The Zambezi River Basin

A Multi-Sector Investment Opportunities Analysis

VOLUME 1

Summary Report

THE WORLD BANK

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THE WORLD BANK
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AFRICA REGION

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Currency Equivalents and Units

Currency Equivalents

Against U.S. dollar

	Angolan new kwanza Kz	Botswana pula P	Euro €	Malawi kwacha MK	Mozambique metical Mt	Namibia dollar N$	Tanzania schilling T Sh	Zambia kwacha K	Zimbabwe dollar Z$
2000	5.94	5.09	1.08	47.10	15.41	6.95	799.27	2,830.00	44.40
2001	11.51	5.72	1.12	70.03	20.33	8.62	876.59	2,845.37	55.26
2002	32.41	6.26	1.06	76.24	23.24	10.52	965.27	4,360.81	55.29
2003	57.65	4.91	0.89	95.24	23.31	7.57	1,036.79	4,841.94	577.19
2004	57.65	4.68	0.80	106.74	22.03	6.46	1,088.20	4,750.53	4,499.18
2005	74.90	5.11	0.80	116.84	22.85	6.36	1,125.36	4,432.60	21,566.90
2006	86.85	5.83	0.80	135.54	25.93	6.77	1,251.28	3,586.09	58,289.86
2007	77.38	6.15	0.73	139.72	25.56	7.06	1,241.24	3,996.41	9,296.66
2008	74.97	6.84	0.68	140.91	24.14	8.25	1,199.75	3,746.63	2,638,293,338
2009	77.97	7.14	0.72	141.75	26.87	8.43	1,324.34	5,049.15	21,830,975.04

Units

1 km^3 = 1,000 hm^3 = 1 billion m^3

1 m^3/s = 31.54 hm^3/year = 0.033 km^3/year

1 l/s/ha = 86.4 m^3/day/ha = 8.6 mm/day

1 gigawatt hour (GWh) = 1,000 MWh = 1,000,000 KWh = 1,000,000,000 Wh

1 km^2 = 100 ha

Unless otherwise specified, the symbol $ refers to U.S. dollars.

Acknowledgments

This report provides a summary of the series of reports and documents prepared to assess the water resources development options and benefits of cooperation among the riparian countries in the Zambezi River Basin. The effort was led by a Bank Team consisting of Vahid Alavian (Team Leader), Marcus Wishart, Louise Croneborg, Rimma Dankova, K. Anna Kim, and Lucson Pierre-Charles. The initial Team Leader for this work was Len Abrams, now retired. The Multi-Sector Investment Opportunities Analysis is based on a series of reports and model simulations prepared by a consortium of BRLi and Niras. The consultants served as partners and members of the team during the course of this work.

The Team gratefully acknowledges the contributions by representatives of the riparian countries of the Zambezi River Basin, the Southern Africa Development Community (SADC) Water Division, and other international development partners. Their participation and input at the regional meeting in Gaborone, Botswana in July 2009, and at the eight national consultation workshops held between September and December 2009 is much appreciated. The financial contribution and support from the Swedish International Development Cooperation Agency (Sida) and the Government of Norway are acknowledged with appreciation.

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Abbreviations and Acronyms

AAP	Africa Action Plan
ACP	Agricultural Commercialization Program (Zambia)
AF	artificial flooding
AMD	acid mine drainage
AMU	Arab Maghreb Union
ARA	Administração Regional de Águas (Regional Water Administrations, Mozambique)
ASDP	Agricultural Sector Development Program (Tanzania)
ASDS	Agricultural Sector Development Strategy (Tanzania)
AU	African Union
BIPP	bankable investment project profile
BOD	biological oxygen demand
BOS	Bureau of Standards
BPC	Botswana Power Corporation
CAADP	Comprehensive Africa Agriculture Development Program
CBA	cost benefit analysis
CEC	Copperbelt Energy Corporation PLC
CEMAC	Central African Economic and Monetary Community
CEN-SAD	Community of Sahel-Saharan States
CEPGL	Economic Community of the Great Lakes Countries
COMESA	Common Market for Eastern and Southern Africa
CPC	Climate Prediction Center
CPFAT	Centro Provincial de Formação Agrária de Tete (Mozambique)
CRU	Climate Research Unit
CS	current situation
CSCO	current situation with coordinated operation
CSNC	current situation without coordinated operation
CVRD	Companhia Vale do Rio Doce (Brazil)
DMC	Drought Monitoring Center
DMU	Disaster Management Unit
DNA	Direcção Nacional de Águas (National Directorate of Water, Mozambique)
DNSA	Direcção Nacional de Extensão Agrária (National Directorate of Agrarian Services, Mozambique)
DPA	Provincial Directorate of Water
DRC	Democratic Republic of Congo
DSS	decision support system
DWA	Department of Water Affairs
DWAF	Department of Water Affairs and Forestry
EAC	East African Community
ECCAS	Economic Community of Central African States
ECMWF	European Center for Medium Range Weather Forecast
ECOWAS	Economic Community of West African States
ECP	Estratégia de Combate à Pobreza (Poverty Reduction Strategy, Angola)
ECZ	Environmental Council of Zambia
EdM	Electricidade de Moçambique (Electricity of Mozambique, Mozambique)
EIA	Environmental Impact Assessment

EIRR	economic internal rate of return
ENE	Empresa Nacional de Electricidad (National Electricity Company, Angola)
ESCOM	Electricity Supply Corporation of Malawi
ESIA	Environmental and Social Impact Assessment
ETo	reference evapotranspiration
ETP	evapotranspiration
EU	European Union
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
EUS	epizootic ulcerative syndrome
FAO	Food and Agriculture Organization
FSL	full supply level
GDP	gross domestic product
GMA	Game Management Area
GPZ	Gabinete do Plano de Desenvolvimento da Região do Zambeze (Office of Development Planning for the Zambezi Region, Mozambique)
GWh	gigawatt hour
ha	hectare
HCB	HidroEléctrica de Cahora Bassa (Cahora Bassa Hydroelectrics, Mozambique)
HEC	Hydrologic Engineering Center
HIPC	Heavily Indebted Poor Countries Initiative
HLI	high-level irrigation
HLIC	HLI with cooperation
hm^3	Cubic hectometer
HPP	hydropower plant
HRWL	high reservoir water level
HYCOS	hydrological cycle observation system
I&C	information and communication
IBRD	International Bank for Reconstruction and Development
ICM	Integrated Committee of Ministers
ICTs	information and communication technologies
IDF	irrigation development fund
IGAD	Inter-Governmental Authority on Development
IMF	International Monetary Fund
INAM	Instituto Nacional de Meteorologia (National Institute of Meteorology, Mozambique)
IOC	Indian Ocean Commission
IP	identified project (for irrigation)
IPC	IP with cooperation
IPCC	Intergovernmental Panel on Climate Change
IRR	internal rate of return
ITT	Itezhi Tezhi Dam
IUCN	International Union for Conservation of Nature
IWRM	integrated water resources management
JICA	Japan International Cooperation Agency
JOTC	Joint Operation Technical Committee
KAZA TFCA	Kavango-Zambezi Transfrontier Conservation Area
kg/ha	kilogram per hectare
KGL	Kafue Gorge Lower Dam
KGU	Kafue Gorge Upper Dam
km^3	cubic kilometers
KWh	kilowatt hour
l/s	liters per second
LEC	Lesotho Electricity Corporation
LRRP	Land Reform and Resettlement Program (Zimbabwe)
LRWL	low reservoir water level
LSL	low supply level
m^3/s	cubic meters per second
MACO	Ministry of Agriculture and Cooperatives (Zambia)
MAP	mean annual precipitation
MAWF	Ministry of Agriculture, Water and Forestry

MASL	minimum active storage level
MDG	Millennium Development Goal
MDRI	Multilateral Debt Relief Initiative
MEA	Ministry of Energy and Water
MERP	Millennium Economic Recovery Program (Zimbabwe)
MFL	minimum flow level
mg/l	milligrams per liter
MKUKUTA	Poverty Reduction Strategy for Mainland Tanzania (kiswahili acronym)
mm/yr	millimeters per year
MMEWR	Ministry of Minerals, Energy and Water Resources
MOL	minimum operating level
MOPH	Ministry of Public Works and Housing
MoU	memorandum of understanding
MPRSP	Malawi Poverty Reduction Strategy Paper
MRU	Mano River Union
MSIOA	Multi-Sector Investment Opportunities Analysis
MW	megawatt
MWh	megawatt hour
NAMPAADD	National Master Plan for Arable Agriculture and Dairy Development (Botswana)
NAP	national agriculture policy
NDMO	National Disaster Management Office
NDP(s)	national development plan(s)
NDP2	National Development Plan 2
NEPAD	New Partnership for Africa's Development
NERP	National Economic Revival Program (Zimbabwe)
NIP	national irrigation plan
NMHS	National Meteorological and Hydrological Services
NMTIPs	national medium-term investment programs
NOAA	National Oceanic and Atmospheric Administration
NPV	net present value
NSC	north–south carrier
NSC	National Steering Committee
NSGRP	National Strategy for Growth and Reduction of Poverty (Tanzania)
NWSDS	National Water Sector Development Strategy (Tanzania)
ODA	official development assistance
OWE	open water evaporation
PAEI	Política Agrária e Estratégias de Implementação (Agriculture Policy and Implementation Strategy, Mozambique)
PAR	population at risk
PARPA	Plano de Acção para a Redução da Pobreza Absoluta (Poverty Reduction Support Strategy, Mozambique)
PARPA II	Plano de Acção para a Redução da Pobreza Absoluta II (2nd Poverty Reduction Support Strategy, Mozambique)
PASS II	Poverty Assessment Study Survey II
PFM	public financial management
PPEI	Política Pesqueira e Estratégias de Implementação (Fishery Policy and Implementation Strategy, Mozambique)
ppm	parts per million
PPP	purchasing power parity
ProAgri	Promoção de Desenvolvimento Agrário (National Agricultural Development Program, Mozambique)
PRSP	poverty reduction strategy paper
PSIP	program and system information protocol
RBO	river basin organization
RBZ	Reserve Bank of Zimbabwe
RCC	roller-compacted concrete
REC	regional economic communities
RIAS	Regional Integration Assistance Strategy
R-o-R	run-of-the-river
RSA	Republic of South Africa
RSAP	Regional Strategic Action Plan
SACU	Southern African Customs Union
SADC	Southern African Development Community
SADC-WD	SADC Water Division

SAPP	Southern African Power Pool
SARCOF	Southern African Climate Outlook Forum
SEA	strategic environmental assessment
SEB	Swaziland Electricity Board
SEDAC	Socioeconomic Data and Applications Center
SIDA	Swedish International Development Cooperation Agency
SIGFE	Sistema Integrado de Gestão Financeira do Estado (Integrated Financial Management System, Angola)
SMEC	Snowy Mountains Engineering Corporation
SNEL	Société Nationale d'Électricité (National Electricity Company, Democratic Republic of Congo)
SSIDS	small-scale irrigation development study
SWOT	strengths, weaknesses, opportunities, and threats
t/yr	tons/year
TANESCO	Tanzania Electric Supply Company
TVA	Tennessee Valley Authority (United States)
TWL	tail water level
UK	United Kingdom
UN/ISDR	United Nations Inter Agency International Strategy for Disaster Reduction
UNDP	United Nations Development Program
UNECA	United Nations Economic Commission for Africa
UNESCO	United Nations Educational, Scientific and Cultural Organization
US$	United States dollar
USAID	United States Agency for International Development
USGS	U.S. Geological Survey
VSAM	Visão do Sector Agrário em Moçambique (Mozambique)
WAEMU	West African Economic and Monetary Union
WAP	Water Apportionment Board
WASP	Web Analytics Solution Profiler
WFP	World Food Program
WHO	World Health Organization
WMO	World Meteorological Organization
WRC	Water Resources Commission
WTO	World Trade Organization
WTTC	World Travel and Tourism Council
ZACBASE	Zambezi River database
ZACPLAN	Action Plan for the Environmentally Sound Management of the Common Zambezi River System
ZACPRO	Zambezi Action Project
ZAMCOM	Zambezi River Watercourse Commission
ZAMFUND	Zambezi Trust Fund
ZAMSEC	ZAMCOM Secretariat
ZAMSTRAT	Integrated Water Resources Management Strategy and Implementation Plan for the Zambezi River Basin
ZAMTEC	ZAMCOM Technical Committee
ZAMWIS	Zambezi Water Information System
ZAPF	Zimbabwe's Agriculture Policy Framework
ZCCM	Zambia Consolidated Copper Mines Ltd
ZESA	Zimbabwe Electricity Supply Authority
ZESCO	Zambia Electricity Supply Corporation
ZINWA	Zimbabwe National Water Authority
ZRA	Zambezi River Authority
ZRB	Zambezi River Basin
ZVAC	Zambia Vulnerability Assessment Committee

1 The Zambezi River Basin: Background and Context

The Zambezi River Basin (ZRB) is one of the most diverse and valuable natural resources in Africa. Its waters are critical to sustainable economic growth and poverty reduction in the region. In addition to meeting the basic needs of some 30 million people and sustaining a rich and diverse natural environment, the river plays a central role in the economies of the eight riparian countries—Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe. It provides important environmental goods and services to the region and is essential to regional food security and hydropower production. Because the Zambezi River Basin is characterized by extreme climatic variability, the River and its tributaries are subject to a cycle of floods and droughts that have devastating effects on the people and economies of the region, especially the poorest members of the population.

