

Climate Change and Water Resources Planning, Development and Management in Zimbabwe

An Issues Paper

Richard Davis and Rafik Hirji



THE WORLD BANK



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Preface



Zimbabwe has embarked on a long-term process of rebuilding its economy following the period of economic decline and the breakdown of social services during the 2000s. Provision of clean water and the safe disposal of effluent are some of the urgent services needing rehabilitation and expansion. Water is essential not only for the health and well-being of Zimbabweans but also for the country's economic recovery. Manufacturing, agriculture and energy as well as the relatively recent, rapidly growing sectors such as mining and tourism all rely on clean, reliable water. Conversely, the Water Sector depends on the recovery and growth of these water using sectors to provide the revenues needed to meet the costs of water provision and management. A massive task lies ahead to rebuild the Water Sector so that it can regain its pre-eminence amongst African countries. Much of the country's water infrastructure needs to be rehabilitated and expanded; staff will need to be trained and capacity expanded; and improved operating procedures need to be implemented. This rebuilding is now underway. The 2013 National Water Policy (NWP) was prepared to guide recovery of the Water Sector. However, one of the challenges that have yet to be factored into the recovery plans is the likely effects of climate change on the country's water resources; and its implications on planning, design and management decision making.

Given the highly variable climate in Zimbabwe, the government is well aware that climate change has the potential to disrupt the economic recovery. Irrespective of the effectiveness of international efforts to curb greenhouse gases, Zimbabwe will inevitably be affected by global warming and so must focus on adapting to these impacts before they seriously affect the country and its economy. The government recognizes that, if its response is to be effective, it must be coordinated across all sectors of the economy. For this reason the government is currently preparing a National Climate Change Response Strategy (NCCRS) to ensure that there is a government-wide approach to climate change adaptation. This Issues Paper has been prepared as a recommendation of the NWP. It will contribute to the NCCRS by examining opportunities for adaptation to climate change in the water resources sector, using both structural and non-structural measures. The paper shows that climate change is likely to lead to a significant reduction in precipitation and available surface and groundwater resources across most of Zimbabwe. Most significant impacts will be felt in the Runde, Gwayi and Mzingwane catchments. Manyame and Mazowe catchments are likely to be affected the least. While the magnitude of the reduction still needs to be determined through more detailed studies and modelling work, the paper makes it clear that climate change, coupled with population growth, has significant implications for water availability in Zimbabwe. The recommendation for a specific Climate Change Adaptation Strategy for the Water Sector in Zimbabwe to complement and strengthen the NCCRS has considerable merit and needs to be supported. Such a strategy would necessarily have to be based on a more detailed understanding of climate change and our opportunities to adapt.

The technical assistance from the World Bank and other development partners in preparing this paper is highly appreciated. This paper will contribute to the formulation of the NCCRS as well as provide valuable information for the Water Sector Investment Analysis currently being prepared and the Water Sector in Zimbabwe in general.

My special thanks go to Dr. Rafik Hirji for providing leadership in delivering this high quality paper under a very tight deadline.

A handwritten signature in black ink, appearing to read 'Saviour Kasukuwere'.

Honorable Saviour Kasukuwere
Minister for Environment, Water and Climate

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The paper was prepared as a team effort between the former Ministry of Water Resources Development and Management (now Ministry of Environment, Water and Climate), the World Bank and various partners and colleagues as a rapid response to the request made by the former MWRDM in December 2012 under the overall leadership of Rafik Hirji of the World Bank. Its principal authors are Richard Davis (Senior Water Resources consultant) and Rafik Hirji (Senior Water Resources Specialist). The paper drew from three thematic inputs, builds on past Climate Change studies in Zimbabwe and the Southern African region, and case studies developed from January 2013 and January 2014.

Thematic inputs on (a) climate change impacts on precipitation and runoff modelled for 2050 and 2080 and water availability was prepared by Professor Amon Murwira, University of Zimbabwe, (b) climate change implications on water resources decision making was prepared by Eng. Zebediah Murungweni, and (c) climate change impacts on groundwater and recharge was prepared by Dr. Richard Owen, University of Zimbabwe.

Draft findings of the Issues Paper were presented to managers and staff of MWRDM, MENR, ZINWA, EMA, Catchment Managers, Provincial Environmental Officers, and representatives from ITRG and GWP at a stakeholder workshop held at Pandhari Lodge outside Harare on October 1, 2013. A revised version was presented to ZINWA management on January 30, 2014, and the final draft paper was presented to Honourable Minister Saviour Kasukuwere, Honourable Deputy Minister Eng. Simon Musanhu, Permanent Secretary Prince Mapuzviriho, Director Tinayeshe Mutazu, Director I. Kunene and Director General M. Chasi and senior staff from the MEWC on June 2, 2014. The team would like to thank staff from these institutions for providing valuable comments. The team acknowledges the guidance provided by former Minister Dr. Samuel Sipepa Nkomo and Permanent Secretary Ringson J. Chitsiko of MWRDM in the preparation of the draft paper and advice and logistical support provided by Mr. Vivarirai Choga, Mr. Tinayeshe Mutazu, Mr. Gilbert Mawere and Mr. Zvikomborero Manyangadze of the MWRDM and Eng. Albert Muyambo and Mr. Samuel Sunguro of ZINWA for organizing and chairing the various review meetings. Continued strong support from the current Minister for Environment, Water and Climate Honourable Saviour Kasukuwere and Honorable Deputy Minister Eng. Simon Musanhu and Permanent Secretary Prince Mapuzviriho is very much appreciated.

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Acronyms

ADMTF	Analytical Multi-Donor Trust Fund
AusAID	Australian Agency for International Development
BCC	Bulawayo City Council
BGS	British Geological Survey
BOD	Biological oxygen demand
DWR	Department of Water Resources
COMESA	Common Market for Eastern and Southern Africa
CSIRO	Commonwealth Scientific and Industrial Research Organization (Australia)
DFID	Department for International Development (UK)
EMA	Environmental Management Agency
ENSO	El Niño-Southern Oscillation
FAO	Food and Agriculture Organization
GCM	global circulation model
GI	Giga-litre (1,000,000 m ³)
GDP	Gross domestic production
GOZ	Government of Zimbabwe
GPS	Global positioning system
GWh	Giga watt-hour
GWP	Global Water Partnership
ICOLD	International Commission on Large Dams
IFPRI	International Food Policy Research Institute
IIED	International Institute for Environment and Development
IMF	International Monetary Fund
IPCC	International Commission on Climate Change
ITRG	Infrastructure Technical Review Group
IUCN	International Union for the Conservation of Nature
IWRM	Integrated water resources management
LIMCOM	Limpopo Watercourse Commission
lpcpd	litres/capita/day
MAMID	Ministry of Agriculture, Mechanization and Irrigation Development
MAR	Mean annual runoff
MAP	Mean annual precipitation
MDG	Millennium development goals
MENR	Ministry of Environment and Natural Resources
MEWC	Ministry of Environment, Water and Climate
MHCW	Ministry of Health and Child Welfare
MI	Mega-litre (1,000 m ³)
Mlpd	Mega-litre per day
MW	Mega watt
MWRDM	Ministry of Water Resources Development and Management
NAC	National Action Committee for Water and Sanitation
NCCRS	National Climate Change Response Strategy
NWP	National Water Policy
RSOP	River System Outline Plan

SADC	Southern African Development Community
SIDA	Swedish International Development Cooperation Agency
STP	Sewage treatment plant
UIM	Urban, industrial and mining (water use)
UN	United Nations
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNICEF	United Nations Children's Fund
WACDEP	Water, Climate and Development Programme
ZAMCOM	Zambezi Basin Watercourse Commission
ZESA	Zimbabwe Electricity Supply Authority
ZESCO	Zambia Electricity Supply Company
ZINWA	Zimbabwe National Water Authority
ZRA	Zimbabwe River Authority

Executive Summary

Water and Water Management

Water is central to the Zimbabwean economy, people's livelihoods and their social well-being; its availability and reliability is a function of highly variable climatic conditions. Irrigated agriculture is the major water using sector while rainfed agriculture depends on reliable rainfall. Agriculture not only has links to other economic sectors such as industry, but it is also important at household level because it employs the majority of the population. Power production which underpins most other production sectors depends to a large part on the flow of the Zambezi River either for hydropower generation or for the cooling of thermal power stations. Even mining, a growth sector, ultimately relies on water for both processing and electricity production.

Clean water is essential for health. The devastating cholera outbreak of 2008-09 arose from the consumption of contaminated water. Other diseases such as typhoid and gastro-enteric infections are spread by water that is contaminated by untreated or partially treated sewage. Water is also needed to maintain wetlands, floodplains and riparian areas which act as buffers against pollution. These areas are now degraded across much of Zimbabwe, exacerbating the population's exposure to pollution. This is most noticeable in alluvial mining where river banks, river beds and floodplains are being destroyed contributing to the siltation of downstream areas. Artisanal mining also adds highly toxic mercury to river systems and reservoirs and contaminates fish consumed by urban and rural populations.

Groundwater provides water to more than 70% of Zimbabwe's population. It is the principal source of water for both the communal and commercial sectors in rural areas and a major source of water for irrigation, mining and tourism. Yet its planning, development and management has received very little systematic attention since the mid-1980s because the country concentrated on the provision of clean water from surface water resources. There is almost no monitoring of groundwater levels (except near mining activities and in some urban areas) and little investigation of groundwater resources. The Government of Zimbabwe (GOZ) has recognized the importance of water to economic development and the living standards of Zimbabweans. To buffer against the vagaries of climate variability, the GOZ has invested in thousands of small and large dams and associated infrastructure for urban and rural water supply and sanitation and irrigation. It introduced a new Water Act in 1998, along with the ZINWA Act to establish a specialist water management agency, the Zimbabwe National Water Authority (ZINWA), has recently endorsed a new National Water Policy (NWP), and is currently preparing a Water Quality and Source Protection Strategy. It is also implementing rehabilitation of Harare Water and Wastewater, advancing investment planning for Bulawayo water supply, finalizing a Water Sector Investment Analysis (WSIA), and engaged in a number of transboundary water initiatives.

Climate Change and Water

Although climate change poses a threat to water resources that is yet to be fully integrated into water planning and management, Zimbabwe's NWP recognizes climate change and calls for establishing specific provisions for understanding the extent of the threat and proposing specific actions to manage potential impacts.

The government of Zimbabwe has long recognized the threat from climate change and joined the United Nations Framework Convention on Climate Change (UNFCCC) in 1992 and acceded to the Kyoto Protocol in 2009. It is currently preparing a National Climate Change Response Strategy (NCCRS) that is intended to mainstream climate change thinking into all key economic sectors and to bring about an integrated response across all economic sectors. Zimbabwe strategy will largely be based around adapting to the threats from climate change so that detrimental economic and social impacts are minimized and opportunities are seized. Given the implications of climate change for the hydrological cycle and the centrality of water to the economy and to social well-being, water needs to be at the core of the NCCRS.

This Issues Paper, requested by the former Ministry of Water Resources Development and Management as a recommendation of the NWP, will contribute to the NCCRS by examining opportunities for adaptation to climate change in the water resources sector, using both structural and non-structural measures. It uses models to provide preliminary estimates of the possible impacts of climate change in 2050 and 2080 on these water resources. A number of opportunities to adapt to these impacts are discussed. Many of these adaptation opportunities constitute no-regrets actions, in that they are actions that are worth undertaking in their own right, irrespective of the severity of impacts from climate change.

State of Water Resources

Mean annual precipitation (MAP) across the country varies from 337 mm/year in the south of the country to 1110 mm/year in the Eastern Highlands. These averages conceal considerable inter-annual variability in climate.

Zimbabwe's long-term average surface runoff is estimated to be 23.7×10^6 MI yr, although this figure is not precise because of the deterioration in stream flow gauging stations and the need to estimate runoff in sub-catchments without gauging stations. Gwayi and Mzingwane catchments have the lowest runoff while Save catchment has the highest (Table A). Zimbabwe stores runoff in a large number of small and large dams with a total storage capacity of about 9×10^6 MI, excluding Lake Kariba. ZINWA dams account for the bulk of water stored in dams because the Authority has taken over permits of dams in the former commercial farming areas in order to ensure that they are maintained.

Water quality is often poor because of pollution from both point and diffuse sources. Pollutants include sediments from artisanal mining and agricultural activities, pathogens from wastewater, nutrients from wastewater and some industrial discharges, and heavy metals from industrial enterprises. Biological oxygen demand (BOD) is often high downstream from industrial discharge points and STPs because of high loadings of organic matter. Mercury and stream-bank destruction from artisanal and alluvial mining activities are particularly worrisome. Uncontrolled water contamination removes water from safe consumption as surely as water shortages do.

Table A Runoff and Storage Potential in Zimbabwean Catchments

Catchment	MAR	Potential Storage (2xMAR)	Potential Yield 10%	Present Commitment		Use
	x10 ⁶ MI	x10 ⁶ MI	x10 ⁶ MI	Storage (x10 ⁶ MI)	10% Yield (MI)	%
Gwayi	1.8	3.7	0.9	0.2	98,144	11.2
Manyame	3.3	6.6	2.0	2.6	942,849	46.6
Mazowe	4.6	9.2	2.8	0.3	488,348	17.6
Mzingwane	1.8	3.4	1.2	1.3	330,329	27.1
Runde	2.1	4.3	1.2	2.5	481,259	41.0
Sanyati	3.9	7.8	2.1	0.6	430,179	20.5
Save	6.1	12.2	4.4	1.2	804,368	18.3
TOTAL	23.7	47.2	14.5	8.7	3,575,476	24.6

Source: World Bank 2012a

Groundwater recharge rates are not generally known although some estimates have been made. Groundwater is generally of good quality, apart from shallow aquifers in urban areas and salinity in the extreme south and southeast of the country. Groundwater forms an important resource for the future.

Water Resources Governance

Zimbabwe has a sound framework for water governance. The 1998 Water Act vested ownership of all water in the President rather than in private land owners, established regional Catchment Councils and sub-catchment councils for undertaking catchment-level water planning, issuing water use permits and monitoring their use, establishing the rights and responsibilities of water users, and assigns responsibility for dam safety. The 1998 ZINWA Act established ZINWA as a specialist agency charged with managing the nation's water resources, and the recent NWP reinforces these decisions, emphasizes the importance of inter-Ministry coordination, recognizes the need to incorporate climate change into water planning and emphasizes the need for recovery of the water sector.

The difficulties lie in implementing this framework. There is little coordination and cooperation between Ministries whose decisions have major implications for water resources planning and management; there are potential conflicts of interest between some institutions; there are no clear mechanisms for protecting water source areas; there are serious capacity constraints; surface water monitoring networks are not fully maintained and there is almost no monitoring of groundwater levels or quality; water prices are low and there is little willingness to pay with the result that ZINWA and local authorities lack operating funds; and regulations are often not enforced.

Zimbabwe developed extensive water storage capacity (Table A) prior to and after independence, as a safeguard against the climate variability. By the early 1990s, Zimbabwe had also developed a modern and well managed water supply and wastewater treatment systems for major urban centres. There was good water supply coverage in rural areas. However, as a result of the economic and financial crisis and international sanctions, regular dam safety

inspections have not been carried out and water supply and wastewater treatment plants and associated infrastructure are now seriously dilapidated. The government is working with development partners to restore many of these systems. While most dams for irrigation remain safe, some need urgent repairs to be operational again, and other irrigation infrastructure, including that on farms, needs maintenance and, in some cases, replacement.

Effects of Climate Change

The methodology for estimating potential climate change impacts on Zimbabwe's water resources was based on the CSIRO Mk3 global circulation model (GCM) recorded in a global database of climate predictions. Its outputs were used to estimate the effects of climate change on Zimbabwe's water resources for 2050 and 2080. The precipitation predictions from the model were downscaled and aggregated to catchment level. These global precipitation data were checked with data from the Meteorological Department of Zimbabwe, and were then coupled to simple rainfall-runoff relationships established by ZINWA for each of Zimbabwe's seven catchments, to provide estimates of runoff.

This simple methodology provides useful preliminary estimates of precipitation and runoff but it also has a number of limitations. Only one GCM was used; the downscaling to catchment scale is subject to considerable uncertainty; the rainfall-runoff relationships may not be reliable under climate change; and other consequences of climate change (such as changes in land use and increases in evaporation rates) were not considered in the simple modelling effort. The method only provides annual average precipitation and runoff estimates and does not provide insight into changes in inter-annual variability, changes in extreme events, or seasonal shifts in precipitation patterns or changes in water use or demand, all of which are expected to change as a result of global warming. Nevertheless, this simple method provides a useful first estimate of the possible effects of climate change on Zimbabwe's water resources.

Results from the GCM show that, whether the world attempts to curb emissions of greenhouse gases or adopts a business-as-usual approach, annual average precipitation will decrease in all Zimbabwean catchments, except Mazowe and Manyame where it would remain similar to current levels. The drier catchments of Runde and Mzingwane will be affected most, with declines in mean annual precipitation of between 12% and 16% by 2050 depending on the emissions scenario. Precipitation could stabilize or start to recover in the more affected catchments-Gwayi, Mzingwane, Runde, Sanyati and Save - between 2050 and 2080 if emissions are curbed, although it would continue to decline in almost all catchments if the business-as-usual emissions scenario persists.

Runoff will be affected by global warming to an even greater extent than precipitation. River flows in Manyame catchment may be little affected, but the river flows in Gwayi and Mzingwane catchments could decline significantly if greenhouse gas emissions are not controlled (the business-as-usual scenario). Given the simplicity of the method, there is considerable uncertainty about the extent of the decreases in river flow, but the general prediction of a drier climate with considerably less river flow across southern and western Zimbabwe, with much smaller impacts in Manyame and parts of Mazowe catchments, is a reliable conclusion.

Groundwater recharge was estimated by assuming that it was primarily determined by MAP. This may be a reasonable assumption for most parts of the country but not all. The expert

opinion of an experienced hydrogeologist was used to estimate the proportion of precipitation that contributed to recharge in each of Zimbabwe's seven catchments. Because of the direct relationship between recharge and MAP, this simple method suggests that the changes predicted in precipitation under climate change will also be seen in recharge. That is, recharge in Manyame and Mazowe catchments will be little affected by climate change while the Mzingwane and Runde catchments will possibly experience major declines in recharge in both 2050 and 2080. General principles suggest that dambos, shallow hard-rock aquifers and other unconfined aquifers that receive direct recharge are likely to receive considerably less recharge than at present.

The results from the present study were compared to the results from two other studies that included the Mzingwane catchment. The decline in runoff in this catchment was much larger in the present study (65-100%) than in the other studies (19-33% and 2-24%). These other studies were able to predict intra-annual changes in precipitation. They found that, not only would mean annual precipitation decline in southern Zimbabwe, but that there would be increased variability in precipitation. One of the studies in the Mzingwane catchment found that the main reduction in precipitation would occur in the dry months of early April to end September.

The predicted effects of global warming are broadly consistent with observed changes in climate over recent decades in Zimbabwe. Daily minimum and maximum temperatures have risen over the last century; the Department of Meteorology states that annual rainfall has become more variable; and there is anecdotal evidence that the wet season has progressively started later. There has been a decline in stream flow over the last 20 years although it is not clear that this decline is because of climate changes. Although some reports claim that mean annual precipitation has declined, a thorough analysis shows that changes in precipitation depend on the time period over which the changes are measured. Although consistent with the expected effects of climate change, none of these changes can be attributed specifically to the effects of climate change.

Implications of Climate Change

These results have major implications for Zimbabwe's water resources. Water supply to urban and rural areas in the south and west of the country could be seriously affected. Given the dependence of many Zimbabweans in rural areas on groundwater, this implies that climate change could also have severe effects on rural populations. A Southern African Development Community (SADC) study supported this conclusion. It found that the population at very high risk from groundwater drought in Zimbabwe could rise from 32% to 86% by 2100 unless measures were taken to adapt to the effects of climate change.

When the reduction in runoff and groundwater recharge is coupled with possible scenarios of population growth, national per capita water availability decreases significantly. Even under the best case greenhouse gas emissions scenario and a low population growth scenario, national per capita water availability declines by 38% from 2.45 ML per capita per year in year 2012 to 1.52 ML per capita per year by 2050. Under medium or high population growth scenarios, national per capita water availability continues to decline to 2080 to the point where Zimbabwe would move from the UNs "water stress" to the "absolute water scarcity" category.

There are also potential economic implications. Both rainfed and irrigated agriculture would face reduced yields; electricity production from both thermal and hydropower stations would be reduced if flows in the Zambezi River were reduced and consequently sectors dependent on electricity, including manufacturing, commerce and mining, would be affected; and many manufacturing enterprises would face water shortages.

There are implications for water resources investments and management. Existing dams built for water supply and irrigation may become less reliable. Current plans to rehabilitate the country's water resources infrastructure do not take account of climate change. Yet reduced precipitation and increased evaporation in southern and western parts of Zimbabwe could have significant implications when selecting dams for rehabilitation or when designing new dams. Increasing investment in infrastructure, by itself, is not likely to be an efficient response to reduced water availability. Instead a multi-pronged strategy including better governance and improved management would help existing water resources go further in a more economical manner.

The final implication of climate change is that there is likely to be increased reliance on groundwater because, unlike surface water, it is shielded from evaporative losses and better buffered against increased climate variability. Surface and groundwater are closely linked and should be managed together. Yet, at present, groundwater in Zimbabwe receives very little management attention.

More generally, water management and planning should take account of the likely effects of climate change, to the point where anticipation of the potential effects of climate change becomes a normal part of operational thinking. There are many opportunities for the water sector to adapt to climate change.

Adaptation Opportunities

Adaptation in advance of climate change means that water can be captured and used more efficiently in the face of declining availability, and managers and water users can respond more flexibly in the face of increased variability. SADC suggests that adaptation can occur at three levels – water governance, infrastructure development, and water management. We have extended this structure by broadening the third category to include water planning and separating out information, communications and education. Many of the most effective adaptation measures constitute no-regrets actions.

Water Governance

Possibly the most important governance action is to ensure genuine coordination between water managers and water using sectors to promote efficiency in water supply and in water demand. Various policy instruments (e.g. the NWP and the Environmental Management Act) promote coordination, but the difficulty has been in putting these intentions into action. Without coordination and determination to enforce legislative provisions, it will be impossible to implement actions that protect water sources, prevent water pollution, plan for efficient water use, or introduce water demand measures that will make better use of existing water. All these actions span the responsibilities of a number of Ministries. Sectoral policies should be examined to ensure that they address climate change.

Given the importance of transboundary waters, especially the Zambezi River and the Limpopo River, to Zimbabwe's economy, Zimbabwe needs to provide strong support for transboundary water institutions to take account of the effects of climate change on their water management. Zimbabwe's hosting of ZAMCOM, the Zambezi Watercourse Commission, is consistent with this approach.

Water pricing should be reviewed to develop a strategy to charge for water's true cost. This will not only improve water use efficiency by encouraging water conservation and water recycling, but will provide the funds for ZINWA and local authorities to carry out important rehabilitation and climate related initiatives. Establishing the independent Water and Wastewater Services Regulatory Unit would help set water prices at levels where costs can be met. Also an informal water market could be investigated as a mechanism to promote more flexible and efficient use of water.

Adaptation should also be encouraged amongst local communities and individual farmers. This may entail shifting more responsibility and authority to local level to legitimize local initiatives.

Conjunctive management of surface and groundwater and greater use of managed aquifer recharge (with appropriate protections for groundwater quality) could be encouraged through regulations and guidelines to increase the efficiency with which groundwater is used.

Water Resources Planning and Management

Water management techniques such as demand management, increased reuse of wastewater and stormwater, conjunctive management, managed aquifer recharge and rainwater harvesting could make greater use of existing resources and help adapt to a drier climate. Operating procedures could also be improved, including increased rates of fee collection, reductions in unaccounted-for water, and pricing water at its true cost.

Natural systems such as wetlands and riparian areas that provide a cost effective buffering capacity against pollution and floods should be better protected and/or restored where they are damaged.

Protection of water sources and improving management of water quality through a more effective arrangement and cooperation between ZINWA and the Environmental Management Agency (EMA) would not only improve human and environmental health but would expand the available supply of useable water.

Building greater capacity and understanding in Catchment Councils would help encourage local responses to the effects of climate change. Nevertheless, it will take some time for this capacity to develop and it would be important for ZINWA to help Councils revise and update River System Outline Plans that are responsive to the likely effects of climate change in individual catchments.

Rules and procedures governing the allocation of water (issuing of water permits are based on historical experience and) may need to be revised to take account of the effects of climate change on rainfall and evaporation patterns.

Water Resources Infrastructure

Plans to help Zimbabwe rehabilitate its water resources infrastructure, including water supply for Bulawayo and Harare, should be assessed in light of the likely effects of climate change. Design standards for dams, bridges, flood levees, etc could also be reassessed to take account of the likely effects of climate change on precipitation variability and extreme events.

ZINWA is currently assessing the acceptable level of risk for agreement water. Increasing the level of risk (for example, from 4% to 10% for urban water supply and 10% to 20% for irrigation water supply) would help increase land under irrigation and promote production. The yields from catchments should be recalculated to incorporate changes in precipitation patterns and evaporation.

Although there is a general drying of the annual rainfall in southern Zimbabwe, there will also be an increased probability of extreme events, such as storms. Flood control measures will need to be designed to take account of more intense storms, employing both structural and non-structural measures. This could include better protection and management of floodplains and wetlands to absorb floodwaters and better operation of flood control dams.

