (EIRR), the rate of discount at which discounting of future benefits is just equal to discount of future capital and operating costs; and the Economic Net Present Value (ENPV), discounted benefits minus the discounted costs of the project. A summary of the benefit to cost ratio for each project, as well as the EIRR and ENPV are given in the following table as:

No.	Project ID	Project name	Year of Operation	B/C Ratio	ENPV Million US$	EIRR
1	P 1	Tan - Ken	2015	8.48	788	43.5%
2	P 2	Tan - Uga	2023	1.20	2	12.1%
3	P 3	Uga-Ken	2023	0.68	-10	6.7%
4	P 4	Ken-Eth	2016	1.37	270	15.3%
5	P 5	Eth-Sud	2016	11.47	4,592	87.4%
6	P 6	Sud-Egy	2016	9.45	7,506	71.4%
7	P 7	Ken-Eth	2020	0.71	-144	7.1%
8	P8	Eth-Sud	2020	3.42	363	32.6%
9	P9	Sud-Egy	2020	6.42	3,289	47.8%
10	P10	Eth-Sud	2025	2.74	162	20.8%
11	P11	Sud-Egy	2025	4.81	1,434	45.5%
12	P12	Uga-Tan&Ken	2023	2.65	69	18.5%

The table shows that P3 and P7 have B/C ratios that are less than one, and negative ENPV. Combining P2 and P3 gave more favourable estimates of their benefits. Finally, the study includes sensitivity analysis of the economic analysis.

The financial analysis refers to revenue obtained from the project and entails estimating the levelized tariff according to the annual revenue required to cover operating costs, depreciation, interest payments, tax payment, and predetermined required return on equity. Similarly, a Financial Internal Return Rate and Financial Net Present Value were modelled. In addition, a simple payback time (in years) and discounted payback time (in years) were determined. The following table shows results of the analysis.

No.	Project ID	Project name	Levelized tariff ($/kWh)	FIRR	FNPV (Million US$)	Simple payback time (Year)	Discounted payback time (Year)
1	P 1	Tan - Ken	0.005	9.86%	6.50	7	19
2	P 2	Tan - Uga	0.009	10.72%	2.15	7	14
3	P 3	Uga-Ken	0.015	9.86%	2.47	7	19
4	P 4	Ken-Eth	0.029	9.23%	3.50	7	28
5	P 5	Eth-Sud	0.007	9.23%	2.11	7	28
6	P 6	Sud-Egy	0.016	9.23%	4.28	7	28
7	P 7	Ken-Eth	0.024	9.23%	2.77	7	28
8	P8	Eth-Sud	0.011	9.23%	0.84	7	28
9	P9	Sud-Egy	0.021	9.23%	3.39	7	28
10	P10	Eth-Sud	0.014	9.23%	0.63	7	28
11	P11	Sud-Egy	0.029	9.23%	2.53	7	28
12	P12	Uga-Tan&Ken	0.013	10.09%	4.62	7	17

Finally risks associated with interconnection projects can be categorized as:

- Design misspecifications
- Construction risks: cost overruns, completion delay, failure to meet performance criteria at completion
- Operating costs: cost overruns, variation demand from the demand forecast, equipment performance, power supply deficiencies
- Environmental risks
- Commercial and counterpart risks
- Financial risks such as failure to raise required finance
- Political risks

For each of these risks, the study identifies allocations (public authorities, concessionaires, contractors, suppliers, insurers, etc) and mitigation measures.

4.4.1.10 Investment plan for the identified interconnection projects

This section presents a summary of development plan for the generation and interconnection projects within the EAPP/EAC region. Then the proposed hydro power plants and thermal power plant projects are re-introduced along with their investment costs. In addition, the disbursement schedules for these projects are presented. An investment plan for 5-year periods, per project and then per country, is developed. The same tasks are repeated for the selected interconnections among EAPP/EAC countries, with a disbursement schedule and a 5-year investment plan included for each of the 12 proposed interconnectors.

A list of the types of results presented in this section is included in the accompanying excel sheet.

4.4.1.11 Analysis of institutional and tariff aspects

In this section, institutional and tariff aspects of the project is reviewed. These include:

- The current level of experience of the project participants in operating interconnectors
- The existing resource base in each country
- The exiting institutional structures within the project participants
- The existence of any subsidies which may hinder future trade over the interconnectors

4.4.1.12 Project funding

This section investigates the supply and demand sides of project funding. It looks at competing claims to funding including funding needs for internal generation, transmission and distribution within each country, and not only interconnection projects. It also shows that Official Development Aid, and government funding of the projects will not be enough. Thus the section investigates conditions for making private sector funding desirable. The study compares various timelines for the various sources of funding, including private and public sector financing, as well as actions that may mitigate delays in funding. Finally, as private sector funding is very competitive, the study presents processes that can be taken by EAPP to make it more competitive in this market.

4.4.1.13 Regional Market Operations Center Location

The study first defines the structure and functions of the Regional Market Operations Center (RMOC). These functions are:

1) System Operation Coordination:
    a. Scheduling pool interconnectors
    b. Monitoring load flows and taking action on variances
    c. Balancing market counterparty for imbalance settlement
2) Market Administrator
    a. Market monitoring and surveillance
    b. Administration of contracts
    c. Dispute management
    d. Membership administration
3) Market Operation
    a. Managing the Balancing Market
    b. Managing the Day Ahead Market
4) Settlement
    a. Meter Reading administration
    b. Balancing Market billing
    c. Day Ahead Market settlement
    d. Payment

Countries in EAPP/EAC were evaluated to choose the location of the RMOC; evaluations were made based on several criteria including how developed institutions were within each country, how developed were infrastructure, how developed was the financial market and commodity, the technological development or accessibility to technology within the country, business practices, evolution of the national electricity market, and other factors such as access to supportive institutions (legal, accounting, etc).

Based on these evaluations, Kenya was chosen as the best location for the RMOC.

4.4.1.14 Final Interconnection Code Report

The Eastern Africa Power Pool and East African Community Interconnection Code (the "Interconnection Code") sets down the technical rules for the coordinated planning and operation of the Pool. The objectives of the Interconnection Code are:

- To implement common standards for satisfactory operational security, reliability and quality of supply in the Eastern Africa Power Pool (EAPP) interconnected Transmission System;
- To encourage integrated planning of generation capacity and transmission expansion;
- To define responsibilities for the operation and management of the EAPP Interconnected Transmission System;
- To ensure non-discriminatory access to the EAPP Interconnected Transmission System for all Users, and
- To ensure that System Operators are adequately trained and authorised.

Following introductory remarks and general conditions, this document lays out the following:

- Planning Code:
    - Details minimum technical and design criteria principles and procedures.
    - This Planning Code is to be used for short and long-term development of the Interconnected Transmission System in East Africa that is to be taken by member states' utilities.
    - It specifies the planning data required in order for this to take place.
    - The Planning Code specifies requirements for the exchange of information between the EAPP Subcommittee on Planning and Transmission System Operators (TSO) in order to take account of developments, new connection sites, modification of existing sites, and changes to factors such as demand, environmental constraints, generation or new technology
- Connection Code:
    - Specifies minimum technical and design criteria of plant which must be complied with in order to maintain a secure and reliable operation of the EAPP Interconnected Transmission System
    - Connection Code minimum requirements are to be applied even at local levels of transmission
    - The Connection Code establishes requirements for characteristics like frequency, voltage, harmonics, and phase unbalance
    - The Connection Code also specifies factors like safety and protection requirements, technical requirements of generating units, monitoring of these units and their maintenance
- Operations Code:
    - The Operations Code allows EAPP and individual TSO to plan out generating unit and transmission line outages, based on demands, scheduled maintenances and other factors

    - A three (3) year window is established, during which information on the Operation Planning will be interchanged between the TSO and EAPP
    - This Operation Planning procedure includes outlining a timetable for the coordination of generation units and transmission line outages
    - The information exchanged will include monthly, hourly demands, load flows and effects of outages on power flows
    - The Operations Code also includes provisions for security and reliability of the generating units and transmission lines based on real time operation of the system. This means that the Code provides requirements and principles for achieving and maintaining security as well as outlining steps for ensuring that the EAPP Interconnected Transmission System operates within the technical parameters set under the Planning and Connection Codes
    - The Operations Code also identifies emergency conditions which may disrupt transmission of electricity, and steps to mitigate or respond to these conditions
    - The security response efforts include identify human and technical sources of the emergency, warnings and alert systems, real-time responses, system restoration, identification of security responsibilities and incident reporting
    - In the case of insufficient capacity to meet demands, and in order to reduce an overloading of the system, the Operations Code also outlines procedures for reducing demand on the system. The identified methods of demand control are automatic, emergency and planned load shedding
- Interchange Scheduling Code
    - One of the main objectives of EAPP is to promote electricity trading between member states, initially between neighboring states, and later through the infrastructure of more complex arrangements
    - This is done through the determination of Net Transmission Capabilities between Neighboring Control Areas, publication of these values to allow TSOs to evaluate potential interchanges, and allocating Net Transmission Capabilities to TSOs in accordance with pre-determined rules and Interchange Schedules
- Balancing and Frequency Control Code
    - The frequency of a power system in an indication of the balance of its generation and demand. This code deals with ensuring that each TSO has sufficient reserve capacity in order to maintain interchange schedule within the EAPP Interconnected Transmission System, and to control system frequency so as to meet minimum standards under normal and emergency conditions
    - Doing that entails implementing an automatic response from synchronised generating units, controlling response from interconnections with external systems (systems external to EAPP Interconnected Transmission Systems), controlling demand
- Ancillary Services Code
    - These services deal with ensuring that services exchanged among generation resources, load customers and transmission providers are done in a way such that EAPP Interconnected Transmission Systems is reliable and there is sufficient separation of generation, distribution and distribution functions; in other words, this section covers those services provided outside and in support of EAPP to ensure the reliability and efficiency of the system

    - Ancillary Services are grouped into frequency control, network control, and system restart capability
- Data Exchange code:
    - Data to be exchanged between TSO and EAPP for purposes of analysis and modelling
    - The Data Exchange Code details how EAPP models are produced, information management across interface between EAPP Sub-Committees on Planning and Operations and TSOs, and to provide a basis of cooperation regarding system analysis
    - Basic data to be monitored for a system study includes electrical characteristics and ratings of transmission facilities and the timing of new facilities
    - A list of data required by EAPP for the system modelling is given as:
        - **Substation**: name, nominal voltage, demand supplied (consistent with the aggregated and dispersed substation demand data supplied) and location
        - **Generating Units (including synchronous condensers, pumped storage, etc.)**: location, minimum and maximum Ratings (net Real and Reactive Power), regulated bus and voltage set point, and equipment status
        - **AC Transmission Line or Circuit (overhead and underground)**: nominal voltage, impedance, line charging, Normal and Emergency Ratings, equipment status, and metering locations
        - **HVDC Transmission Line (overhead and underground):** line parameters, Normal and Emergency Ratings, control parameters, rectifier data, and inverter data
        - **Transformer (voltage and phase-shifting)**: nominal voltages of windings, impedance, tap ratios (voltage and/or phase angle or tap step size), regulated bus and voltage set point, Normal and Emergency Ratings and equipment status
        - **Reactive Compensation (shunt and series capacitors and reactors)**: nominal Ratings, impedance, percent compensation, connection point, and controller device
        - **Interchange Schedules**: Existing and future Interchange Schedules and/or assumptions.
- Metering Code:
    - Metering of each point of interchange of energy and associated data collection equipment
- System Operator Training Code:
    - Ensures that System Operators are continuously provided with operational training

4.4.2 WAPP – Western Africa Power Pool: Update of the ECOWAS revised Master Plan for the Generation and Transmission of Electrical Energy

ECOWAS is the Economic Community of West African States, made up of 15 states: Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. The Western Africa Power Pool (WAPP) is a specialized program within ECOWAS, aimed at integrating the electricity sector within Western Africa for the purpose of optimizing access to electricity in the region. The Revised Master Plan for the Generation and Transmission of Electrical Energy presents to various players of the electrical sector within the region with a clear, coherent vision of the future developments to the infrastructure of electricity. The aim of the Plan is to integrate ongoing developments in a medium to long term strategy of expansion in the electricity sector. The Master Plan extends to the year 2025.

Volume 1: Summary of Data used

Summary of data used provided in Master Excel sheet

Volume 2: Optimal Development Plan and Analysis of Transmission Network Performance and Stability

This document, Volume 2 of a 4 volume series describing the Master Plan, is organized into two parts. The first part presents the methodology, data and results of an economic study which calculates an optimal investment plan of production and transport, so results in a set of priority projects for integrating the electricity sectors within Western Africa; the second part of the document presents results of the network performance calculations and stability analysis of the interconnected system, and highlights modifications to the first list of priority projects for technical reasons.

4.4.2.1 Methodology

The objective of the study is to perform an economic analysis that will result in a list of first priority projects and their corresponding investment plan. A techno-economic simulation will supplement and update the investment plan and further determine the feasibility of list of projects. The study distinguishes between:

1) National projects of production, projects of production supported by regional entities, and regional projects of production, on the one hand; and
2) Regional projects of interconnection

Environmental, financial and institutional impacts of the proposed projects will be studied in later work and will further update the investment plan.

The stages identified through this study are:

1) Scenario 1: evolution of national parks of production until 2025; no new interconnections

2) Scenario 2: optimal development of production at regional level, with no limitations on power transit within the region. The comparison of Scenario 1 and Scenario 2 is equal to the maximum profit that can be obtained from a complete integration of the power system in the region
3) Scenario 3 (Reference): optimizing production and transport at regional level, while taking into account limits of transit related to interconnection
4) Scenarios 4 to 11: sensitivity analysis of Reference Scenario (3). The sensitivity analysis will employ:
    a. Delaying construction of projects by 2 years
    b. Low growth in electricity demand
    c. A target for renewable energy to be 10% of total energy by 2020
    d. A drop in fuel prices (from 100 USD/bbl to 75 USD/bbl)
    e. A rise in fuel prices (from 100 USD/bbl to 125 USD/bbl)
    f. An actualization rate of 8% (from 10%)
    g. An actualization rate of 12% (from 10%)
    h. Limiting hydroelectric capacity in Guinea

The technical analysis in this study explores:
1) Static and dynamic studies for the 2015 peak load (for interconnections of countries and limitations to development of interconnections)
2) Static and dynamic studies for the 2015 off-peak load (for interconnections of countries and limitations to development of interconnections)
3) Static studies for peak load in 2020 and 2025

The model used in this analysis is PRELE. The model optimizes operation and investment decisions of a system by minimizing actualized total costs. It takes into account real constraints such as construction delays, years of dry or wet years (limitations in the hydrology), cost and availability of fuel in each country, and so on. Part of the model's output is to determine whether it is optimal to use existing plants or the construction of new plans as well as the optimum flows of capacity between countries.

4.4.2.2 Data

Volume 1 of the Master Plan details data used. General data referred to in this Volume, however, includes the actualization rate (10%), price of fuel (base, low and high), costs of transporting fuel, availability of fuel within each country and whether it is locally obtained or transported from other countries within the region. Special attention is given to Nigeria as it has the largest reserves of thermal fuel.

The next part of the study determines the load forecast or electricity demand in each country. The following steps are employed in calculating demand forecasts:

1) Historical data of loads, shedding statistics and average time of load supply are obtained from each country. This data includes served and un-served load information
2) Demand forecasts previously calculated within each country, those computed by utility companies within the countries, as well as those produced by other consultants were compiled

3) Demand forecasts were then calculated for each country. Two scenarios (base and low demands) were computed based on either
    a. Combinations of historical trends and macro-economic factors (GDP, population, electrification rates, and so on); or
    b. The semi-comprehensive method of estimating method of forecasting demand by industry and geographic locations

As such, the demand forecasts for each country are presented for the years 2011 to 2025.

In order to determine generation data for each of the countries in Western Africa, the following steps were taken:

1) Estimates of cost of new technologies were calculated for gas turbine, combined cycle, coal, high-speed and medium-speed diesel, and biomass. For these fuel types, where concrete data on the costs of these technologies within each of the countries were available, calculations of cost were based; otherwise, standard investment data were proposed; the modeling platform, Thermoflow, was used to calculate investment costs for these fuel types
2) The study finds that there are large reserves of hydroelectric power in the basins of West Africa (especially the Senegal, Niger, the Gambia and Konkoure river basins)
3) However, the study points out that most of these hydroelectric resources would not be tapped into by 2025 due to the financial limits, environmental impacts and inaccessibility in the region
4) In addition, cost estimates for wind and solar power plants were also estimated

The list of projects from each of the countries within the region is included in an excel sheet. The projects are organized as “decided”, units whose construction is undergoing or for which funding was secured, and “candidate”, units for which studies are not complete or for which no funding has yet been secured.

The study presents results from the PERLE model. Results show the installed capacity and energy produced in the case where no new interconnections are introduced to the energy mix in the region, meaning that energy investment plans are allowed to evolve with current interconnections; the second scenario is where no interconnection limits are imposed, meaning that energy produced is essentially shared over the entire system in a way that is financially optimal for the region; and the third scenario (Reference) allows for specific interconnection projects to be built. In each simulation of the project, hydroelectric power is the dominant source of energy (in particular for Guinea). Additionally, results show the impact of including the mining sector into the energy demand. Such inclusion changes the load demand of each country, in most instances transforming countries from exporters into importers of energy.

For the Reference scenario, ongoing projects (for which financing and studies have been completed) as well as proposed economically viable interconnection projects are given in the study. A summary of interconnection projects are provided in Excel format.