1.1 MOTIVATION FOR THIS ANALYSIS

Despite the regional importance of the ZRB, few improvements have been made in the management of its water resources over the past 30 years. Differences in post-independence development strategies and in the political economy of the riparian countries, as well as the diverse physical characteristics of the Basin, have led to approaches to water resources development that have remained primarily unilateral.

Better management and cooperative development of the Basin's water resources could significantly increase agricultural yields, hydropower outputs, and economic opportunities. Collaboration has the potential to increase the efficiency of water use, strengthen environmental sustainability, improve regulation of the demands made on natural resources, and enable greater mitigation of the impact of droughts and floods. Seen in this light, cooperative river basin development and management not only provide a mechanism for increasing the productivity and sustainability of the river system, but also provide a potential platform for accelerated regional economic growth, cooperation, and stability within the wider Southern Africa Development Community (SADC).

The World Bank, other international financial institutions and development partners have a diverse portfolio of investments and support programs in the countries that share the ZRB. Still lacking, however, is a sound analytical foundation for a coordinated strategy that can optimize the Basin's investment potential and promote cooperative development in support of sustainable economic growth and poverty alleviation.

The overall objective of the Zambezi River Multi-Sector Investment Opportunity Analysis (MSIOA) is to illustrate the benefits of cooperation among the riparian countries in the ZRB through a multi-sectoral economic evaluation of water resources development, management options and scenarios—from both national and basin-wide perspectives. The analytical framework was designed in consultation with the riparian countries, SADC Water Division (SADC-WD) and development partners in line with the Zambezi Action Plan Project 6, Phase II (ZACPRO 6.2). It is hoped that the findings, together with the Integrated Water Resources Management Strategy and Implementation Plan for the Zambezi River Basin that was developed under ZACPRO 6.2 (2008), would contribute to development, environmental sustainability, and poverty alleviation in the region.

In this analysis, the following development paths have been assessed through a series of scenarios.

- *Coordinated operation of existing hydropower facilities, either basin-wide or in clusters.* By how much could hydropower generation increase if existing projects were coordinated? What is the potential impact of coordination on other water users?
- *Development of the hydropower sector as envisioned in plans for the Southern African Power Pool (SAPP).* What is the development potential of the hydropower sector? How would its expansion affect the environment (wetlands in particular), irrigation, tourism, and other sectors? What gains could be expected from the coordinated operation of new hydropower facilities?
- *Development of the irrigation sector through unilateral or cooperative implementation of projects identified by the riparian countries.* How might the development of irrigation affect the environment (wetlands), hydropower, tourism, and other sectors? What incremental gain could be expected from cooperative as opposed to unilateral development of irrigation schemes?
- *Flood management, particularly in the Lower Zambezi and the Zambezi Delta.* What options exist to permit partial restoration of natural floods and to reduce flood risks downstream from Cahora Bassa Dam? How would those options affect the use of the existing and potential hydropower and irrigation infrastructure on the Zambezi River?
- *Effects of other projects using the waters of the Zambezi River* (e.g., transfers out of the Basin for industrial uses). How might these projects affect the environment (wetlands), hydropower, irrigation, and tourism?

Within the context of an integrated approach to the development and management of water resources, all water-related sectors are important. This analysis, however, focuses on hydropower and irrigation because of their special potential to stimulate growth in the economies of the region. Other demands for water—for potable water, environmental sustainability, tourism, fisheries, and navigation, for example—are assumed as givens. Limitations of assigning economic value to non-economic water users, such as ecosystems, are noted. To the degree allowed by the available, published information, they are incorporated into the analysis as non-negotiable.

The initial findings and the various drafts of this analysis were discussed at a regional workshop and at individual country consultations with all riparian countries. Also involved in these consultations were SADC, the international development partners active in the Basin, and other interested parties. The final draft version was shared with the riparian countries as well for comments before finalization. The Swedish International Development Cooperation Agency and the Government of Norway provided financial support.

This report consists of four volumes:

Volume 1: Summary Report
Volume 2: Basin Development Scenarios
Volume 3: State of the Basin
Volume 4: Modeling, Analysis, and Input Data

This section (1.1–1.5) appears as an introduction to all four volumes.

1.2 SUMMARY OF FINDINGS

The ZRB and its rich resources present ample opportunities for sustainable, cooperative investment in hydropower and irrigated agriculture. With cooperation and coordinated operation of the existing hydropower facilities found in the Basin, firm energy generation can potentially increase by seven percent, adding a value of $585 million over a 30-year period with essentially no major infrastructure investment.

Development of the hydropower sector according to the generation plan of the SAPP (NEXANT 2007) would require an investment of $10.7 billion over an estimated 15 years. That degree of development would result in estimated firm energy production of approximately 35,300 GWh/year and average energy production of approximately 60,000 GWh/year, thereby meeting all or most of the estimated 48,000 GWh/year demand of the riparian countries. With the SAPP plan in place, coordinated operation of the system of hydropower facilities can provide an additional 23 percent generation over uncoordinated (unilateral) operation. The value of cooperative generation therefore appears to be significant.

Implementation of all presently identified national irrigation projects would expand the equipped area by some 184 percent (including double cropping in some areas) for a total required investment of around $2.5 billion. However, this degree of development of the irrigation sector, without further development of hydropower, would reduce hydropower generation of firm energy by 21 percent and of average energy by nine percent. If identified irrigation projects were developed alongside current SAPP plans, the resulting reduction in generation would be about eight percent for firm energy and four percent for average energy.

Cooperative irrigation development (such as moving approximately 30,000 hectares of planned large irrigation infrastructure downstream) could increase firm energy generation by two percent, with a net present value of $140 million. But complexities associated with food security and self-sufficiency warrant closer examination of this scenario.

Other water-using projects (such as transfers out of the Basin and for other industrial uses within the Basin) would not have a significant effect on productive (economic) use of the water in the system at this time. But they might affect other sectors and topics, such as tourism and the environment, especially during periods of low flow. A more detailed study is warranted.

For the Lower Zambezi, restoration of natural flooding, for beneficial uses in the Delta, including fisheries, agriculture, environmental uses and better flood protection, could be assured by modifying reservoir operating guidelines at Cahora Bassa Dam. Depending on the natural flooding scenario selected, these changes could cause significant reduction in hydropower production (between three percent and 33 percent for the Cahora Bassa Dam and between four percent and 34 percent for the planned Mphanda Nkuwa Dam). More detailed studies are warranted.

Based on the findings for Scenario 8, which assumes full cooperation of the riparian countries, a reasonable balance between hydropower and irrigation investment could result in firm energy generation of some 30,000 GWh/year and 774,000 hectares of irrigated land. Those goals could be achieved while providing a level of flood protection and part restoration of natural floods in the Lower Zambezi.

The riparian countries together with their development partners may wish to act on the analysis presented here by pursuing several steps, described in detail at the end of volume 1:

- Explore and exploit the benefits of cooperative investments and coordinated operations;
- Strengthen the knowledge base and the regional capacity for river basin modeling and planning;
- Improve the hydrometeorological data system;
- Conduct studies on selected topics, including those mentioned above; and,
- Build institutional capacity for better management of water resources.

1.3 BASIC CHARACTERISTICS OF THE ZAMBEZI RIVER BASIN

The Zambezi River lies within the fourth-largest basin in Africa after the Congo, Nile, and Niger river basins. Covering 1.37 million km^2, the Zambezi River has its source in Zambia, 1,450 meters above sea level. The main stem then flows southwest into Angola, turns south, enters Zambia again, and passes through the Eastern Caprivi Strip in Namibia and northern Botswana. The Zambezi River then flows through Mosi-oa-Tunya (Victoria Falls), shared by Zambia and Zimbabwe, before entering Lake Kariba, which masses behind Kariba Dam, built in 1958. A short distance downstream from Kariba Dam, the Zambezi River is joined by the Kafue River, a major tributary, which rises in northern Zambia. The Kafue River flows through the Copperbelt of Zambia into the reservoir behind the Itezhi Tezhi Dam (ITT), built in 1976. From there, the Kafue River enters the Kafue Flats and then flows through a series of steep gorges, the site of the Kafue Gorge Upper (KGU) hydroelectric scheme, commissioned in 1979. Below the Kafue River confluence, the Zambezi River pools behind Cahora Bassa Dam in Mozambique, built in 1974. Some distance downstream, the Zambezi River is joined by the Shire River, which flows out of Lake Malawi/Niassa/Nyasa to the north. Lake Malawi/Niassa/Nyasa, which covers an area of 28,000 km^2, is the third-largest freshwater lake in Africa. From the confluence, the Zambezi River travels some 150 km, part of which is the Zambezi Delta, before entering the Indian Ocean.

The basin of the Zambezi River is generally described in terms of 13 subbasins representing major tributaries and segments (see map in figure 1.1).

From a continental perspective, the ZRB contains four important areas of biodiversity:

- *Lake Malawi/Niassa/Nyasa*, a region of importance to global conservation because of the evolutionary radiation of fish groups and other aquatic species.
- *The swamps, floodplains, and woodlands* of the paleo-Upper Zambezi in Zambia and northern Botswana, including the areas of Barotseland, Busanga and Kafue, which along with the Bangweulu are thought to be areas of evolutionary radiation for groups as disparate as Reduncine antelope, suffrutices, and bulbous plants.
- *The Middle Zambezi Valley in northern Zimbabwe and the Luangwa Valley in eastern Zambia*, two of the last remaining protected areas extensive enough to support large populations of large mammals.
- *The Gorongosa/Cheringoma/Zambezi Delta* area of central Mozambique, which covers an area of enormous habitat diversity not found in such close proximity elsewhere on the continent.

The hydrology of the ZRB is not uniform, with generally high rainfall in the north and lower rainfall in the south (table 1.1). In some areas in the Upper Zambezi and around Lake Malawi/Niassa/Nyasa, rainfall can be as much as 1,400 mm/year, while in the southern part of Zimbabwe it can be as little as 500 mm/year.

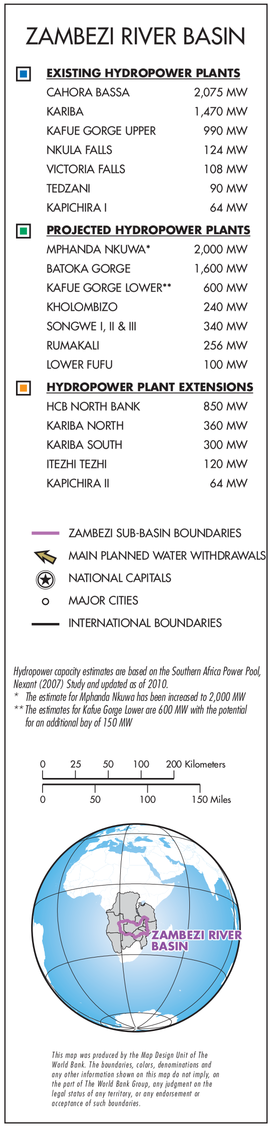
The mean annual discharge at the outlet of the Zambezi River is 4,134 m^3/s or around 130 km^3/year (figure 1.2). Due to the rainfall distribution, northern tributaries contribute much more water than southern ones. For example, the northern highlands catchment of the Upper Zambezi subbasin contributes 25 percent, Kafue River nine percent, Luangwa River 13 percent, and Shire River 12 percent—for a total of 60 percent of the Zambezi River discharge.