Information, Education and Communications

A wide ranging communications strategy is important so that decision makers and those potentially affected by climate change are aware of both the threats and the opportunities for adapting. Senior decision makers inside and outside government need to be fully informed; adaptation actions will only be pursued vigorously when there is a full appreciation of climate change and the importance for the Zimbabwe's economy and social well-being of early adaptation actions in the water sector. But the general public too needs to be forewarned of the consequences of climate change so that they can engage in adaptation responses.

Some of the strategies that farmers and communities already use to adapt to climate variability could be assessed and promulgated to help a wider cross-section of Zimbabwean communities prepare for climate change.

Improving climate and surface and groundwater monitoring is critical to all of the major water management decisions, including understanding climate change. The weather and surface water monitoring network needs to be rehabilitated, and a groundwater monitoring network needs to be established and expanded.

Assessment of groundwater is essential to properly plan, develop and manage this vital water resource. Investigations into groundwater dependent ecosystems would help protect these important systems for times when the climate is drier.

It would be valuable to build capacity in modelling climate change and its effects by forming a Centre of Excellence drawing on expertise from across the government and academic areas. Universities should incorporate climate change into engineering, planning and natural resources courses so that the next generation of professionals is aware of and informed about global warming and its implications for water resources management and other sectors.

Findings and Recommendations

This study has illustrated the need for better scientific information if Zimbabwe is to develop a defensible strategy for climate change adaptation in the water sector. These include better data on climate and surface and groundwater systems gathered through comprehensive monitoring programs; better understanding of groundwater characteristics; predictive models of surface and groundwater systems; accurate assessment of current and future uses of water by the different sector; and a more comprehensive exercise to model the potential impact of climate change on water resources than was possible here. These studies would support a comprehensive Climate Change Adaptation Strategy for the Water Sector to implement some of the adaptation opportunities identified in this report. Such a strategy could constitute the Water Sector's contribution to implementing the NCCRS and recommendations of the WSIA.

The formation of the Ministry of Environment, Water and Climate merging the mandates of the three key areas environment, water and climate under the new cabinet provides an excellent opportunity to re-align and work out effective coordination at the policy, regulatory and institutional levels to systematically address climate change adaptation in the water and water related sectors.

1. Water and the Economy

Water and the Economy

Starting in 2009, the Zimbabwean economy began to recover after almost a decade of decline (World Bank 2012b). Gross Domestic Product (GDP) grew by 6% in 2009 and over 9% in 2010 and 2011, although it slowed to 4.7% in 2012 (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners, 2013a). Agriculture grew by 34% in 2010. Mining grew by 35% between 2009 and 2011. However, this economic resurgence is threatened by both financial factors (limited access to international funding, liquidity shortages and economic uncertainty) and production factors such as power shortfalls, unreliable supply of raw materials and broken or partially functioning infrastructure.

Historically, Zimbabwe's economy has been strongly linked to climate (rainfall in particular), and so there has been a close link between water resources and the overall economy. Before and for almost two decades after independence, Zimbabwe employed a water sector strategy that relied on the development of dams, water supply and sewerage systems and irrigation systems coupled with institutional and legal reforms to counter its highly variable climate and meet its growing water needs for domestic supply and irrigation. This was an effective strategy until the late 1990s but failed in the last decade because of the economic and political crisis. Rehabilitating dams, restoring power supply and irrigation systems, rehabilitating water and sewerage systems and reinstating the institutional and legal reforms as part of the country's recovery, while essential, will no longer be sufficient, because human induced climate change poses an additional burden and threat to long-term economic recovery that is not yet widely recognized, appreciated and integrated in development planning.

Improving water security how well water resources are harnessed, utilized, conserved, protected and managed for multi-sectoral uses-is a core development challenge for Zimbabwe's economic recovery, growth and social development (Government of Zimbabwe, 2013). Water is central to the performance of key sectors of the Zimbabwean economy rural and urban development, agriculture, energy, industry, mining, tourism, and the environment. Figure 1 shows a close relationship between precipitation and GDP from the early 1980s until the mid-1990s. However, this link was broken after 1996 when other factors, including new settlement policies and increasing international isolation led to decline in GDP even when precipitation remained high

The precipitation-GDP relationship occurs primarily because of the centrality of agriculture and electricity production within the economy (Figure 2). Both are heavily dependent on precipitation. Although agriculture itself currently constitutes only about 14% of GDP, it remains central to economic performance because it provides employment for about 60-70% of the population, contributes to export revenue, and has strong links to other sectors, particularly manufacturing where it provides about 60% of the raw materials. Manufacturing and commercial institutions generally have relatively low direct water demands, but they are dependent on reliable power supply. Some 80% of Zimbabwe's electricity comes from the Kariba dam with the remainder from thermal power generators that are largely reliant on cooling water from the Zambezi River, for example, Hwange Thermal Power Station making.

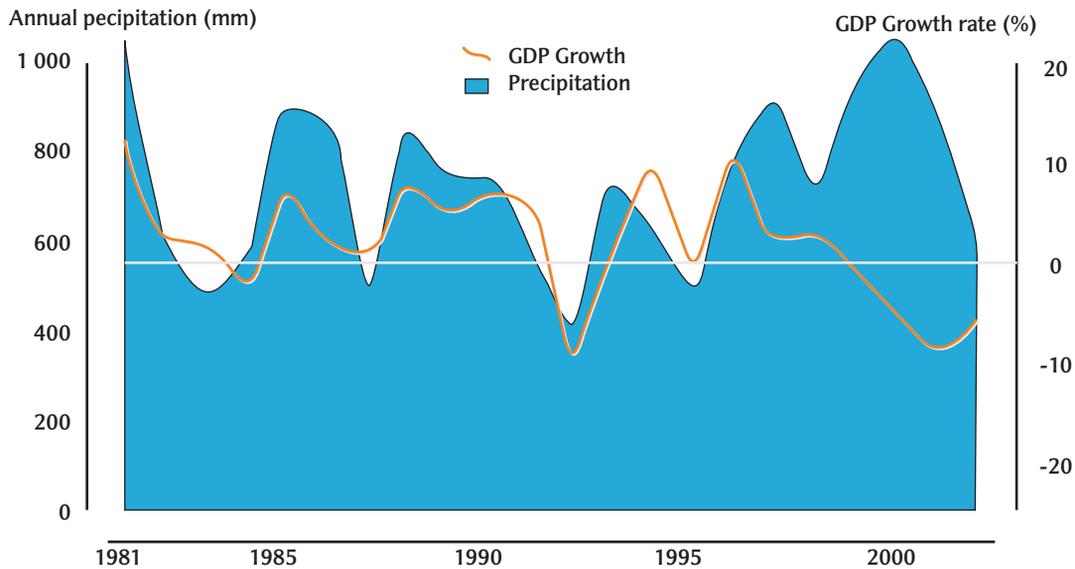


Figure 1 Relationship between annual precipitation and GDP

Source: Zimbabwe Government

electricity supply reliant on sufficient water in the Zambezi River. However some small thermal power stations based on domestic and wastewater supply for cooling were established in Harare, Bulawayo and Munyati. It is also now policy in terms of NWP to establish hydro power stations on some major dams as well as thermal power stations generated from sugar and ethanol power plants.

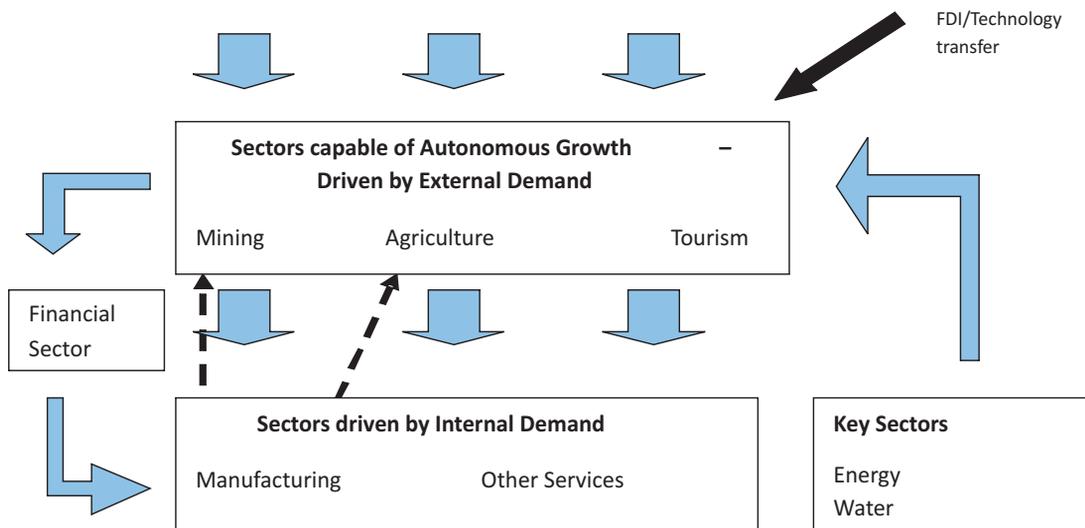


Figure 2 Linkages in the post-crisis Zimbabwean Economy

Source: World Bank 2012b

Reliable power supply is key for water supply and wastewater treatment and disposal, irrigation, manufacturing, and for growing sectors such as mining and tourism. The current national generating capacity of 1300 MW is about 700 MW short of unsuppressed demand resulting in rolling blackouts that have had significant impacts throughout industrial, mining and commercial production. If mining projects now under consideration come on-stream, an additional 500 MW will be required by 2016 (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnel and Partners 2013a). While

electricity production has been hampered by lack of maintenance and lack of spare parts, it is also dependent on maintenance of water levels in reservoirs for both hydropower production and cooling of thermal power plants.

Mining has grown rapidly in recent years and is now one of the main export earners. Water is required for both mineral extraction and processing. While direct water requirements can generally be met by mining companies from surface and groundwater sources and from recycling, reliable water provision for electricity production remains a potential threat to the industry. Pollution from mining can also affect water quality and hence the quantity of useable water.

Tourism, one of the emerging contributors to the economy, is also dependent on water resources, both for maintaining the natural ecosystems (such as Victoria Falls) that many tourists seek and for providing services such as safe food and water and reliable sanitation.

Water, Health and the Environment

Water is essential for social development while reliable, safe water supply and sanitation underpins a healthy, productive society and workforce. Maintaining water resources in good condition assists with meeting Millennium Development Goals (MDGs) such as ending poverty and hunger, promoting access to education, and improving child and maternal health. However, Zimbabwe's water quality has deteriorated significantly over the last decade. The water quality problems arise from four factors:

- increasing population with consequent increasing pollution loads,
- expansion of mining, particularly artisanal mining and increasing pollution loads,
- breakdown in water supply treatment and wastewater treatment, and reduced capacity to control contaminants in water supplies and receiving waters, and,
- deterioration of the natural environment's ability to reduce contamination.

The consequences of pollution and deteriorating water quality are being felt across all segments of the society, with greatest impact on the poor who have fewer alternative sources for water.

Population has grown by about 24% since 1990 (from 10.47 million to 12.97 million in 2012) without a concomitant increase in the capacity of facilities for collecting and safely disposing of wastes. In addition, the breakdown of water supply and sanitation collection and treatment systems has further endangered human health in urban and rural areas. Outbreaks of water-related diseases such as cholera, typhoid and gastro-intestinal diseases that affect economic production and human well-being are partly attributable to unreliable water supply and sanitation services arising from lack of maintenance and unreliable power supply as well as increasing pollution loads from increasing population.

In addition, many of the wetlands and riparian areas that provide a natural buffer against the impacts of pollution are now in a seriously degraded state. These areas are now encroached on and cultivated by local farmers because of their relatively fertile soils. These practices have destroyed their ability to provide a buffer against floodwaters, remove contaminants from overland flow and river waters, act as groundwater recharge zones, and provide habitat for ecologically beneficial organisms. Thus, wetlands and naturally vegetated riparian zones along

the Chinyika River below the Hatfield sewage treatment plant (STP) helped remove excess nutrients before they reached Mazowe Dam and fuelled aquatic weeds and algal blooms (Bere 2007). Natural riparian areas can also help remove heavy metals, toxicants and sediments. Magadza (2008) calls for a policy to protect wetlands from development and introduce additional artificial wetlands, along with behavioural changes by residents to reduce runoff borne nutrients and other contaminants.

In the worst cases, wetlands, floodplains and riparian areas have become sources of contamination that affect human health rather than areas of amelioration. This is most apparent where alluvial mining has destroyed river banks and beds and floodplains, promoted sedimentation of downstream dams and siltation of water supply systems, and introduced mercury into rivers. Artisanal mining has introduced mercury, a highly dangerous neurotoxin, into the environment with significant impacts on human health. A United Nations (UN) project between 2002 and 2007 estimated that about 25 tonnes of mercury were being used in gold panning in Zimbabwe each year and found that children and miners in the panning areas had high incidences of mercury intoxication (Steckling et al 2011) potentially affecting brain development in children and mental functioning in adults.

Zimbabwe Response to Climate Variability and Climate Change

Zimbabwe has always faced a variable climate. Following independence, development of dams became an important policy objective for improving access to and storing water and dealing with climate variability. There are currently more than 8000 large and small dams in Zimbabwe developed by the Government and the private sector to provide a reliable water supply. This figure includes numerous small dams for conservation purposes as well as very large dams such as the Kariba dam on the Zambezi River. About 245 dams are registered as large dams in terms of the Water Act and the International Commission on Large Dams (ICOLD). Over 70% of these dams were owned by syndicates of (commercial) farmers before the land reforms. Most of these farmers are no longer on the land. Accordingly ZINWA has taken over the ownership of these dams and their operation and maintenance to ensure their safety.

In the late 1990s, Zimbabwe introduced policy reforms including the establishment of ZINWA, and basin responsibility for water allocation and management through Catchment and sub-catchment councils. A National Water Resources Management Strategy was also prepared. However, these initiatives to deal with climate variability and efficient use of water were undermined by the economic collapse and Zimbabwe's international isolation. Now, as the economy recovers, it is apparent that simply returning to the previous strategy for water use under a variable climate will no longer be adequate. The growing understanding of the impacts of climate change means that water management and planning and infrastructure design and operations need to be adapted to the potential consequences of a reduced mean annual precipitation (MAP) and increased variability.

The increase in greenhouse gases from burning fossil fuels and land clearing has led to a warming of the global climate over the last 100 years. This is now evident from increases in global average land and sea temperatures, widespread melting of snow and ice cover, retreat of glaciers and rising sea levels. At the time of the last International Panel on Climate Change

(IPCC) report (IPCC 2007a) eleven of the twelve years from 1995-2006 ranked amongst the twelve warmest on record; arctic temperatures have warmed at almost twice the global rate and arctic sea ice has melted earlier and more extensively in recent years; and global sea levels have increased 3.1 mm per year from 1993 to 2003. Land temperatures have increased more rapidly than have temperatures over the oceans, because of the buffering effect of the oceans.

Zimbabwe signed and ratified the UNFCCC in June 1992 and acceded to the Kyoto Protocol on Climate Change in June 2009. However, implementation of these agreements has been fragmented, with legislative and administrative responses contained in diverse sector policies, strategies and plans. In 2012, the Government initiated the preparation of the National Climate Change Response Strategy (NCCRS) as a response to the need for integrating climate change responses across all sectors¹. The Strategy, due for completion later in 2013, is intended to mainstream action on climate change in all key economic sectors (agriculture, industry, energy, mining, transport and tourism), including in water resources, and promote less carbon intensive pathways in economic activities. Even if the world eventually limits green house gas emissions through mitigation actions, there are sufficient greenhouse gases already in the atmosphere to maintain global warming for two or three generations. Consequently, there needs to be a strong emphasis on adaption measures to limit the impacts of climate change locally.

Objectives of the Paper

This paper has been prepared at the request of the former Ministry of Water Resources Development and Management (MWRDM), now part of the new Ministry of Environment, Water and Climate (MEWC), to help highlight the potential impacts of climate change on the hydrological cycle and to strengthen the water-related aspects of the NCCRS. It builds on the recommendation of the 2013 NWP. Not only is economic development strongly dependent on water resources, but nearly 70% of natural disasters in Zimbabwe are water related due to climate variability (floods and droughts). Consequently, the MEWC believes that hydrological implications and water needs to be at the heart of the climate change discourse in Zimbabwe.

The primary objective of the Paper is to develop a common and comprehensive understanding of climate change impacts and risks on water resources, their implication on current and future water resources planning, design and operations, and to identify the types and range of adaptation options and opportunities available to address climate change risks and to build resilience in Zimbabwe.

Apart from supporting and strengthening the NCCRS, this paper will contribute to water resources management by widening the understanding amongst water resources professionals about the predicted impacts of climate change. Climate change will affect a wide range of water resources planning and management decisions and topics, including:

- the design and operation of infrastructure, including the rehabilitation of dams and irrigation systems;
- policy issues relating to the management of transboundary waters, especially sharing the waters of the Zambezi and Limpopo river systems;
- water allocation and water use planning, and;

¹The development of the NCCRS is being led by the Office of the President under the Secretary for Special Affairs portfolio with support from the government of Zimbabwe and UNDP and potentially COMESA.

- management of water pollution, including diffuse source pollution from stream-banks and agricultural lands.

The audiences for this report are policy makers and senior decision makers, technical water resources specialists and water users, including sectoral water agencies.

Methodology

The study is based on three principal methodological inputs. First, the likely impacts of climate change on Zimbabwe's water resources in 2050 and 2080 were estimated using a downscaled global circulation model. These dates were chosen to be compatible with the NCCRS study. Second, lessons were drawn on local impacts of climate change from five diverse water sector case studies - Bulawayo water supply, Harare water supply, Roswa Dam Operations, Limpopo Basin Irrigation, and Kariba hydropower operations. Thirdly, a modified version of the SADC climate change adaptation framework (SADC 2011) was used to suggest options that would allow Zimbabwe to adapt to climate change.

The study is supported through three technical studies that provided specialist information:

- Climate change impacts on precipitation and runoff a national study to model climate change impacts on precipitation and runoff across Zimbabwe in 2050 and 2080 and the implications for per capita water availability;
- Climate change implications on water resources decision making a description of the hydrological assumptions used in current water resources decision making under the assumption of stationarity, and a discussion of the implications of climate change on future water resources decision making;
- Climate change impacts on groundwater and recharge a review of the current groundwater situation in Zimbabwe and projected groundwater and recharge conditions under climate change.

There are a number of initiatives either underway or recently completed that were also integrated into this study (Appendix A). These include:

- Water, Climate and Development Programme (WACDEP) a Global Water Partnership (GWP) project supporting the African Ministers Council on Water initiative to integrate climate resilience into development planning, build climate resilience and support countries increase investments in water security (Global Water Partnership, 2011) (2011-2016)
- The International Institute for Environment and Development (IIED) study to review the impacts, vulnerability and adaptation to climate change in Zimbabwe (Brown et al 2013) (completed);
- An assessment by the International Food Policy Research Institute (IFPRI) of the impact of climate change on irrigation potential in the Limpopo Basin, including Mzingwane catchment in Zimbabwe (completed);
- An economic evaluation of water resources development and management options for the Zambezi River Basin that included a scenario that incorporated the effects of climate change on river flows and increased evaporation (completed);
- The United Nations Development Programme (UNDP) and Global Environment Facility (GEF) Coping with Drought and Climate Change project (the UNDP/GEF project) that as demonstrated a range of approaches for adaptation to climate change among rural communities in Chiredzi district as a model for national action (2007-2011);

- The Water Sector Investment Analysis (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners, 2013 a,b,c) that is prioritizing water infrastructure investment taking account of existing infrastructure and expected demand, although they do not include the effects of climate change.

Structure of the Paper

This report contains seven chapters. This, the first chapter, establishes the importance of water resources to Zimbabwe's economy and the need to place water management at the centre of the NCCRS. The second chapter describes the effects of climate variability and climate change on water resources, while Chapter 3 summarizes the state of Zimbabwe's water resources, and current and future demand for water. Chapter 4 presents the results from the modelling of climate change impacts on surface waters and the potential impact on groundwater resources, and the consequent implications for water resources planning, management and infrastructure. The importance of recognizing the potential impact of climate change is illustrated in Chapter 5 through six case studies. Chapter 6 presents ways in which Zimbabwe can adapt to climate change through both national and local actions, while Chapter 7 summarizes the findings from this study together with specific studies and investigations to help develop a robust climate change adaptation strategy for the water sector. Appendix A provides details of previous and current studies that include climate change on water resources in Zimbabwe or Southern Africa. Appendix B contains details of groundwater resources in Zimbabwe.

2. Water and Climate

Natural climate variability and human induced climate change are sometimes confused. In this chapter we will distinguish between these concepts and explain the implications of both natural climate variability as well as human induced climate change for Zimbabwean water resources.

Climate Variability

Climate variability describes the variability in climate parameters, such as precipitation, on spatial and temporal scales beyond that of individual weather events. The familiar sequence of a rainy season starting in October followed by a dry season starting in March or even April is an example of natural temporal climate variability in Zimbabwe. There is also spatial variability in this climate pattern, with the western parts of Zimbabwe typically being the first to receive the rains while the southern and south eastern parts occasionally experience the incursion of south easterlies that brings in drizzle associated with Guti type of weather².

The climate also varies considerably between years. For example, the rains fail between 1 and 3 years every 10 years (United Nations Development Programme and Global Environment Facility, 2007). Zimbabwe also has a history of severe floods driven by cyclones (Table 1). Droughts and floods have very high social as well as economic costs. Some 80% of Zimbabweans are farmers or are engaged in agro-industry, and so the economic damage, impacts on livelihoods and human suffering associated with extreme weather events can be very high including water and food shortages, poor health outcomes, economic losses to subsistence and commercial farmers, and destruction of infrastructure.

Table 1 Cyclone frequency in Zimbabwe

Month/Year	Name	24-hour Precipitation
January 1976	Danae	78.5
February 1977	Emilie	175
January 1986	Berobia	179
February 1997	Lisette	62.5
February 2000	Eline	153
February 2003	Japhet	204

Source: International Union for the Conservation of Nature, 2005

Some of the natural climate variability results from the El Niño-Southern Oscillation (ENSO), whereby changes in sea surface temperatures in the central and eastern Pacific result in rainfall anomalies in the Pacific and Indian Ocean regions. The correlation between El Nino events and droughts in Zimbabwe is very high. The years in which there were warm sea surface temperatures in the central and eastern Pacific (1982/83, 1986/87, 1987/88, 1991/92, 1994/95, 1997/98, 2002/03, 2004/05, 2006/07 and 2009/10) were all years of drought in Zimbabwe and other southern African countries. El Nino events can now be predicted 6 to 8

²Meteorological Services Department of Zimbabwe. http://www.weather.co.zw/index.php?option=com_content&view=article&id=55&Itemid=70

months ahead and, although there are a number of other factors that influence the severity of the drought in Zimbabwe, this provides an important early warning of likely drought years.

However, the conventional belief has been that, while climate varies between seasons within years and between years, the long-term mean and the variance of climate parameters remain constant. That is, the average climate that we have experienced in the past and its variability around that average will continue into the future. This assumption has been the basis for designing hydraulic infrastructure including dams in Zimbabwe. This belief, called the stationarity assumption, allows engineers to plan for infrastructure by assuming that future hydrology repeats itself and will be the same as that experienced in the past (Davis 2011).

Climate variability has a number of water resource planning and management implications. First, the more variable the climate, the larger irrigation and water supply storages need to be to achieve a given level of security of supply (or risk that would be acceptable). Similarly, flood control dams also need to be larger to cope with increasingly large floods. Secondly, there is likely to be a greater need for irrigated agriculture to maintain food security when dry land farming experiences frequent drought. Thirdly, a high degree of climate variability implies a need for good climate and water resources monitoring, so that approaching droughts can be anticipated and planned for.

Climate Change

Climate change describes the change in climate parameters from the warming of the earth's atmosphere as a result of human activities such as increasing emissions of greenhouse gases such as CO₂, land use change and emissions of aerosols. This warming will likely change the average climate, as well as the variability of the climate, experienced in a particular region or location. That is, the stationary assumption no longer holds, and both the average climate and its variability will change in the future as a consequence of global warming³. The change may occur over periods ranging from decades to millennia. Average temperatures will rise as a result of climate change and climate variability will also increase. Thus, engineers cannot assume that infrastructure designed for past climates will be suitable (or reliable) for the future.

A recent World Bank investigation (World Bank 2013) into the consequences of global warming of either 2°C (best case scenario) or 4°C (increasingly likely scenario) in three regions sub-Saharan Africa (Box 1), South-east Asia and South Asia found that unprecedented heat extremes would occur more frequently and cover larger areas, water availability would decline by between 20-50% depending on the rate of global warming, crop yields could decrease, and terrestrial ecosystems could be altered with temperature extremes well beyond the present range. These impacts constitute significant risks to humans and the natural environment (Box 2).

³According to the UNFCCC (undated), "Climate Change refers to a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods."

Box 1 Climate Change Impacts in Sub-Saharan Africa

For sub-Saharan Africa, the World Bank envisages major risks from global warming:

- Even if global warming is limited to 2°C, there are large regional risks to food production, particularly if adaptation measures are inadequate;
- Up to 30% reduction in annual precipitation with 4°C warming with groundwater recharge decreasing by 50-70%;
- Increased aridity, especially in southern Africa, with shortened growing seasons and declines in crop yields;
- Regime shifts in ecosystems, with the area of savanna grasslands being reduced with consequent reduction in forage for grazing animals;;
- Increases in malnutrition, with even 1.2-1.9°C warming leading to a 50-90% increase in undernourishment.