4.4.2.3 Comparison of the Scenarios

PERLE analysis results in the costs of each scenario. The following table is a summary of each scenario's cost:

Summary of the costs (kUSD)	*Scenario 1*	*Scenario 2*	*Scenario 3*
	Without new interconnection	Without transit limits	Reference scenario
Investments costs			
Generation units	6 316.334	6 868.480	7 010. 508
Transmission lines			103.061
Fixed costs of the generation units	1 012.092	836.852	953.520
Variable costs of electricity (except natural gas)	11 517.466	4 125.571	8 360.262
Cost of natural gas	39 373.910	40 352.594	38 701.317
Total	58 219.802	52 183.497	55 128.668

4.4.2.4 Studies of the Sensitivity

The report presents the following as cost estimates of the sensitivity studies:

Reference Scenario/Sensitivity	Total Cost (kUSD)
Reference Scenario	55,128,668
a. Delaying construction of projects by 2 years	55,374,609
b. Low growth in electricity demand	49,337,339
c. A target for renewable energy to be 10% of total energy by 2020	56,251,999
d. A drop in fuel prices (from 100 USD/bbl to 75 USD/bbl)	44,647,252
e. A rise in fuel prices (from 100 USD/bbl to 125 USD/bbl)	65,374,071
f. An actualization rate of 8% (from 10%)	similar to high fuel costs
g. An actualization rate of 12% (from 10%)	similar to low fuel costs
h. Limiting hydroelectric capacity in Guinea	55,303,181

4.4.2.5 Conclusion: List of Priority Projects

The study then identifies and lists a number of priority projects whose construction proved to be economically viable (results of Reference Scenario analysis). These are provided below:

Name of the project	Country	Technology	Commissioning
Balassa, Boureya, Koukoutamba (OMVS)	Guinea	Hydro	2020
Grand Kinkon	Guinea	Hydro	2018

Kassa B	Guinea/Sierra Leone	Hydro	2018
Souapiti	Guinea	Hydro	2018
Amaria	Guinea	Hydro	2018
Tiboto	Liberia/Ivory Coast	Hydro	2018
Soubré	Ivory Coast	Hydro	2018
Zungeru	Nigeria	Hydro	2018
Mambilla	Nigeria	Hydro	2018
Salkadamna	Niger	Coal	2020
Combined cycle	Togo	Nat. Gas	2020
200 MW park	Senegal/The Gambia	Wind	2016-2020
300 MW park	Nigeria	Wind	2016-2020
150 MW park	Burkina Faso	Solar photovoltaic	2016-2020
150 MW park	Mali	Solar photovoltaic	2016-2020

A similar list of proposed and priority transmission lines is also provided:

Name	Associated production project	Commissioning	Capacity
Median backbone	Zungeru	2020	300 MW
Liberia (Monrovia) - Ivory Coast (San Pedro)	Tiboto	2018	150 MW
OMVS-OMVG interconnection (Tambacounda - Kayes)	Gouina	2017	250MW
OMVS-OMVG interconnection	Koukoutamba, Boureya, Balassa	2018	250MW
(Linsan – Manantali)			
Guinea(Fomi) – Ivory Coast		2018	2x250 MW
(Boundiala)			
Linsan-Fomi (second line)		2018	250 MW
Boundiala-Ferke – Bobo			
(second circuit)		2018	250 MW
Bobo – Ouaga (second line)		2018	250 MW
Ligne CLSG (second circuit)		>2020	250 MW
Coastal backbone section			
Lome-Sakété (second line)		>2020	312 MW
Salkadamana - Niamey	Salkadamna	2020	200 MW
Salkadamana - Center East	Salkadamna	2020	100 MW

4.4.3 Southern Africa Development Community (SADC) Reports

SADC member states are located in 3 of the 7 river basins covered in this report, namely, Congo, Nile and Zambezi basins, therefore there is a certain amount of inter basin policies and programmes under SADC implementation. Relevant reports are summarized below .

4.4.3.1 Regional Water Infrastructure Programme (2010)

This report provides an overview of the origins of the programme and its institutional framework. The Programme is comprised of three main sub-programmes:

- Regional Water Supply and Sanitation Programme (RWSSP) which entails the development of a regional framework for water supply and sanitation, planning and management to facilitate the attainment of the Millennium Development Goals (MDGs).
- Community Livelihood and Integrated Water Resources Management (IWRM) Development Programme which is comprised of projects to demonstrate and promote the benefits of IWRM at community level.
- The Regional Strategic Water Infrastructure Development Programme (RSWIDP) aims to promote the development of strategic water infrastructure including rehabilitation and expansion of existing facilities and the creation of new facilities for water supply and sanitation.

The RWSIDP has a number of bankable water infrastructure projects prepared. These are listed in the report under the headings Small and Medium Priority Projects, Macro-Priority Projects, and IWRM Demonstration Projects.

4.4.3.2 Climate Change Adaptation in SADC: A Strategy for the Water Sector

The Climate Change Adaptation (CCA) report details how the SADC plans to adapt its water management strategies to account for climate change. It begins by describing how climate change will potentially affect water availability in SADC countries and the resulting socio-economic impacts. It specifies adaptation measures in alignment with the Regional Strategic Action Plan (RSAP III) strategic areas which are:

- Water Governance
- Infrastructure Development
- Water management

RSAP III has a series of 15 programmes through which it strives to achieve its operational goals, most of which are making provision for the implementation of interventions relevant to the CCA Strategy. An implementation plan is also laid out including monitoring and evaluation methods.

4.4.3.3 SADC-HYCOS Phase II Project – Final Report: Strategic and Optimum Network Design for the SADC-HYCOS Phase II Project

The overall objective of SADC-HYCOS (Hydrological Cycle Observing System) project is to contribute to regional socio-economic development through the provision of management tools necessary for sustainable and economic water resources development and management.
This report focuses on one specific objective of the Phase II project, namely, the design of a strategic and optimum network.
The specific objectives of this project that are relevant to the SADC-HYCOS Phase II Project are;

- To set up an enabling environmental at the regional and national levels for Integrated Water Resource Management (IWRM) implementation.

- To establish water resources management systems which include hydrological and water demand forecasting models and other tools for joint planning and management in the Zambezi Basin.
- To develop an IWRM strategy for existing and future development plans and management systems.

The design of the network was accomplished by identifying the needs of the member states through a questionnaire survey and network design workshops. These resulted in the allocation of additional hydrological monitoring stations at key points in 15 SADC basins and the improvement of existing water quality and groundwater monitoring strategies.

4.4.4 Central African Power Pool (CAPP) Report

The following is the introduction to the Central African Power Pool report, written in 2004. The report was written in French, and the following is a translation of the introduction. Program Projects Electrification of Cross-Border Cities (PETL) was prepared with the assistance of the Union of Producers, Transporters and Distributors of Electrical Energy (UPDEA) and Electricity Companies members. It covers all five subregions of Africa including Central Africa. The program aims to supply electricity to the border communities, mostly rural, near the borders of a country from a source of hydropower in another neighboring country of the subregion.

The report finds that in both sides of national borders, many communities without electricity, while just a few kilometers away, and even a few hundred meters away, in neighboring towns or localities fed electricity 24 hours with 24 and sometimes over distances exceeding the local need. In some cases, border communities of a country living in the dark or are fed improperly as generators while just on the other side of the border towns in the neighboring country, hydropower is available.

This is the long-standing difficult to justify today in the era of NEPAD and the construction of a regional common market, based African Unity. Therefore, as part of its vision, the Central African Power Pool (PEAC) has made cross-border electrification of localities one of its priority projects in the short and medium term. Public Administrations energy and electricity companies were directly involved and made a contribution in the selection of projects fats by Energy Ministers of ECCAS and will be expected to follow all phases of implementation studies feasibility and construction of technical infrastructure. With this in mind that the attached projects were conducted by experts and local professionals, who know the environmental and technical infrastructure covered by this program.

The Secretariat of the SPCA, following the specific mandate entrusted to him by the Council of Energy Ministers of member countries of the Economic Community of Central African States (ECCAS), research funding needed to carry out these projects with donors of international development funds among which is the first place of Group African Development Bank (ADB).

The Electrification Program Projects of Cross-Border Cities (PETL) pursues the following main objectives:

- The fight against poverty;
- The fight against rural exodus;
- The opening up of rural electric border;
- Increasing the rate of electrification;
- The preservation of the environment in the fight against deforestation;
- Sustainable development.

The decision of Electrification Project selection border communities was taken on the proposal of Experts UPDEA, Committees and Executive Director of the SPCA, the Council of Energy Ministers of ECCAS after its May 2004 session in Malabo.
The following criteria were considered:

1) The project must relate to locations in at least two countries;
2) Feasibility studies or performance exist or may be implemented in a relatively short time by local expertise;
3) The project should have a real impact on the level of life and activity of rural beneficiaries;
4) The cost of the project and took the cost of electricity should be considered in relation to the purchasing power of beneficiaries.

The first list of projects to rural character retained by the decision-making bodies of the Central African Power Pool is as follows

No	Company/Country Involved	Number of Projects	Total Cost (USD)
1	AES-Sonel (Cameroon)	3	2,260,138
	STEE (CHAD)		
2	AES-Sonel (Cameroon)	1	7,400,000
	SEEG (Gabon)		
	SEGESA (Equatorial Guinea)		
3	NIS (Congo)	4	17,529,387
	SEEG (Gabon)		
	MMERPRH (Energy Ministry of Gabon)		
4	ENERCA (Central Africa)	1	12,538,000
	SNEL (DRC)		
5	ENERCA (Central Africa)	1	10,000,000
	SNEL (DRC)		
6	SEGESA (Equatorial Guinea)	1	180,000
	AES-Sonel (Cameroon)		
7	SEGESA (Equatorial Guinea)	1	205,000
	AES-Sonel (Cameroon)		

Project Descriptions:

1) Cameroon to Chad: Electrification of the city of Bongor (Chad) from Yagoua (Cameroon)

a. Transmission line to have HV/MV capacity of 90 kV/30kV
b. Construction of 3.5 km mixed MV/LV three-phase cable
c. Construction of 16.5 km of LV three-phase cable
d. Construction of 6 transformer stations (50kVA, 2x100 kVA, 160 kVA, 250 kVA and 400 kVA)
e. The expected results of the project are to revive economic activity of the city, specifically its cotton ginning, irrigation, fishery and rice milling; and to reduce greenhouse gas pollution by decommissioning the city's thermal power plants
f. The estimated cost of the project is $2,260,138

2) Cameroon to Chad: electrification of Datcheka, Fianga and Gounougaya (Chad) from Maroua and Doukoula (Cameroon)
    a. Transmission line to have HV/MV (90/30/15 kV)
    b. Datcheka
        i. 1 km of MV line 3x54 mm2 Almelec
        ii. 1.5 km of LV 4x25 mm2
        iii. 1 IACM
        iv. 1 MV/LV pole from 50 kVA
    c. Fianga
        i. 2.5 km of MV line 3x54 mm2 Almelec
        ii. 3.5 km of line mixed MV/LV
        iii. 5.2 km of LV 3x50mm2
        iv. 1 IACM
        v. 3 MV/LV pole (1 of 50 kVA to 2 160 kVA)
    d. Gounougaya
        i. 1.6 km of line mixed MV/LV
        ii. 6 miles LV 3x50 mm2
        iii. 1 IACM
        iv. 1 MV/LV pole of 160 kVA
    e. Tikem
        i. 1 km of MV line 1x34 mm2 Almelec
        ii. 1 km from LV 4x25 mm2
        iii. 1 MV/LV pole single phase 25 kVA
    f. Project is estimated to cost $4,741,787

3) Electrification of Lere, Pala, Binder, Ribao, Mombore, Mamboroura towns in Chad, from the interconnected northern Cameroon
    a. Lere
        i. 7 km line mixed phase MV / LV (3x54 mm ² / 3x50 mm ² + PE + NP)
        ii. 4 miles from LV three-phase 3x50 mm ² + PE + NP
        iii. 1 IACM
        iv. 2 MV / LV pole (50 kVA and 100 kVA)
    b. Pala
        i. 8.5 km of MV line 3x54 mm ² Almelec
        ii. 14.5 km of LV three-phase 3x50 mm ² + PE + NP
        iii. 6.5 km of line mixed MV / LV (3x54 mm ² / 3x50 mm ² + PE + NP)
        iv. 5.2 km of LV 3x50 mm ² + PE + NP
        v. 7 IACM 30 kV

vi. 7 MV / LV pole (2 of 50 kVA, 100 kVA 3 and 2 of 160 kVA)

c. Ribao:

i. 17.33 kV single-phase MV line of section 34mm2Almélec: 500m
ii. 220V single phase line section BT 4x25mm2 Aluminum: 1km
iii. MV / LV wood poles on single phase 25 kVA: 1
iv. 2-wire connections (220 V): 22

d. Mombore

i. 17.33 kV single-phase MV line of section 34mm2 Almelec: 500m
ii. BT line single phase 4 x 25mm2 Aluminium: 1 km
iii. MV / LV single-phase pole-wood 25 kVA: 1
iv. 2-wire connections (220 V): 35

e. Mamboroua

i. 17.33 kV single-phase MV line section of 34mm2 Almelec: 500m Line
ii. Single phase BT 4 x 25mm2 Aluminium: 1km
iii. MV / LV single-phase pole-wood 25 kVA: 1
iv. 2-wire connections (220 V): 30

f. Binder

i. Line MV / LV combined (17.33 kV / 220V; Almelec 54mm2 MV and LV Alu
3x50mm2): 1km
ii. BT line single phase 4 x 25mm2 Aluminium: 5.5 km
iii. Post-phase wood pole with a transformer of 25 kVA: 1
iv. 2-wire connections (220 V): 80

g. Establishment of a communications network comprising:

i. Study of propagation
ii. Acquisition and installation of antennas and relay
iii. Acquisition and installation of fixed and mobile radios

h. The whole project is appraised at USD 9,257,824

4) This project aims to supply electrical power from hydropower cities Meyo-Kye Ebebiyin in Gabon and Equatorial Guinea. This Electrification will downgrade thermal-Amban, Olamze Ebebiyin and thereby reducing the gas emissions effects emissions.

a. The following locations will be supplied: Meyo Centre; Akina; Akak Meton; Ngom Adjap; Akomekye; Meyo Elijah; Mekoe; Nkoume Kemi Yama; Zamen Kam; Meyo Nyaka; Ngoazip; Meyo Nkoulou; Meloup; Kono Konossi; Akonangui; Mendong; Nsana; Minyom - Nkam; Meko'onengona; Meko'ossi

b. The main project components are:

i. Installation of an auto-transformer at MV / MT Ebolowa;
ii. Extend the network in MT 30kV cable Almelec section 93mm2 Ebolowa to Kye-Ossi 140 km;
iii. A single phase brettelle 1.5 km Kye-Ossi (Cameroon) at Meyo-Kye (Gabon)
iv. A ramp of three-phase cable 3x54mm2 Ngoazip Olamzé to 25km
v. A three-phase cable strap of Kye-Ossi 3x54mm2 (Cameroon) Ebebiyin (Equatorial Guinea) of 2 km.

c. The project is estimated to cost USD 7,396,771

5) Electrification of cities and Lékéti Okoyo (Congo) from the city of Léconi (Gabon) located 25 km from the border between Gabon and Congo
    a. Project estimated to cost USD 6,925,000
    b. Construction of the line Léconi - Akou - Kabala, in Gabonese territory, 25 km HTA technique;
    c. Construction of a boundary MT / MT switching system with MV metering;
    d. Construction of an overhead line MV 85 km border between Gabon - Congo and the city of Okoyo;
    e. Electrifying the following villages
        i. D'Akou, Kabala, Assiene, Mbie, d'Edzouga, d'Ongali, Leketi, d'Okoyo
6) Electrification of the city Bambama (Congo) from the city of Boumango (Gabon), located 23 km from the border between Gabon and Congo
    a. Construction line Boumango - Doumay - Frontier in the territory Gabon, 23 km in technical hypertension;
    b. Construction of a boundary MT / MT switching system with MV metering;
    c. Construction of an overhead line MV 35 km from the border - Simonbondo - Mavounougou - Bandoye - Bambama (Congo);
    d. Electrifying the following villages
        i. Doumay, Simonbondo, Mavounougou, Bandoye, Bambama
7) Electrification of the city of Divénié (Congo) from the city of Malinga (Gabon) located 05 km from the border between Gabon and Congo
    a. Construction of the line Malinga - Moukondo - Divénié in the territory Congo, 55 km in technical hypertension;
    b. Construction of a boundary MT / MT switching system with MV metering;
    c. Electrification of the Village of Moukondo (100 inhabitants):
        i. Construction of one (1) position H61 phase MV / LV;
        ii. Construction of a network of electrical energy distribution BT of 1 km
        iii. Completion of ten (10) single-phase connections.
    d. Electrification of the city of Divénié (5000 inhabitants):
        i. Construction of four (4) PBS stations MV / LV;
        ii. Construction of a distribution network of electrical energy 10 km BT
        iii. Completion of five hundred (500) single-phase connections.
    e. The project is estimated to cost USD 3 653 509
8) Power supply for the city of Zongo (Democratic Republic of Congo) from Network Distribution (Central African Republic)
    a. The project is composed of three essential elements: Increased Production Capacity hydraulic; increase in production of hydraulic Capacity is to: supply and install two Kaplan turbines of 5 MW at the foot of the Dam
    b. The project is estimated to cost USD 12,538,000
9) Electricity supply of cross-border towns Mobaye, Kongbo, Alindao, Kembe (Central African Republic) from Hydroelectric Mobaye (DRC)
    a. 4.1 - Content of the project
    The project consists of:
    - Install an MV of 1.5 MVA starting at the hydroelectric plant

Mobaye that would discharge the energy by the transmission line
63 Kv of 106 km to Alindao but operated in the first 30 Kv
phase with a view to extend the line up in the second Bambari
phase.
- Building a transmission line of 30 KV and 50 km between Kongbo
Kembe. This line will supply the way the different cities.
- Rehabilitate and expand the distribution network MV / LV in cities
already electrified.
- Building a distribution network MV / LV in cities without electricity.
4.2 - Technical Project
- Install a starting position with a capacity of 1.5 MVA, the game
bar, crossing the Ubangi river with a line of 63 KV on
existing towers, and install a substation (63/30 KV)
- Line 30 KV MT technology
- Line MT technology 20 KV or 15 KV
- The MV / LV will design, pole-type H61. the
powers of deduction will be 25, 50, 100, 160 KVA. tensions
primary will be 15, 20, 30 KV; secondary voltages of 400 V between
phases.
- The BT line will be pre-assembled cable section of 3 x 70 + x 3 and N
35 + N

    b. The project is estimated to cost USD 10,050,000

10) Electrification of the city of KYE-OSSI Republic of CAMEROON from MV 15 KV Ebebiyin in Equatorial Guinea
    a. The project is estimated to cost USD 180,000
    b. No further information provided
11) Electrification of the city in GABON MEDJENG from MV 15 KV Mongomo of Equatorial Guinea.
    a. The main project components are:
       · Construction of an underground 15 kV MV line 35 mm2 copper 4 km between the two localities;
       · Construction of a HV / HV prefabricated MEDJENG to 250 KVA.
    b. The project is estimated to cost USD 205,000

4.4.5 Southern African Power Pool (SAPP) Statistics

The Southern African Power Pool website did not include an investment plan. Instead, annual statistics were produced as well as an annual report that highlighted the year's SAPP events. It does not, however, include any plans for new power plants or transmission lines. The following are tables from SAPP's Annual Statistics reports, published in 2010. It describes SAPP existing generation stations.