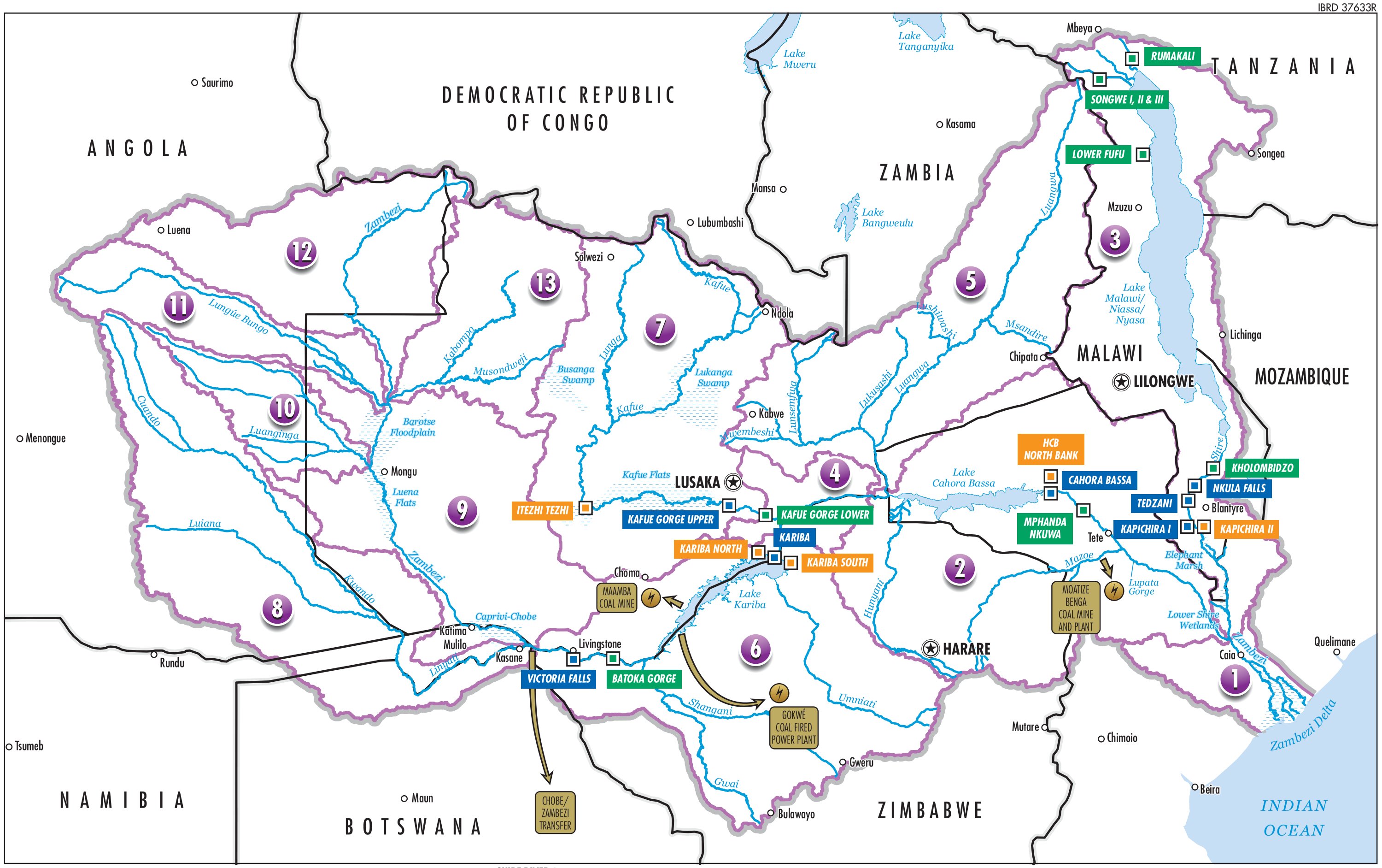
Table 1.1. Precipitation data for the Zambezi River Basin

Subbasin	No.	Mean annual precipitation (mm)
Kabompo	13	1,211
Upper Zambezi	12	1,225
Lungúe Bungo	11	1,103
Luanginga	10	958
Barotse	9	810
Cuando/Chobe	8	797
Kafue	7	1,042
Kariba	6	701
Luangwa	5	1,021
Mupata	4	813
Shire River and Lake Malawi/Niassa/Nyasa	3	1,125
Tete	2	887
Zambezi Delta	1	1,060
Zambezi River Basin, mean		956

Source: Euroconsult Mott MacDonald 2007.

Figure 1.1. The Zambezi River Basin and its 13 subbasins





1 ZAMBEZI DELTA

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	7,664	6,998
IDENTIFIED PROJECTS (IP)	106,774	84,053
UPPER LIMIT POTENTIAL (HLI)	231,774	184,053

2 TETE

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	52,572	35,159
IDENTIFIED PROJECTS (IP)	108,193	65,495
UPPER LIMIT POTENTIAL (HLI)	508,193	265,495

3 SHIRE RIVER & LAKE MALAWI/NIASSA/NYASA

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	60,960	42,416
IDENTIFIED PROJECTS (IP)	162,126	101,927
UPPER LIMIT POTENTIAL (HLI)	766,755	451,927

4 MUPATA

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	21,790	14,200
IDENTIFIED PROJECTS (IP)	30,356	20,060
UPPER LIMIT POTENTIAL (HLI)	30,356	20,060

5 LUANGWA

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	17,794	10,100
IDENTIFIED PROJECTS (IP)	28,857	16,230
UPPER LIMIT POTENTIAL (HLI)	73,814	41,230

6 KARIBA

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	44,531	28,186
IDENTIFIED PROJECTS (IP)	228,919	147,778
UPPER LIMIT POTENTIAL (HLI)	948,825	591,578

7 KAFUE

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	46,528	40,158
IDENTIFIED PROJECTS (IP)	67,048	53,768
UPPER LIMIT POTENTIAL (HLI)	104,448	78,768

8 CUANDO/CHOBE

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	765	620
IDENTIFIED PROJECTS (IP)	1,215	920
UPPER LIMIT POTENTIAL (HLI)	19,215	15,920

9 BAROTSE

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	340	200
IDENTIFIED PROJECTS (IP)	12,753	7,208
UPPER LIMIT POTENTIAL (HLI)	30,466	17,208

10 LUANGINGA

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	1,000	750
IDENTIFIED PROJECTS (IP)	6,000	5,750
UPPER LIMIT POTENTIAL (HLI)	18,500	15,750

11 LUNGÚE BUNGO

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	1,250	1,000
IDENTIFIED PROJECTS (IP)	1,875	1,500
UPPER LIMIT POTENTIAL (HLI)	14,375	11,500

12 UPPER ZAMBEZI

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	3,250	2,500
IDENTIFIED PROJECTS (IP)	8,250	7,500
UPPER LIMIT POTENTIAL (HLI)	20,750	17,500

13 KABOMPO

	IRRIGATED AREA (ha/year)	EQUIPPED AREA (ha)
CURRENT SITUATION (CS)	595	350
IDENTIFIED PROJECTS (IP)	11,314	6,650
UPPER LIMIT POTENTIAL (HLI)	28,328	16,650

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Figure 1.2. Schematic of the Zambezi River with deregulated mean annual discharge (m^3/s) and runoff (mm)

Sub basin	BV	River bank	Tributary	Discharge (m^3/s)	Runoff (mm)	Catchment area (km^2)	Zambezi River mean annual river flow (m^3/s)
Kabompo							
13	13-1	left/right	Kabompo	273.0	109.4	78,683	273
		Subtotal		273.0	109.4	78,683	
Upper Zambezi							
12	12-1	left/right	Zambezi	742	256.2	91,317	1,015
		Subtotal		742	256.2	91,317	
Lungúe Bungo							
11	11-1	left/right	Lungúe Bungo	114	80.8	44,368	1,129
		Subtotal		114	80.8	44,368	
Luanginga							
10	10-1	left/right	Luanginga	69.4	61.0	35,893	1,198
		Subtotal		69.4	61.0	35,893	
Kwando/Chobe							
8	8-1	left	Kwando	32.5	9.0	113,393	
	8-2	left/right	Chobe	−32.5	−28.8	35,601	1,198
		Subtotal		0.0	0.0	148,994	
Barotse							
9	9-1	left/right	Zambezi	−17.6	−4.8	115,753	1,180
		Subtotal		−17.6	−4.8	115,753	
Kariba							
6	6-1	right	Gwayi	84	30.1	87,960	1,386
	6-2	right	Sanyati	104	44.0	74,534	
	6-3	left/right	Lake Kariba	18	55.6	10,033	
		Subtotal		206	37.6	172,527	
Kafue							
7	7-1	left/right	Itezhi Tezhi	336	98.1	108,134	
	7-2	left/right	Kafue Flats	35.0	23.4	47,194	1,758
	7-3	left/right	Kafue D/S	0.7	47.6	477	
		Subtotal		372	75.3	155,805	
Mupata							
4	4-1	left/right	Chongwe	4.1	71.6	1,813	
	4-2	left/right	Zambezi	49.9	72.6	21,670	1,812
		Subtotal		54.0	72.5	23,483	
Luangwa							
5	5-1	left/right	Luangwa	518	102.3	159,615	2,330
		Subtotal		518	102.3	159,615	
Tete							
2	2-1	right	Manyame	26.5	20.6	40,497	
	2-2	right	Luenya	180	99.4	57,004	
	2-3	left/right	Zambezi	987	301.1	103,393	3,523
		Subtotal		1,193	187.3	200,894	
Shire River and Lake Malawi/Niassa/Nyasa							
3	3-1	right	Rumakali	12.5	954.4	414	
	3-2	left	Songwe	35.2	273.4	4,060	
	3-3	left	S. Rukuru+ N. Rumphi	47.0	118.7	12,483	
	3-4	left/right	Tributaries	528	207.5	80,259	4,021
	3-5	left/right	Lake Malawi/ Niassa/Nyasa evaporation	−287	−314.4	28,760	
	3-6	left/right	Lake Malawi/ Niassa/Nyasa outlet	336	84.1	125,976	
	3-7	left/right	Shire	162	220.4	23,183	
		Subtotal		498	105.3	149,159	
Zambezi Delta							
1	1-1	left/right	Zambezi	113	191.3	18,680	4,134
		Subtotal		113	191.3	18,680	

INDIAN OCEAN

Note: Excludes the operational influence at the Kariba, Cahora Bassa, and Itezhi Tezhi dams.

1.4 POPULATION AND ECONOMY

The population of the ZRB is approximately 30 million (table 1.2), more than 85 percent of whom live in Malawi, Zimbabwe, and Zambia within four subbasins: Kafue, Kariba, Tete, and the Shire River and Lake Malawi/Niassa/Nyasa.

Of the total population, approximately 7.6 million (25 percent) live in 21 main urban centers (with 50,000 or more inhabitants). The rest live in rural areas. The proportion of rural population varies from country to country, from over 50 percent in Zambia to around 85 percent in Malawi.

The ZRB is rich in natural resources. The main economic activities are fisheries, mining, agriculture, tourism, and manufacturing. Industries depend on the electricity produced in the hydropower plants (HPPs) of the Basin, as well as on other sources of energy (primarily coal and oil).

The eight riparian countries of the Basin represent a wide range of economic conditions. Annual gross domestic product per capita ranges from $122 in Zimbabwe to more than $7,000 in Botswana. Angola, Botswana, and Namibia have healthy current account surpluses, chiefly due to their oil and diamond resources (table 1.3).

1.5 APPROACH AND METHODOLOGY

Water resources development is not an end in itself. Rather, it is a means to an end: the sustainable use of water for productive purposes to enhance growth and reduce poverty. The analysis reported here was undertaken from an economic perspective so as to better integrate the implications of the development of investment in water management infrastructure into the broad economic development and growth

Table 1.2. Population of the Zambezi River Basin
(in thousands, 2005–06 data)

Subbasin	Angola	Botswana	Malawi	Mozambique	Namibia	Tanzania	Zambia	Zimbabwe	Total	%
Kabompo (13)	4	—	—	—	—	—	279	—	283	0.9
Upper Zambezi (12)	200	—	—	—	—	—	71	—	271	0.9
Lungúe Bungo (11)	99	—	—	—	—	—	43	—	142	0.5
Luanginga (10)	66	—	—	—	—	—	56	—	122	0.4
Barotse (9)	7	—	—	—	66	—	679	—	752	2.5
Cuando/Chobe (8)	156	16	—	—	46	—	70	—	288	1
Kafue (7)	—	—	—	—	—	—	3,852	—	3,852	12.9
Kariba (6)	—	—	—	—	—	—	406	4,481	4,887	16.3
Luangwa (5)	—	—	40	12	—	—	1,765	—	1,817	6.1
Mupata (4)	—	—	—	—	—	—	113	111	224	0.7
Shire River - Lake Malawi/Niassa/ Nyasa (3)	—	—	10,059	614	—	1,240	13	—	11,926	39.8
Tete (2)	—	—	182	1,641	—	—	221	3,011	5,055	16.9
Zambezi Delta (1)	—	—	—	349	—	—	—	—	349	1.2
Total	**532**	**17**	**10,281**	**2,616**	**112**	**1,240**	**7,568**	**7,603**	**29,969**	**—**
%	1.8	0.1	34.3	8.7	0.4	4.1	25.3	25.4	—	100

Source: Euroconsult Mott MacDonald 2007; SEDAC 2008.