Source: World Bank (2013)

The IPCC (2007a) predicts that semi-arid regions of southern Africa are at risk of a reduction in precipitation and water resources during the dry season as a result of climate change. There may also be a delay in the onset of the rainy season. A subsequent analysis of country-level vulnerability to climate change, based on the five broad measures - resilience to stress on water resources, population density, historical exposure to climate related hazards, governance, and household vulnerability-found that countries of the eastern Zambezi Basin (Zimbabwe, Malawi, Mozambique) were the most vulnerable in Southern Africa (Shah et al 2011).

Box 2 Risk, Vulnerability and Resilience

In this report, we follow the IPCC definitions of the important concepts of risk, vulnerability and resilience.

Risk is 'the combination of the probability of an event and its consequences'. Thus risk measures the extent of the expected loss from climate change. Note that hydrologists measure the reliability of water supply in terms of the risk that they will not be able to meet demand in a given year. Currently, ZINWA construct and operate their dams to provide a 10% risk; i.e. 90% reliability of being able to supply water in a given year.

Vulnerability measures the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change (International Panel on Climate Change 2007b).

Resilience describes with the ability of a system, including management systems, to adapt to the impacts of climate change without excessive harm. It is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures.

Source: IPCC 2007b

Implications of Climate Change

Climate change will affect runoff and stream flow as well as groundwater infiltration although there are many factors involved and the relationships are complex and difficult to predict. These factors include changes in evaporation, vegetation response to climate change and associated changes in transpiration, and changes in land uses and patterns of water use. The draft NCCRS states that by 2050 temperature rise alone will cause evaporation to increase by between 5 and 15 percent. It is likely that in countries such as Zimbabwe, where precipitation is predicted to decrease and evaporation is likely to increase under climate change, runoff into rivers will decrease significantly although it is difficult to make accurate quantitative predictions. Reduced river flows will reduce water in storages affecting irrigated agriculture, water supply to urban and some rural communities, industries dependent on water including mining, and the natural environment.

Droughts occur as the result of a number of meteorological and hydrological factors, including the extent and timing of precipitation, evaporation (which itself is dependent on temperature, cloudiness, wind speed, etc), and water use by vegetation. Just as with stream flow and groundwater infiltration, these factors will be affected by climate change in complex ways, making it very difficult to predict how climate change will influence droughts. Nevertheless, from general principles, it is likely that droughts will set in more quickly, be more intense (i.e. drier), and last longer because of climate change, although it is not clear if they will be more frequent (Trenberth et al 2014).

Climate change will affect water demand by water-using sectors because of decreased precipitation and increased evapotranspiration. This will place additional pressure on irrigation and water supply systems. Modelling studies suggest that net farm revenues would decrease by US\$0.4 billion with a 2.5°C temperature increase without adaptation measures (De Witt 2006). In addition, increased variability in precipitation increases the need for dam storage and expansion of irrigation to reduce the dependence on rainfed agriculture.

The reduction in precipitation is also likely to lead to reduced recharge of groundwater although associated changes in land use and vegetation and changes in river flow patterns (where groundwater is connected to surface water) will also affect the extent of recharge reduction. Declining aquifer levels will lead to increased pumping costs, reduced water availability for cities and rural communities dependent on groundwater, and reductions in base flows of rivers in dry seasons.

Climate change poses a threat to both human livelihoods and the functioning of ecosystems. Initially the international community responded by establishing international agreements to reduce the discharge of greenhouse gases through mechanisms such as the Kyoto Protocol. However, mitigation measures such as adoption of more efficient uses of fossil fuels, promotion of renewable sources of energy, and the cessation of forest clearing and expansion of other carbon sinks have largely failed to halt the continuing rise in greenhouse gas concentrations and the accompanying rise in global temperatures. Consequently, there is now more attention being given to making climate-smart investment decisions (Alavian et al 2009) in order to adapt to a warmer world (Box 3). In Southern Africa, adaptation needs to be the main priority because African countries only contribute to a very small portion of global emissions of greenhouse gases (Davis 2011).

Box 3 Climate Mitigation and Adaptation

The IPCC defines mitigation as “human interventions to reduce the sources or enhance the sinks of greenhouse gases”. Adaptation is “the adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities”. Mitigation has primarily global benefits whereas adaptation typically works at regional or local scale. Mitigation has long term benefits whereas adaptation measures can have immediate benefits including by reduction in vulnerability to climate variability. In other words, adaptation can show greater rates of return compared to mitigation measures. Consequently mitigation tends to occur through international agreements whereas adaptation can be initiated through the self-interest of the private sectors facilitated by public policies.

Source: IPCC 2007c

Within the water sector, adaptation actions can include both structural and non-structural measures. Examples include:

- improving coordination between water management agencies and the water using sector;
- investing in infrastructure such as dams to retain water and flood levees because of the predicted increase in frequency and intensity of dry and wet periods promoting recycling and reuse of water to reduce total demand for water;
- protecting water quality to ensure that existing water sources can be used safely;
- building institutional capacity to improve understanding and response to climate change;
- strengthening monitoring and interpretation systems so that decision-makers have reliable information;
- undertaking education programs to improve the uptake of water conservation measures by water users.

Sound adaptation is inextricably linked to sound development practices. It is virtually impossible to separate the two. As these examples illustrate, many adaptation actions are consistent with good water management practices under the Integrated Water Resources Management paradigm that is embraced in Zimbabwe's NWP. These are called “no regrets” adaptation actions because they are worth undertaking in their own right, irrespective of the effects of climate change. More formally, no regrets actions are defined by the IPCC as those “that have negative net costs because they generate benefits that are large enough to offset the costs of implementing the actions”. Low regret actions are those that require relatively small additional expenses to adapt to climate change.

Climate Change in Zimbabwe

These global results are broadly consistent with observed recent climate changes in Zimbabwe, although it is not possible to attribute the changes specifically to global warming. Zimbabwe has experienced more hot and fewer cold days since 1950 (Figure 3) with daily minimum and maximum temperatures rising by approximately 2.6°C and 2°C respectively over the last century (Brown et al 2012).

Zimbabwe is widely reported to have experienced a small decline in MAP (about 5%) since 1900, although this decline is much less than the variability in annual precipitation (up to 20% of the mean). However, the reality of this claimed decline in precipitation appears to depend on which meteorological stations are chosen and the length of record analysed. In a thorough analysis of all reliable records, Mazvimavi (2010) found that there was no evidence of a decline in annual rainfall or seasonal rainfall when records for the 1892 to 2000 period at 40 stations in Zimbabwe were examined. He concluded that “Effects of global warming on rainfall that may have occurred are not yet statistically identifiable within the available rainfall time series”.

There has also been an increasing variability in annual precipitation since 1910 with increasing departures from MAP (Figure 3). Extreme weather events, namely tropical cyclones and drought, are also believed to have increased in frequency and intensity although this has not been verified statistically. According to the Meteorological Services Department, there has been a shift in the mean rainfall start dates for the main rainfall season from 22 November in the 1960s to 27 November under the present climate regime, and many of the wet seasons are punctuated by mid-season dry spells resulting in unreliable crop harvests.

These results accord with farmer perceptions. Gwimbi (2009) found that about 60 percent of surveyed farmers in Gokwe District believed that there had been an increase in temperature and a decline in precipitation. Almost 75 percent of the farmers reported a greater frequency of water-deficit years, with a later on set and an earlier end to the rainy season. While these beliefs are impressionistic rather than scientific, they indicate a perception that the climate is getting drier and more variable and potentially a willingness to adopt adaptive strategies.

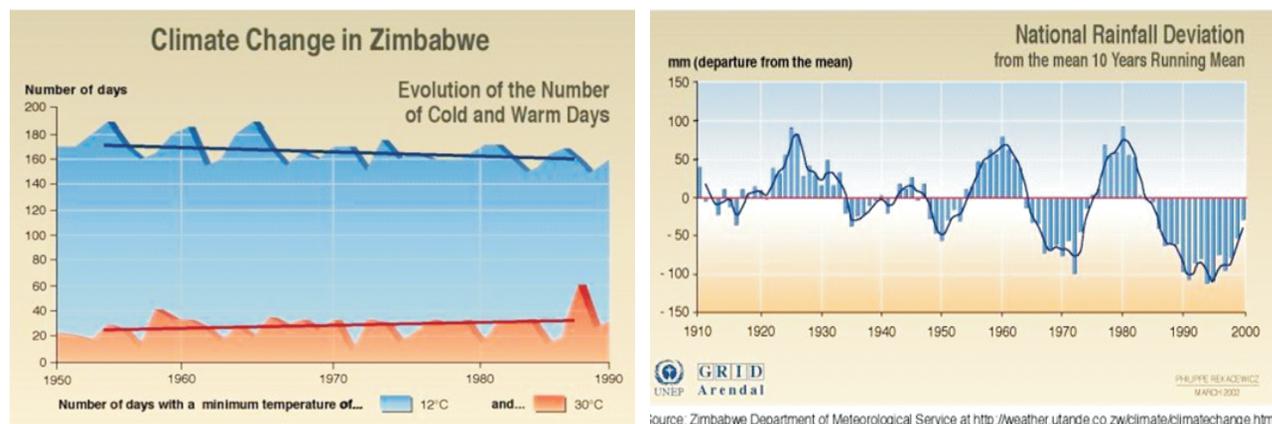


Figure 3 Warm and cold days and precipitation deviation in Zimbabwe

Source: Zimbabwe Department Meteorological Services

Flow records are also broadly consistent with these expectations. There has been a decrease in mean annual runoff of 9-11% at six gauging stations where medium term records (1984-2007) are available (World Bank 2012a) although the decrease cannot be attributed specifically to decreased precipitation and the period of record is too short to attribute this to a long term decline in river flow. Calibrated river flow models would be needed to be able to investigate the role that reduced precipitation may have played in this decline.

3. Water Resources Availability and Use

Climate change will affect the quantity and reliability of Zimbabwe's renewable water resources. In this chapter we discuss the quantity and quality of current surface and groundwater resources, and current demands on those resources.

Water Resources

The Food and Agriculture Organization (FAO) estimates Zimbabwe's internal renewable water resources to be 12.26 km³/year, of which 11.26 km³ are surface water resources and 6.00 km³ are groundwater resources. The overlap between surface water and groundwater resources is estimated to be 5.00 km³.

There are seven river basins within Zimbabwe (Figure 4). Zimbabwe also shares the waters of the Zambezi and Limpopo River basins as well as other smaller transboundary surface waters with Mozambique and Botswana.

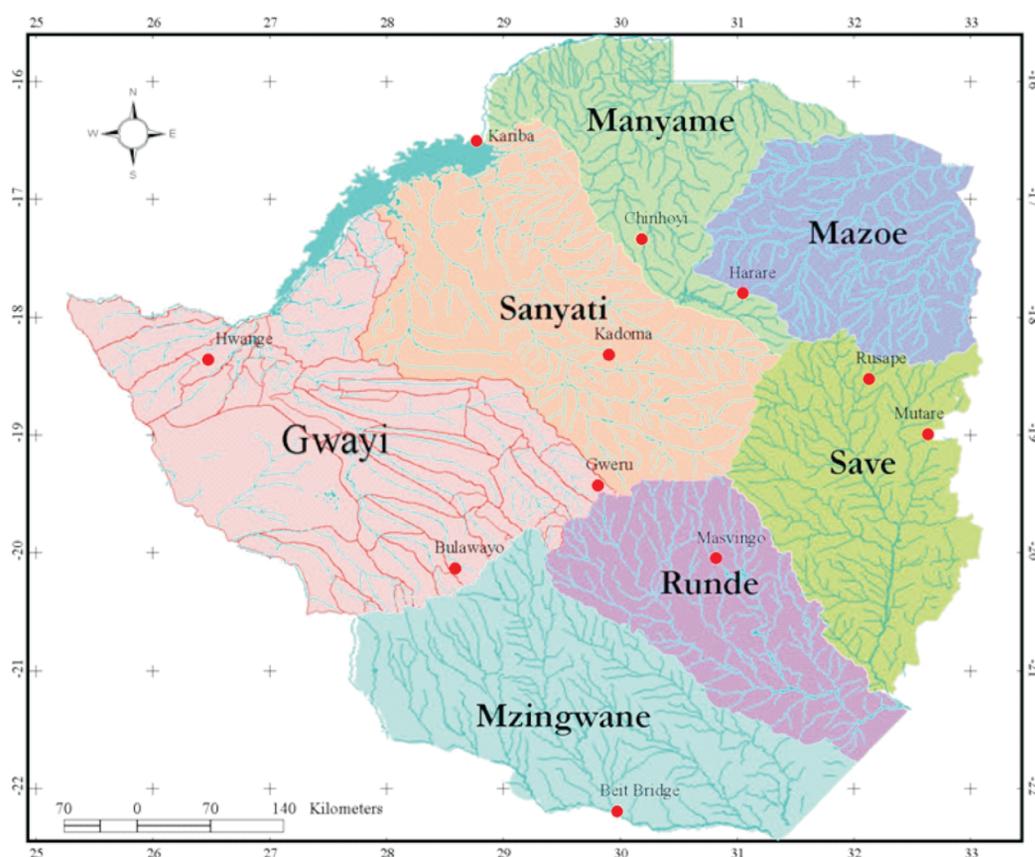


Figure 4 River basins of Zimbabwe

Source: Data and Research Department, ZINWA

The hydrogeology of Zimbabwe is primarily based on lithology with the four main aquifers being the Lomagundi dolomite aquifer, Nyamandhlovu forest sandstone aquifer, Kalahari sands, and Save alluvial deposits. Apart from the alluvial aquifers associated with transboundary rivers, Zimbabwe does not have transboundary groundwater resources (although there may be shared groundwater in the Nata basin).

Precipitation and evaporation

Zimbabwe has a highly variable climate both spatially and temporally. Zimbabwe's mean annual precipitation (MAP) is 657 mm/annum with a distinct gradient from the drier south to the wetter north of the country (Figure 5). The wet season usually extends from October to April with December, January and February being the peak precipitation months. However, there is considerable inter-annual variability in both precipitation (Figure 6) and runoff, ranging from 16 percent on the northern plateau to 48 percent in the Limpopo Valley.

Generally potential pan evaporation exceeds precipitation, with net pan evaporation ranging from 1,400 mm in the high precipitation areas to 2,200 mm in the low lying areas. Consequently, actual evapotranspiration is almost always less than potential evapotranspiration.

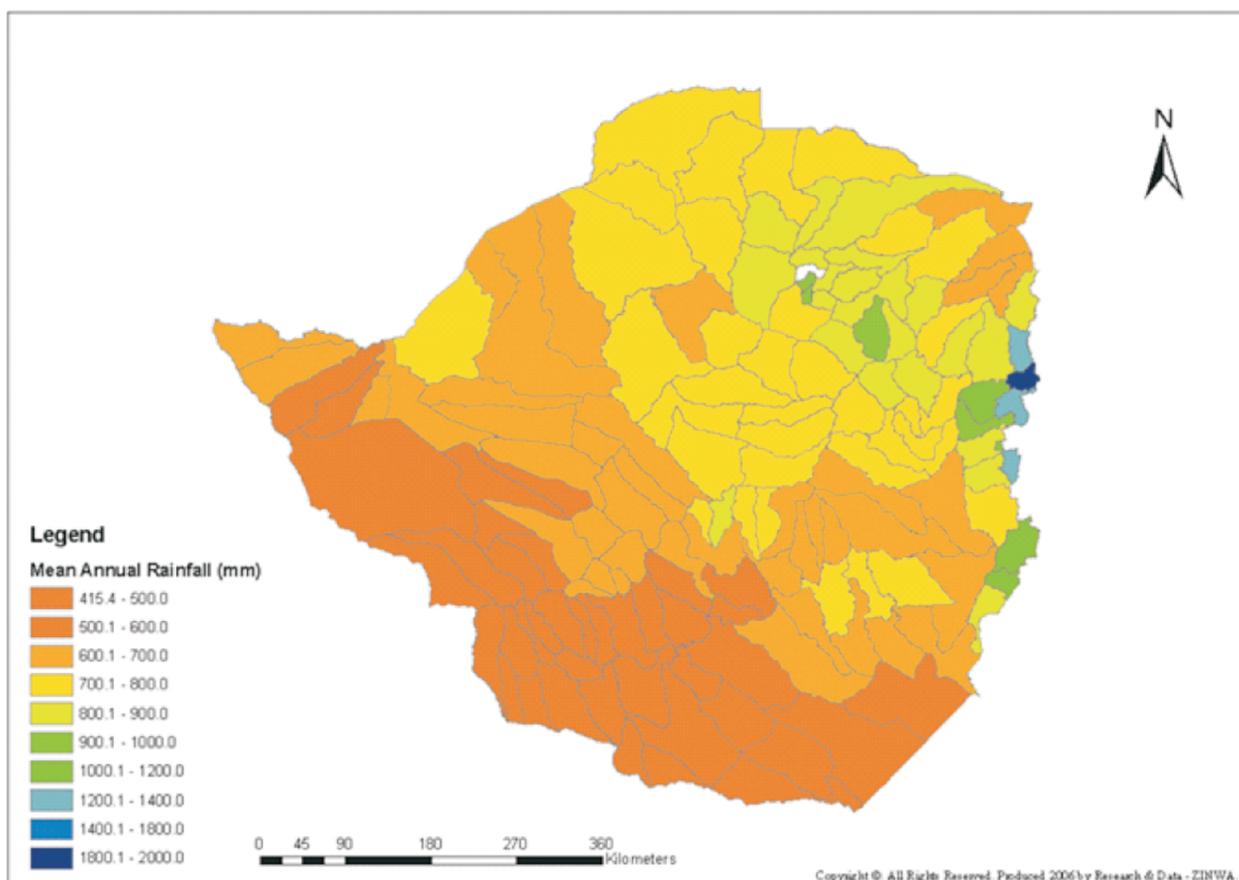


Figure 5 Precipitation distribution across Zimbabwe

Source: Meteorological Service Department

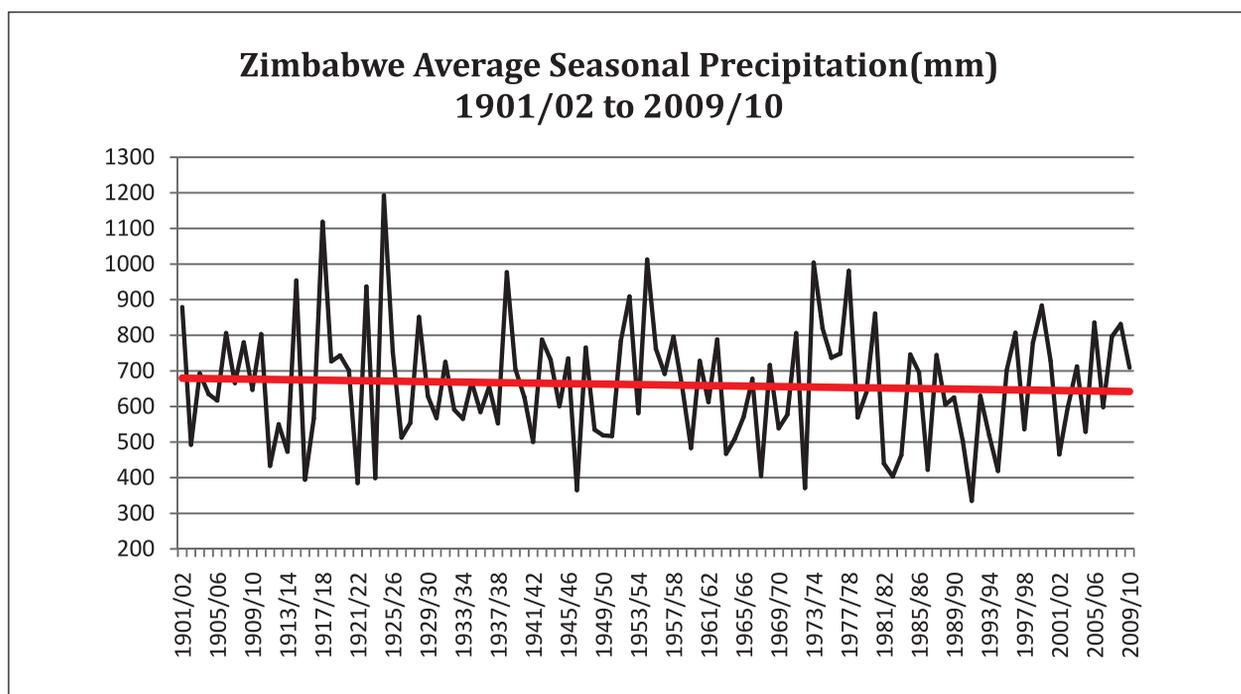


Figure 6 Zimbabwe Precipitation Trend

Source: Meteorological Service Department

Mean Annual Runoff

Zimbabwe's surface water resources were assessed in 1972, 1984 and 2007. The 2007 estimate of mean annual runoff (MAR) was 23.6×10^6 MI, 18% greater than the 1984 estimate of 19.9×10^6 MI. This increase occurred over a period when there has been a decline in MAP. This anomaly probably arises from a decline in the number and quality of gauging stations, a change in methods for estimating MAR in ungauged areas, and an increase in land clearing leading to increased runoff.

However, there is considerable uncertainty about the current state of Zimbabwe's surface water resources because of the deterioration in flow and water quality monitoring. Of the 560 gauging stations built over the last 85 years only 330 are operational and of these 210 are either inoperative or are not functioning well. The major problem is inadequate funding for maintenance and rehabilitation. Many stations are silted up because of poor land and riparian management and severe bank and floodplain damage from alluvial gold mining, while others suffer from leaking walls and foundations of weirs and vandalism and theft of equipment. Rating curves at most gauging stations have not been updated. Methods for storage and analysis of gauging data are obsolete with the risk that data may be lost if computers fail. These problems add to the difficulty of managing water resources under normal climate variability, and if they are not addressed in a timely manner, would be compounded under climate change.

Table 2 summarises the potential water resources available on internal rivers, the storage that must be built in order to achieve the yields for each catchment area, and the present committed use for each catchment. At present only 25% of available yield (assuming a 10% risk of not being able to meet the demand in a given year⁴) is utilized. Even allowing for environmental and social water needs and the unsuitability of some regions for dam construction, this implies that there is still a high potential to develop further water storage in Zimbabwe over the long term where it is sensible and economic to do so.

⁴ i.e. 90% reliability.

Table 2 Surface water resources of Zimbabwe's catchments

Catchment	MAR x10 ⁶ MI	Potential Storage x10 ⁶ MI	Potential Yield 10% x10 ⁶ MI	Present Commitment		Use %
				Storage (x10 ⁶ MI)	10% Yield (MI)	
Gwayi	1.8	3.7	0.9	0.2	98,144	11.2
Manyame	3.3	6.6	2.0	2.6	942,849	46.6
Mazowe	4.6	9.2	2.8	0.3	488,348	17.6
Mzingwane	1.8	3.4	1.2	1.3	330,329	27.1
Runde	2.1	4.3	1.2	2.5	481,259	41.0
Sanyati	3.9	7.8	2.1	0.6	430,179	20.5
Save	6.1	12.2	4.4	1.2	804,368	18.3
TOTAL	23.7	47.2	14.5	8.7	3,575,476	24.6

Source: World Bank 2012a

The Zambezi River and the Limpopo River are Zimbabwe's two major transboundary water courses, while the Save, Buzi and Pungwe rivers in eastern Zimbabwe flow into Mozambique and Nata and Shashe rivers are shared with Botswana. The Zambezi is particularly important to Zimbabwe because it is the source of the country's current and future electricity production. Zimbabwe is party to a number of transboundary and bi-lateral water resources agreements. Zimbabwe has ratified the Limpopo Watercourse Commission and the Zambezi Watercourse Commission Agreements, and ratification of the revised SADC Protocol on Shared Water courses is at an advanced stage. Zimbabwe has also established a Joint Water Commission with Mozambique and similar joint Water Commission Agreements are expected to be signed with the Republic of South Africa, Botswana and Zambia. Negotiations with the three countries have already started.

Zimbabwe stores runoff in a large number of small and large dams including the giant Kariba Dam whose total capacity of 180 km³ is shared with Zambia on a fifty percent (50%) basis. Most of the permits of large dams are owned by the Zimbabwe National Water Authority (ZINWA). The country has invested heavily on the construction of over 8,000 dams with a total storage capacity of 9 x 10⁶ mega litres excluding Kariba Dam. Most of this water is used under the permits of ZINWA.

Groundwater

Groundwater supports more than 70% of the Zimbabwe's population. Yet it has received very little attention by water resources planners and managers since the mid-1980s because the country concentrated on the provision of clean water from surface water resources. Investigation and exploratory drilling virtually ceased at that time. However, drilling for supplying drinking water has increased over the past decade as surface supplies have become unreliable and problematic.

Groundwater occurs in both crystalline basement rocks (covering 65% of Zimbabwe) and in sedimentary formations located in the north-west/north and the south-east of the country. Crystalline aquifers generally have moderate recharge rates but low storage capacities. They are often unconfined but may be perched and semi-unconfined locally. The sedimentary aquifers

are only recharged in unconfined recharge areas, becoming confined when they dip beneath impermeable formations. Although these sedimentary aquifers are considered to have the highest groundwater development potential in Zimbabwe, they occur for the most part in areas with the lowest population densities in the country.