	SAPP UTILITY GENERATION MIX , MW											
Technology / Utility	BPC	EDM	ENE	ESCOM	Eskom	LEC	NamPower	SEC	SNEL	TANESCO	ZESA	ZESCO
Base Load Hydro	-	498	760	286	2,000	72	240	63	2,442	561	750	1,802
Coal	132	-	267	-	37,831	-	132	9	-	-	1,295	-
Nuclear	-	-	-	-	1,930	-	-	-	-	-	-	-
CCGT	-	-	160	1	-	-	-	-	-	485	-	-
Distillate	70	51	-	-	2,409	-	21	-	-	78	-	10
Total	202	549	1,187	287	44,170	72	393	72	2,442	1,124	2,045	1,812

	SAPP UTILITY GENERATION MIX , %											
Technology / Utility	BPC	EDM	ENE	ESCOM	Eskom	LEC	NamPower	SEC	SNEL	TANESCO	ZESA	ZESCO
Base Load Hydro	0%	91%	64%	100%	5%	100%	61%	88%	100%	50%	37%	99%
Coal	65%	0%	22%	0%	86%	0%	34%	13%	0%	0%	63%	0%
Nuclear	0%	0%	0%	0%	4%	0%	0%	0%	0%	0%	0%	0%
CCGT	0%	0%	13%	0%	0%	0%	0%	0%	0%	43%	0%	0%
Distillate	35%	9%	0%	0%	5%	0%	5%	0%	0%	7%	0%	1%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

4.4.6 Master Plan and Transport Project Prioritization in Central Africa

This report describes the Master Plan for the transport sector as developed by the Economic Community for Central African States (ECCAS). It is written in French, and the introduction of which was translated below. The 11 African countries represented are: Angola, Burundi, Cameroon, Congo, Gabon, Guinea Equatoria, Central African Republic, Democratic Republic of Congo, Rwanda, Chad, Sao Tome and Principe. The Heads of State and Government of the Economic Community of Central African States (ECCAS) have adopted - in January 2004 - a master plan for development of the transport sector, called the Master Plan of Transportation in Central Africa (PDCT-AC). The plan includes collective needs of the subregion in terms of infrastructure development in the area of transport, expressed by member states in 2003.

These requirements translate to 184 projects. To ensure their proper promotion, the Monitoring Committee decided on PDCT-AC2, to establish a "portfolio" of projects that can serve as basis for resource mobilization. For this purpose, a study on the prioritization of these projects was conducted by the Subregional Office for ECCAS, at the request of the Monitoring Committee. In October 2005, the Monitoring Committee (SOC and CMS) was held in Libreville (Gabon) with the aim to approve the results of this study, previously reviewed by experts in the Transport and Public Works of Central African States.

The Committee particularly dwelt on the multi-criteria methodology used by the CEA / BSRAC to prioritize projects in the PDCT-AC. Based on the amendments made by the experts it adopted the selection criteria and a system for evaluating and ranking projects.Furthermore, the

Committee requested States to provide information and data necessary to the application of the methodology adopted.
This information relates (a): list (i) road sections belonging to the axes Community and integrators PDCT-AC, (ii) projects PDCT-AC under negotiation or financing, or for which funding is already in place, (iii) projects under implementation; (Iv) funded projects on equity, (b) road maps (c) transit traffic; (d) economic studies, including the internal rate of return projects, (c) the population served by the project, (d) the proximity and / or the crossing of protected areas of the forest equatorial (e) the degree of private sector participation in the implementation and project management; (F) mounting PPP.The Committee also requested that prior to the application of criteria for prioritizing projects, there should be either a completion or classification and codification of development corridors

In March 2006, experts in transportation and public works of the ECCAS member states, met in Yaounde to discuss the progress of the study including prioritization of the, (i) the network Community transport of Central Africa, (ii) development corridors, (iii) priority groups, (iv) the suggestions of donors on prioritization criteria. They have found a deficit of information and data necessary for the application of the methodology of prioritization and requested support for a mission of COS circular data collection and information is conducted in the eleven member countries of ECCAS to allow finalization of the study. This report presents the results of the prioritization of projects PDCT CA-based data and information collected during the mission Circular.

4.4.7 East African Community (EAC)

4.4.7.1 Investment Opportunities in EAC Climate Change Programme: 9th African Investment Forum

This report begins by describing why the EAC is vulnerable to the potential impacts of climate change and why there is a need to invest in climate change mitigation and adaptation strategies. The objectives of the EAC Climate Change Programme are namely:

- To support the development of national climate change adaptation strategies
- To support the development of nationally appropriate mitigation actions and low carbon development pathways

The program has prioritized a number of adaptation action plans that have previously been identified in National Adaptation Programs of Action (NAPAs) and National Adaptation Plans (NAPs). These include:

- Strengthening meteorological services
- Promoting water conservation practices
- Improving agricultural productivity
- Biodiversity and ecosystem protection
- Climate-proofing socio-economic infrastructure

GHG emission level reduction plans are also outlined in the report. Potential beneficiaries and funding requirements are also described.

4.4.7.2 The East African Road Network Project: Detailed project profiles, Jan 2007

This report provides detailed road network projects that were agreed in 1998 for each EAC member state. It includes the objectives, area, history, current status and required intervention for each project.

4.4.7.3 The East African Trade and Transport Facilitation Project: East African Transport Strategy and Regional Road Sector Development Program. Part IV: Consolidated Project List, Sept 2011

Provides a detailed tabulated list of all transport projects in EAC member states, as of Sept 2011. It also includes a breakdown of funding.

4.4.8 Economic Community of West African Stated (ECOWAS) Bank for Investment and Development Strategic Plan 2010-2012

The 2010-2014 Strategic Plan defines agriculture, rural development, infrastructural improvement, and the promotion of the private sector as its priorities. The Plan seeks to optimize the allocation of resources by obliging the Bank to be more selective in its operations and also to put a premium on regional integration.

4.4.9 Congo River Basin

Democratic Republic of Congo, Central African Republic, Congo, Tanzania, Burundi, Cameroon, Zambia, Angola

No relevant reports that covered the Congo River Basin or its respective states were found during the course of this exercise.

4.4.10 Niger River Basin

Mali, Nigeria, Niger, Guinea, Burkina Faso, Cameroon, Cote d'Ivoire, Algeria, Benin, Chad.

The Niger Basin Authority has been involved in two major projects that are relevant to this report. They were involved in the WHYCOS project (also summarized above) and a Sustainable Development Action Plan (SDAP). The SDAP is comprised of three reports that are summarized below.

4.4.10.1 *Niger – HYCOS: An Information System for Water Resources Assessment and Management of the Niger Basin. World hydrological cycle observing system (WHYCOS), 2006*

This document sets out the framework for the implementation of the Niger River basin hydrological observing system, designated Niger-HYCOS. The ultimate objective of the Niger-HYCOS Project is to establish a system of useful information on water resources at the basin level fed with recent, high-quality data easily accessible to all user groups, with a particular emphasis on use of internet technology.
The main outcomes of this project were as follows:

- Establishment of a real time data collection network comprising 65 data collection
- platforms (DCPs)
- Establishment of an operational hydrology data bank
- Construction of flood prediction models
- Training of staff at the NBA Executive Secretariat and in Member States in all areas
- of project activity
- Procurement of major consignments of transport and hydrological equipment
- Construction of buildings to house regional and national forecasting centres.

4.4.10.2 *Elaboration of an action plan for the sustainable development of the Niger Basin, Phase 1: Assessment and analysis - Final Report. Niger Basin Authority (NBA), 2007.*

This report is the SDAP first phase report, the Appraisal Report. It is an assessment of the issues and priority development themes in the Niger catchment area. The top priority concerns and potential actions of the SDAP are (i) the conservation of the basin's ecosystems, (ii) the development of socio-economic infrastructure, and (iii) capacity building and stakeholder involvement.

Altogether 14 different themes were analysed under 3 sectors namely; 1) services sector e.g. drinking water and transport, 2) economics sector e.g. agriculture, energy, 3) crosscutting themes e.g. environment, institutional organisation. They are all directly related to the two key areas of Ecosystem Conservation and the Development of Socioeconomic Infrastructure.

The key issues for integrated water resource management (IWRM) are identified and discussed. They include:

- The balance between dam water control and conservation of the Inner Niger Delta;
- The impact of development of the Middle Niger on downstream areas;
- optimising resources; and
- The impact of the abstractions on conservation of the Outer Delta.

With regards to water, noted knowledge gaps include quantity and quality of water resources, water abstraction, regulation volumes and ecosystems' requirements.
In general for the basin, a critical analysis of the multi-sectorial studies revealed the following two major points:

- The collection of data, especially operation of a hydrometric network, is costly;

- The funding required to make this activity a continuous one is sporadic, often related to projects. This leads to breaks in data collection activities in the field of short and even long durations.

4.4.10.3 Elaboration of an action plan for the sustainable development of the Niger Basin, Phase 2: Master plan for the development and management - Final Report. Niger Basin Authority (NBA), 2007.

The Master Plan for Development and Management of the Niger Basin under the Action Plan for the Sustainable Development of the Niger Basin (SDAP) aims to alleviate poverty, protect the Niger Basin environment and strengthen cooperation between NBA member countries. The SDAP is divided into three fields:

Field 1: The development of socio-economic infrastructure
Field 2: Ecosystem conservation and resources protection
Field 3: Capacity building and stakeholder involvement in IWRM

The analysis is conducted from upstream to downstream and illustrated in a "Pathfinder tree" showing the possible paths for the development of the basin. Both ecological and socio-economic parameters are used to enable the development choices to be compared. The development plan is detailed in several stages:

- Storing water upstream of the main supply lines
- Managing Fomi Dam to meet upstream and downstream demands
- Building one or two more dams on the Niger River supply line
- Feasibility of new storage facilities

The socio-economic and environmental impacts of the proposed development and management plan are examined, including the benefits directly generated by the scenarios and how they can be managed and the environmental risks generated by the plan.

4.4.10.4 Study on the Preparation of the Investment Plan and Formulation of Investment Projects Necessary for Implementing the Shared Vision: Final Report. Niger Basin Authority, 2007

The Investment Programme follows on from the Master Plan for Development and Management and the Action Plan for Sustainable Development (SDAP). It is the final version of the Niger Basin Authority (NBA) Investment Programme. It is accompanied by an atlas showing the location of all the actions listed in the Investment Programme within the basin, and a monitoring and evaluation manual.

The report develops and discusses the following aspects:

- description of the general methodology used for the preparation of the Investment
- Programme (IP);

- the core of the IP, presents all IP actions describing their main features and their estimated cost.
- details of the Five-Year Priority Programme for the period from 2008 to 2012;
- summary of the cost of the whole IP for the 2008-2027 period, i.e. for a period corresponding to four Five-Year Programmes;
- the institutional aspects for implementation and also discusses monitoring and evaluation.

4.4.11 Nile River Basin

Uganda, Rwanda, Sudan, Burundi, Egypt, Ethiopia, Kenya, Tanzania, DRC, Eritrea.

4.4.11.1 Nile Basin Initiative

Investment projects of Nile Basin Initiative fall under the Water Resources Development function of NBI. The portfolio of investment projects is categorised into three sectors: Power, Agriculture, and River Basin Management. This represents the priority needs of member countries – for increased access to reliable and cheap electricity, for increased food security and productivity and for increased protection and management of the environment as a basis for livelihoods of the basin populations. Projects are spearheaded, prepared and coordinated by NBI's Eastern Nile Technical Regional Office (ENTRO) based in Addis Ababa, Ethiopia and the Nile Equatorial Lakes Subsidiary Action Program (NELSAP) Coordination Unit based in Kigali, Rwanda. Project implementation is undertaken at national level. Egypt is implementing the following investment projects:

- Power
  - Eastern Nile Joint Multipurpose Program
  - Ethiopia – Sudan Transmission Interconnection
  - Eastern Nile Regional Power Trade Investment Program
- Agriculture
  - Eastern Nile Irrigation and Drainage Development Project
  - Flood Preparedness and Early Warning Project
  - Regional Agricultural Trade and Productivity Project
- River Basin Management
  - Eastern Nile Integrated Watershed Management
  - Lake Nasser/Nubia Management Framework
  - Baro-Akobo-Sobat Multipurpose water Resources Project
  - Eastern Nile Planning, Information and Knowledge Management Project

4.4.11.2 Eastern Nile Joint Multipurpose Program

The project is looking into cooperative and sustainable development and management of the common Blue/Main Nile water resources, putting in place the requisite trans-boundary institutions, linking the beneficiary countries through multi-purpose storage and power system infrastructure, modernizing irrigation systems and promoting related investments such as in transport, private sector, rural electrification.

Details at:
http://nilebasin.org/newentro/index.php?option=com_content&view=article&id=83&Itemid=111&lang=en

4.4.11.3 Ethiopia – Sudan Transmission Interconnection

This project aims at increasing reliability of supply in Ethiopia and Sudan by taking advantage of the hydro-thermal complementarities and the variability of the peak demand in the two systems. The Project included two Components: The Technical Feasibility study for the Ethiopia/Sudan Transmission Interconnection as well as the Environmental and Social Impact assessment.
Details at:
http://nilebasin.org/newentro/index.php?option=com_content&view=article&id=81&Itemid=110&lang=en

4.4.11.4 Eastern Nile Regional Power Trade Investment Program

There is substantial untapped hydropower potential in EN (Ethiopia and Sudan). However access to electricity is very limited in the region except, Egypt. Power trade and the co-operative development of hydropower and transmission interconnection among the three countries is considered a viable strategy to address this problem. The project objective is to promote EN regional power trade through coordinated planning and development of power generation and transmission interconnection and creation of an enabling environment.

4.4.11.5 Eastern Nile Irrigation and Drainage Development Project

The project supports the development and expansion of irrigated agriculture as well as improvement in the productivity of small- and large-scale agriculture through improved agricultural water use. So far, 15,000 ha equally divided between Ethiopia and Sudan have been identified and studied up to feasibility level. At the same time, a pilot study on the existing irrigation projects in Ethiopia and Sudan has been conducted. The study covered three small scale irrigation schemes of Ethiopia and Rahad irrigation scheme in Sudan.
Details at:
http://nilebasin.org/newentro/index.php?option=com_content&view=article&id=82%3Aeastern-nile-irrigation-and-drainage-study-&catid=64%3Afasttrack&Itemid=109&lang=en

4.4.11.6 Flood Preparedness and Early Warning Project

This project will establish a regional institutional basis and to strengthen the existing capacities of the Eastern Nile countries in flood forecasting, mitigation and management, promoting regional cooperation as well as to enhance the readiness of these countries to subsequent implementation of the later phases of FPEW projects.
Details at:
http://nilebasin.org/newentro/index.php?option=com_content&view=article&id=80&Itemid=113&lang=en

4.4.11.7 Regional Agricultural Trade and Productivity Project

This project will carry out studies that will highlight potential agriculture and agricultural trade opportunities in the Nile basin countries and beyond. It will also increase knowledge of basin agriculture in NBI institutions as well as promote more efficient and sustainable use of water resources and economically viable investment in agriculture.

4.4.11.8 Eastern Nile Integrated Watershed Management

The Project will support beneficiary countries in overcoming natural resources degradation and promote sustainable livelihoods among the communities within the hot spot watersheds by employing various development interventions. This is in addition to contribution towards the reduction of sedimentation of downstream facilities, among other things.
Details at:
http://nilebasin.org/newentro/index.php?option=com_content&view=article&id=95&Itemid=126&lang=en

4.4.11.9 Lake Nasser/Nubia Management Framework

The project will provide the overall framework for integrated Lake Nasser/Nubia basin management to guide development within the lake basin in order to ensure sustainable and integrated development without endangering the lake basin ecosystems.