Table 1.3. Macroeconomic data by country (2006)

Country	Population (million)	GDP (US$ million)	GDP/cap (US$)	Inflation rate (%)
Angola	15.8	45.2	2,847	12.2
Botswana	1.6	11.1	7,019	7.1
Malawi	13.1	3.2	241	8.1
Mozambique	20.0	6.8	338	7.9
Namibia	2.0	6.9	3,389	6.7
Tanzania	38.2	14.2	372	7.0
Zambia	11.9	10.9	917	10.7
Zimbabwe	11.7	1.4	122	>10,000

Source: Euroconsult Mott MacDonald 2007; SEDAC 2008.

objectives of the riparian countries and the Basin as a whole. An international river system such as the ZRB is extremely complex. That complexity is reflected in, but also compounded by, the large number of initiatives being undertaken within the Basin and by the large volume of data and information that already exists. To analyze such a complex system, simplifications and assumptions are unavoidable. Those assumptions and their potential implications are acknowledged throughout the report.

1.5.1 Analytical framework

Operating within the framework of integrated water resources management, this analysis considers the following water users as stakeholders: irrigated agriculture, hydropower, municipal development, rural development, navigation, tourism and wildlife conservation, and the environment. The analytical framework considered here is illustrated graphically in figure 1.3. The present context of the natural and developed resource base, as well as cross-cutting factors, of the ZRB (rows in the matrix) is assessed against the water-using stakeholders (columns in the matrix) for a set of development scenarios. Those development scenarios are focused on two key water-using stakeholders that require major investments in the region: hydropower and irrigated agriculture.

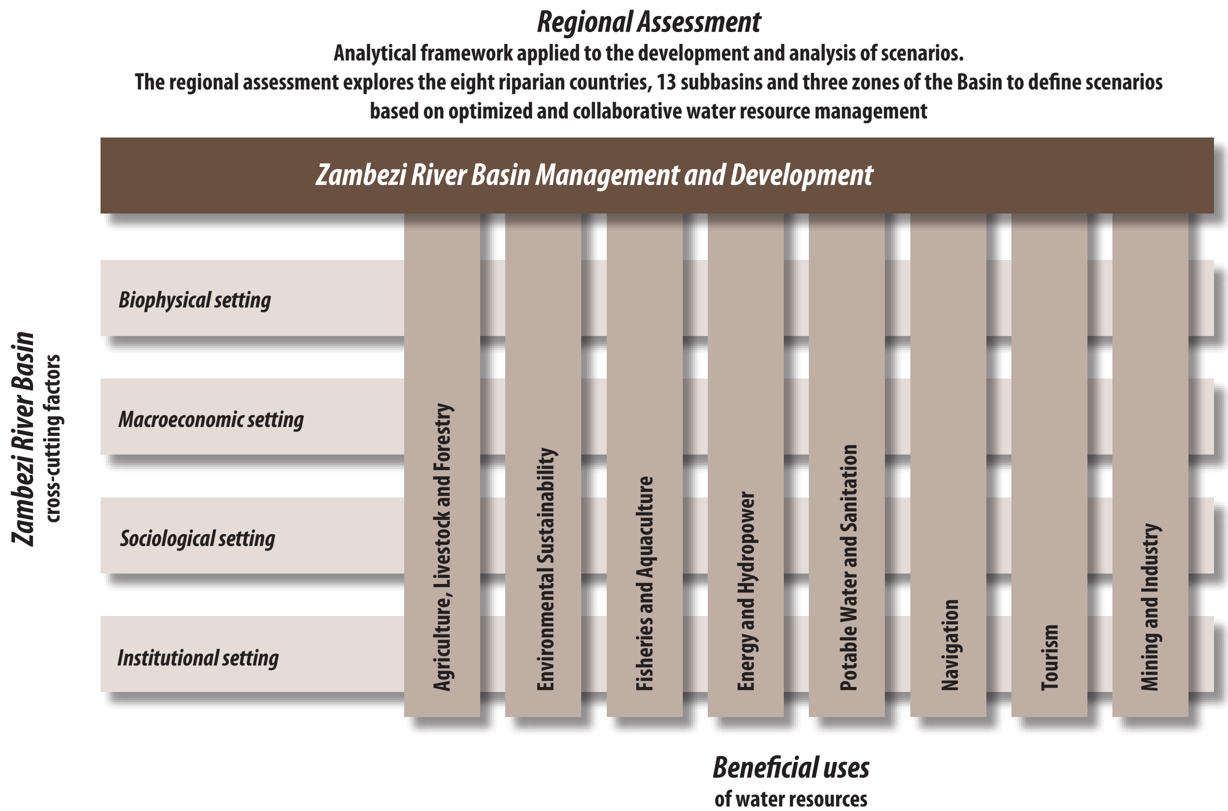
While the need to consider the details of the interaction among all stakeholders is acknowledged, the focus of this analysis is on major water-related investments being considered by the riparian countries in their national development plans. Development scenarios for other stakeholders can be superimposed on this analysis at a later time. For the time being, however, water supply and sanitation, as well as environmental imperatives, are considered as givens in nearly all scenarios considered. In other words, hydropower and irrigation development are superimposed over the continued provision of water for basic human needs and environmental sustainability. This approach differs from the conventional one of assuming basic water needs and environmental sustainability as constraints on the optimized use of water.

It should be noted that the scenarios for full basin-wide hydropower potential and full irrigation development are primarily of analytical interest, rather than for practical application. They are used here to help bracket the range and scope of the analysis and to provide reference points. The scenarios are based on identified projects in national and regional plans, and are dependent on enabling political and economic preconditions for their full implementation. The full potential for hydropower and irrigation in the Basin is not expected to be achieved in the time horizon of this analysis, which is based on the current national economic plans of the riparian countries.

The scenario analysis is carried out for the primary objective of determining and maximizing economic benefits while meeting water supply and environmental sustainability requirements. Full cooperation among the riparian countries is assumed. The scenarios are tested using a coupled hydro-economic modeling system described in volume 4. The purpose of the modeling effort is to provide insight into the range of gains that may be expected from various infrastructure investments along the axes of full hydropower and irrigation development (while continuing to satisfy requirements for water supply and environmental sustainability).

Additionally, the analysis examines the effects of conjunctive or coordinated operation of existing facilities, as well as potential gains from the strategic development of new facilities. The analysis also addresses the potential impact of the development scenarios on the environment (wetlands), tourism,

Figure 1.3. Zambezi River Basin: scenario analysis matrix



flood control, guaranteed minimum river flows in the dry season, and other topics.

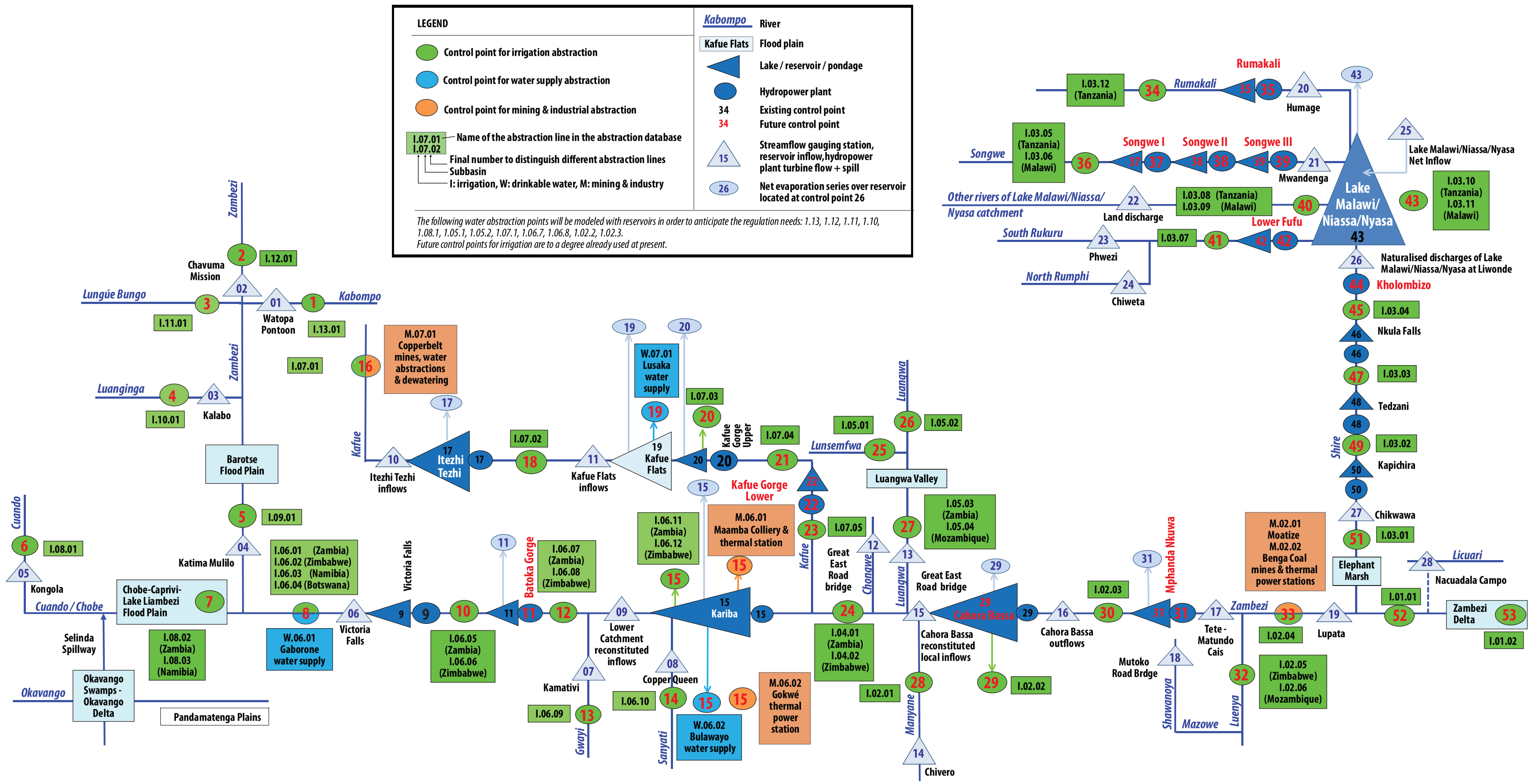
Specific attention is also given to the operational and investment options for reducing flood risks downstream of Cahora Bassa Dam and to the possibility of partial restoration of natural floods to manage the impact on the Zambezi Delta of existing dams on the Zambezi River. In this analysis, the impact of climate change on the hydrology of the ZRB and on the investment options assessed are addressed through a rudimentary incremental variation of key driving factors. Climate change is deemed a risk factor to developments and more detailed analysis is warranted for an in-depth understanding of impact. The ongoing efforts by the riparian countries and the development partners on assessing the impact of climate change on the Zambezi River Basin will provide guidance in due course.

Looming large in the analysis are the economics of different options, conceived in terms of the effect of potential investments on national and regional growth and on poverty reduction. With that in mind, the analysis considers the entire Basin as a single natural resource base while examining potential sectoral investments. This approach is appropriate for initial indicative purposes and provides a common point of reference for all riparian countries. The complexities inherent in national economics and transboundary political relationships are not directly addressed in this analysis. This is left to the riparian countries to address, informed by the results of this and other analyses.

1.5.2 The River/Reservoir System Model

The modeling package adopted for the analysis is HEC-3, a river and reservoir system model developed by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers. The version of the model used in this study, illustrated in figure 1.4, was modified by the consultants to improve some of its features. The same software package was

Figure 1.4. Schematic of the river/reservoir system model for the Zambezi River Basin



adopted during the SADC 3.0.4 project that investigated joint operation of the Kariba, Kafue Gorge Upper, and Cahora Bassa dams. The model is still being used by the Zambezi River Authority (ZRA). The fact that water professionals in the ZRB were familiar with the earlier version of the model partly accounts for its selection. A detailed description of the model appears in volume 4 of this report.

In the present analysis, the modeling time step adopted is one month. All inputs, inflows, evaporation, diversions or withdrawals, downstream flow demands, and reservoir rule curves are on a monthly basis. The outputs of the model—reservoir storage and outflows, turbine flow, spill, and power generation—are also on a monthly basis. The simulation period spans 40 years—from October 1962 to September 2002—long enough to obtain a realistic estimate of energy production. The main inflow series, from the Zambezi River at Victoria Falls, shows that the flow sequence from 1962 to 1981 is above normal, while the sequence from 1982 to 2002 is below normal. The flow data available to the study team were insufficient to consider extending the simulation period beyond 2002. Information on groundwater (e.g., status of aquifers and abstraction levels) was too insufficient to allow for sufficient conjunctive analysis.