Groundwater receives recharge principally from precipitation as both direct recharge and via river-bed infiltration. The sustainable water yield from an aquifer is closely linked to its recharge rate the more water an aquifer receives from recharge, the more water it can supply for productive purposes. Discharge occurs via evapotranspiration, river base flow, inter-aquifer transfers and pumping. In spite of the importance of understanding recharge rates, these rates have not been quantified across Zimbabwe and recharge has only been estimated in semi-quantitative and qualitative terms.

Sibanda et al (2009) propose an average recharge of 2.6 to 3.7% of MAP for the Karoo Forest Sandstone. The range of recharge values for this area cited in the literature range from 0.4% of precipitation to 11%, with a slightly higher percentage recharge rate expected on the adjacent unconsolidated Kalahari sands. Barker et al. (1992) estimated groundwater recharge for the Masvingo province at 2-5% of precipitation. The British Geological Survey (1989) estimated groundwater recharge at between 8 and 16% of MAP.

More recently, groundwater recharge has been estimated using expert knowledge rather than field measurements for each catchment based on the twin assumptions that recharge is an increasing proportion of MAP (Table 3) and that precipitation dominates other factors (soil type, geomorphology, etc) in determining recharge (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners 2013a).

Table 3 Groundwater recharge as proportion of precipitation

Precipitation (mm/yr)	<400	500	600	700	800	900	>1000
% Precipitation	2	2	4	5	7	10	15
Recharge (mm)	8	10	24	35	56	90	150

Appendix B provides further details on Zimbabwe's groundwater resources including the development potential of the various lithologies found in Zimbabwe.

Water Quality

Water pollution from point and nonpoint sources is a serious, widespread and growing problem across the country (World Bank 2012a). Rivers and reservoirs downstream of sewage treatment plants have high pathogen counts, and high nutrient, biological oxygen demand (BOD) and heavy metal concentrations. While cholera outbreaks are a highly visible consequence of poor water quality, gastro-enteric illnesses are more common. Typhoid, spread through contaminated food and water, is an ongoing problem. Heavy metals impact human health and the environment fish from Lake Chivero that are contaminated with heavy metals have recently been identified as potential source of cancer. Of the three barriers protecting

citizens of Harare from pathogens entering their drinking water wastewater treatment and land disposal, natural absorption in well maintained and vegetated river and stream bank and buffers around reservoirs, and water treatment plants only the last is now partially or fully functioning.

Widespread discharges of industrial effluent are contributing nutrients, organic matter and heavy metals to rivers. Nutrient enriched waters impose costs on water supply treatment and increase operating and maintenance costs. Nutrient enrichment also leads to excessive growth of aquatic weeds. High organic loads deplete the water of oxygen when they decay and can lead to the release of metals and other toxic material from aquatic sediments.

Water pollution from diffuse sources in urban and agricultural areas is also increasing. These sources are much harder to monitor and manage because they originate from many sources that are spread over large areas. Alluvial mining activities in particular have become an additional source of sediment and have caused riverine destruction in recent years. Riverine sediments lead to siltation and loss of capacity in dams, eutrophication of reservoirs, additional water treatment costs, degradation of drinking water for primary users, and environmental impacts.

There is evidence that gold panning is also introducing mercury, a powerful neurotoxin, into Zimbabwean rivers. A UN project between 2002 and 2007 estimated that about 25 tonnes of mercury were being used in gold panning in Zimbabwe each year and found that children and miners in the panning areas had high incidences of mercury intoxication (Steckling et al 2011). Mercury contamination stunts brain development in children. No follow up study has been conducted but the rising price of gold is increasing the demand for gold production and there is a likelihood that the use of mercury is growing and the contamination is perhaps worsening.

Little attention has been paid to the protection of natural water sources springs, watersheds, groundwater as well as developed sources dams and reservoirs. There is little information available on degradation of groundwater recharge zones or on groundwater quality apart from monitoring of very few specific sites of possible contamination. Nevertheless, it is likely that aquifers are being polluted from land uses such as urban settlement, leaching from solid waste disposal sites, underground tanks, intensive agriculture, mining and industry. There is growing evidence of deteriorating water quality in most of the dams.

These water quality problems will intensify without government intervention. The recent NWP, amongst other things, recommended the preparation of a strategy for protection of water sources and management of water quality for Zimbabwe as an urgent priority. This strategy will be in two phases. The first phase, which is currently underway, will be a rapid assessment of selected pilot and will be used to identify pollution hotspots. The second phase will be an in-depth assessment of all hotspots with recommendations for government action to reduce water pollution and improve water quality.

Natural groundwater quality in Zimbabwe is mostly good for potable use. There are high fluoride concentrations in the Karoo aquifers in the north and north-east and high salinity levels in the Beit Bridge gneisses in the extreme south and south-east of the country.

Anthropogenic contamination is generally linked to major urban centers and mining. All aquifers will tend to exhibit a reduction in water quality under conditions of reduced recharge. Natural groundwater quality evolves by rockwater interactions towards more saline water, and this process is ameliorated by recharge with fresh rainwater. When recharge is reduced, this process of freshening is reduced and groundwater quality declines. The effect is greater at depth where the freshening effect of new recharge is less.

Wastewater Reuse

Zimbabwe's major cities are situated on high ground at the top of catchments, and so water authorities have been forced to develop water harnessing infrastructures at suitable sites down the catchments at long distances and high pumping heads from the cities. Consequently, treated wastewater forms a potentially important source of water for non-potable uses⁵ because this water can be accessed close to the cities. Over the last 30 years, a number of urban centres (Harare/Chitungwiza/Norton, Bulawayo, Gweru, Kwekwe, Kadoma) developed and operated schemes to treat and reuse wastewater for crop and pasture irrigation, thereby reducing the demand on primary water sources. However, these schemes have mostly fallen into disrepair since the collapse of the water sector in 2008.

About 65% of potable water returns as wastewater. In volumetric terms, this means that treated wastewater could provide about 350,000 MI (approximate volume of Mazvikadei Dam) of additional water if wastewater treatment plants operated at full capacity. Currently, these plants are operating at 0-30% capacity resulting in raw or partially treated sewage being discharged into reservoir or rivers.

Reusing treated wastewater has a number of advantages. Not only does it reduce the pressure on surface and groundwater and pumping costs from downstream storage dams, but it would reduce the pollution of lakes and rivers from discharges of raw sewage. At present sewage from Harare is being detected as far as Mushumbi Pools some 260 km away⁶. Similarly pollution from sewage discharges in Bulawayo is being detected beyond Sawmills, some 100km from Bulawayo. Wastewater is also relatively insensitive to the effects of climate change.

Water Use and Demand

There has been a dramatic change in water demand following the introduction of the land reforms and the subsequent financial crisis. Prior to these influences, surface water in Zimbabwe was used mainly for irrigation (although irrigation water use is known to have declined dramatically since 2008), followed by urban supply, primary water and environment, mining and for cooling towers at thermal power stations (Figure 7 based on 2007 data, the last year for which data are available). Rural areas have relied most heavily on groundwater; it is only more recently that urban demand for groundwater has increased as reticulated water supplies have become unreliable. The data collection procedures do not distinguish in detail between broad sectoral groups and do not include water for primary uses or the environment. Based on these data, total committed surface water⁷ was estimated at 3.57×10^6 MI/yr, with agriculture accounting for 2.93×10^6 MI/yr (80%).

⁵ Treating wastewater to the standards required for direct or indirect safe potable use is beyond the capacity of Zimbabwean water authorities at present.

⁶ Pers comm. Director, Environmental Management and Services, EMA 2011.

⁷ Committed water is water allocated for various uses; actual water use is often much less than this and is not well known.

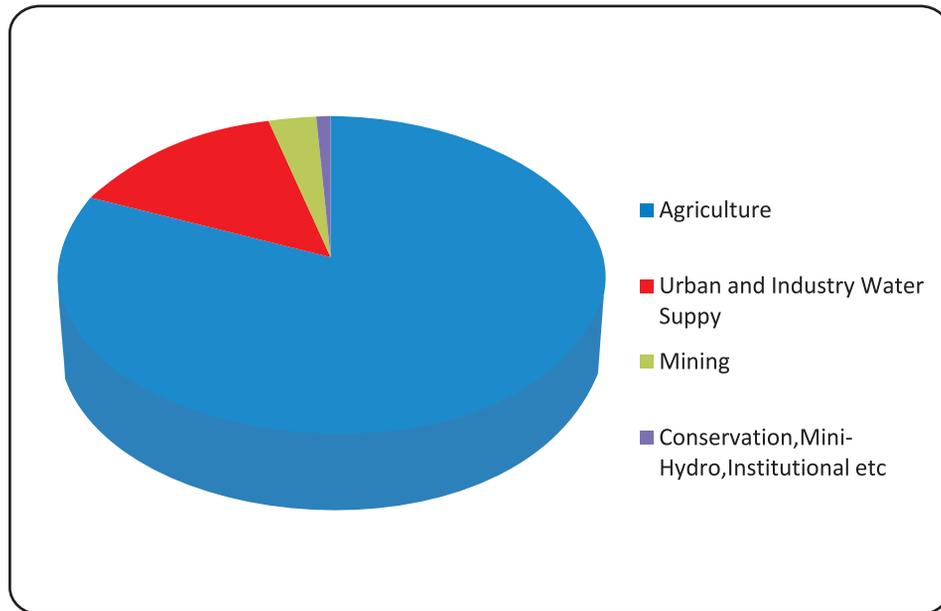


Figure 7 Sectoral water use in Zimbabwe, excluding primary uses, power generation and environmental uses

Source: ZINWA, 2009

The area under irrigation is estimated to have declined from 120,000 ha in 2000 to 51,000 ha in 2012 based on satellite imagery (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnel and Partners 2013a), with the Runde and Save catchments being the only ones where irrigation has not declined precipitously. The low level of irrigation water use in 2010 and 2011 (following the land reforms) is shown in Figure 8. In all catchments, except Runde, less than 30% of the potential water available was utilized in 2010 and a similar low level of utilization is projected in 2011. It is only in the south-eastern lowveld where meaningful irrigation is taking place on about 40,000 ha. Although the utilisation of water resources has drastically dropped, there is still high demand for water in communal and lowveld areas where the government imports food staples. Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnel and Partners (2013a) considers low (2.7% p.a.) and high (5.4% p.a.) growth rate rehabilitation of irrigated agriculture but these projections do not include estimates of the increase in demand for water.

Groundwater has served the both the communal and commercial sector in rural areas as the principal source of potable water and a major source of water for irrigation, mining and tourism. Hand pumps in rural areas supply potable water for the vast majority of the rural village population, along with hand pumps or motorized pumps for rural clinics, schools and business centers. Concern has been raised that some shallow, fractured aquifers may be under threat from rural water demand. However Ó Dochartaigh et al. (2011) working in a wide range the semi-arid areas in Africa suggest that there is 'considerable resilience to short-term inter-annual variation in precipitation and recharge, and rural groundwater resources are likely to sustain diffuse, low volume abstraction.' The high yielding boreholes in the A1 and A2 settlement schemes require pump testing and pumps installed not only for drinking water but for other productive uses.

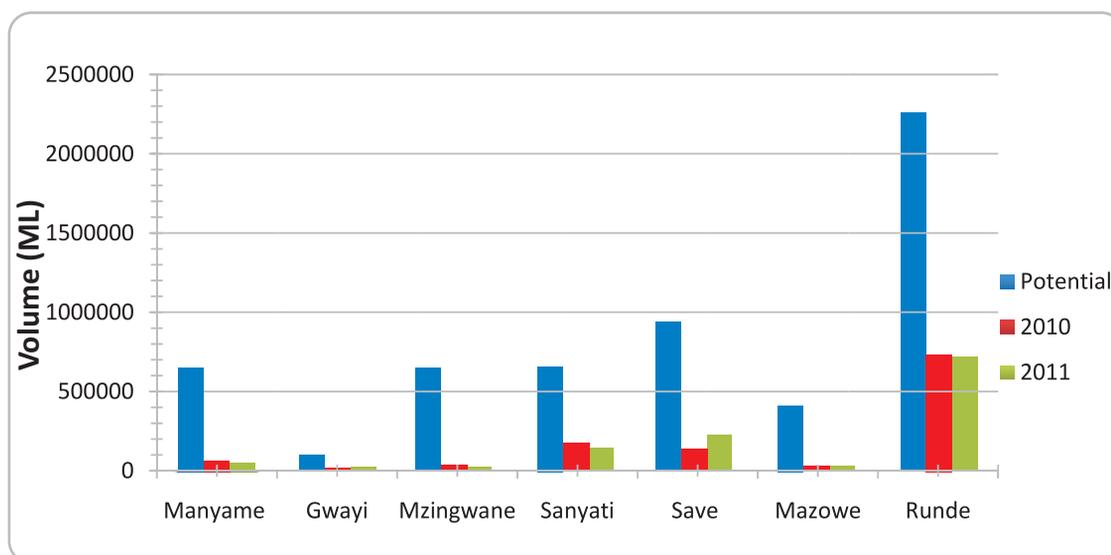


Figure 8 Potential and volume of water actually sold in catchments in 2010 and 2011.

Source: Manzungu 2012

A recent study of groundwater drought risk⁸ in southern Africa (Villholth et al 2013) concluded that drought resilience is strongly linked to secure groundwater access and proper development and management of this resource. Zimbabwe, along with Mauritius, South Africa and Malawi, has one of the highest risk indices in the SADC region. Under the present climate regime, Zimbabwe has about 5% of its area and 32% of its population in the very high groundwater drought risk category.

Urban water supply is at present not meeting current demand, with urban populations obtaining additional water from informal sources such as rainwater harvesting, boreholes and unsafe surface water. Truck mounted water sellers have mushroomed, selling water to those who do not have boreholes. All this has taken place without detailed collection of drilling and abstraction data. There is very little groundwater level monitoring, but anecdotal evidence from drilling and pump fitting companies suggest that, in Harare, the groundwater level has declined by around 15m over the last 5 to 10 years.

Both water treatment capacity and urban water storage capacity are inadequate. Based on the Urban Water Tariff Study and the 2012 Census, a recent study (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnel and Partners, 2013a) estimated that total (reticulated plus informal) urban water consumption ranges from 93 litres/capita/day (lpcpd) in Chitungwiza to 358 lpcpd in Kwekwe. This equates to just on 500 Mlpd for the 7 major urban centres of Harare, Bulawayo, Chitungwiza, Mutare, Kwekwe, Masvingo and Chegutu. Water demand in Harare is estimated at around 1,200,000 m³ per day⁹ for the Greater Harare area, compared to current production of around 600,000 m³ per day. Chagutah (2010) reports that raw water sources for the largest urban centres such as Harare, Bulawayo and Chitungwiza are only sufficient for normal rainy seasons. Clear water reservoir capacity is now too small with Harare, for example, having only half the clean water storage capacity it requires.

⁸ The index of drought risk was constructed from a suite of variables covering hydrogeology, climate and social data.

⁹ Estimate by the City of Harare Water Department

The situation is possibly even worse in rural areas. Rural water demand is estimated to be 251 lpcpd in 2012 (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners 2013a) with this demand predicted to increase by 72 lpcpd and 88 lpcpd in the low and high growth scenarios respectively. Chagutah (2010) states that water coverage had declined in the rural areas from 75 percent in 1999 to 66% in 2007, with use of safe sanitary facilities declining from 60 percent of rural households in 1999 to only 30 percent in 2006.

Water for mining is included in the consolidated urban/industry/mining category. However, about 0.4×10^6 MI/year of surface water was believed to be used for mining in 2007. With the rapid expansion of mining and mineral processing in recent years, this quantity is likely to have increased substantially. Most water for this sector is sourced privately from both surface and groundwater resources and from recycling and is not readily captured in government records. Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners (2013c) examined both low (4.8% p.a.) and high (8.1% p.a.) growth scenarios for mining with mining rising to over 20% of GDP in 2033.

The manufacturing sector has a relatively low water demand and is not expected to grow rapidly. In particular, the water intensive manufacturing industries are expected to grow more slowly than the sector as a whole.

With 80 percent of the country's electricity supply coming from the Lake Kariba Dam, commercial, mining domestic electricity supply is heavily reliant on water resources in the Zambezi River basin. The planned run-of-river Batoka Dam upstream of the Kariba Dam will have an additional capacity of 1600 MW. Previous droughts have led to major falls in reservoir levels and concomitant reduction in energy generation (Hulme and Sheard 1999). Cooling water for the existing Hwange power generators, together with additional cooling water for the 600 MW Hwange extension and the new 2,400 MW Sengwa station, is expected to be met by water pumped from the Zambezi River. Thus, both hydropower and thermal power generation rely totally on maintenance of flow in the Zambezi River. If the existing Hwange power generators were restored to full operation, the demand for water would be about 12,000 MI per annum.

The amount of water committed to primary water use (basic domestic needs, provisions for animals, making of bricks, and use of dip tanks) is not known. This water use is central to maintenance of rural livelihoods and the achievement of MDGs.

Putting these sectoral demand scenarios together, Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners (2013a) estimates that there will be a growth in total water demand of 2.8% p.a. under the low scenario and 4.9% p.a. under the high scenario. These growth rates would mean that the 1998 level of water demand would not be equaled until after 2032 in the low growth scenario and in 2026 in the high growth scenario. None of these projections considered the effects of climate change on water availability and water demand.

4. Climate Change Impacts on Water Resources: A Preliminary Assessment

In order to develop adaptation responses to climate change, it is important to understand the extent, location and timing of the likely impacts on Zimbabwe's water resources. In this chapter we first review previous studies of climate change on specific regions of Zimbabwe. We then report the results of a national study to model climate change impacts across the whole country and the implications of these impacts.

Zimbabwe Climate Change Studies

There have been two recent catchment-scale studies that have modelled the possible impacts of climate change on precipitation and agriculture in specific Zimbabwean regions.

IFPRI undertook a regional study of the implications of climate change in 2030 on irrigated food production within those parts of Botswana, South Africa, Zimbabwe and Mozambique that lie within the Limpopo Basin in order to gauge the effects of climate change on irrigation reliability (Zhu and Ringler 2010). The various scenarios that have been published by the IPCC for future emission of greenhouse gases can be grouped into four families (IPCC 2000):

- The A1 family describes a future world of very rapid economic growth, global population that peaks in mid-21st century and declines thereafter, with the rapid introduction of new and more efficient technologies;
 - The A2 scenario family describes a very heterogeneous world where fertility patterns converge very slowly, economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slow;
 - The B1 scenario family describes a convergent world where global population peaks in mid-century and declines thereafter, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies;
 - The B2 scenario family describes a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 families.
- The IPCC has developed a number of subsidiary emissions scenarios (A1a, A1b, etc) within these four families.

IFPRI used four emissions scenarios (A1FI, A2a, B1a, B2a) with the Had CM3 model. While the study was primarily focussed on irrigation, it also provided estimates of MAP and seasonal changes in precipitation, changes in evaporation, and changes in runoff under this emission scenario. The study provided predictions for only the Mzingwane catchment within Zimbabwe.

Zhu and Ringler (2012) subsequently used the CNRM-CM3 and ECHam5 models with just the A1b emissions scenario to estimate the changes in the same hydrological parameters to 2050 for the Limpopo Basin. These two models were chosen because they were known to provide moderate and severe precipitation changes respectively. Again the study focussed on irrigation potential under climate change and included only the Mzingwane catchment within Zimbabwe. In a second study, the UNDP/GEF applied 10 downscaled climate models to the Save catchment (United Nations Development Programme 2009) as part of a project to understand

adaptation actions for dry land agriculture and livestock farming in the Chiredzi district. They concluded that, while total precipitation is not likely to change significantly, the precipitation pattern may be modified by 2050 with “rainfall increases in most months followed by decreases in the second part of the season”. Runoff in the Save catchment is expected to become more variable. However, quantitative results are not available from this study. In addition, SADC have undertaken a comprehensive regional study of climate change from two emissions scenarios over the 2036-2065 period on precipitation, wind and temperature for southern Africa using two approaches – statistical downscaling of 10 GCMs and dynamic downscaling of six GCMs (Davis 2011). While there were some notably different predictions between models and downscaling methods for some climate parameters, there was general agreement that minimum, mean and maximum temperatures are very likely to increase by between 0.3°C and 3.6°C and heatwaves would increase throughout the region. There would be a decrease in precipitation during September-February in Zimbabwe. Changes in runoff and other water resources parameters are discussed but were not modelled.

An older study (de Witt 2006), used three GCM models - GCM2, HadCM3 and PCM - to predict changes in mean temperature and precipitation for 2050 and 2100 in southern Africa. They predicted an increase of 2°C - 4°C in temperature and a decrease of 10% - 17% in precipitation for Zimbabwe by 2100. They then used empirical relationships between agricultural production and temperature and precipitation to estimate that impact of these climate changes on agricultural production.

Methodology of National Study

These previous studies have focused on the possible impacts of climate change on either the southern Africa region or a specific part of Zimbabwe, generally with a focus on food production. There has not been a national study that investigated the potential impacts on Zimbabwe's water resources and the opportunities for adapting to these impacts. As part of the current work (which draws from and extends the preliminary work done for the NCCRS), the potential impacts of climate change to 2050 and 2080 on precipitation and runoff in Zimbabwe's seven catchments were modelled using the CSIRO Mk3 global circulation model (Gordon et al, 2002). Two emission scenarios were modelled:

- A2a describes a heterogeneous world of independent nations with regionally oriented economies. The main driving forces are a high rate of population growth, increased energy use, land-use changes and slow technological change (business as usual scenario);
- B2a describes a regionally oriented world with local rather than global solutions to economic and environmental sustainability. Population is still growing but less rapidly than in A2a and there are more diverse technological changes and slower land-use changes (ecologically aware scenario).

The CSIRO Mk3 model was chosen because its downscaled data are readily available (Hijmans et al, 2005), it gives similar temperature and precipitation predictions to other models such as the widely used Hadley Centre models, and it has been developed for Southern Hemisphere climatic conditions.

Empirical relationships developed by ZINWA between precipitation and runoff (ZINWA 2009) for each catchment were used to translate MAP into annual average runoff (MAR) (Box 4). These relationships were developed from long term rainfall data and flow records from

gauging stations with reliable data and flow records of more than 25 years.

Box 4 Equations for estimating mean annual runoff for ungauged sub-zones

Gwayi Catchment	
MAR = 0.405 MAP – 221.4	$r^2 = 0.75$
Sanyati, Manyame, Mazowe, Save (excl. Eastern Highlands)	
MAR = 0.393 MAP – 197.4	$r^2 = 0.75$
Save Catchment (Eastern Highlands)	
MAR = 0.786 MAP – 662.7	$r^2 = 0.76$
Runde Catchment	
MAR = 0.00033 MAP ² – 0.094 MAP – 12.02	$r^2 = 0.90$
Mzingwane Catchment	
MAR = 0.0003 MAP ² – 0.0936 MAP – 12.02	$r^2 = 0.81$

Source: ZINWA 2009

There are a number of limitations in this modelling method that need to be kept in mind when interpreting the results. First, only one climate change model was used in the study. Use of additional climate change models would have provided a wider range of temperature and precipitation predictions. Nevertheless, the CSIRO Mk3 model results are broadly consistent with the predictions of decreased water resources in southern Africa obtained from the integrated results from 14 climate models (IPCC 2007a). Secondly, the downscaling of global circulation models predictions to regional scale was undertaken using curve fitting methods that are known to be less accurate in regions where there are few weather stations (Hijmans et al 2005). Thirdly, the precipitation-runoff relationships were developed based on historical precipitation and flow data and may be less applicable when precipitation changes outside of the observed patterns. Lastly, mean annual runoff is influenced by a number of parameters apart from precipitation, including evaporation, vegetation, and land use patterns all of which will change with global warming. These are not included in the runoff estimation. Nevertheless, with these cautions in mind, the method provides a reasonable preliminary estimate of the potential impacts of climate change on Zimbabwe's water surface resources.

Changes in Precipitation

Climate data, including current precipitation, are available from two sources – the Zimbabwe Meteorological Department and the World Climate database¹⁰. The former is obtained from observations¹¹, while the latter is calculated through global circulation models. The World Climate data set also provided the temperature and precipitation predictions for 2050 and 2080. These were from the CSIRO MK3 GCM model downscaled to 4.5 km resolution. These precipitation predictions were then aggregated up to catchment scale (Table 4) to give the estimated MAP under the two scenarios for 2050 and 2080. The observed and the modelled current precipitation data differ significantly, with the world climate precipitation being higher than the observed precipitation in six of the seven catchments 100 mm higher in three of the catchments. We will use the World Climate current precipitation data in order to have a consistent baseline for comparing with predicted precipitation data for 2050 and 2080. These

¹⁰ <http://www.worldclim.org/>

¹¹ Spatially interpolated climate data from 100 stations managed by the Zimbabwe Meteorological Services Department (4.5 km resolution).

differences illustrate the importance of establishing a reliable meteorological basis on which climate change projections can be based fro Zimbabwe.