4.4.11.10 Baro-Akobo-Sobat Multipurpose water Resources Project

This project will enhance the water resources planning and management capabilities in the sub-basin through preparation of water resources development plans and projects that respect social, environmental and economic sustainability.
Details at:
http://nilebasin.org/newentro/index.php?option=com_content&view=article&id=84&Itemid=112&lang=en

4.4.11.11 Eastern Nile Planning, Information and Knowledge Management Project

An essential element for cooperation on the Eastern Nile is the development of a shared knowledge base and appropriate analytical tools, used effectively to support decision making among multiple stakeholders. Currently, the knowledge base is fragmented and inconsistent, sharing of information is minimal, and there is lack of shared, modern, flexible analytical tools to envision various development scenarios and analyze their implications from economic, environmental and social viewpoints.
Details at:
http://nilebasin.org/newentro/index.php?option=com_content&view=article&id=79&Itemid=108&lang=en

4.4.12 Orange River Basin

South Africa, Lesotho, Namibia, Botswana.

The Orange-Senqu River Commission (ORASECOM) has created a major Integrated Water Resource Management (IWRM) document that covers water resource supply, demand, policy, climate change adaptation and power. It is summarized below.

4.4.12.1 Orange River Integrated Water Resource Management (IWRM) Plan ORASECOM 2007

In view of the existing and possible future developments which will influence the availability of water in the Orange River, a project was initiated by ORASECOM involving all four basin states (Botswana, Lesotho, Namibia and South Africa). The main objective of the project is to facilitate the development of an IWRM Plan for the Orange River Basin.
The IWRM plan was undertaken in phases. Phase 1 includes a) identifying and highlighting deficiencies in the knowledge base and b) developing a preliminary Water Resource Management Plan which can be used as the basis from which the final plan can ultimately be developed. Reports resulting from these studies include:

- Review of Existing Infrastructure in the Orange River Catchment
- Review of Surface Hydrology in the Orange River Catchment
- Flood Management Evaluation of the Orange River
- Review of Groundwater Resources in the Orange River Catchment
- Environmental Considerations Pertaining to the Orange River
- Summary of Water Requirements from the Orange River
- Water Quality in the Orange River
- Demographic and Economic Activity in the four Orange Basin States
- Current Analytical Methods and Technical Capacity of the four Orange Basin States
- Institutional Structures in the four Orange Basin States
- Legislation and Legal Issues Surrounding the Orange River Catchment.

Phase II resulted in 19 reports detailing a number of topics including the development of an Integrated Orange-Senqu River Basin Model, updating and extension of Orange-Senqu River Basin Hydrology, the preparation and development of integrated water resources quality management plan, assessment of global climate change, assessment of environmental flow requirements and recommendations for water demand management in the irrigation sector.

There are a number of broad conclusions and strategic recommendations that came out of the study as a whole and which could be considered as providing some key elements of a strategic framework for, among others, the design and implementation of the basin-wide IWRM plan including an improved knowledge of the resource base, improved water resource modelling and increased basin-wide transparency.

4.4.13 Senegal River Basin

Mali, Mauritania, Senegal, Guinea

No reports related to infrastructure development and climate change were found for the Senegal River Basin or its member states.

4.4.14 Volta River Basin

Ghana, Burkina Faso, Mali, Benin, Cote d'Ivoire

One major project was identified in the Volta River Basin. The GLOWA Volta project carried out by German Federal Ministry of Education and Research (BMBF) is summarized below.

4.4.14.1 GLOWA Volta Phase III Completion Report. Jens Liebe, Claudia Arntz and Paul L.G. Vlek (Eds.) 2010

The central objective of the GLOWA Volta Project (GVP), which was conducted over a 9 year period from 2000 to 2009, was the analysis of the physical and socio-economic determinants of the hydrological cycle in the Volta Basin in the face of global climate change. Key aspects of the GVP research included sampling strategies and scaling techniques to bridge data gaps, and the development of models on land use and land cover change, water supply and demand, and to simulate human-environmental interactions. The main aim was the development of "Decision Support Resources" that will help the authorities in Ghana, Burkina Faso, and the other riparian countries to optimize water allocation.

The GLOWA Volta Project has authored more than 200 scientific publications, co-developed the hydro-economic model M³WATER for the whole Volta Basin which makes use of the joint hydro-meteorological model MM5-WaSiM and introduced a water resources model (Mike Basin). Furthermore, the limited human and institutional capacity has been effectively advanced, through the development of human capital, infrastructural and technological capacity building, and support for institutions. The lack of international collaboration – both north-south and south-south – has also been improved through the formation of the GLOWA Volta Research network.

4.4.15 Zambezi River Basin

Zambia, Malawi, Zimbabwe, Mozambique, Angola, Tanzania, Botswana, Angola.

Five major projects were identified in the Zambezi River Basin. These cover development investment strategy reports, water management plans and climate change adaption studies. It is believed that this above average number of identified projects is due to the fact that the Zambezi River Basin is part of the SADC which has invested much in the development of its community states (see section 3.4.3 above).

4.4.15.1 The Zambezi River Basin: A Multi-Sector Investment Opportunities Analysis. World Bank, 2010

The overall objective of the Zambezi River Multi-sector Investment Opportunity Analysis (MSIOA) is to illustrate the benefits of cooperation among the riparian countries in the ZRB through a multi-sectoral economic evaluation of water resources development, management options and scenarios—from both national and basin-wide perspectives.

Using the River/Reservoir System Model and an Economic Assessment Tool, a number of development paths are assessed through different scenarios including:

- Coordinated operation of existing hydropower facilities, either basin-wide or in clusters
- Development of the hydropower sector as envisioned in plans for the Southern African Power Pool (SAPP)
- Development of the irrigation sector through unilateral or cooperative implementation of projects identified by the riparian countries
- Flood management, particularly in the Lower Zambezi and the Zambezi Delta
- Effects of other projects using the waters of the Zambezi River (e.g., transfers out of the Basin for industrial uses).

The analysis focuses on hydropower and irrigation because of their special potential to stimulate growth in the economies of the region. The report also gives an overview of basic characteristics of the ZRB including a detailed map of the ZRB showing existing and planned hydro power plants and extensions, schematic of the river's mean annual discharge and runoff and precipitation data for the ZRB. The report includes a very simple sensitivity analysis of the potential effect of climate change to alter mean annual runoff (flow).

4.4.15.2 Draft Integrated Water Resources Management Strategy And Implementation Plan For The Zambezi River Basin. SADC-WD/ Zambezi River Authority, 2008

This Strategy document starts with a summary of the existing situation. It then gives a detailed description of the Challenges, Issues, Strategies and Main Actions for each of the four Strategic Objectives. The Implementation Plan presents proposals for the short, medium and long term and includes suggestions for financing.

The strategy has been constructed around four "Challenges":

1. Integrated and coordinated water resources development
2. Environmental management and sustainable development
3. Adaptation to climate variability and climate change
4. Basin-wide cooperation and integration.

The main challenges are to quickly increase power production to sustain economic development in the urban centres, manufacturing and mining, to meet the growing demand for food in a global situation of food grain shortages and sharply rising prices through support to irrigated and rain-fed agriculture, to mitigate floods and droughts, and to change from a single to multi-functional use of reservoirs.

4.4.15.3 Transboundary Water Management In SADC - Dam Synchronisation And Flood Releases In The Zambezi River Basin Project: Executive Summary. SADC, ZAMCOM, 2011

This Executive Summary presents a synopsis of the overall challenges, findings and recommendations of the “Dam Synchronization and Flood Releases in the Zambezi River Basin” Project. The project investigated the extent to which the timing of water releases for electricity production, agricultural demands, environmental flow, dam safety, and flood protection from existing and proposed new dams can result in more collective win-win advantages.

Often, the environmental requirements are perceived as competing with other interests such as hydropower generation. During execution of the Project, effort was made to show that flood management and release of environmental flows can be achieved in tandem. This Project aims to provide expert input, amongst other objectives, by finding ways and means to address positively the water infrastructure management and development scenarios in the Zambezi River Basin in respect to flood management, improved livelihoods and water for the environment.

The findings and recommendations of this Project include a) Concepts and recommendations for improved basin-wide management; b) Summary report of compiled literature and existing studies, geodata, measuring/gauging stations and available data; c) Concepts and recommendations for dam management; d) Concepts and recommendations for precipitation and flow forecasting; and e) Recommendations for investments.

4.4.15.4 Responding to Climate Change Impacts: Adaptation and mitigation strategies as practiced in the Zambezi River Basin, SARCD & HBS, 2010

This report gives a detailed assessment of the impacts of climate change on the environment, emphasizing the threat to sustainability of the rich environmental and water resources in the Zambezi basin. There are implications on settlements and societies where lives have been lost, and people have been displaced due to heavy flooding.

Climate change has implications on health, and the report shows the increase in the occurrence and spread of water-borne, respiratory and vector-borne killer diseases including malaria and cholera. Food security is also addressed in this report. There has been drought-induced crop failure which has reduced farmers to beggars with the collapse of the traditional credit delivery systems.

The report gives a description of climate change adaptation and mitigation measures being taken to counter the impacts. These include adaptation strategies at national, basin, regional and global levels.

4.4.15.5 Climate volatility and poverty vulnerability in Tanzania. World Bank Development Research Team, 2009.

Climate models generally indicate that climate volatility may rise in the future, severely affecting agricultural productivity through greater frequency of yield-diminishing climate extremes, such as droughts. For Tanzania, where agricultural production is sensitive to climate, changes in climate volatility could have significant implications for poverty.

This study assesses the vulnerability of Tanzania's population to poverty to changes in climate variability between the late 20th century and early this century. Future climate scenarios with the largest increases in climate volatility are projected to make Tanzanians increasingly vulnerable to poverty through its impacts on the production of staple grains, with as many as 90,000 additional people, representing 0.26 percent of the population, entering poverty in the median case. Extreme poverty-increasing outcomes are also found to be greater in the future under certain climate scenarios. In the 20th century, the greatest predicted increase in poverty was equal to 880,000 people, while in the 21st century, the highest possible poverty increase was equal to 1.17 million people (approximately 3.4 percent of the population). The results suggest that the potential impacts of changes in climate volatility and climate extremes can be significant for poverty in Sub-Saharan African countries like Tanzania.

5 Models

5.1 Introduction

5.1.1 Concepts of modeling

Water related problems are diverse and location and timing specific and ranges from issues as water shortage, water flooding, to contamination. The problems the water sector faces can be attributed to a wide variety of factors such as climate change, population growth, socio-economic development, mismanagement, changing priorities by societies, amongst others. Decision makers and water managers are confronted with insufficient knowledge about the current state of water resources, and have even more problems in assessing future changes and impact of potential decisions to be taken.

Data are essential to assess the current condition of water resources and to understand past trends. However, to explore options for the future tools are required that are able to explore the impact of future trends and how we can adapt to these in the most sustainable way. Simulation models are the appropriate tools to do these analyses.

In summary one can say that the two main objectives of models are to: (i) understanding processes and how they interact, and (ii) scenarios analyses. Understanding processes is something that starts at during model development. In order to build our models we must have a clear picture on how processes in the real world function and how we can mimic these in our models. The main challenge is not in trying to build in all processes, which is in fact impossible, but lies in our capability to simplify things and concentrate on the most relevant processes of the model under construction.

The main reason for the success of models in understanding processes is that models can provide output over an unlimited time-scale, at an unlimited spatial resolution, and for difficult to observe sub-processes (e.g. Droogers and Bastiaanssen, 2002). These three items are the weak point in experiments, but are at the same time exactly the components in the concept of sustainable water resources management.

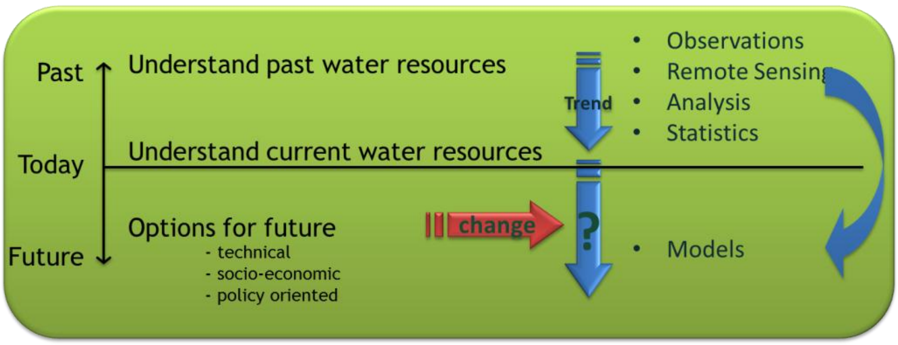


Figure 2. The concept of using simulation models in scenario analysis.

The most important aspect of applying models, however, is in their use to explore different scenarios. These scenarios can capture aspects that cannot directly be influenced, such as population growth and climate change (Droogers and Aerts, 2005). These are often referred to as *projections*. Contrary to this are the *management scenarios* or interventions where water managers and policy makers can make decisions that will have a direct impact. Examples are changes in reservoir operation rules, water allocation between sectors, investment in infrastructure such as water treatment or desalinization plants, and agricultural/irrigation practices. In other words: models enable to change focus from a re-active towards a pro-active approach. (Figure 2).

Hydrological models contain mathematical descriptions of the major elements of the water system, i.e. rivers, lakes, groundwater, soil, snow. Oceans and atmosphere are usually not considered. They area able to capture the impact of natural (e.g. climate change) and/or anthropogenic (e.g. water withdrawals) disturbances on the fluxes and states of elements in the water cycle, e.g. runoff, evapotranspiration, groundwater recharge and soil moisture. Hydrological models can be applied on different scales, ranging from local to global, with the degree of complexity usually being dependent on the scale for which they were designed. Some models cover water quality or other ecological aspects.

Mathematical descriptions of the major water stores and water flows between the different compartments of the water system are the backbone of hydrology models. Deterministic hydrological models are based on the conservation equations of mass and energy or on simplifications thereof. They are driven by meteorological forcings like precipitation and radiation interacting with vegetation, land surface, soils and geological settings. Scenarios on natural and anthropogenic disturbances are fed into the models and the resulting changes in water flows and stocks are calculated. Results are usually presented based on Geographic Information.

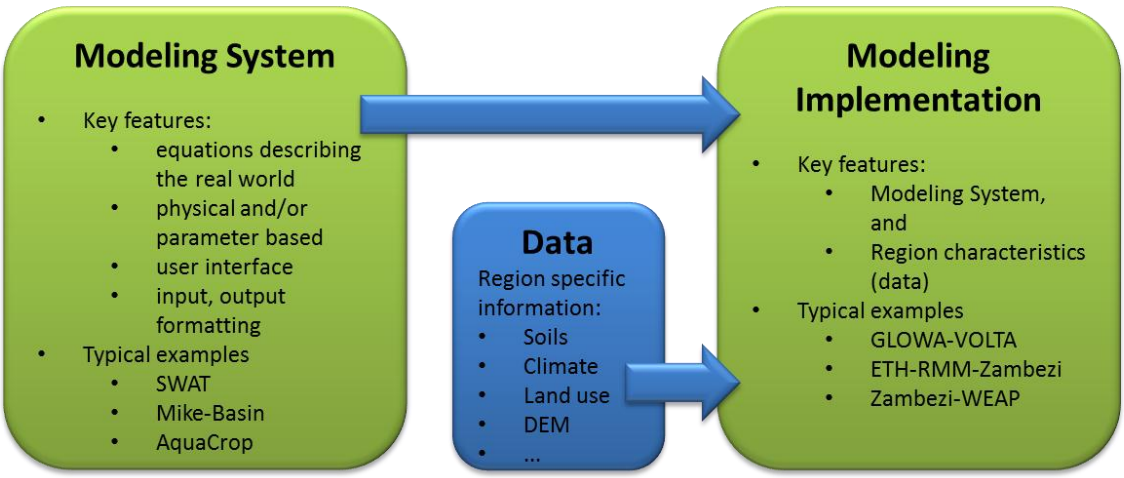


Figure 3. Ambiguous use of the word "model" where reference can be made to "Modeling System" or Modeling Implementation".

The term "**model**" is confusingly used for two distinct meanings. On the one hand refers "model" to a system which is programmed in a certain computer language (fortran, Delphi, C++, etc) describing real-world processes in physical and/or parametric based equations. Typical examples are SWAT, Mike-Basin, WEAP, AquaCrop, amongst many others. The term "M**odelling System**" can be used for.

On the other hand can "**model**" refer to a modelling system in which all the characteristics of a region are included and the model is in fact ready to be used to support policy making and/or operational management. Typical examples include Glowa-Volta or ETH-RMM-Zambesi. The term "**Modeling Implementation**" can be used for this.

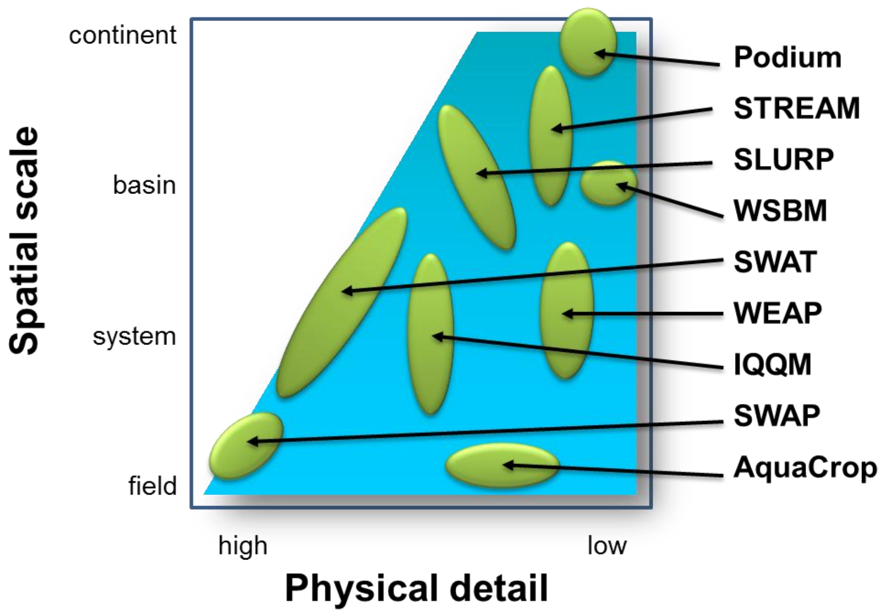


Figure 4. Spatial and physical detail of hydrological models.