While the focus of this analysis is on hydropower and irrigation, the river/reservoir system model takes into account all sectors concerned with water management, notably tourism, fisheries, environment such as environmental flows (e-flows) and specific important wetlands, flood control, and industry. Details of the guidelines and rule curves used in the model for reservoir operations, flood management, delta and wetlands management, environmental flows, tourism flows, and fisheries flows are given in volume 4 of this series.

Maintaining e-flows throughout the system was a major consideration in this analysis. Reaches of the Zambezi River upstream of the Kariba and Cahora Bassa dams are generally considered in near-pristine condition. The tributaries rising in Zimbabwe are highly developed, with river-regulation infrastructure for irrigation. The Kafue River is also regulated and sustains a large number of water-using sectors. The Zambezi River downstream from the Kariba and Cahora Bassa dams, like the Zambezi Delta, has been permanently altered by river-regulation infrastructure.

To take into account e-flows in the various reaches of the Zambezi River, some assumptions had to be made related to the amount of water available at all times. The following e-flow criteria were used in the river/reservoir system model in almost all the scenarios: the flow should never fall below historical low-flow levels in dry years of the record,[1] where records are available. Moreover, the average annual flow cannot fall below 60 percent of the natural average annual flow downstream from Kariba Dam. The minimum flow in the Zambezi Delta in February was set at 7,000 m^3/s for at least four out of five dry years.

The development scenarios, the state of the basin, and the modeling, analysis, and input data are described in detail in volumes 2, 3, and 4, respectively. Together, they strengthen the analytical knowledge base available for making informed decisions about investment opportunities, financing, and benefit sharing. Moreover, the analysis can assist the Zambezi River Watercourse Commission awaiting ratification (ZAMCOM), SADC, and riparian countries by providing insight into options for joint or cooperative development as well as associated benefit sharing.

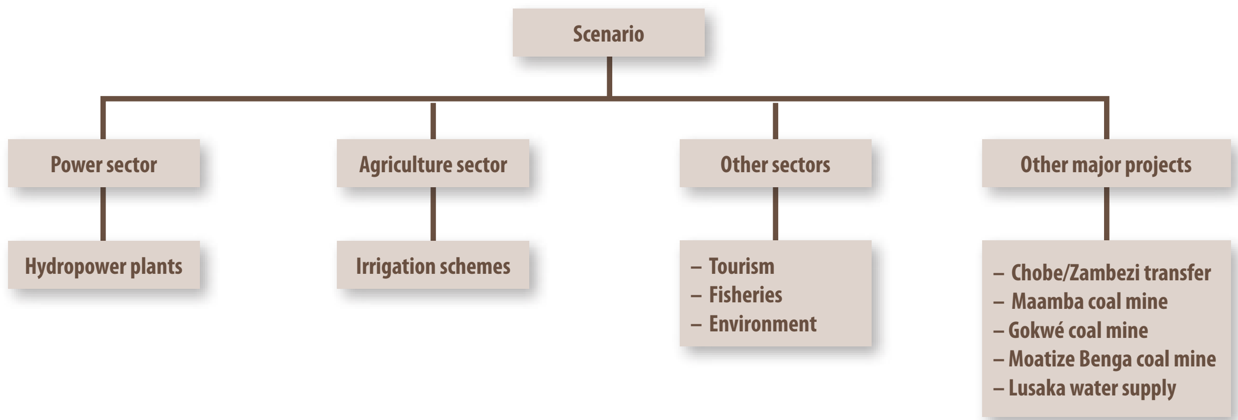
1.5.3 The Economic Assessment Tool

The economic assessment approach used here incorporates the inputs from the various projects for sector analysis to provide an overall analysis of the economic implications of development and investment scenarios. A schematic of the elements of the development scenario is given in figure 1.5. The development scenarios were compared to assess the relative viability of a given option. For hydropower and irrigation, the basic elements of the analysis are the projects identified by the riparian countries. This analysis is multi-sectoral by design; the major link among the sectors (and associated projects) is the allocation or use of water.

The economic analysis uses input from the river/reservoir system model.

1 The statistical dry year considered here is the natural flow with a five-year return period.

Figure 1.5. Schematic of the elements of the economic analysis tool



- *Hydropower.* The model uses the production figures from the hydropower installations (described in detail in the section on the hydropower in volume 3) and attributes these to the various hydropower projects.
- *Irrigation.* Based on the allocated water and development scenarios, the appropriate models for the relevant irrigation projects are used at specific abstraction points in the river/reservoir system model, and the associated costs and benefits are calculated.
- *Other sectors.* Data on flows at Victoria Falls is used to assess their impact on tourism. Financial and economic values of different flood management options and their impact on the Zambezi Delta are calculated. The value of wetlands used in the analysis tool is derived from the analysis of the environmental resources (details are provided in volume 3).
- *Other major projects.* Water-transfer schemes associated with these major projects are included in the scenario analysis.

The economic assessment is based on a number of assumptions regarding its parameters. It includes the following:

- *Scenario level* – starting date, time horizon;
- *Sector* – sector-specific parameters and prices, the specific irrigation models used in sector projects (e.g., crop budgets); and
- *Project* – project time frames, project-specific costs and benefits.

Details of the economic analysis assumptions can be found in volume 4.

The economic assessment tool provides, as output, a summary table, which includes:

- Hydropower generation and agriculture output, presented in the agricultural and irrigation calculations;
- Cash flows based on project cash flows;
- Economic internal rate of return and net present value (NPV) by development scenario, based on the appropriate time frame and project implementation schedule;
- Employment impact (jobs) calculated as the ratio of jobs to gigawatt hours of installed capacity or jobs to hectares of a particular crop; and,
- A sensitivity analysis that was carried out for variations in investment costs, prices, and production values.

2 Development in the Zambezi River Basin

The two key users of water considered in this analysis of growth-based water investments are hydropower and irrigated agriculture. Water needs for other sectors are considered as given and are used as inputs. The potential for the development of the water-using sectors, as identified by the riparian countries, is reviewed here for the purpose of identifying investment opportunities.

2.1 CURRENT AND POTENTIAL HYDROPOWER

The Zambezi River Basin has close to 5,000 MW of installed hydropower generation capacity (table 2.1). Potential plans for the construction of new plants or the expansion of existing plants were identified from various sources and are compiled in table 2.2. These are included in the analysis. The base case described in table 2.2 reflects the addition of hydropower units called for in national power generation plans, while the alternative case reflects additions called for in the least-cost power generation plan of the integrated regional SAPP.

Under the full hydropower potential development scenario, which would include some 53 projects (NEXANT 2008), the potential production of firm energy[2] would be doubled, from 22,776 to around 43,000 GWh/year. Average energy production would also double—from 30,000 to around 60,000 GWh/year. The increase is due to the extension of existing facilities and the addition of new infrastructure.[3] A factor considered in the analysis is that new hydropower facilities with storage would increase river regulation and evaporation, potentially affecting the overall water balance.

[2] Firm energy is defined as the dependable amount of energy produced by a hydropower plant at a given reliability level, which in the present study is defined as the energy available 99 percent of the time. In the case of plants with an annual or carry-over reservoir, this energy is produced when the reservoir goes from full supply level to minimum operating level during the critical dry-flow sequence.

[3] One identified program may be an agglomeration of many smaller neighboring projects. For instance: "Rehabilitation/optimization of the use of reservoirs in the Luenya subbasin in Zimbabwe" is considered as one program, whereas it may involve many different schemes.

Table 2.1. Existing hydropower projects and reservoirs in the Zambezi River Basin

Name	Utility	River	Country	Type	Capacity (MW)
Victoria Falls	ZESCO	Zambezi	Zambia	Run-of-river	108
Kariba	ZESCO, ZESA	Zambezi	Zambia, Zimbabwe	Reservoir	1,470
Itezhi Tezhi	ZESCO	Kafue	Zambia	Reservoir	n/a
Kafue Gorge Upper	ZESCO	Kafue	Zambia	Reservoir	990
Mulungushi	ZESCO	Mulungushi	Zambia	Reservoir	20
Lunsemfwa	ZESCO	Lunsemfwa	Zambia	Reservoir	18
Lusiwasi	Private	Lusiwasi	Zambia	Pondage	12
Cahora Bassa	HCB	Zambezi	Mozambique	Reservoir	2,075
Wovwe	ESCOM	Wovwe	Malawi	Pondage	4.35
Nkula Falls A&B	ESCOM	Shire	Malawi	Pondage	124
Tedzani	ESCOM	Shire	Malawi	Pondage	90
Kapichira stage I	ESCOM	Shire	Malawi	Pondage	64

Source: NEXANT 2008.

Table 2.2. Future hydropower projects included in the analysis

					Base case		Alternative case	
NEXANT project name	Utility	River	Country	Type	Capacity (MW)	Operating Year	Capacity (MW)	Operating Year
Tedzani 1 & 2, refurbishment	ESCOM	Shire	Malawi	Pondage	40	2008	40	2008
Kariba North, refurbishment	ZESCO	Zambezi	Zambia	Reservoir	120	2008–2009	120	2008
Kafue Gorge Upper, refurbishment	ZESCO	Kafue	Zambia	Pondage	150	2009	150	2009
Kapichira II	ESCOM	Shire	Malawi	Pondage	64	2010	64	2010
Kariba North, extension	ZESCO	Zambezi	Zambia	Reservoir	360	2010	360	2012
HCB North Bank	HCB	Zambezi	Mozambique	Reservoir	n/a	n/a	850	2012
Itezhi Tezhi	ZESCO	Kafue	Zambia	Reservoir	120	2013	120	2013
Kariba South, extension	ZESA	Zambezi	Zimbabwe	Reservoir	300	2014	300	2014
Songwe I, II & III	ESCOM	Songwe	Malawi, Tanzania	Reservoirs	340	2014–2016	340	2024
Batoka Gorge South	ZESA	Zambezi	Zimbabwe	Pondage	800	2017	800	2023–2024
Batoka Gorge North	ZESCO	Zambezi	Zambia	Pondage	800	2017	800	2023–2024
Kafue Gorge Lower	ZESCO	Zambezi	Zambia	Pondage	750	2017	750	2017–2022
Mphanda Nkuwa	EdM	Zambezi	Mozambique	Pondage	1,300	2020	2,000	2024
Lower Fufu	ESCOM	S. Ruhuru	Malawi	Run-of-River	n/a	n/a	100	2024
Kholombidzo	ESCOM	Shire	Malawi	Pondage	n/a	n/a	240	2025
Rumakali	TANESCO	Rumakali	Tanzania	Reservoir	222	2022	256	n/a

Source: NEXANT 2008.

Note: The estimated capacity of Kafue Gorge Lower is 600 MW with an additional bay for 150 MW. The estimate for Mphanda Nkuwa has been increased to 2,000 MW.

2.2 CURRENT AND POTENTIAL IRRIGATION

Estimates of current irrigation areas in the ZRB are presented in table 2.3. The area equipped for irrigation is also known as the *command* or *irrigable* area, and the irrigated area is also referred to as the *cropped* area. Depending on the intensity of use, an irrigable area could potentially be cropped twice a year. For example, a hectare planted with irrigated wheat in the dry season may also be irrigated for maize in the wet season of the same year. In this case, the cropping intensity is doubled, and the irrigated area is twice the equipped area.

The area currently equipped for irrigation in the ZRB is approximately 183,000 hectares. The average annual irrigated area is around 260,000 hectares. That includes 102,000 hectares of irrigated perennial crops (76 percent sugarcane), representing about 56 percent of the total irrigable area. A detailed description of these irrigation parameters is given in volume 4.

Identified irrigation projects. Over a large part of this irrigated area, climatic conditions generally permit two productive seasons: a summer season (or wet season, November or December to March or April), and a winter season (or dry season, April–May to September–October). In the summer season, little irrigation is needed because of precipitation. In the winter, irrigation is the main source of water for crops.

Some of the irrigated areas are associated with flow-regulation facilities. This is the case for the irrigation schemes of the Kafue Flats (with regulation provided by the Itezhi Tezhi reservoir); irrigation schemes downstream from the Lake Malawi/Niassa/Nyasa, Lake Kariba, and Lake Cahora Bassa; and irrigation schemes that withdraw water from the Zimbabwean tributaries (with regulation provided by reservoirs).