Table 4 Estimated current, 2050 and 2080 MAP (mm) in Zimbabwe catchments under two emissions scenarios

Catchment	Current		2050 Business as usual scenario (A2a)	2050 Ecologically aware scenario (B2a)	2080 Business as usual scenario (A2a)	2080 Ecologically aware scenario (B2a)
	Observed	World Climate Data				
Gwayi	599	605	545(10%)	576 (5%)	515 (15%)	587 (3%)
Manyame	709	785	769 (2%)	795(-1%)	757 (4%)	800 (-2%)
Mazowe	824	915	854 (7%)	907 (1%)	864 (6%)	899 (2%)
Mzingwane	547	506	430 (15%)	447 (12%)	379 (25%)	445 (12%)
Runde	606	706	592(16%)	622 (12%)	534 (24%)	616 (13%)
Sanyati	635	738	684 (7%)	716 (3%)	655 (11%)	723 (2%)
Save	815	915	784(14%)	839 (8%)	756(17%)	832(9%)

Percentage decreases in MAP are shown in brackets. A negative percentage indicates an increase in rainfall.

Table 4 shows that by 2050 and 2080, under both emission scenarios, MAP is predicted to decrease in all catchments, except for Manyame where it could increase slightly under the ecologically aware scenario. The most affected catchments are in the south of Zimbabwe Mzingwane and Runde catchments where MAP could decline by 12-16% by 2050 and by 12-25% by 2080. MAP is likely to remain relatively constant in the northwest of the country (Manyame and Mazowe catchments) (Figure 9). MAP could stabilize or start to recover in the more affected catchments - Gwayi, Mzingwane, Runde, Sanyati and Save - between 2050 and 2080 under the ecologically aware emissions scenario, although it would continue to decline in almost all catchments if the “business as usual” emissions scenario is maintained.

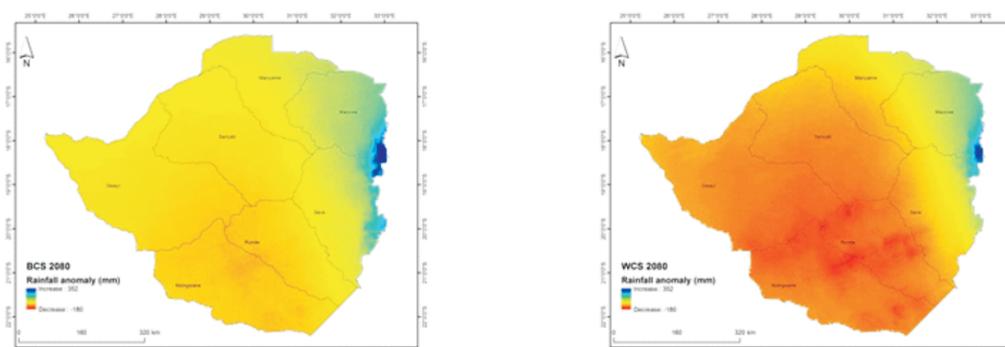


Figure 9 Projected precipitation anomalies (difference between current and projected precipitation) for the year 2080 for the ecologically aware (left) and the business as usual scenarios (right)

These decreases in precipitation are significant a 15% decrease in Mzingwane catchment by 2050 under the business as usual case, or a 12% decrease even if the world adopts ecologically aware growth patterns. The uncertainties in the choice of development scenario, the features of the particular GCM model employed, and the uncertainties in the downscaling method, mean that the predicted MAPs in Table 4 have large uncertainty bands. Even so, the pattern of a

decline in MAP across western and southern Zimbabwe to 2050 with continuing precipitation declines to 2080 if emissions of greenhouse gases are not curbed should be regarded as a reliable conclusion. This modelling does not show the additional changes that may occur in inter-annual precipitation variability (i.e. climate variation) or in intra-annual variability (e.g. shifts in seasonality of precipitation).

Changes in Water Resources

Runoff

Potential changes in MAR in the seven catchments are shown in Table 5 and Figure 10. The World Climate MAP data were used to calculate the current MAR in order to have a consistent basis for comparison with predicted runoff in 2050 and 2080.

Table 5 Estimated current, 2050 and 2080 MAR (GI) in Zimbabwean catchments under two emissions scenarios

Catchment	Current (World Climate data)	2050 Business as usual scenario (A2a)	2050 Ecologically aware scenario (B2a)	2080 Business as usual scenario (A2a)	2080 Ecologically aware scenario (B2a)
Gwayi	2,088	-	1,047 (50%)	-	1,432 (31%)
Manyame	4,496	4,244 (6%)	4,661 (-4%)	4,046 (10%)	4,736 (-5%)
Mazowe	5,665	4,825 (15%)	5,559 (2%)	4,974 (12%)	5,443 (4%)
Mzingwane	1,082	-	379 (65%)	-	356 (67%)
Runde	3,530	1,967 (44%)	2,343 (33%)	1,311 (63%)	2,271 (36%)
Sanyati	6,905	5,314 (23%)	6,248 (10%)	4,483 (35%)	6,471 (6%)
Save	8,010	5,455 (32%)	6,558 (18%)	4,970 (38%)	6,414 (20%)

Percentage decreases in MAR are shown in brackets. A negative percentage means runoff is predicted to increase.

As has been found in other countries (e.g. CSIRO 2008), there is a proportionately greater decline in runoff than in precipitation. For example, a 3-7% decline in precipitation in Sanyati catchment by 2050 will result in a 10-23% decline in runoff. This multiplier effect on runoff means that even small declines in MAP can have significant impacts on water availability. Thus, Manyame catchment which is predicted to face only small decline in precipitation by 2080 if global greenhouse gas emissions continue in a business as usual way, could still face a 10% decline in MAR.

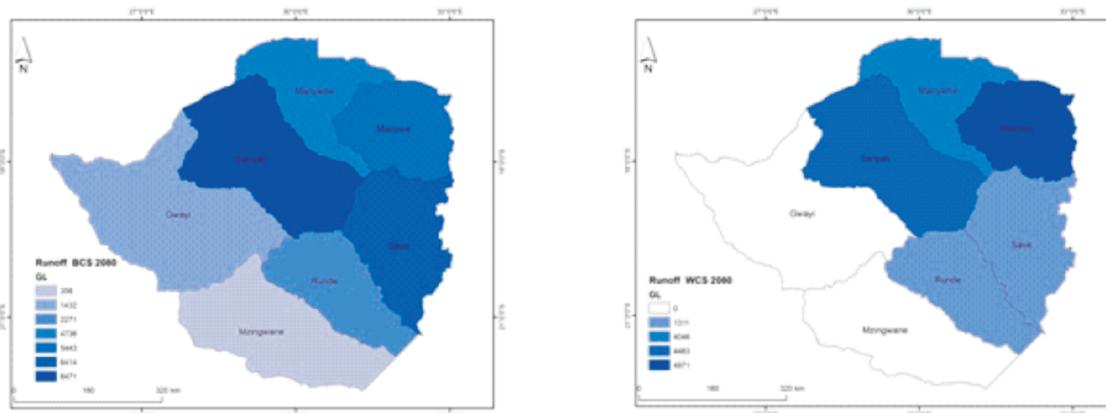


Figure 10 Projected runoff in 2080 under reduced emissions (left) and business as usual (right) scenarios

The table shows a particularly sharp decline in runoff in Gwayi, Mzingwane and Runde catchments under both scenarios, to the point where the calculated MAR drops to zero in Gwayi and Mzingwane catchments under the “business as usual” scenario in both 2050 and 2080. While there is some precedence for this dramatic result¹², the apparent drying up of these two catchments at the predicted levels of MAP may be an artefact of the method used. First, using annual precipitation and runoff rather than monthly or daily measures conceals considerable intra-annual variation between both precipitation and runoff. Secondly, the MAR measurements are derived from manual rather than automated gauging stations and so may miss flows that occur between flow readings. Thirdly, there are fewer years where low MAP and MAR have been recorded compared to years of average MAP and MAR and so the relationships are more heavily influenced by the years of moderate MAP. Consequently, the equations used to predict MAR are unreliable at the low precipitation levels predicted in the global database, and so the values in Table 5 should be regarded as indicative rather than as definite predictions. Nevertheless, the general result holds true - there is likely to be a large decline in MAR across western and southern Zimbabwe to 2050 with continuing declines to 2080 if emissions of greenhouse gases are not reduced.

Groundwater Recharge

Groundwater recharge was estimated for the seven catchments using the simple approach described in Table 3. These recharge proportions were applied to the precipitation and area for each sub-catchment within each of the seven Zimbabwean catchments and then aggregated to catchment scale. Table 6 shows the groundwater recharge as a result of MAP under the two climate change scenarios for 2050 and 2080. These are only preliminary estimates and do not take account of the many other effects of climate change that will influence recharge such as changes in evaporation, vegetation cover and land use.

Because of the simple method used, the change in recharge will be directly proportional to the change in precipitation under the two climate change scenarios. Consequently, groundwater recharge is least affected by climate change in the north of Zimbabwe and most affected in the dry southern catchments of Mzingwane and Runde.

¹² Gwayi catchment contains significant areas with Kalahari sands where the equations are known to be unreliable (ZINWA 2009) because precipitation preferentially recharges the extensive aquifers of this region. Zero runoff has been recorded in drought years in some streams in Gwayi catchment. Mzingwane catchment has the lowest MAP of the seven catchments and zero runoff has been observed at some gauging stations during droughts in the 1970s and 1990s.

Table 6 Estimated groundwater recharge (Gl/yr) for Zimbabwean catchments

Catchment	Recharge as % MAP	Current	2050 Business as usual scenario (A2a)	2050 Ecologically aware scenario (B2a)	2080 Business as usual scenario (A2a)	2080 Ecologically aware scenario (B2a)
Gwayi	3%	1596	1438 (10%)	1520 (5%)	1359 (15%)	1549 (3%)
Manyame	6%	1907	1868 (2%)	1932 (-1%)	1839 (4%)	1944 (-2%)
Mazowe	6%	1918	1791 (7%)	1901 (1%)	1811 (6%)	1844 (2%)
Mzingwane	2%	632	537 (15%)	558 (12%)	473 (25%)	556 (12%)
Runde	5%	1449	1215 (16%)	1277 (12%)	1096 (24%)	1265 (13%)
Sanyati	5%	2750	2549 (7%)	2668 (3%)	2441 (11%)	2694 (2%)
Save	6%	2660	2279 (14%)	2439 (8%)	2197 (17%)	2418 (9%)

Percentage decreases in recharge are shown in brackets. A negative percentage means that recharge is predicted to increase.

Some general statements can be made about the types of aquifers (Figure 11) that are more susceptible to detrimental impacts from climate change:

- Shallow perched dambo¹³ aquifers developed over the granite and gneiss in the eastern and northeastern parts of Zimbabwe. Whitlow (1983) estimates that there are 1.2million ha of dambo wetlands in Zimbabwe. They are susceptible to increased evapotranspiration, reduced recharge and increased baseflow discharge. Dambos are widely used for garden irrigation and the dambo areas tend to coincide with higher population densities, and are possibly a fundamental cause of such a demographic pattern;
- Granite and gneiss aquifers on the post-African erosion surface and Shamvianaquifers. Groundwater is stored in the thin, upper weathered layers and the fractures and is therefore susceptible to high evapotranspiration rates, baseflow discharge and reduced recharge. These aquifers provide water for rural communities and, under both climate change scenarios, water supply wells in these units are under increasing threat of drying out;
- All unconfined aquifers that receive direct recharge. However those aquifer systems that have greater thickness, that are deep enough, and that have higher volumes of stored groundwater will be less susceptible to the impacts of climate change. Some of these host some of the most important agricultural soils and also most of the gold mines in Zimbabwe;
- Aquifers that occur in highly dissected terrain are more likely to drain into streams as baseflow. Decline in these aquifers would constitute a threat to groundwater resource sustainability.

It is clear that the crystalline rock areas in the west of the country are likely to be severely affected by climate change and only hand pump supplies in these areas may be considered sustainable and 'safe'.

¹³ Dambo wetlands are groundwater discharge zones that lie above river level and discharge groundwater to the surface, forming local wetlands that are widely used for water supply and garden irrigation.

Aquifers that are less susceptible to the impacts of climate change are:

- Sedimentary aquifers with that may occur at significant depths below the surface. Such aquifers tend to have large volumes in storage, and often extend well below baseflow discharge and evaporation levels. These are the sedimentary aquifers in the north west of Zimbabwe (Gwayi catchment) and in the south (Mzingwane catchment);
- Confined aquifers that occur at depth and are not susceptible to evapotranspiration or baseflow loss. Recharge is indirect and as such reduced recharge is only an indirect threat. Such aquifers tend to have large volumes in storage and can act as important buffers in times of drought and general water scarcity. The Karoo sedimentary units are the most frequently occurring confined aquifer units in Zimbabwe (Upper Karoo Escarpment units in Figure 11);
- Primary unconfined sedimentary aquifers that have favorable recharge characteristics and/or extensive storage potential. These are the Kalahari sands and recent alluvial aquifers in active river channels (Kalahari and Recent-Older Alluvium units in Figure 11).

Villholth et al (2013) have modelled the population at risk of groundwater drought in Zimbabwe under the A1B emissions scenario to 2100¹⁴. They estimate that the percentage of population at very high risk of groundwater drought could rise from 32% to 86% without measures to adapt to the effects of climate change (Figure 12).

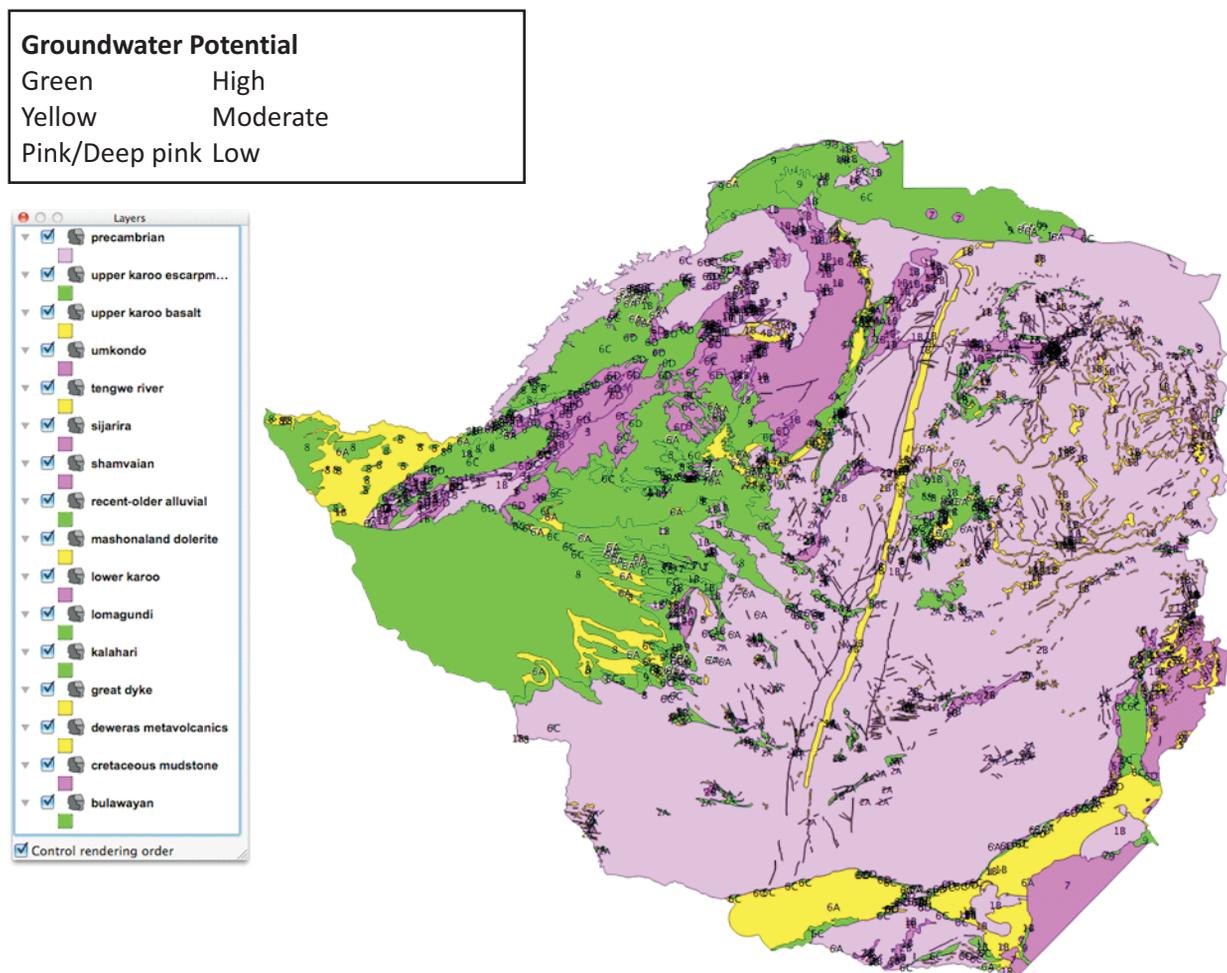


Figure 11 Hydrogeology Map of Zimbabwe

Source: Zimbabwe Ministry of Energy and Water Resources Development, 1985

¹⁴ The regional climate model HIRHAM5 (Christensen et al 2007) was used to downscale results from the ECHAM5/MPI-OM1 coupled GCM (Roeckner et al. 2006).

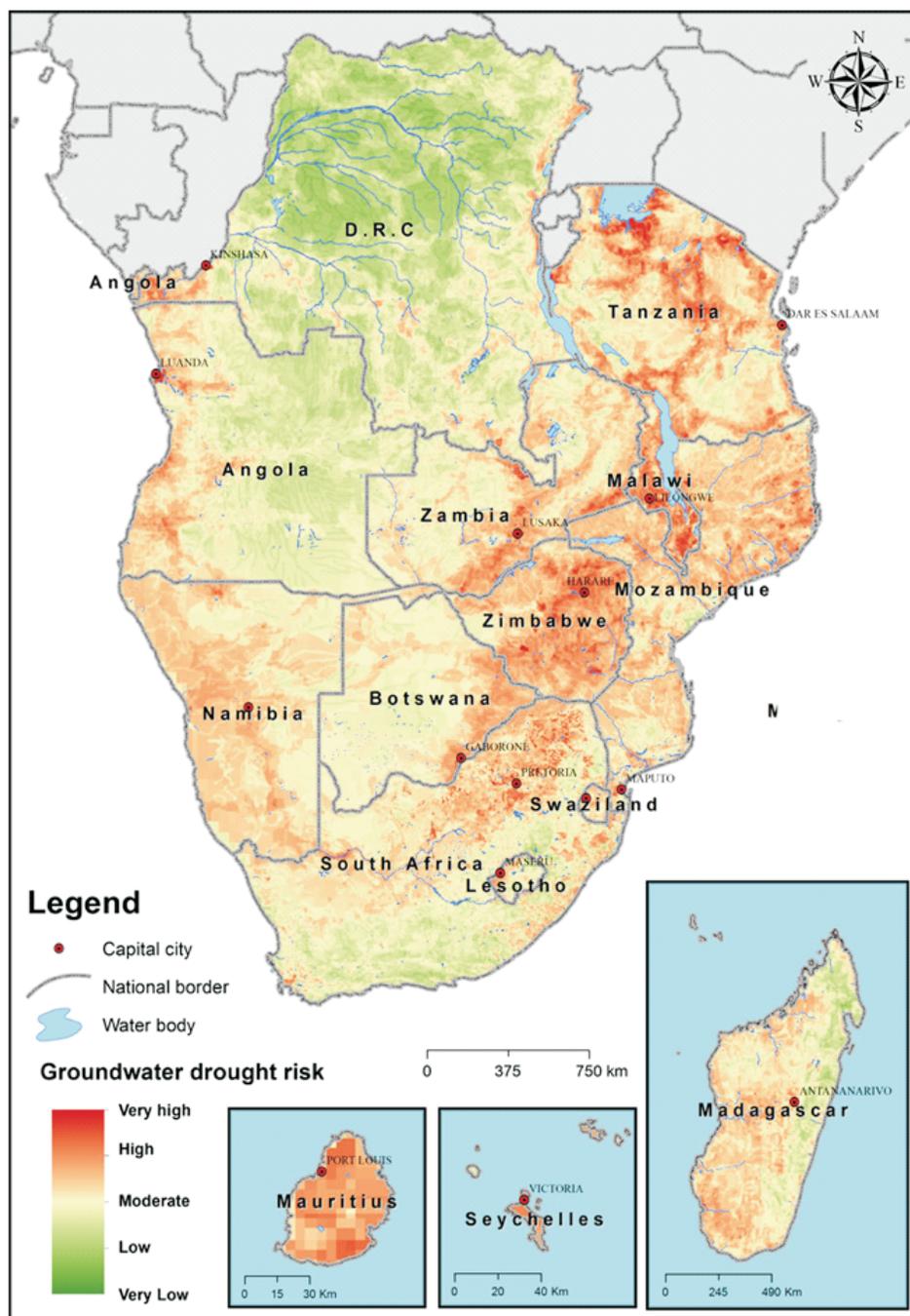


Figure 12 Groundwater drought risk for Southern Africa

Source: Villholth et al, 2013

Comparison with Other Studies

None of the previous studies for which quantitative predictions are available covered the same area or time period as the current study. Nevertheless, it is possible to compare three studies in the Mzingwane catchment, although one is for 2030 and two are for 2050 (Table 7). The current study shows a much larger decline in runoff in Mzingwane catchment than do the other two studies. The probable reasons for this are explained above. While the values for precipitation, evapotranspiration and runoff differ between the studies, there is general consensus that there will be a decline in MAP and an even larger decline in MAR in this catchment by 2050.

Table 7 Precipitation, evapotranspiration and runoff predictions for Mzingwane catchment

Study	Date of prediction	Mean annual precipitation(decline)	Mean annual evapotranspiration (increase)	Mean annual runoff (decline)
IFPRI (Zhu and Ringler2010)	2030	13-21%	4-6%	19-33%
Zhu and Ringler(2012)	2050	6-23%	3%	2-24%
Current study	2050	12-15%	-	65-100%

These results are also consistent with the precipitation predictions from the downscaled SADC modelling for southern Africa. However, the modelling in the current study for Save catchment (8-14 % decrease in precipitation by 2050) differs from the qualitative results from the UNDP/GEF modelling which proposed a relatively constant MAP although with increased variability.

Zhu and Ringler (2012) found that the main reduction in precipitation occurs in spring and early summer (October through December) in the Mzingwane catchment. The SADC study also concluded that precipitation would decrease during September-December.

Implications on Water Resources Planning, Management and Investment

Even without population growth, increased temperatures and potential evapotranspiration and reduced precipitation in the south and west of Zimbabwe, indicate that there will be less water available and increased water stress. When coupled with possible scenarios of population increase¹⁵ (Table 8 and Figure 13) the per capita water availability decreases significantly by 2050.

Using aggregate runoff as the measure of water availability, Table 8 shows that even under the best case emissions and the low population growth scenarios, per capita water availability declines by 38% from 2.45 Ml per capita per year in 2013 to 1.52 Ml per capita per year by 2050; under the business as usual scenario water availability declines by 48% even with low population growth. However, per capita water availability then starts to increase again by 2080 under the low population growth scenario for both the Ecologically Aware and the Business as Usual scenarios because the low fertility assumption underlying the low population growth leads to a population decline that is faster than the decline in runoff because of climate change. The UN currently rates Zimbabwe as water stressed (1.0-1.7 Ml per capita per year). Under the medium or high population growth scenarios, per capita water availability continues to decline to the point where Zimbabwe would be categorized in the “absolute water scarcity” category.

Note that these are nation-wide indicators and do not account for the spatial variation in both population growth and water availability if the decline in runoff occurs in the less populated regions of Zimbabwe then water availability may not decline as much as indicated here. Increased climate variability, manifest as more intense droughts and floods, and delayed starts to the wet season will add to the water stress faced by both rural and urban communities¹⁶.

¹⁵ Population data for current (2013), 2050 and 2080 taken from UN (2011).

¹⁶ Under the medium and low population scenarios, Zimbabwe's population falls and the per capita water availability increases between 2050 and 2080 for the business as usual emissions scenario. The reason for this decline in population under these two scenarios is not known.