The history of hydrological models goes back to the 1960s. One of the first models is the so-called Stanford Watershed Model (SWM) developed by Crawford and Linsley in 1966, but the main principles are still used in current catchment models to convert rainfall into runoff. SWM did not have much physics included as the catchment was just represented by a set of storage reservoirs linked to each other. The value of parameters describing the interaction between these different reservoirs was obtained by trying to optimise the simulated and the observed streamflows. At the other end of the spectrum are the field-scale models describing unsaturated flow processes in the soil and root water uptake. One of the first to be developed was the SWATR model by Feddes et al. (1978) based on Richards' equation. Since these models are based on points and use the concept that unsaturated flow is dominated only by vertical transport of water, much more physics was built in from the beginning.

A huge number of hydrological models exist, and applications are growing rapidly. The number of pages on the Internet including "hydrological model" is over 5.9 million (using Google on March 2012). Using the same search engine with "water resources model" returned 125 million pages. A critical question for hydrological model studies is therefore related to the selection of the most appropriate model. One of the most important issues to consider is the spatial scale to be incorporated in the study and how much physical detail to be included. Figure 4 illustrates the negative correlation between the physical detail of the model applied and spatial scale of application. The figure indicates also the position of commonly used models in this continuum.

5.1.2 Model classification

The number of existing hydrological simulation models is probably in the tens of thousands. Even if we exclude the one-off models developed for a specific study and count only the more generic applied models it must exceed a thousand. Some existing model overviews include numerous models: IRRISOFT (2000): 105, USBR (2002): 100, CAMASE (2005): 211, and REM (2006): 675, amongst others. Interesting is that there seems to be no standard model or models emerging in catchment modelling, contrary to for example in groundwater modelling where ModFlow is the de-facto standard. Two hypotheses for this lack of standard can be brought forward. The first one is that model development is still in its initial phase, despite some 25 years of history, and therefore it is easy to start developing one's own model that can compete with similar existing ones with a reasonable amount of time and effort--indeed a serious scientist is considered to have his/her own model or has at least developed one during his or her PhD studies. A second possible reason for the large number of models might be that hydrological processes are so complex and diverse that each case requires its specific model or set of models.

It is therefore interesting to see how models can be classified and see whether such a classification might be helpful in selecting the appropriate model given a certain question or problem to be solved. Probably, the most generally used classification is the spatial scale the model deals with and the amount of physics included (Figure 4). These two characteristics determine such other model characteristics as data need, expected accuracy, required expertise, and user-friendliness amongst others.

5.1.3 Existing model overviews

A substantial number of overviews exist listing available models and providing a short summary of each. Most of this information is provided by the developers of the model themselves and tends therefore to be biased towards the capabilities of the model. The most commonly referenced overviews are discussed briefly here, keeping in mind that these are changing rapidly, in size and number, since the Internet provides almost unlimited options to start and update such an overview in a automatic or semi-automatic way. A clear example is the Hydrologic Modelling Inventory project from the United States Bureau of Reclamation, where about 100 mainly river basin models are registered by model developers (USBR, 2002).

An overview of agro-ecosystem models is provided by a consortium named CAMASE (Concerted Action for the development and testing of quantitative Methods for research on Agricultural Systems and the Environment; CAMASE, 2005). The following types of models are distinguished: crop science, soil science, crop protection, forestry, farming systems, and land use studies, environmental science, and agricultural economics. A total of 211 models are included and for each model a nice general overview is provided. Unfortunately the last update of the register was in 1996 and advances in model development over the last decade are not taken into account.

The United States Geological Survey (USGS, 2006) provides an overview of all their own models (about 50) divided into five categories: geochemical, groundwater, surface water, water quality, and general. Some of the models are somewhat outdated, but commonly used ones are included as well. All the models are in the public domain and can be used without restrictions. For most of the models source code is provided as well.

The United States Department of Agriculture also provides models to be used in crop-water related issues. The National Water and Climate Center of the USDA has an irrigation page (NWCC, 2006) with some water management tools related to field scale irrigation.

The United States Environmental Protection Agency is very active in supporting model development. The SWAT model, originating from their research programs, might have the potential to become the de-facto standard in basin scale modelling, and has been included in the BASINS package (BASINS, 2006). More linkages to models and other model overviews are provided too (EPA, 2006).

Modelling efforts of USGS, USDA, USACE, and EPA, combined with some other models, are brought together by the USGS Surface water quality and flow Modelling Interest Group (SMIG, 2006a). SMIG has set up the most complete references to model archives nowadays including links to 40 archives (SMIG, 2006b).

The Register of Ecological Models (REM, 2006), with 675 models as of 12-Dec-2005. Besides this overview of models the same website provides general conceptual definitions and links to other websites about modelling. http://ecobas.org/www-server/

The Meta-Analysis of Crop Modelling for Climate Change and Food Security Survey, organized by The Consultative Group on International Agricultural Research (CGIAR), 2011. A survey recently done to better understand the global extent of model development and to identify gaps in capabilities.

Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change, by UNFCCC Secretariat Pinto, Kay, and Travers, 2008. A summary of principle models available compared with each other based on their usefulness for climate change studies.

5.1.4 Model reviews

In the previous section an overview of existing model inventories has been given. Although useful as a catalogue it does not provide any independent guide to model quality. The “best” model does not exist: selection is a function of the application and questions to be answered. A few studies have been undertaken where a limited number of models have been thoroughly tested and reviewed. The majority of these studies focus on two or three models that are rather similar in nature and in most cases it was concluded that the models perform comparably.

A survey of Australian catchment managers, model users and model developers revealed the following conclusions about the state of catchment modelling in the late 1990's (http://www.catchment.crc.org. au/toolkit/current.htm):

- There are almost as many models as there are modellers, and there is significant duplication of effort in model building.
- The standard of computer code employed in these models, and their supporting documentation is generally poor.
- User interfaces are generally poor and inconsistent in their design and function.
- There are no agreed standards on how to code, document and deliver the models to end-users.
- Virtually no holistic modelling is being undertaken at large spatial scales, partly due to the lack of a suitable paradigm for linking models.
- Access to many catchment models is restricted.

This negative viewpoint is to a certain extent still valid, although a some modelling tools have overcome most of these shortcomings. However, the perspective of many water managers is still quite suspicious about model application and only by demonstration projects can those views change.

The Texas Natural Resource Conservation Commission evaluated 19 river basin models, referred to as Water Availability Models, in order to select the most suitable model for management of water resources, including issuing new water right permits (TNRCC, 1998). A total of 26 evaluation criteria were identified as important functions and characteristics for selecting a model that fits the needs of the 23 river basins in Texas. Most important was the ability of the model to support water rights simulation. During the evaluation process, each model was assessed and ranked in order of its ability to meet each criterion. The 19 models in the first phase narrowed down to five: WRAP, MODSIM, STATEMOD, MIKE BASIN, and OASIS. Models not selected included WEAP (no appropriation doctrine) and SWAT (not intuitive and user-friendly). The final conclusion was to use the WRAP model with the HEC-PREPRO GUI. As mentioned, the study focused only on models able to assist in water rights questions.

A similar study was performed to select an appropriate river basin model to be used by the Mekong River Commission (MRC, 2000). In fact, it was already decided that considering the requirements of the MRC not one single model could fulfil the needs, but three different types of model were necessary: hydrological (rainfall-runoff), basin water resources, and hydrodynamic. Three main criteria were used to select the most appropriate model: technical capability, user friendliness, and sustainability. Considering the hydrological models 11 were evaluated and the SWAT model was considered as the most suitable one. Since water quality and sediment processes were required models like SLURP were not selected. Interesting is that grid based models were not recommended as they were considered as relatively new. The selected basin simulation model was IQQM. ISIS was reviewed as the best model to be used to simulate the hydrodynamic processes.

An actual model comparison, where models were really tested using existing data, was initiated by the Hydrology Laboratory (HL) of the National Weather Service (NWS), USA. The comparison is limited to hydrological models and their ability to reproduce hydrographs, based on detailed radar rainfall data. This model comparison, referred to as DMIP (Distributed Model Intercomparison Project, 2002) has the intention to invite the academic community and other researchers to help guide the NWS's distributed modelling research by participating in a comparison of distributed models applied to test data sets. Results have been published recently, but no clear conclusions were drawn (Reed et al., 2004).

The UNFCCC categories the models into three categories, each with its associated application tool:

- Hydrologic models (physical processes)
    - Simulate river basin hydrologic processes
    - Examples – water balance, rainfall-runoff, lake simulation, stream water quality models
- Water resource models (physical and management)
    - Simulate current and future supply/demand of system
    - Operating rules and policies
    - Environmental impacts
    - Hydroelectric production
    - Decision support systems (DSS) for policy interaction
- Economic models
    - Macroeconomic
        - Multiple sectors of the economy
        - General equilibrium – all markets are in equilibrium
    - Sectoral level
        - Single market or closely related markets (e.g., agriculture)
    - Farm level
        - Farm-level model (linear programming approach)
        - Microsimulation

5.2 Modeling Systems

The term “modelling system” refers to computer code in a certain computer language (fortran, Delphi, C++, etc) describing real-world processes in physical and/or parameter based equations. This is often also just called “model”. In this report we will follow the normal convention to use the word model for this, but it is important to realize that the word “model” is also used for “Modeling Implementations” (see next section).

5.2.1 SWAT - Soil and Water Assessment Tool

5.2.1.1 General

The Soil and Water Assessment Tool (SWAT) is a river basin scale model developed to quantify the impact of land management practices in large, complex watersheds. SWAT is a public domain model actively supported by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas, USA.

SWAT is a process-based continuous daily time-step model which evaluates land management decisions in large ungauged rural watersheds. A natural subbasin is usually composed of several land uses (or crops) and soil types. In SWAT modeling, a subbasin is required of representing a unique landuse (or crop rotation) and soil type. A straight forward approach is to use predominant landuse (or crop rotation) and soil. SWAT model also allows for non- spatial subdivision of subbasins into smaller sub-units based on landuse and soil variations, a concept of virtual subbasins. Virtual subbasins represent percentages of the larger subbasin area.

5.2.1.2 Input

SWAT requires spatial distributed data for the basin. The most important ones are DEM (Digital Elevation Model), land cover and soils. From the DEM the sub catchment are generated automatically as well as the stream network. These sub catchment and the land cover and soils are then used to obtain the so-called Homogenous Response Units (HRU). Meteorological data at one or more locations in the basin provides sufficient information to run the model. Optional is to include reservoirs and operational rules for these.

Multiple standardized databases are included to parameterize different land use types, crops as well as soils.

5.2.1.3 Output

The output of SWAT can be distinguished in stream flow output and land based results. Stream flow can include water quality aspects as well for every stream in the basin. The land based results are extensive and include all the components of the hydrological cycle as well as erosion, pollutants, nutrients and crop growth. All this information is available per sub catchment as well as per HRU.

5.2.1.4 Evaluation

SWAT has been applied in various basins in different countries and has been calibrated and validated for different conditions. It is used for modeling basins and in the USA and is actively supported by the USDA Agricultural Research Service.

SWAT can be considered as the de-facto standard in hydrological basin scale modeling where land use interactions are relevant.

5.2.1.5 Availability and costs

SWAT can be downloaded from the internet and is free of charge. There is extensive support by the developers as well as a group of active users.

5.2.2 ACRU - Agricultural Catchments Research Unit model

5.2.2.1 General

The ACRU model has its hydrological origins in a distributed catchment evapotranspiration based study carried out in KwaZulu-Natal Drakensberg of South Africa in the early 1970s (Schulze, 1975). The acronym ACRU is derived from the Agricultural Catchments Research Unit within the Department of Agricultural Engineering of the University of Natal in Pietermaritzburg. The agrohydrological component of ACRU first came to the fore during research on an agrohydrological and agroclimatological atlas for Natal. The model has been verified on data from southern Africa and the USA, and used extensively in decision making in southern Africa. The model has also been applied in research in Botswana, Chile, Germany, Lesotho, Namibia, Swaziland and the USA.

The ACRU Agrohydrological Model - a multi-purpose and multi-level daily soil moisture budgeting model (Schulze, 1990) can be used to determine what the soil water moisture status is for a given catchment area and this model requires inter alia continuous amounts of daily rainfall as input. ACRU can be used to estimate, inter alia, runoff volume, sediment yield, peak discharge, reservoir water budgets, crop yield and irrigation water demand and supply.

The ACRU Agrohydrological Modelling System (Schulze, 1995) uses a programme called the Menubuilder to assist the user in preparing an input dataset, called a menu, to the ACRU model.

ACRU can operate as a point or as a lumped small catchments model. However, for large catchments or in areas of complex land uses and soils ACRU can operate as a distributed cell-type model. In distributed mode individual subcatchments (ideally not exceeding 30 km2) are identified, discretised and flows can take place from "exterior" through "interior" cells according to a predetermined scheme, with each subcatchment able to generate individually requested outputs which may be different to those of other subcatchments or with different levels of input/information. The ACRU model is not integrated in GIS-software. In the catchment or basin mode in ACRU, the basic mapping units - lumped small catchments - are polygons from which the basic data are derived and on which the calculations are based. Results are linked to vector based GIS-files, through polygon attribute files.

5.2.2.2 Input

Daily rainfall, daily or monthly evaporation, soils and land use parameters.

5.2.2.3 Output

Simulated streamflows, sediment and crop yield, reservoir yield analysis.

5.2.2.4 Evaluation

The model has been applied in been applied in different South African basins. Relatively small user-community outside South Africa, although several cases of application outside South Africa of ACRU are known (e.g USA and Germany).

5.2.2.5 Availability and costs

The model can be obtained from the School of Bioresources Engineering and Environmental Hydrology of the University of Natal, Pietermaritzburg and can be downloaded from the internet. User documentation on ACRU was first published in 1984 and updated in 1989 and is also available from the internet.

5.2.3 WEAP - Water Evaluation and Planning model

5.2.3.1 General

The WEAP model includes a semi-physical, irregular grid, lumped–parameter hydrologic simulation model that can account for hydrologic processes within a water distribution system. WEAP works with nodes and arrows as indicators of water flow and distribution.

While the model can be run on any time-step where routing is not a consideration, the model description assumes a monthly time-step. The time horizon can be set from the user, from as short as a single year to more than 100 years. Scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

WEAP contains built-in models for: rainfall runoff and infiltration, evapotranspiration, crop requirements and yields, surfacewater and groundwater interaction, and instream water quality. It has a GIS-based, graphical "drag and drop" interface. WEAP allows user-defined variables and equations and has a model builing facility. It has dynamic links to spreadsheets and other models. Data structures are flexible and expandable.

5.2.3.2 Input

Since WEAP primarily goal is to evaluate water allocation options is the major input related to so-called demand and supply sites (nodes) that are connected by links. Examples of required input: urban areas, agricultural areas, groundwater, reservoirs, catchment nodes, rivers, canals. The catchment nodes can be specified to be more hydrological oriented including rainfall-runoff processes.

5.2.3.3 Output

WEAP operates always in an optimization water allocation mode, based on priorities set for each demand site. This makes WEAP unique in comparison to other water allocation tools such as RIBESRSIM or MIKE-BASIN.

Output of WEAP includes flows for all connection lines (rivers, canals) and met and unmet demands for all the demand sites. Outputs are generated in a very attractive form and has similarity with the EXCLAIM (EXploratory Climate Land Assessment and Impact Management) modeling environment as developed by University of Newcastle.

5.2.3.4 Evaluation

Although the WEAP model comprises both a hydrological component and a water management component, it is more of a water planning model, focused on the water division, infrastructure, and economic evaluation than on the physical water hydrology.

Support of the model in terms of manuals, training and support of developers is excellent.

5.2.3.5 Availability and costs

Single site license for Accredited academic institution based in an industrialized country $1000 and non-consulting license $2500. Non-profit, governmental or academic organization based in a developing country: free of charge.

5.2.4 MIKEBASIN

5.2.4.1 General

MIKE BASIN is a user-friendly water allocation model with a Arc-Gis interface. MIKE BASIN builds on a network model in which branches represent individual stream sections and the nodes represent confluences, diversions, reservoirs, or water users. The ArcGIS interface has been expanded accordingly, e.g., such that the network elements can be edited by simple right-clicking. Technically, MIKE BASIN is a quasi-steady-state mass balance model, however allowing for routed river flows. The water quality solution assumes purely advective transport; decay during transport can be modeled. The groundwater description uses the linear reservoir equation.

Typical areas of application of MIKE BASIN are:

- Water availability analysis: conjunctive surface and groundwater use, optimization
- Infrastructure planning: irrigation potential, reservoir performance, water supply capacity, waste water treatment requirements
- Analysis of multisectoral demands: domestic, industry, agriculture, hydropower, navigation, recreation, ecological, finding equitable trade-offs
- Ecosystem studies: water quality, minimum discharge requirements, sustainable yield, effects of global change. Regulation: water rights, priorities, water quality compliance

5.2.4.2 Evaluation

MIKE BASIN is a water planning model, focused on the water management, water division, and the infrastructural planning of water division rather than on the physical aspects of hydrology. However, the very user-friendly interface and the ability to build quickly models makes MIKE BASIN suitable for quick policy oriented water resources planning at basin or sub-basin scale.