Two levels of irrigation development are used for this analysis: a lower level based on identified projects and a much higher level based on potential projects (projects not yet proposed, let alone underway).

Identified projects. Almost 100 irrigation projects or programs were identified from various bibliographical sources and from meetings with stakeholders in all riparian countries (table 2.4). The additional equipped irrigation area promised by the identified projects is approximately 336,000 hectares. If added to the presently equipped irrigation area, the equipped area would be around 520,000 hectares—almost triple the present level. Detailed descriptions are provided in volume 4 of this series.

High-level irrigation. Potential irrigation projects beyond those already identified make up the high-level irrigation scenario. These potential projects were identified by each riparian country for this analysis. As shown in table 2.5, the additional area equipped for irrigation in the high-level irrigation scenario is around 1,209,000 hectares—more than three times the area in the identified projects scenario and more than six times the area now equipped,

Table 2.3. Existing irrigation areas in the Zambezi River Basin (ha)
By country

Countries	Irrigated area	Equipped area	Dry season	Wet season	Perennial
Angola	6,125	4,750	3,375	1,375	1,375
Botswana	0	0	0	0	0
Malawi	37,820	30,816	7,066	7,004	23,750
Mozambique	8,436	7,413	1,023	1,023	6,390
Namibia	140	120	120	20	0
Tanzania	23,140	11,600	11,540	11,540	60
Zambia	74,661	56,452	18,448	18,209	38,004
Zimbabwe	108,717	71,486	39,210	37,231	32,276
Total	**259,039**	**182,637**	**80,782**	**76,402**	**101,855**

Table 2.4. Identified projects: Additional irrigation areas in the Zambezi River Basin (ha)
Projected increases compared with current situation

Countries	Irrigated area (ha)	Increase (%)	Equipped area (ha)	Increase (%)	Dry season (ha)	Wet season (ha)	Perennial (ha)
Angola	10,625	173	10,500	221	5,375	125	5,125
Botswana	20,300	—	13,800	—	6,500	10,800	3,000
Malawi	78,026	206	47,911	155	36,791	30,115	11,120
Mozambique	137,410	1,629	96,205	1,298	41,205	41,205	55,000
Namibia	450	321	300	250	300	150	0
Tanzania	23,140	100	11,600	100	11,540	11,540	60
Zambia	61,259	82	37,422	66	23,837	23,837	13,585
Zimbabwe	183,431	169	118,464	166	64,967	64,967	53,497
Total	**514,641**	**199**	**336,202**	**184**	**190,515**	**182,738**	**141,387**

bringing the total area that could potentially be equipped for irrigation to almost 1,730,000 hectares.

These figures are based on estimates provided by the riparian countries and are used in this analysis to mark the upper limit of irrigated agriculture in the ZRB. The degree of realism in the high-level development scenario cannot be known, but the three levels of irrigation development considered here are depicted in figure 2.1 to illustrate relative magnitudes.

Figure 2.1. Irrigation levels considered in this analysis (ha)
Annual irrigated area, in hectares

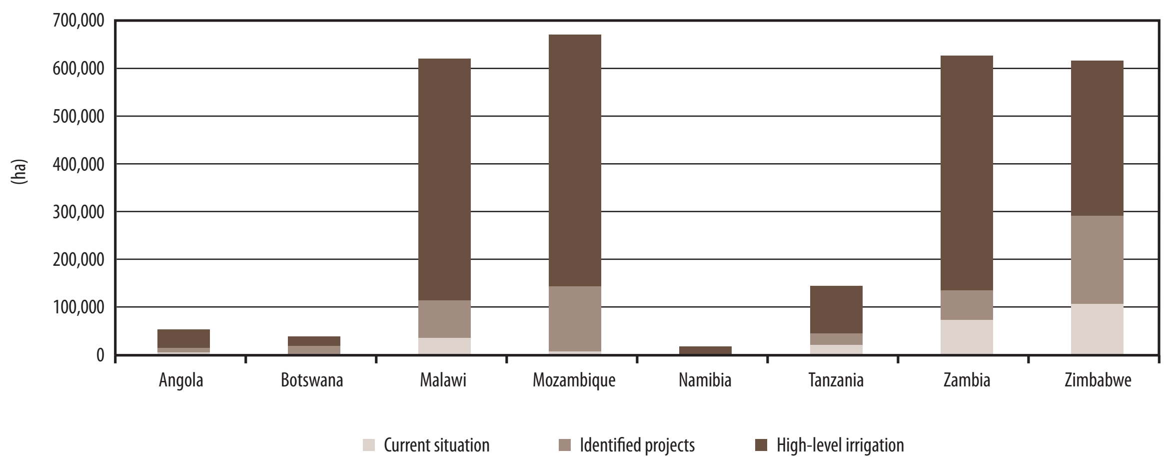


Table 2.5. High-level irrigation scenario: Additional irrigation areas in the Zambezi River Basin
Projected increases compared to current situation, together with identified projects

	Irrigated area (ha)	Increase (%)	Equipped area (ha)	Increase (%)	Dry season (ha)	Wet season (ha)	Perennial (ha)
By subbasin							
Kabompo (13)	17,014	159	10,000	159	7,014	7,014	2,986
Upper Zambezi (12)	12,500	250	10,000	200	7,500	2,500	2,500
Lungúe Bungo (11)	12,500	2000	10,000	2000	7,500	2,500	2,500
Luanginga (10)	12,500	250	10,000	200	7,500	2,500	2,500
Barotse (9)	17,713	143	10,000	143	7,713	7,713	2,287
Cuando/Chobe (8)	18,000	4000	15,000	5000	3,000	3,000	12,000
Kafue (7)	37,400	182	25,000	184	12,400	12,400	12,600
Kariba (6)	719,906	390	443,800	371	276,106	280,406	163,394
Luangwa (5)	44,957	406	25,000	408	19,957	19,957	5,043
Mupata (4)	0	0	0	0	0	0	0
Shire River – Lake Malawi/ Niassa/Nyasa (3)	604,629	598	350,000	588	273,110	254,630	76,890
Tete (2)	400,000	719	200,000	659	200,000	200,000	0
Zambezi Delta	125,000	126	100,000	130	25,000	25,000	75,000
Total	**2,022,120**	**393**	**1,208,800**	**360**	**846,801**	**817,620**	**357,699**
By country							
Angola	37,500	353	30,000	286	22,500	7,500	7,500
Botswana	20,300	100	13,800	100	6,500	10,800	3,000
Malawi	504,888	647	300,000	626	223,369	204,888	76,631
Mozambique	525,000	382	300,000	312	225,000	225,000	75,000
Namibia	18,000	4000	15,000	5000	3,000	3,000	12,000
Tanzania	99,741	431	50,000	431	49,741	49,741	259
Zambia	491,524	802	290,000	775	201,524	201,524	88,476
Zimbabwe	325,166	177	210,000	177	115,166	115,166	94,834
Total	**2,022,120**	**393**	**1,208,800**	**360**	**846,801**	**817,620**	**357,699**

3 Scenario Analysis and Findings

3.1 THE DEVELOPMENT SCENARIOS

In order to explore the development potential of various degrees of expansion of hydropower and irrigation, and consistent with the analytical framework described in section 1.5, a series of development scenarios were devised. A basic set of five primary scenarios takes the current situation as the base case (Scenario 0) and builds upward, reflecting increasing levels of cooperation, hydropower development, and irrigation development. Additional scenarios also evaluate other water-use projects (e.g., interbasin transfers and flood management and the potential impact of climate change). Two more scenarios are added to address options related to flooding in the Lower Zambezi and investment and management options in the Delta (e.g., partial restoration of natural flooding).

Because the scenarios are complex, several were divided into sub-scenarios. The impact of climate change in this analysis is shown as a scenario superimposed on Scenario 8. In practice the impact of climate change is treated as a constraint, rather than a scenario. Moreover, due to the highly uncertain nature of climate change projections in the Basin, the results of the single variable approach to climate change impact (i.e., change in temperature) should be viewed with the normal assumption and caution in mind. In all, 28 scenarios beyond the current situation were evaluated. As indicated in table 3.1, all of them take water supply for domestic use, and most take e-flows as givens (based on information available in current literature).

The development scenarios considered and their respective investment levels (described in terms of level of development and total cost) are designed and assessed to explore the following development paths and to help answer the questions associated with each.

- *Coordinated operation of existing hydropower facilities, either basin-wide or in clusters.* By how much could hydropower generation increase if current projects were coordinated? What is the potential impact of coordination on other water users?
- *Development of the hydropower sector as envisioned in plans for the SAPP.* What is the development potential of the hydropower sector? How would its expansion affect the environment (wet-

lands), irrigation, tourism, and other sectors? What gains could be expected from coordinated operation of new hydropower facilities?

- *Development of the irrigation sector through unilateral or cooperative implementation of projects identified by the riparian countries.* How might the development of irrigation affect the environment (wetlands), hydropower, tourism, and other sectors? What incremental gain could be expected from cooperative as opposed to unilateral development of irrigation schemes?
- *Flood management, particularly in the lower Zambezi and the Zambezi Delta.* What options exist to permit partial restoration of natural floods and to reduce flood risks downstream from Cahora Bassa Dam? How would those options affect the use of existing and potential hydropower and irrigation infrastructure on the Zambezi River?
- *Effects of other projects using the waters of the Zambezi River* (e.g., transfers out of the Basin for industrial uses). How might these projects affect the environment (wetlands), hydropower, irrigation, and tourism?

Table 3.1. Development scenarios evaluated

Scenario		Water supply needs	E-flows	Hydropower			Irrigation					Restoration of natural flooding in the lower Delta							Flood protection in Tete	Other projects	
				CSNC	CSCO	SAPP	CS	IP	IPC	HLI	HLIC	NAF	AF1	AF2	AF3	AF4	AF5	AF6	FP		CC
0	Base case: current situation																				
1	Coordinated operation of key existing HPP facilities																				
2	Development SAPP hydropower (up to 2025)					A															
2A	2 + e-flows					A															
2B	2A with hydropower coordination (4 clusters)					B															
2C	2A with hydropower coordination (2 clusters)					C															
2D	2A with full hydropower coordination					D															
3	Base case for hydropower + identified projects + e-flows																				
4	Base case for hydropower + high-level irrigation + e-flows																				
5	2A + Identified irrigation projects					A															
5A	2A + Identified irrigation projects (with cooperation)					A															
6	2A + high-level irrigation					A															
6A	2A + high-level irrigation (with cooperation)					A															
7	5 + Other projects					A															
8	7 + Flood protection					A															
9	8 + impacts of climate change					A															
10-A	Assess effects of restoring natural floodings with 4,500 m^3/s in the Delta in February					A															
10-B	Assess effects of restoring natural floodings with 7,000 m^3/s in the Delta in February					A															
10-C	Assess effects of restoring natural floodings with 10,000 m^3/s in the Delta in February					A															
10-D	Assess effects of restoring natural floodings with 4,500 m^3/s in the Delta in December					A															
10-E	Assess effects of restoring natural floodings with 7,000 m^3/s in the Delta in December					A															
10-F	Assess effects of restoring natural floodings with 10,000 m^3/s in the Delta in December					A															

Continued on next page

Table 3.1. Development scenarios evaluated *(continued)*

Scenario		Water supply needs	E-flows	Hydropower			Irrigation					Restoration of natural flooding in the lower Delta							Flood protection in Tete	Other projects	CC
				CSNC	CSCO	SAPP	CS	IP	IPC	HLI	HLIC	NAF	AF1	AF2	AF3	AF4	AF5	AF6	FP		
11-A	Assess effects of flood protection (maximum of 10,000 m^3/s)	■	■			A	■					■							■		
11-B	10-A + Flood protection	■	■			A	■						■						■		
11-C	10-B + Flood protection	■	■			A	■							■					■		
11-D	10-C + Flood protection	■	■			A	■								■				■		
11-E	10-D + Flood protection	■	■			A	■									■			■		
11-F	10-E + Flood protection	■	■			A	■										■		■		
11-G	10-F + Flood protection	■	■			A	■											■	■		

LEGEND

Hydropower:
- CSNC: Current situation without coordinated operation
- CSCO: Current situation with coordinated operation (Kafue, Kariba, Cahora Bassa)
- SAPP: Development SAPP hydropower
  - A : All hydro independently operated
  - B : 4 clusters: Kariba/Kafue/Mozambique/Malawi
  - C : 2 clusters: Kariba + Kafue/Mozambique + Malawi
  - D : All clusters coordinated

Irrigation:
- CS: Current situation
- IP: Identified projects
- IPC: Identified projects (with cooperation)
- HLI: High-level irrigation
- HLIC: High-level irrigation (with cooperation)

OP: Other water withdrawal projects

E-Flows: Environmental flows in all basin

CC: Climate change

Restoration of natural floodings:
- NAF: No Artificial Flooding
- AF1: 4,500 m^3/s in lower Delta in February (4 weeks)
- AF2: 7,000 m^3/s in lower Delta in February (4 weeks)
- AF3: 10,000 m^3/s in lower Delta in February (4 weeks)
- AF4: 4,500 m^3/s in lower Delta in December (4 weeks)
- AF5: 7,000 m^3/s in lower Delta in December (4 weeks)
- AF6: 10,000 m^3/s in lower Delta in December (4 weeks)

Flood protection:
- FP: Maximum of 10,000 m^3/s D/S Lupata

3.2 OVERALL FINDINGS

The results of the scenario analysis, with incremental changes in the level of development for hydropower and irrigated agriculture, are summarized in figure 3.1. The vertical axis indicates levels of hydropower production, while the horizontal axis denotes incremental levels of irrigated area.