Table 8 Current and projected per capita water availability (ML per capita per year) for 2050 and 2080 under three population growth scenarios

		2050		2080	
Population growth scenario	Current	Ecologically aware scenario	Business as usual scenario (A2a)	Ecologically aware scenario	Business as usual scenario
Low fertility	2.38	1.52	1.27	1.76	1.31
Medium	2.38	1.29	1.08	1.23	0.91
High fertility	2.38	1.11	0.93	0.88	0.65

Source: United Nations 2011

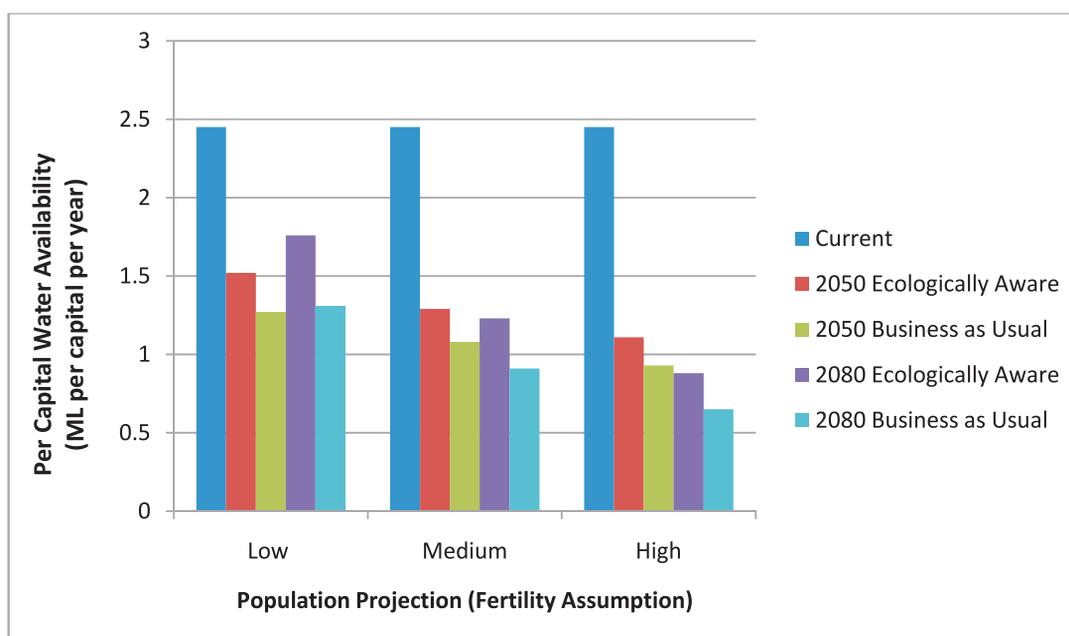


Figure13 Current and projected per capita water availability (ML per capita per year) for 2050 and 2080 under three population growth scenarios

One obvious implication of these findings is that water resources infrastructure dams, irrigation systems will need to be rehabilitated and expanded to meet the increasing population demand. Investments in new dams for irrigation could be delayed in the short to medium term, with the exception of priority areas, until many of the existing irrigation dams are first put into use; this would improve productivity in the agriculture sector and generate revenue for ZINWA.

However, increasing investment in infrastructure alone is not likely to be sufficiently flexible response to increasing demand in the face of climate change because the increase in runoff variability that results from climate change means that dams will have to be bigger to provide the same level of security (McMahon and Mein 1978). Instead, a multi-pronged strategy will be needed that includes water resources infrastructure along with improved water resources governance and water resources planning and management, to make most efficient use of existing water resources. In particular, water resources management will need to be better coordinated with the planning and management of water using sectors agriculture, water supply and sanitation, mining, industrial and commercial users, and tourism.

The findings also have implications for water demand. Water conservation measures for both rural and urban water users may be more cost effective than increasing water supply measure, particularly in those parts of the country that will experience diminished MAP. The pattern of agricultural water demand may also be affected. The delayed onset of the rainy season in the south of Zimbabwe and increased variability may shift cropping towards areas of more reliable precipitation and require the introduction of more drought resistant varieties.

Climate change is likely to significantly accentuate the importance of groundwater resources. Even in areas where there is no decline in precipitation, the higher temperatures will mean higher evaporation losses and less surface water for distribution and use. If there is also a decrease in precipitation, then the stresses on the water system will be even greater, and the groundwater resource will become a vital water source. Groundwater cannot replace surface water in the economy, but conjunctive use of surface and groundwater, based on realistic assessments of water availability from both of sources, and deliberate operational policies to use both resources jointly could help make better use of existing water resources. The increasing importance of groundwater is likely to promote more management attention to this vital but neglected resource. Investment is urgently needed in ground water monitoring and investigations, and improved groundwater professional capacity in ZINWA, water supply authorities and Catchment Councils.

One final result of this analysis is that sector policies that are considerably removed from water resources could have a profound effect on longer-term water availability. As shown above, policies that reduce fertility and consequently reduce population growth rates could counter the decline in water resources from climate change. Land use decisions can also have a profound impact on groundwater recharge and quality. These examples illustrate the importance of taking a government-wide approach to adaptation not all adaptation measures are concerned with water resources. The newly formed Ministry of Environment, Water and Climate brings together some of the important sectors under one ministry contributing towards a government-wide approach. The key now will be to also work closely with agriculture, energy, industry, mining and other key sectors and keeping water as a central link in the climate change adaptation discourse.

5. Case Studies of Climate Change Vulnerability and Adaptation Opportunities

Most studies of climate change adaptation in Zimbabwe have focussed on adaptation within the agricultural sector, particularly by subsistence farming communities who are likely to be severely affected in the south of Zimbabwe (IMAT Development Consultants 2008; Ungani 2009; Mano and Nhemachena, 2007; Chigwada, 2005). However, adaptation within the water resources sector must necessarily go beyond local community actions. It includes adjustment and change in behaviours and procedures at all scales from transboundary, to national, to regional and local levels. Adaptation is about both prevention and response and is concerned with both built and natural systems (SADC 2011).

SADC (2011) have proposed a 3-tier framework for reducing vulnerability and improving resilience to climate change, and therefore, adaptation options and opportunities. These tiers water governance, infrastructure development, and water management recognize that climate change adaptation occurs at multiple levels of intervention. To explore adaptation options and opportunities, we have extended the water management category to include water planning and distinguished Information, Education and Communications as a separate category because of the importance of involving all water users in adaptation activities.

In this chapter, we review five water resources case studies, representing diverse water resources situations across Zimbabwe, using this extended framework.

- The first two Harare and Bulawayo water supply illustrate issues and adaptation opportunities for large urban centres. Both currently face severe water shortages because of increasing demand, lack of supply expansion, dysfunctional water treatment plants and leaking distribution systems. Harare also has water quality problems because the city lies within its own water supply catchment.
- The third case study, Roswa Dam, represents a small multi-use system where the existing water source is not fully utilized. However, climate change along with increasing demand from nearby growth centres will likely lead to a shortfall in water availability for irrigation. There are many opportunities for adapting to climate change by improving management and community participation.
- The fourth case study examines irrigation in the Limpopo River Basin, a transboundary water resource. Existing water resources are already heavily allocated at the top of the catchments. The basin is predicted to face significant decreases in water availability as a result of climate change. While there are still some opportunities for developing new water sources, the major adaptation opportunities lie in improved management.
- The final case study, Kariba Hydropower on the Zambezi River Basin, representing another transboundary water resource. Although hydropower is the major water use, other uses have arisen since the dam was constructed. Lake Kariba faces both reduced inflows and increased flood risk as a result of climate change. Additional infrastructure investments as well as operational improvements provide adaptation opportunities.

Case Study 1: Harare Water Supply

Background

Harare was established in the late 19th Century as a fort on the watershed that separates the Mazowe Catchment from the Manyame Catchment. The city is located in a region with relatively good rainfall (MAP of 800 mm). The city shares the water supply system with the

satellite towns and settlements of Chitungwiza, Norton, Ruwa and Epworth. Total population served is about 2.2 million. The surface raw water supply sources for Harare consist of four dams on the Manyame River (Table 9). The 4% yield from the dams is 437 Mlpd while the combined water treatment capacity is 710 Mlpd. The balance can be met from reclaimed water and treated effluent.

Table 9 Water supply dams for Harare City

Dam	Year	Capacity(MI)	Annual Yield (MI)	
			4% Risk	10% risk
Harava Dam	1973	9,250	3,928	7,175
Seke Dam	19	3,380	1,153	2,471
Chivero Dam	1952	247,181	93,916	119,159
Manyame Dam	1976	480,236	60,379	85,083
TOTAL		740,047	159,376	213,888

Note: Harare's share of Chivero and Manyame dams is 80%. The remaining 20% meets raw water demand for Chitungwiza, Norton, Ruwa, Chinhoyi and irrigation upstream of Biri Dam.

Source: Zinwa Data and Research Department 2012

Groundwater use in Harare has risen sharply as a result of poor service delivery by Harare Municipality. Old, low-yield boreholes are now used extensively and many new boreholes have been drilled in the city area. All northern and north-eastern suburbs rely on ground water and the United Nations Children's Fund (UNICEF) have drilled and equipped boreholes in high density residential areas and clinics to ensure safe drinking water. Groundwater development is however largely unplanned, unregulated and unmanaged. Chapter 3 describes the lack of comprehensive assessment of aquifers to inform drilling and the absence of monitoring to determine the vulnerabilities of groundwater, especially in light of the breakdown of sanitation and sewerage systems and growing contamination.

International donors have assisted the government rehabilitate water treatment plants on an emergency basis following the 2008/09 outbreak of cholera, and planning is now underway for a more systematic improvement in water treatment for Zimbabwe's major urban areas. The rehabilitation of Harare water works has commenced recently with the support of the Chinese government.

Harare has six wastewater treatment plants, with a potential annual treated capacity of 240,000 MI, far below the desired annual capacity of 400,000 MI. Currently, wastewater collection systems require extensive repair and many of these treatment plants are only partially operational. Consequently, untreated and partially treated effluent is being discharged into raw water supply dams. Previously, much of this treated wastewater was used for irrigation and so relieved pressure on fresh water supplies. Treated wastewater can potentially replace 150,000 MI per year of raw water while the rest is used for irrigation.

Issues

The area around Harare is undergoing rapid expansion with new formal settlements being developed on the understanding that they will be connected to the existing city's distribution network. Consequently, unconstrained demand will rise sharply over coming decades placing even more stress on a water supply system that cannot cope with existing demand.

There are high losses in the current water supply system with about 60% of treated water being lost due to broken pipes and illegal connections. In addition, there is little effort to manage water demand, even though experience during the 1981/2-83/4 drought showed that household demand could be reduced markedly from the current high levels (600 l/day in high density areas, 900 l/day in medium density areas, and 1500 l/day in low density areas) to 400 l/day without causing consumer complaints. Reducing losses and controlling demand would delay the need for investment in new water supply infrastructure.

Water management authorities lack funds. The recent announcement by the government that all local authorities should cancel outstanding debts on water rates will severely limit Harare City Council's and ZINWA's ability to manage water supply. Similarly, the imposition of very low tariff rates on raw water to consumers affects ZINWA's operational capacity.

Additional sources of water are under consideration. The proposed Musami, Kunzvi, Nyagui and Nyatana Dams would provide new sources from the adjacent Mazowe catchment, while the Kudu Dam on the Sanyati River can provide a link with the proposed Kariba Dam pipeline. Wastewater discharges form a potential source of contamination for Harare's raw water supplies as well as contributing nutrients that fuel extensive growths of water weeds on dams such as Lake Chivero. However, these discharges could be turned into an asset rather than a liability by treating them to a level where they could be used for non-potable purposes. There are potential new sources of surface water available in the adjacent Sanyati and Mazowe catchments.

Climate change is likely to result in warmer temperatures that could increase water demand for both urban water use as well as irrigation, although modelling conducted in this report shows that the Harare region is not likely to experience major reductions in MAP or MAR. However, there could be increased variability with more intense droughts and floods. While dams such as Chivero dam have spillways capable of passing large floods, rafts of water hyacinth can cause obstructions leading to potentially severe damage to infrastructure.

Neither groundwater drilling nor groundwater use are regulated. In addition, groundwater information is limited. For example, the sustainable yield of groundwater resources is not known and areas where groundwater is vulnerable to contamination have not been established.

Adaptation Options

Water Resources Governance. The establishment of the proposed independent Water and Wastewater Services Regulatory Unit would remove political considerations from water pricing decisions and help ensure that prices were based on considerations of production costs and efficiency measures. It would also help ensure that customers receive adequate levels of service.

Water Resources Planning and Management. A thorough analysis of the implications of climate change for Harare water supply and water demand would contribute to improved water planning for the city. If the results of the preliminary study reported here are confirmed, then the focus should be on planning for a more variable climate rather than a drier one. Given Harare's national importance, it is important that the government of Zimbabwe continues working cooperatively with the City of Harare Council and Manyame Catchment Council in both water planning and management.

There are a number of opportunities whereby current water management practices can adapt to a more variable future water supply. It would be sensible to explore conjunctive management of groundwater and surface water sources under an increasingly variable climate. Given the likely increased reliance on groundwater, it would be sensible to improve records of groundwater drilling, groundwater levels and groundwater use keeping in mind the capacity of authorities to collect and analyse water use records. This is particularly important in Harare where groundwater abstractions are, at present, almost uncontrolled.

Demand management practices could be introduced along with water conservation measures. Demand can be reduced through techniques such as public education and, to some extent, increasing water prices. Water conservation measures would clearly include leakage reduction and increased reuse of treated wastewater, together with other measures such as pressure reduction and water conserving techniques at household level. Modelling suggests that water use can be reduced from an expected 1600 Mlpd in 2018 to 950 Mlpd by undertaking a suit of such practices and measures.

Instituting effective pollution control through rehabilitation of wastewater treatment plants and controls over diffuse and point source discharges would help protect downstream water storages from contamination as well as provide water for irrigation, some of which would offset potable water use. It is also important to work with environmental authorities to protect the resilience of natural systems to increased climate variability. If maintained, these wetlands and riparian areas form one of the lines of defence to protect Harare's water supply system.

Improved revenue collection is essential for a sustainable water supply network. Harare water managers could improve their accounting and collection management by learning from their twinning arrangements with eThekweni Water managers in South Africa who achieve 95% collection efficiency. However, consumer willingness to pay is closely linked to reliability of water supply and so increased revenue collection can only occur as part of improvements in water supply.

Water Resources Infrastructure. There are important public health reasons for the current emphasis on improving reliability and quality of water supply. However, rehabilitation of wastewater treatment collection and treatment also needs to be strategically planned because it not only contributes to public health and environmental outcomes but also provides an additional source of water.

Development of groundwater may be sensible given that it is buffered against the increasing climate variability likely to be experienced in the Harare region.

New sources of surface water under consideration include the Kunzvi, Musami, Nyagui/Mazowe and Nyatana dams in Mazowe catchment and the Kudu dam in Sanyati catchment. However, it would be sensible to subject any decision to proceed with any of these new sources to cost effectiveness comparisons with demand management, water conservation and groundwater development alternatives under the changes expected under global warming. This analysis would need to rely on a detailed and credible climate change analysis for the Harare region.

Information, Public Education and Communications. Harare water users will play an important role in adapting to climate change. Water users are central to demand management; they are central to improving revenue collection for funding water management; and they are central to encouraging city and central government to take action while there is time to adapt to climate change. Public education programs will be needed to build understanding amongst water users about climate change implications for Harare's water supply.

There is a strong case for improving monitoring of groundwater use, groundwater levels and groundwater quality because of its likely current over-exploitation at a time when it could play an increasingly important role in the city's water supply. This may require changes in current regulations and sharing of information between city and central government agencies. Many water managers left during the national economic crisis and there is now a dearth of professional expertise at Harare City Council. Additional water managers need to be hired. Both water managers and City Councillors lack a detailed understanding of climate change and would benefit from specialized education programs.

For the reasons outlined above, a detailed and thorough modelling analysis of climate change and its potential impacts on water demand and supply for the Harare region is an essential foundation for strategic planning of the City's water supply.

Case Study 2: Bulawayo water supply

Background

The City of Bulawayo with a 2012 population of 655,700 people has been experiencing severe water shortages for nearly 40 years; supply has far exceeded demand and development of water supply infrastructure has lagged significantly. The city is situated on the watershed between the Mzingwane and Gwayi catchments. The city currently draws its water resources from the Mzingwane catchment together with groundwater from the Nyamadhlovu aquifer and it discharges effluent waste water into the Gwayi Catchment. Consequently, the dams have not been polluted from the discharge of partially treated and untreated effluent apart from the Khami dam on the Gwayi River.

The raw water supply for the city of Bulawayo is drawn from six dams, four of which are owned by Bulawayo City Council (BCC) and two by MEWC through ZINWA. When built, the dams initially enjoyed a monopoly on the available water resources, and so their yields at 4% risk (i.e. 96% reliability levels) were quite high at 172.5 Mlpd. However, under the 1998 Water Act ownership of water was transferred to the President and all water users were required to obtain permits. Because the city's permits now carry the same weight as newer dams and flow permits, the dam yields are now much less at 87 Mlpd (about 50% of previous yields). In addition, the

rainfall in Mzingwane catchment has declined by 15% over the last century although this decline (plus future declines from climate change) has yet to be factored into yield calculations.

The surface water resources were supplemented with groundwater from the Nyamadhlovu aquifer in 1993 after the severe 1991/2 drought. The present estimated yield from this source is 9 Mlpd. In addition, the City of Bulawayo was a pioneer within Zimbabwe when it commenced recycling treated wastewater in the early 1960s. The six wastewater treatment plants have a combined capacity of 65.5 Mlpd with most treated wastewater being used for non-contact uses such as irrigation and stock watering. However, wastewater from the Thorngrove STP (10 Mlpd) was treated to tertiary standard and supplied for industrial and commercial use and irrigation of public parks, thus saving potable water.

Issues

Bulawayo's water supply and wastewater treatment systems have become dilapidated since the financial crisis and require rehabilitation to return to their full design capacities. At present the city's water treatment plants are operating at about 57% capacity. The Nyamadhlovu borefield also requires rehabilitation of some wells to be fully operational. In addition, up to 45% of water is lost in the city's water distribution systems from leakage and illegal connections¹⁷.

The city also requires additional water sources to respond to population growth with the last dam Mutshabezi dam being commissioned in 1994. However, there is some confusion about Bulawayo's population figures with the population from the 2012 census (655,000) being substantially less than that assumed prior to the census and so it is difficult to estimate future urban water demand reliably. The Water Sector Investment Analysis study accepted the Census figures and assumed an annual population growth of between 2.4% and 3% (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners 2013a).

The wastewater treatment plants are also in need of rehabilitation. A number of bilateral and multi-lateral donors (SIDA, DFID, UNICEF, AusAID, IMF) are working with GoZ to rehabilitate both surface water supply and wastewater treatment facilities. It is not clear whether these improvements will also result in the re-establishment of wastewater recycling from the wastewater treatment plants. UNICEF has assisted with the rehabilitation of the Nyamadhlovu wellfield (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners 2013b). Nevertheless, further actions and investments will be needed to meet future urban water and wastewater requirements.

The modelling in Chapter 4 shows that the area where Bulawayo is located between Mzingwane and Gwayi catchments will be the area most affected by climate change in Zimbabwe. MAP levels in Mzingwane and Gwayi catchment could decrease by 12-15% and 5-10% respectively by 2050, and MAR could decline by 65-100% and 50-100% respectively. Recharge to groundwater may also decrease although the amount is not known. These potential effects have not been factored into the future urban water supply calculations in the Water Sector Investment Analysis study.

¹⁷ Pers comm, BCC Water and Sanitation Department 2013.

Appointing an independent Water and Wastewater Services Regulatory Unit would help remove water pricing from political influence and provide better certainty to both water consumers and urban water management authorities such as BCC.

Water Resources Planning and Management. Reducing the reliability from 96% to 90% for Bulawayo's water supply dams would provide an additional 40 MI/day; even if only Insiza dam (the most reliable supply dam) was operated at 90% reliability, it would provide an additional 15.2 MI/day.

Distribution losses could be reduced from the current high level of about 45% to 15% over 15 years through pipe lining, pipe replacement and detection of illegal connections, giving a saving of 45 MI/day. This is likely to be a cost effective action over the short term compared to developing new water sources.

Once the Nyamadhlovu wellfield is rehabilitated, there may be opportunities to continue using it and other new groundwater sources conjunctively with surface water sources.

Increasing water prices would help reduce demand, encourage adaptive behaviours and provide revenue to BCC and ZINWA. However, the recent announcement that local authorities should cancel all outstanding debts on water and rates runs counter to the message that water is a precious resource and needs to be used efficiently. This measure may not assist the poor, since the bulk of the money owed to BCC is by Government Institutions, industry and the wealthy.

Improving revenue collection would also help provide operating funds for BCC. BCC could apply lessons learnt from its twin organization eThekweni Water in South Africa which collects 95% of its water rates. BCC's recent decision to ring-fence its water revenue, based on a directive from Ministry of Local Government, will improve its financial resources.

Water Resources Infrastructure. Current projects to rehabilitate both water supply and wastewater treatment infrastructure will make substantial contributions to helping BCC adapt to the expected decline in precipitation and increase in evapo-transpiration under climate change. Nevertheless, even if some of the water savings discussed above are achieved in the near term, there will be a need to develop additional water supply infrastructure. When completed, the Gwayi Shangani project will provide an additional 270 Mlpd of raw water. The project consists of three phases the Gwayi-Shangani Dam, the pipeline from the dam to Bulawayo, and the pipeline from the Zambezi River to the dam. However, the project cost is very high (US\$1,500 million) and raising funds has been difficult. Recently the GoZ has announced that the Government of China will provide funds to complete the project.

The Epping Forest groundwater source may provide an additional 15 Mlpd of raw water in the short-medium term.

Information, Public Education and Communications. There are a number of areas where better information would help BCC adapt to the effects of climate change. Thus, the yields of dams could be reassessed to include the likely effects of climate change, to give BCC a clearer idea of surface water supplies. There is also a need to better understand the customer base and the best methods for reducing water demand.

Because of the history of water shortages, the citizens of Bulawayo already exhibit a culture of water conservation. The government and BCC can reinforce the importance of this conservative approach to water use through education programs and other support actions. This includes publicity campaigns and education of school children and adults in the importance of water conservation given Bulawayo's vulnerability to the effects of climate change.

Case Study 3: Roswa Dam Operations

Background

The Roswa dam is located on the Roswa River adjacent to Nyika growth point, in Bikita District about 100 km east of Masvingo in southern Zimbabwe. It is a multi-purpose dam built to supply water to Nyika and Bikita Service Centres and to irrigate a small holder irrigation scheme south of Nyika. Ten percent of MAR is also released to meet environmental and other downstream needs. Under normal circumstances, the urban water supply needs have precedence over irrigation water needs.

The catchment of 62 km² has a relatively high MAP of about 700 mm/yr. Mean annual evaporation is 2000 mm/yr. The rainy season runs from November to April. There are often severe mid-season dry spells and so the region is marginal for crop production, unless it is under irrigation.

The irrigation scheme, which was developed in 1994, is the major consumer of water from the dam. It has a potential irrigated area of 138 ha of which 80 ha is in the process of being fully developed and 50ha is under a functional irrigation system. The irrigation farmers grow maize, wheat, beans, tomatoes and other vegetables on 1.5 hectare, 1 hectare or 0.5 hectare plots.

The Roswa irrigation scheme is a resettlement government financed small-holder irrigation scheme and so receives technical and extension services from Agritex. Capital developments are financed by Government through appropriation from parliament and donors. However, the smallholder farmers are nowadays required to pay the full operation and maintenance costs to service providers including electricity supply.

The dam has a capacity of 2,850 MI with a design yield is 1,050 MI at 4% risk, rising to 1,450 MI at 10% risk. Irrigation water use is estimated at 240 MI/annum (Ncube 2010). Because of the high MAR, the dam can refill every year even if it was completely drawn down the previous year. At present, there is sufficient water to satisfy primary water releases and the water supply demand from the growth centres for many years along with the allocation of 12MI/ha/annum for irrigation.

An ecotourism operation has also been established based on the wetland formed by the dam (Mawere and Mubaya 2012).

Issues

Although Roswa dam is structurally sound, the reservoir is probably silting up because of extensive erosion in the catchment. There are also significant operational issues associated with the irrigation scheme (Food and Agriculture Organization, 2000). Electricity supply for pumps is unreliable. Because of poor maintenance some hydrants leak and drag hoses are now being used to deliver water to irrigation furrows. This is labour-intensive and less efficient.

There are problems with crop selection whereby some farmers grow low value crops such as maize. The high inputs costs of fertilizers and other chemicals together with low commodity prices tend to influence the size of land that can be put under irrigation at any one given time. Irrigation practices are not coordinated which makes it difficult to schedule irrigation water releases efficiently.

There are also management problems. Originally, farmers felt that the government was imposing the project on them. In the process of convincing the farmers to accept the project, the government made some unrealistic promises, which it failed to fulfil and so farmers felt let down. In addition, different communities sharing the scheme find it difficult to work together effectively (Food and Agriculture Organization 2000).

There has been a declining trend in rainfall with an increasing trend in temperature over the last 60 years, although these trends are not statistically significant (Ncube 2010).

Although the dam is currently under-utilised, there could be irrigation water shortages in the future as a result of reduced MAR from climate change and increased demand from the growth centres. The analysis undertaken for this report showed that rainfall is likely to decrease by 76mm to 131mm in Save Catchment by 2050. This in turn will result in decreases of MAR in the Roswa River and inflows to the Roswa Dam. Ncube (2010) shows that, even if MAR declines by 50%, there will still be sufficient water available to meet the current level of demand. However, if there is increased demand for water from the growth centres, an expanded area under irrigation and downstream users along with a 50% reduction in MAR because of climate change, then allocation reliability is affected and full allocations are not realised 32% of the time. Under current allocation priorities, irrigation water allocations would be reduced under these circumstances while primary uses would be protected.

Adaptation Options

Water Resources Governance. In the long term, the Roswa irrigation scheme could become more efficient if the distrust between farmers and government was reduced by increasing the level of responsibility of farmers. They would then be more likely to manage the scheme more effectively, reduce costs, and innovate in the face of climate change and increased demand for water from other user groups.

Water Resources Planning and Management. There are opportunities to be more efficient with current water use, especially for irrigation water use by employing technologies such as drip irrigation and managing water scheduling more efficiently. Scheduling could be based on actual water deficit to help improve efficiencies. Modifying crop selection towards more water efficient and higher value horticultural crops would not only make better use of existing water but would contribute to improved profitability for the farmers. Increased water prices would help shift cropping practices towards higher value crops as well as provide ZINWA with increased operating funds. Domestic water use efficiency could also be improved through both technical (e.g. reducing leakage) and non-technical (e.g. public awareness campaigns and increased water prices) means.