5.2.4.3 Availability and costs

Licenses costs are available on request by DHI but are substantial.
More info at : http://www.dhisoftware.com/Products/WaterResources/MIKEBASIN.aspx

5.2.5 MIKE-SHE

5.2.5.1 General

MIKE-SHE is a dynamic, user-friendly modeling tool that can simulate the entire land phase of the hydrologic cycle and can be summarized as an integrated modeling environment that allows components to be used independently and customized to local needs

MIKE-SHE includes powerful preprocessing and results presentation tools for making your results understandable and convincing. The developers claim to have a proven track record in hundreds of consultancy and research applications around the world.

5.2.5.2 Input

The input data requirements and model parameters for the fully integrated MIKE SHE model are comprehensive (such as horizontal and vertical soil hydrologic conductivity). Each component of the model applies a range of input data types and parameters. The parameters may be physically measurable or empirical specific to the equations solved in the model.

5.2.5.3 Output

Output of MIKE-SHE includes maps and time series graphs of all hydrological processes included in the model.

5.2.5.4 Evaluation

MIKE-SHE can be considered as a complete package to analyze hydrological processes into detail. Input requirements are therefore substantial. MIKE-SHE requires a high-level of knowledge both on technical aspects as well as on conceptual hydrological and water resources issues.

5.2.5.5 Availability and costs

Licenses costs are available on request by DHI but are substantial.

5.2.6 MIKE11

5.2.6.1 General

MIKE-SHE is a dynamic, user-friendly modeling tool that can simulate the entire land phase of the hydrologic cycle and can be summarized as an integrated modeling environment that allows components to be used independently and customized to local needs

MIKE-SHE includes powerful preprocessing and results presentation tools for making your results understandable and convincing. The developers claim to have a proven track record in hundreds of consultancy and research applications around the world.

5.2.6.2 Input

The input data requirements and model parameters for the fully integrated MIKE SHE model are comprehensive (such as horizontal and vertical soil hydrologic conductivity). Each component of the model applies a range of input data types and parameters. The parameters may be physically measurable or empirical specific to the equations solved in the model.

5.2.6.3 Output

Output of MIKE-SHE includes maps and time series graphs of all hydrological processes included in the model.

5.2.6.4 Evaluation

MIKE-SHE can be considered as a complete package to analyze hydrological processes into detail. Input requirements are therefore substantial. MIKE-SHE requires a high-level of knowledge both on technical aspects as well as on conceptual hydrological and water resources issues.

5.2.6.5 Availability and costs

Licenses costs are available on request by DHI but are substantial.

5.2.7 SWAP - Soil, Water, Atmosphere and Plant model

5.2.7.1 General

SWAP (Soil, Water, Atmosphere and Plant) simulates transport of water, solutes and heat in unsaturated/saturated soils. SWAP is the successor of the well known Swatre model which originates from 1978. The department of Water and Environment of the Alterra Institute and the sub-department of Water resources of WUR have developed the computer model SWAP in close co-operation. The program is designed to simulate the transport processes at field scale level and during entire growing seasons. The model offers a wide range of possibilities to address both research and practical questions in the field of agriculture, water management and environmental protection.

Some of the typical applications of SWAP are: field scale water balance, evapotranspiration, plant growth as affected by water and/or salinity stress, improvement of surface water management, soil moisture indicators for natural vegetations.

5.2.7.2 Input

Physical and hydrological soil properties, crop characteristics (soil cover, leaf areaindex, crop height etc.), daily meteorological data, drainage and irrigation specific data. Flow rate through profile, state variables, crop rate and state variables.

5.2.7.3 Output

Flow rate through profile, state variables, crop rate and state variables. Time interval of simulation: 1 day. Basic spatial unit: m^2 to field level.

5.2.7.4 Evaluation

SWAP is a point scale model that includes all unsaturated flow processes including crop growth modeling at several levels of detail. Some semi-2D components exit in terms of drainage and surface water flow. SWAP has been used extensively all over the world to evaluate field scale water and salt management issues.

5.2.7.5 Availability and costs

SWAP is free of charge and can be downloaded from the internet.

5.2.8 PC-RASTER

5.2.8.1 Overview

PCRaster is a modeling system in which many hydrological models have been built. PCRster is a Geographical Information System which consists of a set of computer tools for storing, manipulating, analyzing and retrieving geographic information. It is a raster-based system that uses a strict data type checking mechanism. This means that data type information is added to all spatial data, based upon the kind of attribute that the data represent. The use of data types controls the way the data are stored in the database and the possibilities for manipulation and analysis of the data.

The dynamic modelling language can be used for building a wide range of models, from very simple (point) models up to conceptually complicated or physically based models for environmental modelling (for instance erosion models). A dynamic model developed in the PCRaster Dynamic Modelling module can carry out all steps performed in modelling with ordinary low level GIS integrated models such as MODFLOW, MICROFEM (i.e. validating and calibrating).

PCRaster can be obtained free of charge. Details can be found at: http://pcraster.geo.uu.nl

5.2.9 WATERGAP - Water Global Assessment and Prognosis model

5.2.9.1 General

WaterGAP – the integrated global water model has been developed at the Center for Environmental Systems Research at the University of Kassel in Germany in cooperation with the National Institute of Public Health and the Environment of the Netherlands. WaterGAP computes both water availability (surface runoff, groundwater recharge and river discharge) and water use at a spatial resolution of 0.5 degree (55 x 55 km at the equator). WaterGap is based on many global data sets.

WaterGAP belongs to the class of environmental models which can be classified as ‘integrated’ because they seek to couple and thus integrate different disciplines within a single integrated framework. The Global Hydrology Model simulates the characteristic macro-scale behavior of the terrestrial water cycle to estimate water resources, while the Global Water Use Model computes water use for the sectors households, industry, irrigation, and livestock. All calculations cover the entire land surface of the globe (except Antarctica) and are performed on a 0.5° by 0.5° spatial resolution (this is presently the highest feasible resolution for global hydrological models because climatic input is usually not available at higher levels of detail).

The WaterGAP Global Hydrology Model calculates a daily vertical water balance for both the land area and the open water bodies at each of the 0.5° cells. The vertical water balance for the land fraction in a cell consists of a canopy water balance and a soil water balance. These are calculated as functions of land cover, soil water capacity, and monthly climate variables (i.e. temperature, radiation, and precipitation).

5.2.9.2 Applications

In the course of the development of WaterGAP global datasets were generated that could be of interest for the Green Water Initiative: a global map of irrigated areas, a global drainage direction map and a global lakes and wetlands data set. WaterGap includes a hydrological model.

5.2.10 HSPF

5.2.10.1 General

HSPF (Hydrological Simulation Program) is a public domain software program distributed by the U.S. EPA's Center for Exposure Assessment Modeling (CEAM). HSPF first version originates from the 1960’s and was called Stanford Watershed Model, one of the first hydrological models.

In the 1970's, water-quality processes were added as well as improved concepts and computer engineering. In the 1980's, preprocessing and postprocessing software, algorithm enhancements, and use of the USGS WDM data file system were developed. The current release is Version 11.

5.2.10.2 Input

HSPF requires a substantial amount of data at high spatial and temporal resolution. Meteorologic records of precipitation and estimates of potential evapotranspiration are required for watershed simulation. Air temperature, dewpoint temperature, wind, and solar radiation are required for snowmelt. Air temperature, wind, solar radiation, humidity, cloud cover, tillage practices, point sources, and (or) pesticide applications may be required for water-quality simulation. Physical measurements and related parameters are required to describe the land area, channels, and reservoirs.

5.2.10.3 Output

The amount of output HSPF can generate is impressive and overwhelming. Output is either printed tables at any time step, a flat file, or the WDM file. The postprocessing software uses data from the WDM file format. Hundreds of computed time series may be selected for the output files.

5.2.10.4 Evaluation

HSPF can be considered as a classical hydroloigcal rainfall-runoff model with a very long history. The model is not particular user-friendly and requires a high-level of computational as well as hydrological skills.

5.2.10.5 Availability and costs

HSPF can be obtained free of charge.

5.2.11 WOFOST

5.2.11.1 General

WOFOST is a dynamic water balance model and is different from other models. Most hydrological flow process based models require saturated and unsaturated soil hydraulic conductivity data of soils, which are lacking for most soils of tropical and subtropical Africa.

The well tested and world-wide used crop growth model WOFOST includes a soil-crop-atmosphere water balance that allows working with a minimum soil dataset that is available in the SOTERSAF database (FAO and ISRIC, 2003).

The crop growth simulation model WOFOST-version 7.1 is a generic model, which simulates potential, water-limited and nutrient-limited production situations (Boogaard et al. 1998).

WOFOST calculates on a daily basis crop growth and water balance for varying climate, crop and soil, and management conditions such as of infiltration enhancing practices and crop germination date. It can be used at field level as well as regional level, for example it is used in the European Crop Growth Monitoring System (Van Ittersum et al., 2003).

The WOFOST water balance calculations is based on a daily book-keeping of in- and out-going water flows between the components soil, crop, atmosphere. The soil is divided into two dynamic compartments. Firstly, the variable actual rooting depth, from small at germination till maximum rootable depth at the end of the growing period. Secondly, the deeper subsoil, which is the subsoil below the rooted soil. Rainfall infiltrates and the part that does not infiltrate is considered runoff. The return vapor flow of the water stored in the soil to the atmosphere is calculated through evaporation and transpiration processes. The infiltrated water that exceeds the storage capacity of the two soil compartments percolates downward and contributes to the aquifer and river base flow.

5.2.11.2 Model data input

Six yield and water balance determining factors are assessed in WOFOST: (i) climate, (ii) soil available water content, (iii) rootable depth, (iv) crop, (v) crop management restricted to germination date, and (vi) soil management restricted to practices of enhanced water infiltration.

The WOFOST climate file requires 6 parameters: radiation, temperature, relative humidity of the air (or vapor pressure), wind speed, precipitation and number of rain days. The WOFOST rainfall generator facility mimics daily rainfall based on monthly rainfall data and number of rainy days.

The WOFOST model is operational for a wide range of crops (Van Ittersum et al. 2003). It has some widely cultivated well tested annual crop files

Soil type determines the soil water storage capacity that is controlled by soil thickness, soil water holding capacity and effective rootable depth.

The WOFOST soil moisture characteristics include water retention and hydraulic conductivity. WOFOST recognizes the option of a soil with free drainage conditions that requires a minimum dataset, which is limited to the Available Water Capacity (AWC) of the soil. For free draining conditions the hydraulic conductivity of the saturated soil and the percolation rate are assumed to be high and kept at a fixed high value at 10.0 cm d^{-1}. Once measured soil conductivity data becomes available, these fixed values can be replaced.

5.2.11.3 Availability and costs

WOFOST can be obtained free of charge.

5.2.12 AQUATOOL

AquaTool (Andreu et al. 1996) is a decision-support system (DSS) which was originally designed for water resources planning of complex river basins. Subsequently, it was expanded to incorporate modules relating to the operational stage of decision-making. Computer-assisted design modules allow complex water-resource systems to be represented in graphical form, with connections to geographically referenced databases and knowledge bases. Modelling components include basin simulation and optimization, an aquifer flow modelling module and two modules for risk assessment. The DSS was also extended with modules for water quality assessments and economic evaluations and cost studies.
More: http://www.upv.es/aquatool/

5.2.13 AQUATOR

AQUATOR (Oxford Scientific Software 2008) is an application for developing and running conjunctive use water resource system models. It is used principally in the United Kingdom. Both the natural river system and the water supply network can be modelled. River regulation, forecasting, travel times, the ability to include catchment (hydrological) models and the differentiation of river flow at any point into its 'natural', 'cumulative abstraction' and 'release' components are some of the features available on river networks. On the supply side, water is used to meet demand using a proven algorithm that seeks to minimise cost, but preserve the state of resources.
More: http://www.oxscisoft.com/aquator/

5.2.14 EPANET

EPANET is a public-domain, water distribution system modeling software package developed by the United States Environmental Protection Agency's Water Supply and Water Resources Division. It performs extended-period simulation of hydraulic and water-quality behavior within pressurized pipe networks and is designed to be "a research tool that improves our understanding of the movement and fate of drinking-water constituents within distribution systems".

EPANET first appeared in 1993. EPANET 2 is available both as a standalone program and as an open-source toolkit (Application Programming Interface in C). Its computational engine is used by many software companies that developed more powerful, proprietary packages, often GIS-centric. The EPANET ".inp" input file format, which represents network topology, water consumption, and control rules, is supported by several free and commercial modeling packages. Therefore, it is arguably considered as the industry standard.
More: http://www.epa.gov/nrmrl/wswrd/dw/epanet.html

5.2.15 MODSIM

MODSIM (Labadie and Baldo 2000) and MODSIM-DSS were designed for highly complex and constantly evolving river basins. MODSIM-DSS has been linked with stream-aquifer models for analysis of the conjunctive use of groundwater and surface water resources. MODSIM-DSS has also been used with water quality simulation models for assessing the effectiveness of pollution control strategies. MODSIM-DSS can also be used with geographic information systems (GIS) for managing spatial data base requirements of river basin management.

MODSIM-DSS is structured as a Decision Support System, with a graphical user interface (GUI) allowing users to create any river basin system topology. Data structures embodied in each model object are controlled by a data base management system. Formatted data files are prepared interactively and a network flow optimization model can be executed from the interface. Results of the network optimization are presented in graphical plots (see example in Fig. 18).
More: http://modsim.engr.colostate.edu/

5.2.16 OASIS

OASIS (Options AnalysiS in Irrigation Systems) is a planning model for medium to large-scale canal irrigation systems, typically several thousand hectares (Randall et al. 1997). It specifically takes account of surface-groundwater interactions to assess the impacts on water use, depletion and productivity of a broad range of interventions in irrigated agriculture. Examples of such interventions include: lining of canals, development of storage, and introduction of alternative cropping patterns, water deliveries and on-farm irrigation practices. The model can thus be used to provide guidance to irrigation system managers and water policy-makers to make a more efficient and productive use of limited water resources in agriculture in the context of rising food demand, competitive water use from other sectors and the uncertainties brought about by climate change.

OASIS is based on water balance and includes a strong management component. The main innovation of the model lies in its capacity to capture irrigation return flows and integrate recycling of water through conjunctive drainage and groundwater use. OASIS also factors in non-irrigated areas, such as natural vegetation and fallow lands. These features distinguish the model from previous ‘integrated’ irrigation simulation models, which largely focus on canal delivery scheduling and incorporate only parts of the water balance within irrigation projects.
More:
http://www.iwmi.cgiar.org/Tools_And_Resources/Models_and_Software/OASIS/index.aspx

5.2.17 REALM

The REsource ALlocation Model (REALM) is a Windows based computer program that can simulate the operation of both urban and rural water supply systems during droughts as well as during periods of normal and high streamflows (Perera et al. 2005). It is designed to simulate simple water supply systems as well as large and complex ones. It has been maily applied in Australia. Water supply system can be configured as a network of nodes and carriers

representing reservoirs, demand centres, waterways, pipes, etc. A wide range of operating rules can be modelled either directly or indirectly by exploiting the basic set of node and carrier types and their corresponding attributes. It uses a network linear programming algorithm to optimise the distribution of water within the network for each time step of the simulation period, in accordance with user-defined operating rules. Output can be presented graphically, either in raw form or after post-processing using a suite of utility programs separate from the simulation model. Input and output data (ASCII) files have the same format and can be easily transferred to other software.
More: http://www.water.vic.gov.au/monitoring/surface-water-modelling/realm

5.2.18 RIBASIM

RIBASIM (WL Delft Hydraulics 2004) is a model package for simulating the behavior of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool that links the hydrological water inputs at various locations with the specific water users in the basin. It allows the user to evaluate a variety of measures related to infrastructure and operational and demand management, and to see the results in terms of water quantity and flow composition.

RIBASIM can also generate flow patterns that provide a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs. Demands for irrigation, public water supply, hydropower, aquaculture, and reservoir operation can be taken into account, surface- and groundwater resources can be allocated and minimum flow requirements and flow composition can be assessed.
More: http://www.deltares.nl/en/software/479948/ribasim2

5.2.19 SIC

The SIC (**S**imulation of **I**rrigation **C**anals) software has been specifically developed at CEMAGREF in France for the simulation of the hydraulic behaviour of most of the irrigation canals or rivers, under steady and unsteady flow conditions. The model allows canal managers, engineers and researchers to quickly simulate a large number of hydraulic conditions at the design or management level. The model is built around three main computer programs (TALWEG, FLUVIA and SIRENE) that respectively carry out the topography and geometry generation, the steady flow computation and the unsteady flow computation. The software is menu driven in order to facilitate its use and on line help is available at any moment.

The main purposes of the model consist in **(i)** providing a tool to improve the knowledge of the hydraulic behaviour of the main and secondary canals, **(ii)** identifying operational practices for improving canal operations, **(iii)** evaluating the effect of modifications of canal characteristics, **(iv)** testing automatic operational procedures and evaluate their efficiency, and **(v)** being easily usable by canal managers as a decision support tool, in order to help them in the daily operation and maintenance of their system.

5.2.20 WARGI

WARGI (Sechi and Sulis 2009) is a tool specifically developed to help users understanding interrelationships between demands and resources for multi-reservoir water systems under water scarcity conditions, as frequently occur in the Mediterranean regions. Since the middle of 1990s, WARGI has been extended and new modules have been developed by the Water Research Group (WRG) at the Department of Land Engineering, University of Cagliari, Italy. The WARGI modelling capability includes several interrelated macromodules, the main ones being a simulation-only module, a deterministic optimization module, a reservoir quality optimization module and a module of scenario optimization.