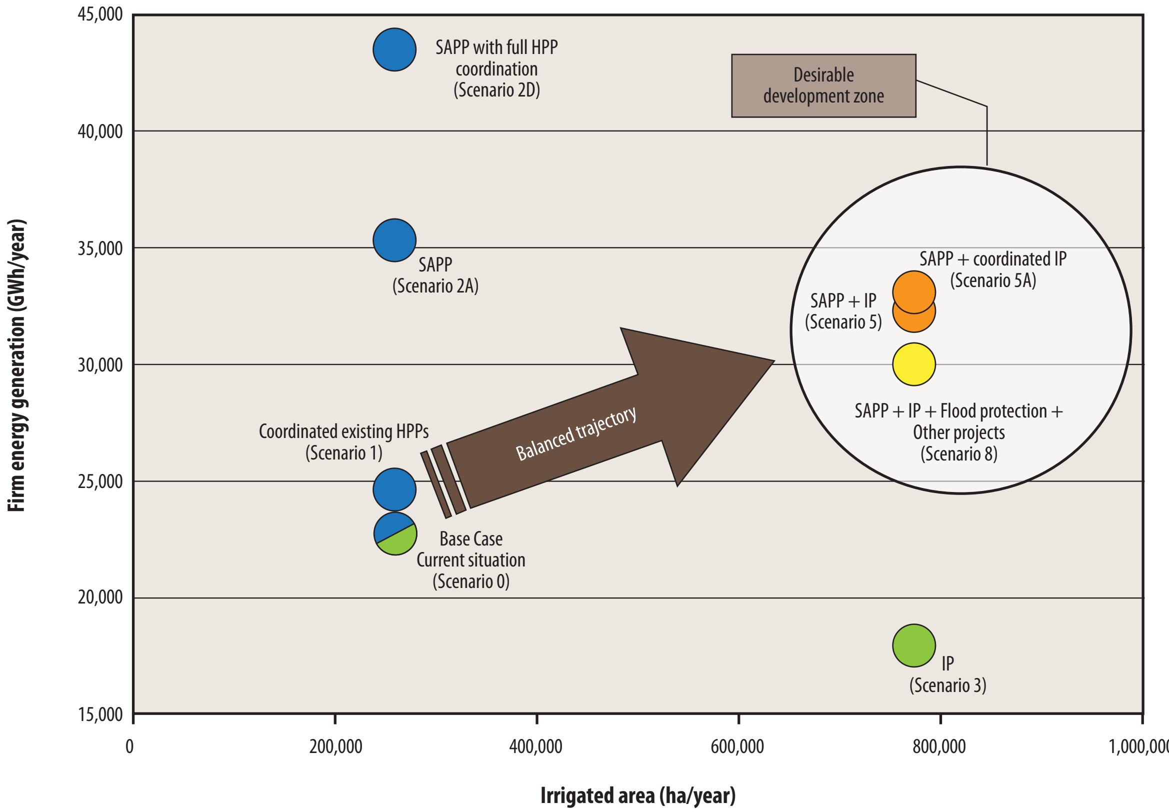
3.2.1 General observations

The first increment in the development of the hydropower sector is the coordinated basin-wide operation of existing hydropower facilities. Scenario 1 would make it possible to increase firm energy production by seven percent over the current situation—from 22,776 to 24,397 GWh/year. The economic value of basinwide cooperation, in terms of additional generation with minimal investment, is estimated at $585 million over a 30-year period.

The next increment in development of the hydropower sector is the realization of SAPP hydropower investments (Scenario 2), with the inclusion of e-flows (Scenario 2A) and the gradual addition of coordinated operation (scenarios 2A to 2D). Taking environmental flows into account would cause a nine percent reduction in total firm energy generation annually, an amount easily offset by coordinated operation, for a gain of 23 percent in firm generation. The investment cost associated with realization of the SAPP plans is estimated at $10.7 billion.

Along the irrigation axis, the first increment in development is associated with the realization of the identified irrigation projects (IP), superimposed on the current situation. Scenario 3 assumes investment

Figure 3.1. Potential for energy generation and irrigation by development scenario



SAPP = Southern Africa Power Pool ; IP = Identified Irrigation Projects.

to equip an additional 336,000 hectares for irrigation. In this development scenario, water for consumption would reduce firm annual hydropower generation from the current situation (22,776 GWh/year) to 18,052 GWh/year, a 21 percent reduction. This scenario, however, has the potential to create some 250,000 job opportunities in the irrigation sector. The estimated cost of investment associated with the scenario is $2.3 billion. With the assumptions used (see volume 2), the additional NPV created by this irrigation investment cannot compensate fully for the losses in hydropower production.

In Scenario 5, the combined development of the irrigation sector (corresponding to the IP level) and hydropower sector (realization of SAPP plans) would yield a total of 774,000 irrigated hectares (514,000 more than at present) and a production of 33,107 GWh/year of firm energy and 56,993 GWh/year of average energy.

High-level irrigation development without any hydropower sector development (Scenario 4) yields 2,795,000 hectares of potentially irrigated area, but with a 50 percent reduction in the production of firm energy, compared with the current situation. Scenario 4 represents an imbalanced approach designed to set the upper limit for irrigation development.

A balanced development approach would combine hydropower and irrigation investment and is reflected in Scenario 8:

- Full development of hydropower, with firm energy of around 30,000 GWh/year and average energy of around 55,800 GWh/year;
- Implementation of identified irrigation projects, with an average irrigated area of 774,000 hectares;
- Restoration of natural flooding (subscenario level AF2, with 7,000 m^3/s in February) in the

Zambezi Delta and flood protection in the Tete Region (not more than 10,000 m^3/s) of the Lower Zambezi;
- Implementation of other water transfers (e.g., Botswana off-take and important industrial projects in Zambia, Zimbabwe, Mozambique); and
- Preservation of e-flows all around the Basin.

This investment option would cost approximately \$16,100 million to implement, with a potential NPV of \$110 million and a return on investment of about 10 percent.

The impact of climate change on investment in hydropower and irrigation in the ZRB can be significant because of the region's highly variable hydrology. A preliminary assessment of the impact of climate change considers reduced runoff yield and increased irrigation deficits, as well as a temperature increase of 1.5ºC for evapotranspiration calculations, indicates a reduction of 32 percent in firm energy generation compared with Scenario 8. The range of indicators of the impact of climate change in the 2030 time frame was obtained from a 2010 World Bank study on water and climate change. The uncertainty in analyzing climate change impacts calls for caution in interpreting any climate change induced results.

The economic benefits of increased hydropower production are substantial, and the associated investments are viable, as demonstrated in this analysis. It is clear that cooperation can play a significant role in maximizing the benefits that can be expected from the investments. Even without further substantial investment, cooperation among the riparian countries has the potential to offer substantial benefits while allowing the region to postpone some investments in new infrastructure while maintaining the Basin's long-term sustainability. That conclusion is supported by a comparison of Scenarios 1 and 2A, Scenarios 5 and 5A, and Scenarios 6 and 6A, among others.

3.2.2 Economic analysis

Key parametric assumptions made in the economic analysis are reported in table 3.2. The results of the economic analysis performed using the tool described in volume 4 are illustrated in figure 3.2. The analysis is carried out for each investment in NPV terms. For the scenarios that involve irrigation development, the additional employment opportunities created by the investment are also depicted.

As shown in figure 3.2, the investment scenarios involving hydropower development only (scenarios 1 and 2) show a positive NPV. The gain in NPV for Scenario 1 is based solely on increased cooperation. As irrigation development and investment options are introduced, the total NPV begins to fall (Scenarios 3 and 4), but combinations of hydropower and irrigation development (Scenario 5) reveal opportunities for improving it. Again, the impact of cooperation is evident through the increase in NPV in Scenario 5A.

The high-level irrigation development scenarios would greatly curtail hydropower generation and, for that reason, are not considered viable. Including other water-using projects (e.g., out-of-basin transfers), as presently defined, does not seem to have a major impact on the economics of the development scenarios considered (Scenario 7). Scenario 8 offers the most balanced approach to hydropower and irrigation development.

The analysis shows that the trade-off between hydropower generation and irrigation can be significant. In strictly economic terms, the trade-off does not seem to favor intensive irrigation development, despite the employment opportunities and the food security that such development might provide. Even if irrigation schemes may be profitable in themselves, their development benefits in economic terms are offset by the value lost in hydropower generation. This is due to the premium assigned to firm energy. In fact, the outcome of the analysis is extremely sensitive to the value of firm energy. The break-even point, in terms of NPV, seems to be at \$0.05/KWh.

The development of irrigation in this analysis has another important aspect: direct employment. Building and operating irrigation systems demands a lot of labor and thus creates job opportunities. In this analysis, about 270,000 jobs would be generated in Scenario 8 and more than 1 million with high-level irrigation. Hydropower generation also produces direct jobs, of course, but except in the relatively short construction period, employment opportunities are limited to those with necessary skills. The strongest employment effects from

Table 3.2. Main assumptions used for the economic analysis

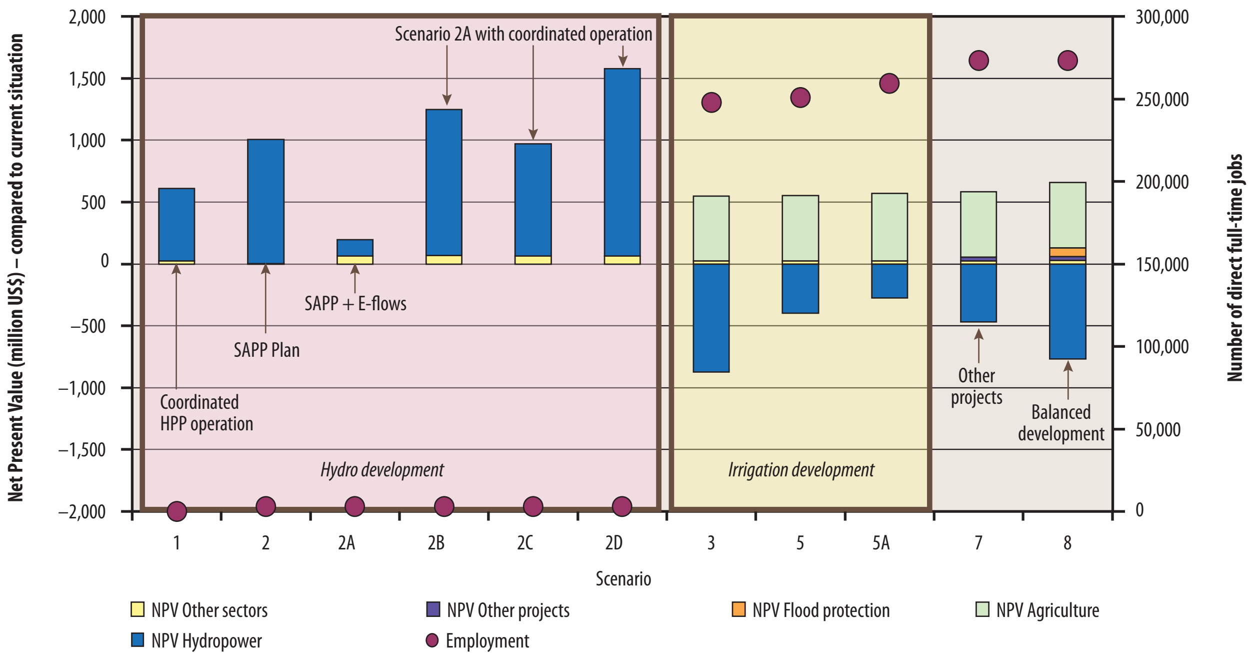
Parameter	Assumption
General	
Discount rate	10%
Base year of prices	2010
Price development	Constant prices
Time horizon for sectors	50 years
Time horizon for projects	30 years
Hydropower	
Value of firm energy	$0.058/KWh
Value of secondary energy	$0.021/KWh
Depreciation period	50 years
Employment factor investment, staff/MW installed	2.3
Employment factor operation, staff/MW installed	0.23
Agriculture	
Cost US$ (thousands) per hectare investment: range	3.7–7.8
Cost US$ (thousands) per hectare investment: average	5.6
Depreciation period	30 years
Employment factor per crop (jobs/ha)	
Winter wheat	0.5
Summer maize	0.5
Winter maize	0.5
Summer rice	1
Winter rice	1
Sugar cane	0.3
Vegetables	2
Soya summer	0.5
Cotton	1
Citrus	2
Pasture	0.1
Other winter	1
Summer sorghum	0.5
Beans	1
Gross margin US$ per hectare range (economic, excluding financing costs, taxes, and indirect costs such as income forgone)	Low: 240; sorghum High: 3,212; vegetables
Gross margin US$ per hectare average (IP) (economic)	1,312

Note: Refer to detailed descriptions in volume 4.

hydropower development arise as the increased quantity and reliability of power production turn the wheels of the economy and creates new jobs. This indirect effect has not been examined in the analysis but warrants further study.