The life of the dam could be extended by instituting erosion control measures (such as better farmer education and protection of vulnerable areas) in the catchment above the dam.

Water Resources Infrastructure. Increasing the size of the night storage dam would help alleviate the problems from the unreliable power supply. More water could be held for supplying to the irrigation area under gravity when the electricity supply fails.

Although Roswa dam's storage capacity is not an issue at present, there is potential to increase storage in the long run if an increase in demand begins to outstrip a reduced supply of water. There is a potential storage capacity in the catchment (at twice MAR) of 9,600 Ml under current rainfall. While the potential storage capacity will fall as rainfall reduces under climate change, it may still be possible to construct a new dam or raise the capacity of the existing dam to store additional water, particularly if there is an increase in the intensity of storm events.

Information, Public Education and Communications. Clearly, many of the above adaptation actions would require a good understanding by farmers especially, but also by government agency staff and local leaders, of the potential for improving operating methods to adapt to the likely impacts of climate change. Given the relative vulnerability of irrigators compared to other water using groups, many of the adaptation actions fall on the irrigation sector. Officials in the Department of Irrigation, ZINWA, and Agritex would require additional training in order to enhance their capabilities in integrated water resources management (IWRM) and scheme design and their understanding of climate change.

If farmers are to take greater responsibility for scheme management, they will need training in irrigation operations and management skills.

Officials in the growth centres would also need training to gain a better understanding of the potential for more efficient urban water use. It is important that the public understands and supports the need for change and so education campaigns could be designed to make them aware of the adaptation actions that will be needed in anticipation of climate change.

Case Study 4: Limpopo Basin: Irrigation

Background

The Limpopo River Basin is shared by four countries - Botswana, South Africa, Zimbabwe and Mozambique. The basin has a total area of about 408,000 km² of which nearly half lies in South Africa. About 15% lies in Zimbabwe, largely in the Mzingwane catchment.

The basin's climate varies spatially and temporally. Precipitation ranges from 250 mm in the western part of the basin to 1,050 mm in the eastern escarpment areas. Evaporation varies from 1,500 mm to 2,600 mm per annum across the basin. The Mzingwane catchment receives 475 mm MAP and has a mean annual potential evaporation of 2,065 mm. About 95 percent of precipitation occurs between October and April with significantly variation between years (Zhu and Ringler 2012).

Given the low and highly variable rainfall and high evaporation rates, it is difficult to grow crops reliably within the basin and so there has been considerable investment in irrigation dams within the basin. There is a high level of water resources development within the basin. Total annual water demand is 4,700 Mm³, which is 65% of the 7,200 Mm³ MAR. Irrigation is the largest water use across the basin, although urban, industrial and mining (UIM) water use (690 Mm³ p.a.) constitutes the largest user within the Zimbabwe portion of the basin followed by

agriculture (640 Mm³ p.a.) (Direcção Nacional de Águas 2010). Water demand in Zimbabwe is concentrated in the upper part of the catchment in the Upper Mzingwane River and the Mwenezi River sub-catchments. Bulawayo obtains its water from the Upper Mzingwane River catchment and therefore influences development of water resources in that sub-catchment.

Although Basin waters are already heavily committed, there is opportunity for some further infrastructure development (Direcção Nacional de Águas 2010). The irrigation potential of soils of the Limpopo basin within Zimbabwe is estimated at 10,900 ha. Of this area, approximately 36 % is currently under irrigation. The area under smallholder irrigation is 1,550 ha with water sourced mostly from dams and sand abstraction. There has been widespread introduction of low cost drip irrigation kits in the communal lands (Love et al 2005). However, water scarcity rather than suitable soils is the limiting factor for economic development in the basin (Zhu and Ringler 2012).

All riparian countries have signed the SADC Revised Protocol on Shared Watercourses whose principles are the key for joint management of transboundary waters. All countries also have the laws and regulations and institutions required for a cooperative management of shared waters. In 2003 the riparian countries agreed to establish the Limpopo Watercourse Commission (LIMCOM) to encourage cooperative management of the basin.

Issues

Climate change will affect the basin severely, although the extent is unclear. The Zimbabwe portion of the basin may potentially receive 12-15% less MAP and 65-100% less MAR by 2050 according to this report, while Zhu and Ringler (2012) suggest 6-23% decline in MAP and 2-24% decline in MAR.

The climate of the Limpopo basin is highly variable. The Limpopo River experienced major floods in 1967, 1972, 1975, 1997 and 2000. There were severe droughts in 1980, 1981, 1983, 1984, 1987, 1991, 1992, 1994, 1995, 2002 and 2003. Extreme events, such as these, are predicted to increase in intensity under climate change. Given the existing high degree of development of the basin's water resources, these changes pose a considerable threat to both urban and industrial water uses and irrigated food production in southern Zimbabwe.

Management of the basin's water resources will also come under stress as the effects of climate change become more apparent. Upstream countries will be under pressure to abstract more water in the face of decreasing MAP and all countries will experience more intense droughts and floods.

Increased infrastructure development will reduce downstream flows and threaten delicate aquatic ecosystems along the river particularly in the estuary.

Climate monitoring (i.e. rainfall, temperature and potential evaporation) and flow gauging stations in the Zimbabwe portion of the basin are inadequate for understanding the effects of climate change. There are about 70 rainfall stations and 85 gauging stations although none of the latter are real-time gauging stations and many require maintenance. There has been improved sharing of meteorological information between basin countries following severe floods in the basin. Nevertheless, there is a need to extend this cooperation to sharing of flow data and flood forecasting (World Meteorological Organization 2012).

Adaptation Options

Water Resources Governance. Although the Limpopo has a good governance regime in principle, through the legislation and institutions of the four riparian countries and the formation of LIMCOM, there are serious weaknesses in practice. Cooperative management of the basin's water resources will be essential for meeting the challenges posed by climate change, but there will be pressures for each country to act independently. Zimbabwe along with other riparian countries will need to actively support LIMCOM in their role to bring about coordinated management of the basin waters.

Within Zimbabwe there is potential to improve the capacity of water and water-related agencies and to strengthen the role of the Mzingwane catchment councils and sub-catchment councils in water allocation decisions when water becomes scarcer.

Water Resources Planning and Management. Perhaps the single most important adaptation action would be to improve the capacity of management agencies within the basin, including those in Mzingwane catchment, so that they can understand the implications of climate change and identify adaptation actions.

Irrigation water managers would need to access improved information on water resources as climate becomes more variable and be able to anticipate changes in flows. Farmer, too will require information to make appropriate cropping decisions.

There may be opportunities to use water more conservatively through improved planning and better operating irrigation procedures. Thus, there may be opportunities to undertake conjunctive use of surface and groundwater to reduce water losses through engineering improvements and to reuse discharge waters. There may also be opportunities to modify operating procedures and farming decisions (such as choice of crop types and planting times) to adapt to the changing environment.

Water Resources Infrastructure. There are opportunities for irrigation to expand in the Zimbabwe portion of the basin, with 73% of the MAR undeveloped. Zhu and Ringler (2012) assumed an annual growth in irrigated area of 1.6% in their modelling, although in the long term climate change will restrict irrigation expansion. However, given the importance of downstream ecosystems, any further infrastructure will need to be planned so that environmental flows are provided to protect these ecosystems.

There may also be opportunities for development of groundwater resources. Apart from South Africa, ground water is not extensively used for agriculture in the LRB. Zimbabwe, South Africa and Botswana use water stored in river beds for both irrigation and domestic water supply. More work is needed in groundwater exploration in order to quantify this resource and its recharge.

There are also opportunities for improvements in irrigation efficiency to help make better use of existing water resources. The adoption of drip irrigation shows the adaptability of irrigators when training and support are made available.

Information, Public Education and Communications. Given the breadth of the predicted declines in MAR and hence water availability in the Zimbabwe portion of the Limpopo basin, it would be valuable to undertake detailed investigation of the effects of climate change on both MAR and inter-annual and intra-annual variability in runoff.

There have been a number of initiatives to improve climate and flow monitoring in the Limpopo Basin over the last decade. These have met with very limited long-term success because of inadequate project design, technical issues and lack of maintenance (World Meteorological Organization 2012). There is a need for improved climate monitoring and river gauging in the Zimbabwe portion of the basin together with improved data exchange and information sharing between the basin countries for flow forecasting. In particular there is a need for an integrated flood and drought forecasting system for the basin; freely accessible historic and future climate change data; and impact and variability assessments from a single authoritative national or regional source to guide local adaptation programming.

Farmers, including irrigators, already understand that they have to live with a highly variable climate and believe that the basin is getting warmer and drier with an increase in the frequency of droughts and the timing of rains. Maponya and Mpandeli (2013) propose adaptation strategies in the South African portion of the basin including soil management, water management, and financial management. However, farmers throughout the basin need a better understanding of climate change and its local implications and better government support if they are to integrate scientific based knowledge with the indigenous knowledge that they have traditionally relied on.

Case Study 5: Kariba Hydropower Operations

Background

Lake Kariba was created by the construction in 1958 of a 128 m high double curvature arch dam on the Zambezi River. The dam's catchment upstream of Lake Kariba covers 815,000 km² and includes five riparian states - Angola, Botswana, Namibia, Zambia and Zimbabwe.

Kariba reservoir was designed for hydropower generation currently providing 750 MW of generating capacity for Zimbabwe and 720 MW for Zambia. Its vital role for Zimbabwe was discussed in Chapter 3. The Zambian side is being expanded by an additional 360 MW while preparations are underway to expand the South Bank generating capacity by 300 MW for Zimbabwe. The hydropower generation and transmission system has been designed to operate as one system between Zambia and Zimbabwe, with linked control centres in Harare, operated by the Zimbabwe Electricity Supply Authority (ZESA), and Lusaka, operated by Zambia Electricity Supply Company (ZESCO) Ltd. The planned run-of-river Batoka Dam to be constructed upstream of Kariba (1600 MW) will be operating conjunctively with Kariba dam.

However, the Kariba reservoir now provides multi-purpose benefits including fishing, tourism, transportation, irrigation, domestic and industrial water supply uses as well as the generation of power. The Zambezi River also supplies cooling water for Hwange thermal power station (600 MW) and for the planned Gokwe North thermal scheme with a capacity of 1400 MW. These water uses on the Zambezi River are managed by various institutions in the two countries, Zambia and Zimbabwe.

Although the Zambezi River Authority Act of 1987 requires the Zambezi River Authority (ZRA) to manage and operate Kariba Dam and Lake Kariba, ZRA has no prosecuting responsibilities. Such responsibilities are diffuse and are provided in other legal provisions administered by 14 other organisations in Zambia and Zimbabwe. In short, there is no single institution with the mandate to manage, protect and operate Lake Kariba.

Management of the Zambezi basin as a whole (which also encompasses Angola, Botswana, Malawi, Mozambique, Namibia, and Zambia and Zimbabwe) is coordinated by the Zambezi Basin Watercourse Commission (ZAMCOM) which was established in June 2011 after six of the eight riparian countries ratified the ZAMCOM Agreement. ZAMCOM is still an interim commission. Amongst other things, ZAMCOM helps riparian countries collect and share data; harmonize the management and development of the water resources of the basin; avoid disputes over the management and development of the waters of the Zambezi basin; and improve public awareness of the use of the waters of the basin.

Issues

The impact of climate change on investment in hydropower and irrigation in the Zambezi River Valley can be very significant because of the region's highly variable hydrology (World Bank 2010a). Preliminary indications show that some parts of the Basin would be affected more than others with potential reduction of up to 30 percent in hydropower generation. Even though these preliminary results should be viewed with caution they illustrate the need for a more detailed understanding of climate change impacts on water resources and energy in Zimbabwe.

The key issue is the variability of the Zambezi river flows and changes in the Kariba lake levels, which would not only impact consumptive and non-consumptive uses of water (such as irrigation and hydropower generation) but also the productivity of the lake and lake fisheries. The Zambezi multi-sector investment analysis study assumed that climate change could bring about reductions in flows within catchments of the Zambezi basin of between 13% (Zambezi delta) and 34% (Kafue sub-basin) by 2030 (World Bank, 2010a). Evaporative water loss from large reservoirs such as Lake Kariba will also increase as temperatures increase under climate change and further decreases water availability for downstream use (Beilfuss 2012).

Major floods have occurred in the Zambezi basin in the past 20 years resulting in significant damage and loss of life. While there has been no specific modelling of the likely impacts of climate change on these extreme events in the Zambezi basin, it is a general conclusion that extreme events will become more intense (i.e. floods will become larger and droughts will be drier) as a result of climate change (IPCC 2007a).

Some authorities claim that the impacts of climate change are already apparent in Lake Kariba. The MAR appears to have reduced since construction of Kariba dam, leading to reduced flow at the dam although there is not yet a consensus that this reduction is the result of climate change. Lake Kariba's lowest water level was recorded in 1989/90 when the level was only 0.75m above the minimum supply level (or the permissible power generating level). Magadza (2010) reports that the lake has undergone changes in its thermal properties which affect its physical properties such as a shallower and warmer surface layer, and a higher heat content. This has affected its ecology, most notably a change in algal species and in some invertebrate species. These changes have in turn, led to a major reduction in food for the economically important *Limnothrissamiodon* fish (Magadza 2011) and a decline in the fishery from 37,000 tonnes around 1990 to 20,000 tonnes in 2000. This also impacts the local diet as lake fish forms an important source of protein. Magadza attributes these changes to climate change.

In addition to reduced flows, the Zambezi River has become more polluted, with Zimbabwe being a major source of this pollution from cities and towns, mining and agriculture. Pollutants include agro-chemicals, sediment and nutrients. The increase in nutrient loads has been a major cause of invasive water weeds on Lake Kariba (primarily water hyacinth (*Eichornia Crassipes*) and Kariba weed (*Salvinia Molesta*)) that cause operational problems for hydro-power generation and for tourism and recreation on the lake.

The present fragmented administrative and regulatory arrangements make management of the lake and the Zambezi River cumbersome and ineffective. These arrangements are inadequate at a time when management of the lake and the river needs to be flexible, forward looking and decisive. Water users are disconnected from the lake and river managers. Magadza (2010) says that “there is a real danger of mistaking a bureaucratic process with little connection with stakeholder priorities and concepts for an effective management regime”. At present, miners, farmers and other land users in the lake's catchment are unaware of many management plans such as the 'Combination Master Plans for Shoreline Development' and several Zambezi Action Plan documents (Magadza 2010).

Adaptation Opportunities

Water Resources Governance. The fragmentation of responsibilities between multiple agencies within the eight countries comprising the Zambezi River Basin is possibly the greatest impediment to adaptability in the face of climate change. The formalization of the ZAMCOM would be an important step towards improving the situation. While its responsibilities are limited, they include strategic planning, information gathering and early warning, and monitoring water abstraction all of which provide capability for adapting to climate change.

Water Resources Planning and Management. Climate change will bring increased uncertainties to the management of the Zambezi River with reduced flows and increased risks of severe droughts and floods. Management of all water uses, and hydropower operations in particular, will need to be better informed and more adaptable to adjust to these changes. For example, World Bank (2010a) shows that coordinated basin-wide operation of existing hydropower facilities could lead to an increase in hydropower production of about 1600 Gwh/year, as well as help build a more flexible management system.

Beilfuss (2012) sees the development of strong institutional capacity as the single most important factor in the successful adaptation of existing hydropower systems in the Zambezi Basin to cope with climate change. Significant technical, financial, and social capacity is required at different scales, from strong and well-governed national water ministries and river basin operators, through regional departments and basin councils, to local river basin offices and water user associations. Improved capacity should also include the capacity to manage the vital fisheries and environmental resources offered by critical ecosystems in Lake Kariba.

Water users other than hydropower operators, particularly those downstream of hydropower operations, will require improved certainty of access to flows if they are to continue operations under climate change. Consequently, environmental flow provisions will be critical if tourism operators, recreation facilities and local communities downstream of dams are to adapt to a changing climate.

Water Resources Infrastructure. The proposed Batoka run-of-river hydropower dam will reduce Zimbabwe's and Zambia's reliance on Kariba Dam for power production. However, fundamental design criteria such as MAR and maximum probable floods for all dams, existing and proposed, should be reviewed in light of the changes that will occur under climate change. Risk assessments should also be reviewed for dams and other infrastructure such as cooling water provision for thermal power stations, using multiple climate scenarios given the heightened potential for both catastrophic failure of structures and lack of water under new climate realities. New infrastructure proposals should also be analysed for their financial risks, as a result of precipitation and evaporation changes within the Zambezi basin.

The major Zambezi river dams such as Kariba and Cabora Basa and new dams such as Batoka should be operated conjunctively as recommended by the World Bank (2010a) to optimize the benefits from the uses of water and for effective flood management. Flood management can also be improved through non-structural interventions such as improved precipitation monitoring and flow modelling, and retention of floodplains for reducing flood peaks.

It would be sensible to also examine options for reducing Zimbabwe's reliance on the Zambezi River for power generation by increasing investment in solar and wind energy.

Information, Public Education and Communications. It will be important to improve the information basis for decisions in the Zambezi Basin and to strengthen the regional capacity for river basin planning, modelling and operations. There is a need for better weather forecasting so that any increase in flood heights can be anticipated and managed, including for communities downstream of dams. Management tools such as flood forecasting systems, routing models, conjunctive management systems, and monitoring and adaptive management protocols could be assessed to assist managers of all water uses, especially hydropower and thermal power operations.

Overall there is a need for better understanding of the likely effects of climate change on the water resources of the Basin. The multi-sector investment opportunity analysis study of the Zambezi River basin modelled the effects of a single climate change scenario on catchment yield, open water evaporation from large reservoirs and crop water demand but did not explore a wider range of climate change scenarios and their implications largely because of lack of information (World Bank 2010a).

Planners and managers need to engage extensively with water dependent and water related communities within the Basin, such as fisher folk, irrigators, tourism operators, miners, and urban water authorities so that all groups have a thorough understanding of the potential impacts of climate change and their adaptation options.

6. Adaptation Opportunities

This chapter summarizes the opportunities for undertaking the climate change adaptation activities that have been discussed in the preceding two chapters. These activities are organized under the modified SADC headings used in Chapter 5 – water resources governance; water resources planning and management; water resources infrastructure; and information, public education and communications.

Water Resources Governance

Under the 1998 Water Act, MEWC takes the lead in the water sector. ZINWA is the main operating arm of government guided by the Department of Water Resources (DWR) within MEWC for regulation. MEWC is assisted by stakeholder institutions in the form of Catchment Councils and Sub-Catchment Councils. The Catchment Councils have responsibility for water allocation planning through River System Outline Plans (RSOPs) and the issuing of water use permits while sub-catchment councils have responsibility for enforcement of permits. EMA is responsible for water for the environment and for controlling pollution in surface and groundwater systems.

There are a number of structural shortcomings with these administrative arrangements that will inhibit climate change adaptation. First, there is a lack of coordination across Ministries. Instead Ministries and even their subsidiary components usually act independently even on cross-cutting issues such as water quality and land-water interactions. Secondly, RSOPs do not take account of the effects of climate change on water allocations as well as being out of date. There are also some potential conflicts of interest between Catchment Councils and ZINWA over administration of permit water and agreement water. Thirdly, there is no clear mechanism for protecting water source areas for both surface and groundwater systems (runoff to streams, and recharge zones for aquifers). Under the Environmental Management Act (2006) EMA has been given prime responsibility for protecting these areas, but this requires close cooperation with other resource management agencies such as ZINWA, the Ministry of Agriculture, Mechanization and Irrigation Development (MAMID) and the Ministry of Health and Child Welfare (MHCW). The current National Action Committee for Water and Sanitation (NAC) has not been an effective mechanism for bringing about cross-sectoral cooperation.

The NWP provides an excellent basis for promoting climate change adaptation into water resources governance. The policy recognizes that climate change increases the risk from floods and droughts, reduces water availability for agriculture, and will affect the design and operation of dams. It advocates that climate change be taken into account in all water resources design, planning and management activities, that the NAC coordinates collaborative action with other stakeholders (a no-regrets action), and that further research be undertaken into the effects of climate change. Cross-sectoral coordination is important because adaptation requires action by both the water resources and the water using sectors – the first to promote efficiency in water supply and the other to promote efficiency in water demand. The NAC needs to be reviewed and restricted to make it more effective.

Complementary sectoral policies need to enable rather than inhibit adaptation actions. For

example, if there is an increase in small scale irrigation as a response to food security under changing agricultural conditions, then the water sector will need to be part of that initiative in order to provide reliable water. Similarly, the policies of other sectors, such as forestry, may have an impact on water resources and so should be coordinated with the NWP through the NCCRS.

The Environmental Management Act also provides, at least on paper, a strong base for climate change adaptation because it provides the legislative authority to protect natural systems wetlands, riparian areas, floodplains, etc from degradation and to build resilience against climate change. However, the provisions in this Act and in the Water Act are not always enforced. For example, Zimbabwe is projected to be even more susceptible to floods than it is at present due to climate change. However, the provisions under both the Water Act (1998) and the Environmental Management Act (2000), to prevent the cultivation of wetlands and stream banks and the destruction of these areas from artisanal mining are not enforced.

Local adaptation to climate change should be encouraged as well as national adaptation actions. Chagutah (2010) states that “local participation and accounting for household coping strategies remain real challenges in the development of adaptation policies, because there is a tendency for interventions to focus at the sectoral level. There is a danger that nationally prescribed adaptation solutions, without participation from those intended to adopt the practices, will actually limit, rather than create, spaces for local adaptation”. The studies into agricultural climate change adaptation have demonstrated that local communities and individual farmers are already highly adaptable to a variable climate and potentially capable of adapting to climate change, particularly if obstacles are removed and assistance is provided. However, local communities have little legal responsibility for water management and local methods for coping with water stresses are not taken into account by government agencies. Moving away from a centralized to a decentralized approach to water management and treating local communities as partners will take considerable courage on the part of government and would require a major increase in the skills and funds available to Catchment Councils.

Despite the intention of setting a price for water that initially reflects operating and maintenance costs during the economic recovery period and subsequently reflects the full cost of water provision, water is still subsidized. This not only exacerbates ZINWA's shortage of operating and maintenance funds but also prevents consumers from appreciating the true value of water. Actions that help adapt to a drier and more variable climate, such as water reuse and conservation, are not encouraged when water prices are held artificially low. An independent Water and Wastewater Services Regulatory Unit would be effective way to remove the issue of water pricing from the political arena and place prices on a rational footing.

Transboundary water agreements need to be able to adapt to future climates where water in major river systems such as the Limpopo and the Zambezi becomes scarcer. Whilst both river basins are managed through transboundary institutions ZAMCOM and LIMCOM neither has the capacity to investigate and adapt to changing climate conditions without robust support from their member governments. It would be in Zimbabwe's interest to advocate strengthening these transboundary institutions and reducing the complexity of water resources management in the Zambezi Basin so that there is a more coordinated and flexible response to changes in

Chagutah (2010) claims that the water rights system in Zimbabwe may not be sufficiently robust in both its design and implementation in the face of climate change. There are no strong legal provisions to handle conflicts over water, and the dual system for allocating water lacks flexibility and simplicity. On the other hand Levina (2006) believes that the system of time-limited water abstraction permits “increase flexibility and allow abstraction to be stopped when water levels become too low” although he agrees that the implementation of water abstraction permits is still very weak.

Introducing a market mechanism for water trading would also increase flexibility and efficiency of use (Levina 2006). While a formal water market would be impractical for Zimbabwe at present, informal, local markets could be authorized under legislation without requiring excessive overheads to establish. Such markets could be established in local areas where neighbouring water users buy and sell water rights without oversight from an external regulatory authority (Easter et al, 1999).

While the NWP recognizes the importance of managing both surface and groundwater, it does not emphasize conjunctive management or managed aquifer recharge. Yet both management techniques offer opportunities for making better use of existing water resources and coping better with increased climate variability.

Possible adaptation actions:

- Coordination between land and water management agencies should be improved to protect water sources. The role of the NAC should be reviewed.
- Need to review existing national and water-related sectoral policies to ensure they adequately address climate-related challenges.
- Enforcing legislation to protect wetlands, floodplains riparian zones and other ecologically important aquatic areas.
- Increase local involvement in water management through user groups and strengthening catchment and sub-catchment councils.
- Investigate politically acceptable methods for increasing water prices to reflect the true cost of water provision raising water prices, including appointment of an independent Water and Wastewater Services Regulatory Unit.
- Reduce the complexity of management institutions in the Zambezi Basin and provide increased support to transboundary water management institutions in the Zambezi and Limpopo Basins to help provide more coordinated and flexible responses as the climate changes.
- Examine methods for strengthening and simplifying the water permit system
- Examine possibility of introducing an informal market for trading water permits to improve water efficiency.
- Investigate whether there are regulatory or other methods for promoting conjunctive use of surface water and groundwater and for making greater use of managed aquifer recharge in appropriate areas.

Water Resources Planning and Management

Improved water management will help conserve existing water resources as well as cope with increased variability resulting from climate change. There are a range of water management techniques that could be adopted or extended in areas of likely water stress, including demand management, managed aquifer recharge, greater re-use of wastewater and stormwater, conjunctive management, greater use of drip irrigation in small scale irrigation such as the

Roswa Irrigation Scheme, and rainwater harvesting. Clifton et al (2010) summarizes adaptation options for groundwater management.