WARGI has been also implemented in a GRID environment to satisfy the requirement of massive simulation-optimization runs for the analysis of complex water system under drought condition. Requests for a non-commercial license and detailed documentation can be addressed to the authors.

5.2.21 WaterCAD

WaterCAD is a geographic information management system for your water utility design and water distribution modeling. It allows analyzing water quality, determine fire flow requirements, calibrate large distribution networks and with different hydraulic analysis tools. It is a complex tool that enables engineers and decision makers to analyze and manage distribution networks. It can be customized with additional modeling platforms and modules.
More: http://www.bentley.com/en-US/Products/WaterCAD

5.2.22 WaterWare

WaterWare (Cetinkaya et al., 2008) is an integrated, model-based information and decision support system for water resources management. WaterWare integrates results of the EUREKA project EU487 and related RTD projects; The System is designed to support the implementation of the Water Framework Directive (2000/60/EC) or similar national legislation. WaterWare is implemented in an open, object-oriented client-server architecture, web-enabled and Internet based, supporting the integration of databases, GIS, simulation and oiptimization models, and analytical tools. This includes a multimedia user interface with Internet access (using a standard web browser as the only client software required), a hybrid GIS with hierarchical map layers, object data bases, time series analysis, reporting functions, an embedded expert system for estimation, classification and impact assessment tasks. Real-time data management, simulation and non-linear multi-objective, multi-criteria optimization modeling, with data assimilation, forecasting, and reporting, and support for operational management can be provided with a real-time rule-based expert system. Auxiliary tools manage user requirements and stakeholder preference structures for the participatory optimization.
More: http://www.ess.co.at/WATERWARE/

5.2.23 WRSM2000

Water Resource Simulation Model Is a model used to simulate hydrological systems. WRSM2000 is of a modular construction, with four different types of modules (run-off, channel reach, reservoir and irrigation) linked by means of routes. The run-off module is the heart of WRSM2000.

5.2.24 HEC-HMS

Watershed scale, event based hydrologic simulation, of rainfall-runoff processes
Sub-daily rainfall-runoff processes of small catchments

5.2.25 HEC-RAS

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and systems operation.
More: http://www.hec.usace.army.mil/software/hec-hms/

5.2.26 HEC-ResSim

HEC-ResSim (USACE 2007) has been developed by the Hydrologic Engineering Center of the US Army Corps of Engineers to aid engineers and planners performing water resources studies in predicting the behavior of reservoirs and to help reservoir operators plan releases in real-time during day-to-day and emergency operations. The following describes the major features of HEC-ResSim: HEC-ResSim provides a view of the physical river/reservoir system using a map-based schematic with a set of element drawing tools. Also, with the hierarchical outlet structure, the modeler can represent each outlet of the reservoir rather than being limited to a single composite outlet. For reservoir operation rules, HEC-ResSim includes advanced features such as outlet prioritization, scripted state variables, and conditional logic.
More: http://www.hec.usace.army.mil/software/hec-ressim/

5.2.27 VIC

The Variable Infiltration Capacity (VIC) model is a semi-distributed grid-based macroscale hydrology model which solves for full water and energy balances. It was developed at University of Washington and Princeton University and is based on the work of Xu Liang. The VIC model in its various forms has been applied to the Columbia, the Ohio, the Arkansas-Red, and the Mississippi River Basins, and also to many other large river basins around the world. The VIC model code and lots of information about running the model are available at the VIC model home page at the University of Washington:
(http://www.hydro.washington.edu/Lettenmaier/Models/VIC/)

5.2.28 WatBal

A water balance model combined with the Priestly-Taylor method for computing potential evapotranspiration has been developed as an integrated tool for modeling the response of river basins to potential climate change. The system was designed within the EXCEL 5.0 spreadsheet environment making use of the Visual Basic programming language. The model is simple to use and takes advantage of IIASA's mean monthly hydrologic data base. (http://content.imamu.edu.sa/Scholars/it/VisualBasic/WP-94-064.pdf)

5.2.29 CliRun

CLIRUN-II is a model in a family of hydrologic models developed specifically for the analysis of the impact of climate change on runoff. Kaczmarek (1993) presents the theoretical development for a single-layer lumped watershed rainfall runoff model-CLIRUN. Kaczmarek (1998) presents the application of CLIRUN to the Yellow River in China. Yates (1996) expanded on the basic CLIRUN by adding a snow-balance model and providing a suite of possible PET models and packaged it in a tool named WATBAL. CLIRUN-II (Strzepek et al. 2008) is the latest in the —Kaczmarek School of hydrologic models. It incorporates most of the features of WATBAL and CLIRUN but was developed specifically to address extreme events at the annual level modeling low and high flows.
http://climatechange.worldbank.org/sites/default/files/documents/EthiopiaAnnexes.pdf

5.3 Modeling Implementations

The term “modelling implementations” refers to a “modelling system” (see previous section) in which all the characteristics of a region are included and is in fact ready to be used to support policy making and/or operational management. So one can say that the model VB-WAS (Volta Basin Water Allocation System) is built using the Mike-Basin model. In fact one should say thet the “model implementation” VB-WAS is built using the Mike-Basin “model system”. In this report we will follow the normal convention to use the word model for this, but it is important to realize that the word “model” is also used for “Modeling Systems” (see previous section).

5.3.1 Congo

5.3.1.1 SADC-HYCOS-SPLASH

The SPLASH model concept of a catchment is a set of four different storage zones: the upper and lower zone, together with two groundwater zones. Evaporative losses from the upper zone are assumed to occur at the same rate as the potential evaporation. Once the moisture store in the upper zone is depleted, evaporative losses are assumed to take place from the lower zone according to a non-linear function of soil moisture. Overland flow and interflow are derived from the upper zone. When the lower zone storage is lower than a predetermined value, overland flow is determined by the storage level of the upper zone only. When the predetermined upper zone storage level is exceeded both overland and interflow are controlled by the moisture level in the lower zone. The two groundwater stores are replenished from the upper zone, the amount also controlled by the moisture store in the lower zone. The groundwater stores contribute to the baseflow. The model is characterised by a mixture of linear and non-linear functions.

Details can be found at: http://sadchycos.dwaf.gov.za/Documents.aspx

5.3.2 Niger

5.3.2.1 Mike-Basin Niger Model

The Mike Basin Niger Model was developed as part of a program of Integrated Water Resources Management (IWRM). It concerns the implementation of a management model of water resources across the Niger River basin, which covers nine countries (Guinea, Benin, Burkina Faso, Ivory Coast, Mali, Niger, Nigeria, Cameroon and Chad). The model implemented in MIKE BASIN can analyze current practices and future to illustrate the impact of changing water needs and environmental changes. It is a true tool for decision support to optimize the water management on a global scale.

Large-scale dam projects are under study in different countries of the basin to meet the growing demand for water for urban supply, irrigation, hydropower, etc.. This is a first step to study the impact of these projects on the current uses and resources available in general. Long time series of runoff are generated, including the severe drought of the early 1980s. Particular attention is paid to complex hydrological processes in the inland delta (Mali), where much water is lost by evaporation.

The model allows individual countries, as well as the Niger Basin Authority, to create a strategy for a sustainable development of the basin. As part of the project training and technology transfer has taken place as well as development of a customized interface of the model focusing toward use by senior key management staff.

Detailed information can be found at:
http://www.mikebydhi.com/SuccessStories/WaterResources/WaterManagement/Niger.aspx

5.3.3 Nile

5.3.3.1 Nile Mike-Basin

DHI, the UK Met Office Hadley Centre and the Egyptian Ministry for Water Resources and Irrigation (MWRI) are collaborating on the project “Regional Climate Modelling of the Nile Basin: Preparation of climate scenario outputs for assessment of impact on water resources in the Nile Basin”. This project is funded by UNEP and UNESCO. The Nile is a crucial resource for agriculture, energy production and the economy of eastern and north-eastern Africa. Therefore, the assessment of the impact climate change may have on water resources is critical for the region and its people. The overall objective is to assess the possible impacts of climate change on the Nile river flow and in particular the inflow to the High Aswan Dam. There are large uncertainties in General Circulation Model (GCM) projections of climate change over the Nile. Therefore, this project will use a Regional Climate Model (RCM) to dynamically downscale to a spatial scale of relevance to hydrological assessment. An ensemble approach will be used to address the uncertainty related to climate change predictions. Results from the RCM are used in a Mike-Basin model.

Details can be found at: http://www.unepdhi.org/WhatWeDo/WaterResourcesModelling.aspx

5.3.3.2 NBI-DSS

The riparian countries of the Nile – Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda; Eritrea participates as observer – have embarked on the Nile Basin Initiative (NBI). The NBI is governed by the Council of Ministers of Water Affairs of the Nile Basin states (Nile Council of Ministers, or Nile-COM) and seeks to develop the river Nile in a cooperative manner, share substantial socioeconomic benefits, and promote regional peace and security. Their shared vision is: to "achieve sustainable socioeconomic development through the equitable utilization of, and benefit from, the common Nile Basin water resources," leading to a Strategic Action Program (SAP) to translate this vision into concrete activities and projects. Under the aegis of its Water Resources Planning and Management (WRPM) Project, DHI will develop and deploy the Nile Basin Decision Support System (NB DSS) to support water resources planning and investment decisions in the Nile Basin, especially those with cross-border or basin level ramifications. The system comprises an information management system, a regional river basin modelling system, and a suite of analytical tools to support multi-objective analysis of investment alternatives. NBI-DSS will aid the development of core national capabilities to assist in the evaluation of alternative development paths and the identification of joint investment projects at sub-regional (ENTRO and NELSAP-CU) and regional levels (NBI). The project includes the design, development, adaptation, testing and deployment of NB DSS at regional, sub-regional and national level as well as proof-of-concept, training, and continued support after the final deployment of NB DSS.

Details available at: http://www.unepdhi.org/WhatWeDo/DecisionSupportSystems.aspx

5.3.3.3 Nile PCR-GLOBWB

A very detailed integrated water resources and hydrological model for the entire Nile was built and applied recently. The model is based on a revised version of the PCR-GLOBWB (PCRaster Global Water Balance) hydrological model and has a resolution of 1 km^2. PCR-GLOBWB can be described as a conceptual, dynamic and distributed model written in the meta-language of the PCRaster GIS package. PCR-GLOB is fully distributed and implemented on a regular grid. Within this grid, variations in soil, land cover and topography are taken into account by parameterizing sub-grid variability. Such a grid-based approach is, over large areas, often preferred over the traditional sub-basin approach.

Details can be found at: http://www.futurewater.nl/wp-content/uploads/2012/03/Phase1_v05.pdf

5.3.4 Orange

5.3.4.1 Water Resources Simulation Model 2000 (WRSM2000)

WRSM2000 is a mathematical model to simulate the movement of water through an interlinked system of catchments, river reaches, reservoirs, irrigation areas and mines. WRSM2000 is of a modular construction (running under Windows), with five different types of modules (runoff, reservoir, irrigation, channel and mine) linked by means of routes. The routes represent lines along which water flows, such as river reaches.

The model was first developed in 1969 and has been subject to numerous enhancements over the years. WRSM2000 has been used to analyse the hydrology on a monthly time scale for a number of diverse applications ranging from very small to very large catchments varying in complexity from being totally undeveloped to highly developed. It has been used throughout South Africa, SADC countries and even in certain overseas countries.

Some common uses of the model are:

- to calibrate streamflow records taking land-use changes over time into account by comparing the observed flows against those simulated by the model;
- for broad regional assessment of water resources;
- to produce naturalised flow records i.e. take out man-made land-use effects;
- to estimate flows in ungauged catchments by transferring parameters.;
- when the density of flow gauges is insufficient to cover all catchments, when record periods are too short and/or when records show changes in land-use over time;
- simple reservoir yield analysis;
- input to complex system models of water resources (eg. WRYM, WRPM and
- WSAM);
- input to water quality studies and
- input to Ecological Water Requirement models.

The model is not appropriate for flood design and for determining yields of dams in a complex system of competing water users. Each of the 5 Modules contains one (or offers a choice between more than one) hydrological Models that simulate a particular hydrological aspect. The Modules are linked to one another by means of Routes. Multiple instances of the different Modules, together with the Routes, form a Network. By choosing and linking several modules judiciously, virtually any real-world hydrological system can be represented.

The first step in simulating any hydrological system is to set up the Network of Modules and Routes to represent this system. The Windows version of WRSM2000 allows for much larger networks than ever before and offers interactive creation and editing of all Modules, Routes and Networks. The program supports the user by means of extensive error checking and does away with the error prone and time consuming chore of creating data files in an editor, external to the program. Where files of older versions of the program are supplied, WRSM2000 will automatically update these files to be compatible to this latest version. WRSM2000 simulates flows in a catchment and by comparing against observed flows, the user can analyse statistics and graphs of various water resource parameters and manipulate calibration parameters to achieve a good ‘fit’ between observed and simulated flows. Once this has been achieved for the network, naturalised flows can be determined i.e. flows without any man made effects of reservoirs, industry, towns, irrigation schemes, mines etc.

The original version of the NAMRON rainfall/runoff model was developed within the Hydrology Division of the Namibian Department of Water Affairs in 1981. It can be run on a monthly or annual timestep. In the case of the Fish River it has been run using a monthly time step. One of the main differences between NAMRON and models used in South Africa and elsewhere, is that it allows for “negative serial correlation”. It has been observed in many of the more arid parts of Namibia that higher than average antecedent previous rainfall years tend to generate above average vegetation coverage in the catchment and that this has a runoff inhibiting effect. NAMRON allows the user to take into account the effects of the previous three years of rainfall.

Detailed information about the model and its setup and performance can be found at: http://www.orasecom.org/

5.3.4.2 Water Resources Yield Model (WRYM)

The WRYM is a monthly stochastic yield reliability model used to determine the system yield capability at present day development levels. The model allows for scenario-based historical firm and stochastic long-term yield reliability analysis. In addition, short term reservoir yield reliability can be determined, given current starting conditions.

The WRYM was developed by the South African Department of Water Affairs (SA-DWA) for the purpose of modelling complex water resource systems and is used together with other simulation models, pre-processors and utilities for the purpose of planning and operating the country’s water resources.

The WRYM uses a sophisticated network solver in order to analyse complex multi-reservoir water resource systems for a variety of operating policies and is designed for the purpose of assessing a system’s long- and short-term resource capability (or yield). Analyses are undertaken based on a monthly time-step and for constant development levels, i.e. the system configuration and modelled demands remain unchanged over the simulation period. The major strength of the model lies in the fact that it enables the user to configure most water resource system networks using basic building blocks, which means that the configuration of a system network and the relationships between its elements are defined by means of input data, rather than by fixed algorithms embedded in the complex source code of the model.

Recently, SA-DWA has developed a software system for the structured storage and utilisation of hydrological and water resource system network model information. The system, referred to as the WRYM Information Management System (IMS), serves as a user friendly interface with the Fortran-based WRYM and substantially improves the performance and ease of use of the model. It incorporates the WRYM data storage structure in a database and provides users with an interface which allows for system configuration and run result interpretation within a Microsoft Windows environment.

SA-DWA recently made available WRYM Release 7.5.6.7 which incorporates a number of new sub-models designed to support the explicit modelling of water resource system components in various studies. Detailed information in this regard may be obtained from the Water Resources Yield Model (WRYM) User Guide - Release 7.4 (WRP, 2007).

Detailed information about the model and its setup and performance can be found at: http://www.orasecom.org/

5.3.4.3 Water Resources Planning Model (WRPM)

The WRPM is similar to the WRYM, but uses short term yield reliability relationships of systems to determine for a specific planning horizon what the likely water supply volumes will be, given starting storages, operating rules, user allocation and curtailment rules. The model is used for operational planning of reservoirs and inter-dependant systems, and provides insight into infrastructure scheduling, probable curtailment interventions and salt blending options.

A unique feature of the analysis methodology is the capability of the WRPM to simulate drought curtailments for water users with different risk requirements (profiles) receiving water from the same resource (see Basson et. Al, 1994 for a technical description). This methodology makes it possible to evaluate and implement adaptive operating rules (transfer rules and drought curtailments) that can accommodate changing water requirements (growth in water use) as well as future changes in infrastructure (new transfers, dams and/or dam raisings) in a single simulation model. By combining these simulation features in one model gives the WRPM the ability to undertake risk based projection analysis for operation and development planning of water resource systems. The WRPM therefore simulates all the interdependencies of the aforementioned variables and allow management decisions (operational and/or developmental) to be informed by results where all these factors are properly taken into consideration.

Detailed information about the model and its setup and performance can be found at: http://www.orasecom.org/

5.3.5 Senegal

5.3.5.1 SIMULSEN

SIMULSEN was developed to simulate on a daily basis and run over a hydrological series of several decades various scenarios of water release patterns. The aim of the simulations was to evaluate in what manner (from a statistical point of view) the various water uses could have been compatible with one another. It allows determine at each point in time what the level in the reservoir should be in order to fulfill the uses with a given degree of certainty.

Details can be found in (Bader & al., 2003; Bader& al, 2006) and
http://www.omvs.org/fr/gestion/simulsen.php

5.3.6 Volta

5.3.6.1 VB-WAS

VB-WAS serves as a decision support platform for water authorities that allows simulations of water resources development and climate change, and to identify transnational competing water uses, such as irrigation schemes and hydropower supply under predefined climate change and water use scenarios.

The VB-WAS is a decision support tool that allows incorporating the impact of possible future climate conditions and projected water demand scenarios on future water resources management and infrastructure development in the basin. For example, the impact due to the expansion of small reservoirs, further large dam development, and that of other water users on the available water resources of the Volta basin can be assessed.

VB-WAS simulates the impact of various water users (water demand) on the water allocation (water supply) within the Volta Basin using a sequence of data coupled and fully coupled models.