There are also improvements available to operating procedures, including improved collection of water fees (coupled with use of the fees for maintenance), reducing water leakages, more efficient water scheduling in irrigation districts, and removing unauthorized connections in urban areas such as Harare and Bulawayo, and pricing water at its true cost so that ZINWA receives adequate operating funds. Water pricing is based on a national uniform blend that is set low relative to other countries, in order to stimulate water use and help revive irrigated agriculture. However, this policy exacerbates ZINWA's shortfall in operating funds and could be reviewed, along with the establishment of a Water and Wastewater Services Regulatory Unit to remove pricing from the political arena.

Under the 1998 Water Act water allocation planning is undertaken by Catchment Councils. This is important for climate change adaptation, because it allows locally responsive responses to effects of climate change. However, with the exception of Manyame catchment, the Councils lack the capacity to develop these plans and have relied on ZINWA to produce RSOPs. It will be even more demanding to write RSOPs that incorporate the likely effects of climate change on both water supply and water demand.

Water permits are issued on the basis of historical records of MAR and do not take account of changes in precipitation and runoff because of climate change.

It is important that the resilience of natural systems to climate variability be protected through management activities. Improved water quality protection through better enforcement of existing provisions and closer cooperation with EMA would not only improve human and environmental health but would expand the available supply of useable water in cities such as Harare where natural ecosystems filter pollutants from wastewater before it enters water supply treatment plants. In another example, both the Water Act (1998) and the Environmental Management Act (2000) forbid the cultivation of wetlands and stream banks and also their degradation through artisanal mining, yet subsistence farmers and miners continue to work in these restricted areas. As a consequence, the natural buffering capacity of these important ecosystems has been lost. In other cases, such as at Kariba dam, sufficient environmental flows need to be allocated under changing river flows to ensure the integrity of the downstream ecosystems (particularly the Zambezi delta) on which many communities rely.

Ensuring environmental flows in RSOPs, as well as in transboundary water systems such as the Limpopo and Zambezi Rivers, will provide better protection for natural ecosystems that provide important ecosystem services for many communities.

Possible adaptation actions:

- Examine opportunities for increased use of techniques such demand management, managed aquifer recharge, greater re-use of wastewater and stormwater, conjunctive management and rainwater harvesting.
- Examine opportunities for better operating procedures such as increased collection of water fees, better enforcement of water use permits, reducing leakage and introducing full cost recovery.

- Expand the capacity of Catchment Councils to broaden their understanding and operational implications of climate change
- Reassess rules governing water permits in light of the effects of climate change.
- Protect natural systems wetlands, floodplains, riparian areas from degradation to provide a resilient buffer against increased climate variability and to maintain important ecosystem services.
- Incorporate adequate environmental flows into water plans under climate change to protect downstream ecosystems and dependent communities.

Water Resources Infrastructure

Urban water supply and wastewater infrastructure is seriously deteriorated. The level of service coverage has declined with 2008 figures showing about 46% access to improved drinking water and 30% to improved sanitation. Wastewater collection systems are often blocked or broken and treatment plants have largely ceased to function apart from primary treatment, leading to the discharge of only partially treated sewage into rivers. There was also a loss of skilled staff during the financial crisis further exacerbating the maintenance problem.

There is a need to move from emergency assistance for urban water supply and wastewater treatment towards a more systematic approach. Technical investigations are now underway for a strategic upgrade plan for water supply and sanitation facilities across Zimbabwe.

Dams for supplying irrigation water are under-utilized because of the decline in irrigated agriculture. The 2012 dam safety report found that, while the dam structures themselves were generally in a good state, maintenance had been neglected. Small dams, particularly those for which ZINWA is responsible for maintenance following the land reform program, are likely to be in a worse state. Much of the irrigation infrastructure, both on state farms and small holder irrigation infrastructure needs maintenance (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners 2013b) and a strategy is being developed for rehabilitating this infrastructure.

There is little information available on the status of rural water supply schemes apart from 12 schemes assessed by the Water Sector Investment Analysis project (Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners 2013b). These schemes were generally rated as being in Fair or Good condition, with abstraction equipment being in poor condition but treatment works and pipelines generally operating satisfactorily. Three rural wastewater disposal systems were assessed and all were rated as poor.

Thus it is now timely to move away from the assumption of climate stationarity and incorporate the medium-long term effects of climate change into water resources infrastructure planning and operations. Climate change not only means that new infrastructure needs to be sized to suit a drier climate in some areas but that it also needs to be designed for a more variable climate. Risk assessments could be revised for both existing and planned infrastructure, such as the Batoka dam on the Zambezi River, to take account of climate change. Future investments in energy provision could include examination of water independent options, such as solar and wind energy, to avoid the reduced water availability arising from climate change. In the longer term, climate change effects will need to be reflected in design standards for dams, bridges, flood levees, etc.

The current practice in the MEWC is to offer water at a constant yield with 90% reliability for agricultural use and 96% reliability for UIM. Prior to ZINWA acquiring responsibility for private dams, farmers would adopt a higher risk of failure in order to expand their land under irrigation. ZINWA is currently considering a strategy of reducing the reliability to 90% and 80% for UIM and agriculture respectively where it is feasible. Thus, Bulawayo could receive an additional 40MI/day if the reliability factor was reduced to 90%. The yields of each catchment should be recalculated since they are dependent on precipitation and temperature, both of which will change under climate change.

Flood control measures will also need to be designed to take account of more intense storms and floods. These measures could include a mixture of structural and non-structural measures (such as land use controls and land management, and restoration of wetlands) as well as better medium term weather forecasting. Large dams, such as the Kariba dam, would need to be informed by early warning systems and operated so as to allow for increased floods. Cascades of dams, such as those on the Zambezi River, should be operated conjunctively to maximize their flood protection potential.

Possible adaptation actions

- Incorporate climate change outcomes into water resources infrastructure design and planning for irrigation, water supply and flood control purposes
- Investigate the incorporation of climate change outcomes in design standards for infrastructure
- Examine the benefits and costs of increasing the risk factor for agricultural and urban water provision to accept the increased variability under climate change
- Expected yields should be recalculated for each catchment taking account of the temperature and precipitation changes expected under climate change.
- Risk assessments could be undertaken for all major infrastructure, existing and planned, to account for the effects of climate change
- Water-independent energy options, such as wind and solar farms, could be included in future energy planning.

Information, Public Education and Communications

A comprehensive information and education program is needed to build greater understanding of climate change and the need for adaptation. The level of understanding of climate change amongst politicians and senior decision-makers inside and outside government is still limited. Most of them are not conversant with the subject, which makes it difficult for them to understand, authorize and encourage adaptation actions. There is little understanding of fundamentals, for example that implementing IWRM principles constitutes a no regrets action that goes a long way towards building adaptability to climate change.

More generally, there is a need to provide information and training on climate change and its potential impacts to water resources managers and users, so that they can make informed decisions about adaptation activities. There is already a strong awareness amongst farmers of climate variability along with a belief that variability has been increasing, as is illustrated in surveys conducted in some Limpopo irrigation areas. This provides a platform for introducing the concepts of climate change and the need to take action now to adapt to a drier and more variable climate. Few of the strategies employed by farmers to coping with drought have been recorded to promote their wider adoption as adaptation strategies.

There are also serious capacity constraints in central government agencies, Catchment Councils and local government water departments as a result of the economic crisis. Transboundary institutions, such as LIMCOM and ZAMCOM, also need training in climate change and its potential implications for managing transboundary water resources. In particular professionally trained staff are in short supply.

Surface water flow monitoring networks within Zimbabwe are dilapidated. Gauging stations have suffered from lack of maintenance resulting in siltation, leaking foundations and walls, and damaged or missing equipment. In addition the data base holding the flow records is old and difficult to interrogate. There is very little groundwater level or water quality monitoring, apart from some site specific monitoring near mining sites and in some urban areas. Although it is known that drilling of boreholes accelerated when urban water supplies became unsafe or unreliable, there is no central registry of boreholes. Weather forecasting and gauging stations could also be improved in transboundary waters such as the Zambezi river so that managers of critical infrastructure such as the Kariba dam have advanced warning about weather extremes.

Responsibility for both surface and groundwater monitoring is divided between the catchment authorities and ZINWA for water resources and the EMA for water quality. Much of the water quality information is difficult to obtain because it is regarded as commercially sensitive.

An early warning drought alert system has been developed by the Zimbabwe Meteorological Services to provide a pre-season assessment and another midway through the rainy season. However, these systems are only useful if farmers and irrigators are educated in using them.

While there have been a number of research studies into climate change impacts on agricultural activities within Zimbabwe, there is little active research into water resources impacts. In particular, there has been neither a thorough analysis of the extent and severity of changes to climate parameters (such as precipitation, evaporation and temperature) across Zimbabwe as a result of climate change, nor the consequent effects on water resources. There is a need for basic climate change predictions that are accepted across government and that can act as the basis for medium-long term planning. The preliminary study undertaken here was very restricted and can only be regarded as indicative of the extent of impacts on water resources. This information is fundamental to making good decisions about adapting to climate change.

A Centre of Excellence could be established where the country's expertise could be harnessed to develop these predictions and to undertake priority research into critical topics such as effects of climate change on the long-term viability of groundwater systems, particularly the groundwater dependent ecosystems that people in rural areas often rely for food, provision of fibre and natural medicines, and areas for cropping and cattle grazing. Management of transboundary basins, such as the Zambezi Basin, could also be improved if a study was undertaken of the potential impacts of a range of possible climate change scenarios.

Possible adaptation actions:

- Develop a comprehensive information and education program for decision makers, water users and resource managers.
- Document farmer coping mechanisms for climate variability and investigate opportunities for scaling up best adaptation practices by communities.

- Strengthen capacity in central government agencies, catchment councils and water authorities to improve water management expertise
- Rehabilitating the weather monitoring stations, surface water monitoring network and establishing a groundwater monitoring network would provide advance warning of changing groundwater conditions as a result of climate change
- Improve sharing of both water quantity and water quality data between agencies
- Communicating information on weather forecasting to rural communities as adaptation strategies to climate variability
- Undertaking a thorough analysis of the extent and impacts of climate change on Zimbabwe's water resources.
- Form a Centre of Excellence in Water and Climate Change to undertake essential research into the impacts.
- Support a comprehensive study into the potential effects of a range of climate change scenarios in the Zambezi River basin.

7. Findings and Recommendations

Findings

Previous studies by the IFPRI, IIED, UNDP/GEF and SADC together with a current project conducted by GWP are all contributing towards a better understanding of the potential impacts of climate change on Zimbabwe. The present study adds to this growing body of knowledge by focussing specifically on the potential impacts of climate change on Zimbabwe's water resources. The study has found that:

1. The potential threats from climate change are not yet well widely appreciated and are still not properly integrated into water planning and management.
2. Preliminary climate change modelling using simple methods suggests that MAP will decline in southern Zimbabwean catchments by up to 16% by 2050 whether or not the world succeeds in curbing greenhouse gas emissions. The northern catchments (Manyame and Mazowe) will remain relatively unaffected. Temperatures and hence evapotranspiration will increase everywhere and the climate will become more variable than it is at present.
3. MAR will be even more affected by climate change than will MAP. The extent of the decline in runoff is difficult to quantify without calibrated flow models. However, preliminary estimates from this study suggest that flows in Manyame and Mazowe catchments are likely to be little affected by climate change, while flows in drier southern catchments such as Mzingwane and Gwayi could be reduced significantly.
4. Groundwater will also be affected. While there is insufficient understanding to calculate the effect of climate change on groundwater recharge, expert understanding suggests that the greatest impacts will be felt in the drier catchments, especially Runde and Mzingwane. Thus the southern parts of Zimbabwe will experience declines in both surface and groundwater availability as climate change takes hold.
5. Dambos, aquifers in gneiss and granite rocks, unconfined aquifers that receive direct recharge from rainfall, and aquifers in highly dissected terrain are all likely to receive less recharge and become less reliable sources of water for rural water supply and irrigation.
6. On the other hand, deeper sedimentary aquifers and primary unconfined aquifers such as the Kalahari sands and recent alluvial aquifers are less likely to be affected by climate change and may become valuable sources of water as MAP declines across southern parts of Zimbabwe.
7. These results, if they are confirmed by more detailed analysis, have major implications for Zimbabwe. Existing sources of water for urban and rural areas in southern Zimbabwe will become more unreliable; irrigated and dry land agriculture and food security will be jeopardized; electricity production from both hydropower and thermal stations could be affected; and activities such as mining, irrigation, water supply and sewage treatment that are dependent on reliable electricity will be affected.
8. Overall, this reduction in water availability coupled with national population growth, means that per capita availability could decline by 38% by 2050 even with attempts to curb greenhouse gas emissions. By 2080, Zimbabwe could fall into the United Nations "absolute water scarcity" category if medium or high population growth occurs.
9. Zimbabwe has a good framework for water resources management that suffers from poor implementation. However, this weak implementation offers many opportunities for adaptation actions.

10. These opportunities to adapt to climate change range from strengthening the governance framework, to improving water planning and management, to continuing to invest in infrastructure, to educating and training, to supporting greater involvement by water users and the community in decision making. They occur at all levels, from transboundary water management, to strengthening the national water governance framework, to improving regional water planning and its implementation, to supporting local efforts to adapt to climate change. Most of these are “no regrets” activities in that they strengthen IWRM irrespective of the extent of climate change impacts.

Recommendations

This study has also highlighted some technical issues that should be addressed to help improve government's ability to understand and adapt to climate change impacts on the water sector. These include:

1. Improved monitoring of climate, rivers flows and groundwater levels to provide the factual basis for understanding the growing impact of climate change on Zimbabwe's water resources.
2. Undertaking scientific studies into groundwater characteristics (recharge rates, transmissivities, water dependent ecosystems, etc) and developing models of surface water and groundwater flows that would help predict climate change impacts on water resources and explore adaptation options.
3. Undertaking a more thorough analysis than was possible in this study of climate change impacts on water resources, including:
 - a. Use of multiple GCMs to simulate possible climate futures
 - b. Exploring a wider range of emission scenarios
 - c. Utilizing a monthly time step in the models so that seasonal changes can be assessed
 - d. Including the effects of temperature changes on evaporation
 - e. Coupling climate outcomes to river flow models
 - f. Partitioning precipitation into runoff and groundwater recharge, and
 - g. Exploring impacts on water demand as well as water supply
4. Reaching agreement on the climate and hydrological data to be used in climate change studies so that the dependence of the predictions on the choice of precipitation data, encountered in this study, can be avoided.

A wide range of adaptation opportunities have been proposed in Chapter 6. These opportunities could be embedded in a Climate Change Adaptation Strategy for the Water Sector to assist their adoption and implementation. Such a Strategy could constitute the Water Sector's contribution to implementing the NCCRS and recommendations of the WSIA.

The formation of the Ministry of Environment, Water and Climate merging the mandates of the three key areas – environment, water and climate under the new cabinet provides an excellent opportunity to re-align and work out effective coordination at the policy, regulatory and institutional levels to systematically address climate change adaptation in the water and water related sectors.

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Appendix A Climate Change Initiatives

Water, Climate and Development Programme (WACDEP)

In late 2010, the African Ministers Council on Water asked the Global Water Partnership (GWP) to implement the Water, Climate and Development Programme (WACDEP). The program will be implemented from 2011 to 2016 to integrate climate resilience into development planning, build climate resilience and support countries adapt to a new climate regime through increased investments in water security. The program is being initially implemented in eight countries including Zimbabwe, as well as in four river basins including the Limpopo Basin.

WACDEP will support other initiatives that are improving climate resilience within Zimbabwe, including the development of the NCCRS, the implementation of the new National Water Policy, the rehabilitation and development of water supply systems through the multi-donor Trust Fund, and the revision of the River System Outline Plans.

WACDEP will be operationalized through in Zimbabwe through four components:

- Investments in regional and national development
- Innovative Green Solutions
- Knowledge and capacity development
- Partnership and Sustainability

WACDEP will work at multiple levels. It investment options at local level, help integrate water security in local government strategies and plans, help develop Water Security and Climate Resilience Investment Options for two water-related sectors (Agriculture and Energy), and will also contribute to transboundary basin level work of relevance to Zimbabwe (Limpopo, Zambezi, and Pungue River Basins).

International Institute for Environment and Development (IIED)

The International Institute for Environment and Development (IIED) has undertaken a review of the impacts, vulnerability and adaptation to climate change in Zimbabwe. They found that while local farmers have developed strategies for coping with risks arising from climate variability, these coping mechanisms are unlikely to be capable of responding to the changes that will arise because of global warming.

The study provided recommendations for adaptation projects as well as recommendations for policy and governance. The former included improved community participation, better use of climate information, and conducting vulnerability assessments across sectors in rural and urban areas; the latter included exploration of the benefits of LDC status for developing a climate change framework, accessing new adaptation funds, improving multi-level risk governance that links communities, civil society, private sector and government, better inclusion of marginalized groups in decision making, and climate awareness campaigns aimed at government, civil society and the general public (IIED 2012).

International Food Policy Research Institute (IFPRI)

IFPRI has published a report on the implications of climate change on water resources in the Limpopo Basin (Zhu and Ringler 2010) using a single climate model for four emission scenarios. There was a significant decrease in precipitation and water availability under all four scenarios resulting in increased stress on irrigation and adding further constraints on the capacity of the basin to support increased irrigation development. Even small changes in precipitation patterns will need to be incorporated into water resource and agricultural planning.

Improvements in water infrastructure and management could potentially mitigate these stresses. The report points out that it is important to gain a more thorough understanding of the effects of climate change on irrigation because expansion of irrigated agriculture has been identified as one of the development strategies in basins such as the Limpopo.

IFPRI has also undertaken an analysis of the effects of climate change on maize and sorghum production in Zimbabwe as part of the Southern African Agriculture and Climate Change project using four climate change models and a number of country-level GDP scenarios. Modelling results suggest that maize yields within Zimbabwe will more than double between 2010 and 2050 under all scenarios and climate models. Millet and sorghum yields were also predicted to rise dramatically during this period, although increased domestic consumption of these crops could result in a fall of exports.

Zambezi River Multi-sector Investment Opportunity Analysis (MSIOA)

The World Bank funded the Zambezi River Multi-Sector Investment Opportunity Analysis (MSIOA) to illustrate the benefits of cooperation among the riparian countries in the Zambezi river basin. The study undertook a multi-sectoral economic evaluation of water resources development, management options and scenarios from both national and basin-wide perspectives. The scenarios ranged from coordinated operation of existing hydropower facilities, development of new hydropower facilities as envisaged by the Southern African Power Pool, development of the irrigation potential of the region, and flood management infrastructure.

The study found that there were many opportunities for development in the basin, with the greatest opportunities arising from cooperative development amongst the Zambezi riparian nations. Thus, cooperative development of the basin's hydropower potential would provide 23% more energy generation than would uncoordinated development. The effects of climate change were included through a rudimentary incremental variation of key driving factors including reduced runoff, increased irrigation deficits and increased evapotranspiration. The analysis indicated a reduction of 32 percent in firm energy generation compared with the no climate change. The authors emphasize that these results rely on major assumptions and should be taken as indicative only.

Southern African Development Community (SADC)

The Southern Africa Development Corporation has produced a handbook on climate change in order to provide current information on the impact and risk of climate change and the potential for adaptation. The handbook does not predict outcomes from climate change at country or even river basin level; nor does it offer particular solutions to the effects of climate change. Rather it provides a factual basis upon which decision-makers can rely when making decisions.

UNDP

The UNDP has implemented the Coping with Drought and Climate Change program in Zimbabwe since 2007. Its aim is to demonstrate and promote a range of gender segregated approaches for adaptation to climate change among rural communities currently engaged in agriculture in vulnerable areas of Chiredzi district as a national model. The programme is partially funded through the Global Environment Facility (GEF) small grants programme which has been operational in Zimbabwe since 1993. The program has helped develop downscaled climate change scenarios for the Runde and Save catchments, undertaken a sensitivity assessment of surface water supplies in Save and Runde catchments to climate change impacts, and undertaken risk and vulnerability assessment for Chiredzi District within Save catchment.

Appendix B Zimbabwe Groundwater Resources and Development Potential

This summary follows the method in Ministry of Energy and Water Resources Development (1985) where geological rock type is used as the primary means of characterizing the various aquifer systems. Rainfall, topography and relief and land use/land cover are used to provide a secondary level of characterization of the hydro-geological units.

Approximately 65% of Zimbabwe is covered by crystalline basement rocks such as gneiss, granite, meta-volcanics and meta-sediments. These lithologies give rise to fractured aquifers with low porosity and permeability. Aquifers develop where there is increased fracture density, favorable topography, soil use and land cover that favors recharge and higher rainfall. These aquifers are typically unconfined (i.e. not covered by an impermeable soil or rock layer) although some may be perched and semi-unconfined locally.

The remaining 35% of the country consists of extensive sedimentary formations, mostly located in the north-west/north and the south-east of the country. These sedimentary formations have high porosity and permeability and form extensive aquifer systems. Such aquifer systems are unconfined in their recharge areas, becoming confined when they dip beneath impermeable formations. Although these sedimentary aquifers are considered to have the highest groundwater development potential in Zimbabwe, they occur for the most part in areas with the lowest population densities in the country.

Preliminary calculations suggest that there is considerable potential for further developing Zimbabwe's groundwater resources¹⁸. On the assumption that the average annual recharge is a proxy for the long term sustainable yield, the calculations in Table 6 show that up to 12,900 Gl / yr could be available. Table B1 shows the characteristics of groundwater in each catchment and its potential for development. Generally, those rated as having high groundwater development potential are suitable for commercial irrigation development and for urban water supplies; those with moderate potential are suitable for small-scale irrigation and small piped water supplies for villages and growth points; while those with low potential can support rural water supply development.

The estimates in Table 6 over-estimate the true sustainable yield because they fail to recognize the need to retain groundwater to be used as a buffer in times of drought. In the case of sedimentary aquifers (Karoo sandstone and the Kalahari) and deeply weathered areas, this storage may be vast, amounting to decades of demand. The assumption also does not recognize the need to maintain discharge to baseflows in rivers and groundwater dependent ecosystems (GDEs) which comes off the top of the groundwater column. A more nuanced definition of sustainable yield is needed to provide drought reserves and protect groundwater discharge to the environment.

In addition, not all groundwater can be recovered profitably. Some may be of poor quality, some may be too deep to be economically worth recovering, and some may be too far from potential places of use to be worth pumping. In an irrigation project in the Save valley, for

¹⁸ This material taken from Chapter 5 of Economic Consulting Associates, Dorsch International Consultants, and Brian Colquhoun, Hugh O'Donnell and Partners (2013a).

example, the water from 1 in 4 boreholes was found to be too saline to be used for irrigating crops. Adding treatment costs to pumping of groundwater would likely make it prohibitively expensive even for domestic uses, let alone for irrigation. Groundwater cannot be a solution to climate change by itself, but it may provide a potentially important source of water when surface water becomes scarcer and less reliable under climate change. However, the government will need to make a commitment to increased groundwater investigations if there is to be an understanding of the actual extent of the resource and its potential for economic development.

Table B1 Characteristics and development potential of groundwater in each catchment

Catchment	Groundwater recharge (Gl/pa)	Geological formations	Comments on groundwater potential
Manyame	1,907	80% crystalline and metamorphic rocks (granites and gneisses, and greenstone belts) 20% Karoo sedimentary formations (in the Zambezi valley)	Secondary fracture porosity in the crystalline rocks. Deeper regolith on water shed, but thinner downstream. Moderate to low groundwater potential. Primary porosity Karoo sediments in Zambezi valley s. Deeper groundwater potential but some water quality issues and low yield boreholes where silts and clays are found.
Mazowe	1,918	100% crystalline and metamorphic rock	Fracture porosity only. Deeper regolith on watershed areas gives moderate groundwater potential, but downstream, regolith thinner – poor groundwater
Save	2,660	80% crystalline and metamorphic rock. Save valley alluvium, Karoo sediments and basalt to south.	Fracture porosity and low groundwater potential for the crystalline rocks. Save valley alluvium – good groundwater potential; Karoo basalts moderate groundwater potential
Runde	1,449	65% crystalline and metamorphic rock. 15% Karoo and 20% cretaceous sediments; Alluvium along river channels	Crystalline rocks - fracture porosity only and have poor groundwater potential. Karoo basalt – moderate potential. Cretaceous – mostly fine grained siltstone – low yields. Alluvium along river channels - good potential

¹⁹ There is an extensive academic literature on the calculation of sustainable yield (e.g. Sophocleous 2000).

Catchment	Groundwater recharge (Gl/pa)	Geological formations	Comments on groundwater potential
Mzingwane	632	75% crystalline; 25% Karoo basalt; Alluvium along river channels	Alluvium good potential, basalt moderate and crystalline low
Gwayi	1,596	85% sedimentary formations: Kalahari and Karoo. 10% Karoo basalt and 5% metamorphic formations	Good primary porosity aquifers. Very large groundwater potential
Sanyati	2,750	70% crystalline and metamorphic rocks to the east and 30% Karoo sediments to the northwest. Lomagundi dolomites in centre.	Lomagundi dolomite very good groundwater potential. Karoo sediments good groundwater potential, crystalline rocks low potential
Total	12,912		

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