The simulated historic and future discharge time series of the coupled climate-hydrological model (MM5/WaSiM) serve as water supply input data for a river basin management model (MIKE BASIN). MIKE BASIN uses a network approach, and allows fast simulations of water allocation and of the consequences of different development scenarios on the available water resources.

The water demand of different basin users (agricultural, domestic, hydropower) is dynamically simulated with the economic model (M3WATER) assuming different policy scenarios.

Details at: http://www.glowa-volta.de/results_vb-was.html

5.3.7 Zambezi

5.3.7.1 Zambesi-CliRun-II

CliRun-II was implemented for the Zambesi to study projected interactions between climate-driven changes in water availability and growing demand for water in the hydropower and irrigation sectors as investment plans are implemented. CliRun-II was used for modeling surface water availability (runoff), reservoir storage, hydropower, and major demands in the Zambezi Basin in order to allow investigation of intersectoral competition between water demands.

Computations were performed on a monthly time scale for 90 years for a base-case scenario (i.e., no climate change) and the four climate change scenarios. Each climate change scenario was characterized by unique inflows and growing irrigation demand, hydropower, and reservoir storage. A total of 28 sub-basins in the Zambezi were distinguished and implemented in CliRun-II. In total changes in climate were modeled for each of the 56 GCM scenarios included in the study. Details can be found in (Strzepek et al., 2011).

5.3.7.2 Zambezi-WEAP

The WEAP model was developed for Zambezi to serve as a water planning model to evaluate the potential interactions between growing municipal and industrial (M&I) water use, irrigation, and hydropower demands under climate change. The model evaluates these intersectoral effects between 2001 and 2100, and generates time series of impacts to irrigated agricultural yields and hydropower generation under each of the climate scenarios. In particular, the study focuses on projected interactions between climate-driven changes in water availability and growing demand for water in the hydropower and irrigation sectors as investment plans are implemented. The analysis projects perturbations, or "shocks," to hydropower production and irrigated crop yields resulting from these conflicts from 2001 to 2100 across the Zambezi Basin.

Municipal and industrial (M&I) sources also withdraw water from available runoff, and are projected based on World Bank sources (World Bank 2009). Hydropower production is calculated for existing and planned projects based on an expected investment and construction schedule using the relevant scenario data from the prior World Bank (2010) study. Details are described in (Strzepek et al., 2011).

5.3.7.3 The Zambesi River/Reservoir System Model

The River/Reservoir System Model was developed using HEC-3, the river and reservoir system model developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers. The version of the model used in this study was modified to improve some of its features.

The modeling time step adopted is one month. All inputs, inflows, evaporation, diversions or withdrawals, downstream flow demands, and reservoir rule curves are on a monthly basis. The outputs of the model—reservoir storage and outflows, turbine flow, spill, and power generation—are also on a monthly basis. The simulation period spans 40 years—from October 1962 to September 2002—long enough to obtain a realistic estimate of energy production.

While the focus of this analysis is on hydro-power and irrigation, the river/reservoir system model takes into account all sectors concerned with water management, notably tourism, fisheries, environment such as environmental flows (e-flows) and specific important wetlands, flood control, and industry.

The model can assist the Zambezi River Watercourse Commission awaiting ratification (ZAMCOM), SADC, and riparian countries by providing insight into options for joint or cooperative development as well as associated benefit sharing. The model is still being used by the Zambezi River Authority (ZRA). Application of the model is described in World Bank, 2010a, while details can be found in World Bank, 2010b.

5.3.7.4 ETH-RRM Zambezi integrated model

A single modeling framework was developed to explore the potential implications of climate change and changes in water demand for water availability in international river systems. The model was used in combining a comprehensive set of water demand scenarios and climate change projections with a hydrological model to estimate future water availability in key parts of the Zambezi river basin (ZRB) until 2050.

The developed model consists of a lumped rainfall-runoff model (RRM) including surface- and base-flow, regulated dams for hydropower production, and water storage dams for consumptive water use. Concerning dam/reservoir operation rules, it was assumed that the only objective is to prioritize water demand for power production and neglect an exact seasonal timing to coordinate with specific environmental water needs after dams.

The model is based on the thirteen sub-basins (RRM's) to a consistent hydrological model for the entire ZRB. The model focuses on long-term mean annual water flows for two reasons. First, projected effects of climate change are rather small compared to inter-annual climate uncertainties and could be blurred by uncertainties concerning precipitation and evapotrans-piration. Second, the different data sources for discharge measurements we use for calibration are, in many cases, not seasonally consistent, but match in a long-term perspective and at the basin- scale.

Details of the model can be found in (Beck and Bernauer, 2011) and http://www.ied.ethz.ch/newsletter/newsletter10/research/ir

5.3.7.5 SADC-HYCOS-SPLASH

The SPLASH model concept of a catchment is a set of tour different storage zones: the upper and lower zone, together with two groundwater zones. Evaporative losses from the upper zone are assumed to occur at the same rate as the potential evaporation. Once the moisture store in the upper zone is depleted, evaporative losses are assumed to take place from the lower zone according to a non-linear function of soil moisture. Overland flow and interflow are derived from the upper zone. When the lower zone storage is lower than a predetermined value, overland flow is determined by the storage level of the upper zone only. When the predetermined upper zone storage level is exceeded both overland and interflow are controlled by the moisture level in the lower zone. The two groundwater stores are replenished from the upper zone, the amount also controlled by the moisture store in the lower zone. The groundwater stores contribute to the baseflow. The model is characterised by a mixture of linear and non-linear functions.

Details can be found at: http://sadchycos.dwaf.gov.za/Documents.aspx

6 Datasets

The datasets attached to this report include data on global, continental, regional and national scales. 39 data sets were acquired and are listed and detailed in the Excel Database that accompanies this report. Dataset spread sheet contains the following structure:

Field Name	**Description**
Name	Name of Dataset
Related Report	The report that contains the data (summarized in section 3 of this report)
Organization	The organization that commission the dataset
Related Sector	Roads, Water, Energy
File Type	The format of the data e.g. Portable Document Format (Pdf), Shape/GIS File (SHP)
Description	Description of the dataset
Variables	Variables of the dataset
Units	Variable units
Temporal Coverage	What year does the data cover
Spatial Coverage	What areas does the data cover
Temporal Resolution	The time step of the data
Spatial Resolution	Pixel size and scale of data
Measurement Techniques	How the data was measured
Publication year	What year the data was published
Availability	Whether the data has been acquired or not / link to data website
Property Rights	Who owns the data

Continental data include Aquastat data which is a record of all African dams including capacity, area, location etc. Regional data is again inconsistent with some regions such as the Zambezi, Orange and Niger and Volta basins having many available data sets including infrastructure and hydrology maps and other basins such as the Senegal providing very little if any data. On a national level the report contains maps of all planned and existing roads, electricity transmission lines and power plants for each of the countries included in this study. These were provided by AfDB and were compiled over various years.

7 Investment Plans

300 Investment plans were identified during the course of this exercise. A detailed list of these plans can be found in the accompanying database under the spread sheet names ‘Investment Plans’ and ‘Power Pool Projects’. The structure of each can be seen below:

Field Name	**Description**
Project Number	The reference number assigned to the project by its donor agency/implementing authority
Name	Name of the project
Authority	Organization/Institution responsible for the project
Related Report/website	Report/website that contains the project (summarized in section 3 above)
Related Sector	Roads, Water, Energy
Area Involved	River Basin in which the project is being implemented
Country	Country/Countries in which the project is being implemented
Budget	The projected budget for the project (varying currencies)
Timespan	How long the project is expected to last
Goals	Objectives of the project
Status	Completed/Ongoing/Pipeline
Year Published	When Website was accessed or project brief was published
Project Brief/Plan	The name of the acquired project brief

The investment plans section of this report provides information on infrastructure development plans for water supply and irrigation, roads and energy sectors. These plans were taken from Regional Economic Community websites and reports, power pool reports, donor agency and multilateral investment bank websites and national agency websites. Included in these are the PIDA investment plans. Infrastructure project plan documents are also provided where possible. These were for the most part provided by investment banks and donor agencies. It can be seen in the database that the majority of investments have been financed by the World Bank and the African Development Fund.

8 Conclusions

This report and the associated database maps out the extent of existing work on infrastructure and climate change in Africa. It documents and summarizes on-going activities (investment plans, programmes, projects etc.), relevant models and data-sets related to the energy, water and roads sectors.

It was found during the compilation of this report that there is a notable lack of climate change adaptation in Africa's infrastructure development plans. This lack of climate change adaptation can also be seen in Program for Infrastructure Development in Africa (PIDA) report. This is possibly due in part to the recommendations by organizations such as the African Development Fund (ADF) whose study on climate change adaptation costs found that "Africa's immediate adaptation priority is to improve its current adaptive capacity, much of which will be operationally indistinguishable from – and needs to be fully integrated with – traditional development activities".

Many of the listed studies in this report have found that there is a need to improve institutional capacity and financing if climate change and development policies and strategies are to be enforced. The review of the NEPAD Infrastructure Short Term Action Plan revealed that all the implementing agencies viz. RECs, Regional Power Pools, River Basin Organizations etc. were facing capacity constraints (severe in some cases). The PIDA report revealed that the lack of alignment with national and regional priorities and financial problems were the principal drags on efficiency.

Recently though there have been various projects and plans aimed at reducing these institutional capacity constraints. Many of the donor agencies and multi-lateral banks are investing in capacity building operations but as they are on an institutional level and not directly linked to infrastructure development, they are not included in the infrastructure investment plans of this report.

In summary the **overall objective** of this report and the interlinked database is to present a rapid stock-taking exercise. More specifically, the following results are described in the report/database and can be summarized as:

- **Relevant institutions**. A total of 62 institutions have been identified with an interest in infrastructure and climate change in Africa. In total 99 contacts working in these institutions has been included in the database and information from these sources was combined with internet information, literature and knowledge available at the consultant. Results can be found in the database and are summarized in Chapter 2 of this report.
- **Existing analytical work**. Relevant reports, internet pages and literature that have been produced in the context of infrastructure and climate change were collected. It appeared that the amount of analytical work was quite substantial, although at a wide range of level of detail. In general work varied from a more research oriented approach with limited or no stakeholders' involvement to large-scale studies involving stakeholders at all levels. In general focus has been on the latter. The analytical work has been divided in (i) global reports (12), (ii) Africa wide reports (10), and (iii) regional/basin reports (12). Results can be found in this report (Chapter 3).

- **Relevant modeling tools**. The modeling tools have been divided into two sections: modeling systems (model frameworks that can be used to build an actual model for a certain region) and modeling implementations (actual models ready to be used). The modeling implementations have been grouped into the seven basins. Overall many modeling systems exist, but the number of modeling implementations vary substantially per basin. For example for the Nile and the Zambezi various existing modeling systems have been found, but for the Congo and the Senegal limited models could be identified. It remains somewhat unclear to what extent all of these models are still active and whether these are ready to apply directly. Results can be found in this report (Chapter 4).
- **Datasets**. In general sufficient global datasets are available to undertake further analysis. The advent of remote sensing and the internet have boosted the amount and detail of available data. A weak point remains flow data records and operational data on reservoir management. All other data, such as topography, climate, soils, and landuse are in general available at a reasonable level of detail for basin scale analysis. Results can be found in the database and are summarized in this report (Chapter 5).
- **Infrastructure investment plans.** A quite substantial and variety of relevant infrastructure investment projects that are planned for Africa were identified. A total of 300 investment projects related to hydro-power schemes, dam projects, irrigation projects, roads, flood control projects, and water supply projects were identified. These projects were grouped by basin/country and as much as possible project status, budget and investor/donor were indicated. Results can be found in the database and are summarized in this report (Chapter 6).

Table 1. Organizations identified and approached during the stock-taking exercise (details can be found in the database)

Contacts	Organizations	Persons
Regional Economic Communities	5	10
River Basin Organizations	7	14
Multilateral Development Banks	3	8
Donor Agencies (local AFD)	26	26
Research Institutes	6	13
National Ministeries	11	18
Power Pools	4	10
Total	***62***	***99***

Table 2. Investment plans per sector (details can be found in the database)

Sector	Count	US$ (billion)
Energy	28	12
Irrigation	19	2.1
Transport	163	14.5
Water	66	6.7
Water Supply	17	2.4
Miscellaneous	7	0.2
Total	***300***	***37.9***

Table 3. Investment plans per basin (details can be found in the database)

Basin	Count	US$ (billion)
Africa	1	0.0
Congo Basin	12	2.1
Niger Basin	19	3.5
Nile Basin	192	16.7
Orange Basin	4	1.1
Senegal Basin	13	2.4
Volta Basin	12	1.0
Zambezi Basin	47	11.1
Total	***300***	***37.9***

Table 4. Investment plans per project status (details can be found in the database)

Status	Count	US$ (billion)
Ongoing	111	*16.0*
Preparation	72	*15.5*
Completed	25	*0.6*
Unknown	92	*5.8*
Total	***300***	***37.9***

Annex I: Terms of Reference

3.1 Conduct rapid stock-taking exercise

The purpose of the rapid stock-taking exercise is to ensure that – before the main work begins – there is a thorough understanding of the actors, on-going activities and available models and datasets upon which the new work will build. Accordingly, the stock-taking comprises the following tasks.

- Make contact with all relevant institutions.
- Provide a quick overview of existing analytical work.
- Collect and technically document relevant modeling tools.
- Collate relevant infrastructure investment plans.

3.1.1 Make contact with all relevant institutions

The consultant will make contact with all relevant institutions with an interest in infrastructure and climate change in Africa, which are likely to include the following. The consultant should do an initial Google search with a view to extending and completing this initial list.

a) African Union
b) Regional Economic Communities (COMESA, EAC, ECCAS, ECOWAS, SADC, etc)
c) River Basin Organizations (Congo, Niger, Nile, Orange, Senegal, Volta, Zambezi, etc)
d) Power Pools (Central, East, Southern and West Africa Power Pools)
e) Multilateral Development Banks (African Development Bank in particular PIDA team, World Bank, Development Bank of Southern Africa, and other sub-regional Banks)
f) Donor agencies (AFD, DFID, European Union, JICA, KfW)
g) Africa Climate Policy Center at UNECA
h) Research institutes (IFPRI, IWMI, Stockholm Environment Institute, Delft Institute, ++)
i) Universities (Colorado, Massachusetts, etc)

Contact will be made by telephone and email, with a view to establishing whether the institution has been active in this area, and who the key internal contacts are for any relevant activity. The consultant will set-up teleconferences with these contacts in order to address the remaining components of the task.

3.1.2 Provide a quick overview of existing analytical work

The consultant will collect any relevant reports that have been produced by the institutions. In the case of work in progress, the consultant will attempt to collect Terms of Reference and/or Interim Reports that can provide a sense of the thrust of the work.

The consultant will organize all the material in an electronic archive and provide a text file containing an annotated bibliography of these items, including a paragraph summarizing each of the initiatives identified and highlighting its potential relevance to the study underway.

3.1.3 Collect and technically document relevant modeling tools

The consultant will also attempt to collect from the contacted institutions any *models* that may be relevant to the current exercise. Such models include: hydrological models of African river basins and African aquifers, models of flood patterns, models of power systems, irrigation systems, water supply systems and disaster risk protection.

In cases, where it is not possible to collect the models themselves, the consultant will collect detailed meta data on the model specifications and capabilities (including software platform, key inputs, outputs, assumptions, resolution, spatial coverage, etc). The consultant should also document any proprietary issues or purchase costs that may be associated with gaining access to the model in future.

The consultant will produce a text file containing a structured tabulation of all the key features of the models identified and/or collected.

3.1.4 Collect and technically document relevant datasets

The consultant will also attempt to collect from the contacted institutions any *datasets* that may be relevant to the current exercise. Such datasets include:

In cases, where it is not possible to collect the datasets themselves, the consultant will collect detailed meta data on the contents of the database (including variables, units, time periods, spatial coverage, measurement techniques, etc). The consultant should also document any proprietary issues or purchase costs that may be associated with gaining access to the dataset in future.

The consultant will produce a text file containing a structured tabulation of all the key features of the datasets identified and/or collected.

3.1.5 Collate relevant infrastructure investment plans

The consultant will collate from a variety of different sources a list of relevant infrastructure investment projects that are planned for Africa. This should include investment projects relating to hydro-power schemes and other dam projects, irrigation projects, flood control projects, major water supply projects.

These project lists may be found within the existing studies that were collected under Section 3.2 above. Or they may be derived from other regional planning and strategy documents produced by the various target institutions already identified.

It will also be necessary to review national level development plans where these exist, particularly for power, irrigation and hydraulic infrastructure. The consultant will attempt to secure such plans, either through the regional institutions or through a desk review of national agency websites, following-up where needed by teleconference.

The consultant will provide an Excel file tabulating the different investment projects and their principle features.

Annex II: Generic email requesting data for this report

Dear Sir/Madam,

The World Bank is re-evaluating its investment strategy regarding investments in the water, transportation and energy sector.

The World Bank has asked us (FutureWater and Industrial Economics Inc.) to conduct a stock-taking exercise for a World Bank report titled “Addressing Climate Vulnerability of Africa’s infrastructure” and we are currently looking for relevant information that may pertain to this project. We are at this time collecting reports concerning infrastructure development (roads, water and energy) in Africa.

In an initial search for documentation we have seen that your organisation has carried out work in this area. We would therefore greatly appreciate any reports and data relating to infrastructure development projects that your organisation has been or still is involved in.

Please find attached a summary of the project and a list of required documents.

We would like to emphasise that the World Bank policies regarding investments will be influenced by information obtained.

Kind Regards,

Julie Helleman-Melling

Peter Droogers

FutureWater