Regarding other topics and sectors (wetlands, tourism, fisheries), other water-transfer projects, and restoration of natural flooding, estimates indicate minimal influence on the expected viability of investments in hydropower and irrigation projects. Decisions made on development investments, however, are seldom based strictly on economics. Many other factors, most outside the water sector, play a role in the decision process.

Figure 3.2. Summary of economic analysis: Net present value and employment results by scenario *(compared to current situation)*



Note: NPV near zero reflects a return of aprox.10% on investment.

3.3 FINDINGS BY DEVELOPMENT SCENARIO

A short narrative on the objectives and anticipated effects of each development scenario is provided in this section, which provide a pictorial summary of hydropower generation (firm and average), irrigation development (equipped and average total area), and associated water abstractions for all of the scenarios considered in this analysis. The figures are intended as a visual comparison of the scenarios and their impacts and serve as points of reference for the narrative that follows.

Scenario 0: Base Case – Current Situation

Firm energy production is 22,776 GWh/year and 260,000 irrigated hectares/year.

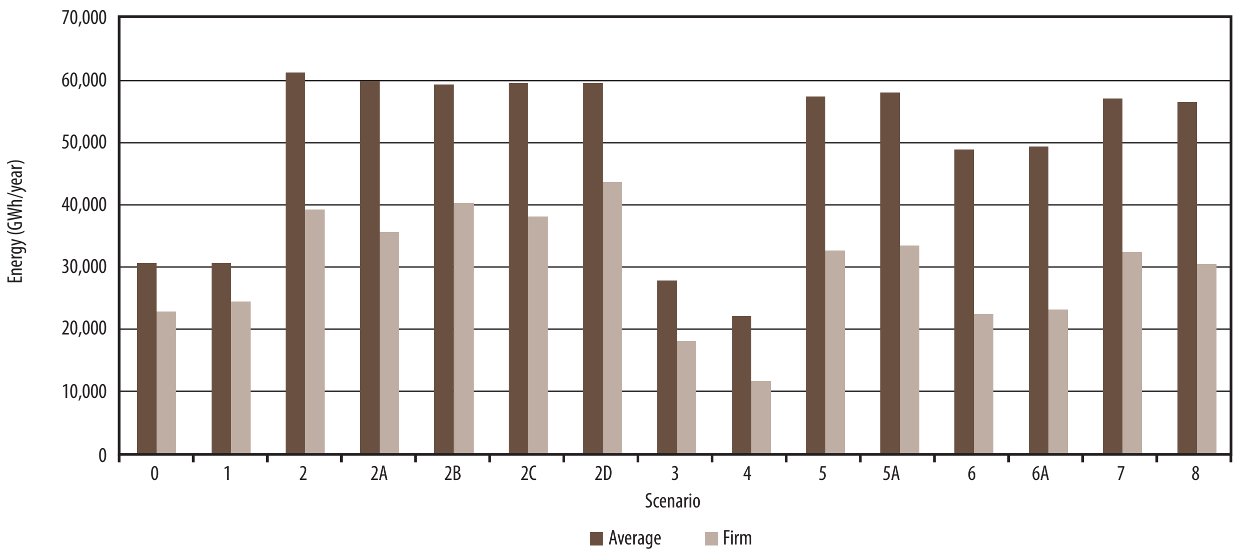
Scenario 1: Coordinated operation of existing hydropower facilities

Objective: To determine the amount of firm energy produced through cooperation among riparian countries.

Findings: Coordinated operation of the existing system of hydropower plants increases firm energy from 22,776 to 24,397 GWh/year, a gain of 7.1 percent (table 3.3). Average energy remains nearly constant (30,323 GWh/year for Scenario 1 versus 30,287 GWh/year for Scenario 0).

Coordinated operation of hydropower generation in Malawi, Mozambique, Zambia, and Zimbabwe has the potential to eliminate current deficits in the base load demand without changes in system capacity. The gain from coordinated operation would make it possible to postpone additional capital investment to meet these deficits. The coordinated system could operate at an even higher level of output if more interconnections were available. One such interconnection is under construction between Malawi and Cahora Bassa, but to operate efficiently and share benefits equitably, the whole system should be interconnected. This viable investment option is a medium-term objective of the SAPP. The estimated benefit from coordinated operation of the existing hydropower system could be as high as $585 million over a 30-year period.

Figure 3.3. Synthesis of firm energy generation for all scenarios



Scenario 2: Development of SAPP's hydropower plans

- Scenario 2A: Scenario 2 with e-flows
- Scenario 2B: Scenario 2A with hydropower coordination in four clusters (Kariba, Kafue, Mozambique, and Malawi)
- Scenario 2C: Scenario 2A with hydropower co-ordination in two clusters (Kariba/Kafue and Mozambique/Malawi)
- Scenario 2D: Scenario 2A with hydropower coordination in all clusters.

Figure 3.4. Average annual irrigated area by scenario

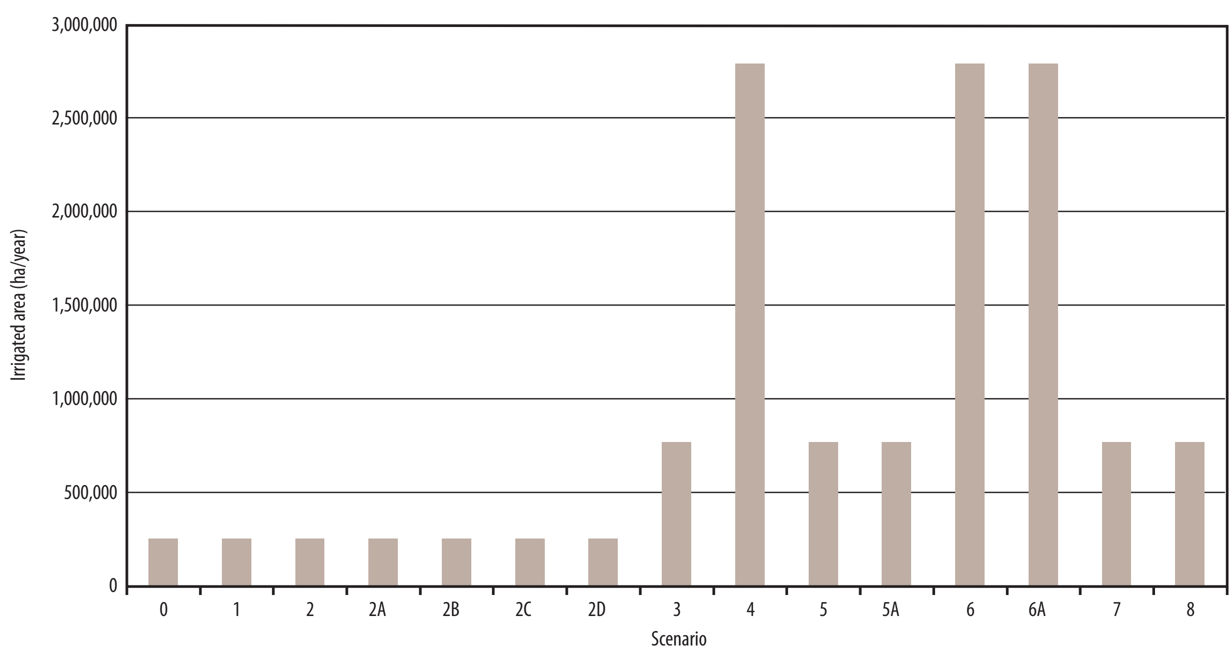
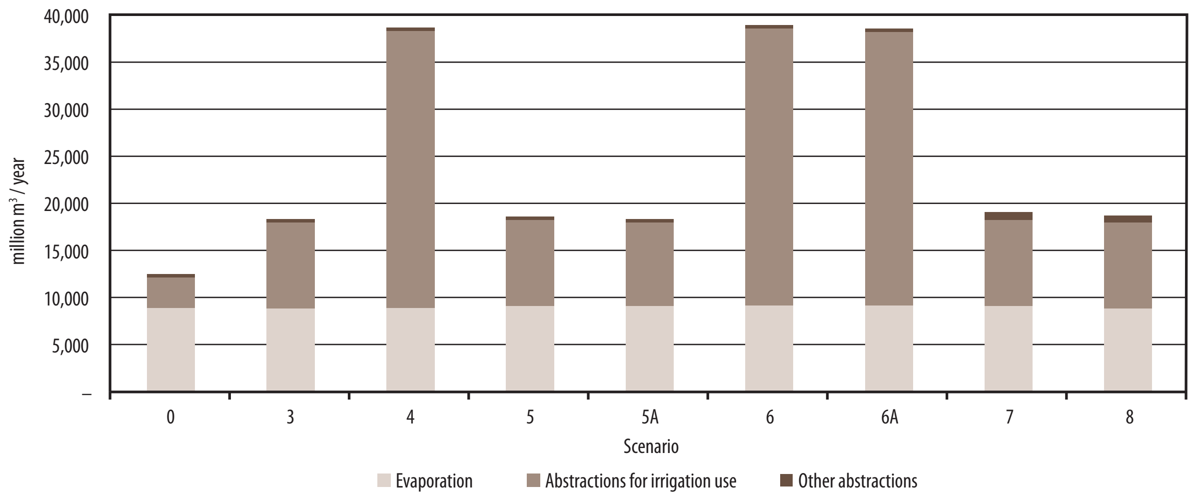


Figure 3.5. Mean annual water abstractions by scenario



Objective: To assess the increase in power production from future additions to the power system (Scenario 2A). To assess the effects of greater regional integration (cooperation) on hydropower production (Scenarios 2B to 2D).

Findings: In Scenario 2A, a total of 35,302 GWh/year is generated from unilateral (uncoordinated) operation (table 3.3). The potential for hydropower development associated with coordination in Scenario 2D is almost 43,500 GWh/year of firm energy. That amounts to a gain of 8,200 GWh/year in comparison with Scenario 2A—a significant increase of 23 percent. The practical aspects of achieving this gain should be further studied.

Scenario 3: Current hydropower + identified irrigation projects + e-flows

Objective: To determine the impact of identified irrigation projects on the energy production of existing hydropower facilities.

Findings: An irrigation-development scenario in which identified projects involving some total 774,000 hectares of irrigated area were implemented would reduce firm energy production from the existing power system to 18,050 GWh/year. Through irrigation development projects, this scenario would create an estimated 250,000 employment opportunities.

Scenario 4: Current hydropower + high-level irrigation projects + e-flows

Objective: To determine the impact of carrying out a set of ambitious irrigation projects (projects not yet identified or planned) on the energy production of the existing hydropower developments.

Findings: An ambitious irrigation-development scenario that would open some 2,800,000 hectares to irrigation would reduce firm energy production from the existing HPP system to 11,600 GWh/year. Though more than 1 million jobs would be created, the impact on hydropower production would be significant: a 49 percent reduction in firm energy and a 28 percent reduction in average energy.

Scenario 5: Scenario 2A + identified irrigation projects

Objective: To assess the effects of a gradual increase in irrigation-equipped area based strictly on existing national plans and programs, together with development of new hydropower plants in accordance with the SAPP plan. Irrigation development is unilateral: each country develops its own projects without taking into account their impact downstream. No specific strategy for cooperation among riparian countries is assumed.

Findings: Under this medium-scope irrigation-development scenario, involving some 774,000 hect-

Table 3.3. Effect of coordinated hydropower operation on firm and average energy production

Item	Existing facilities: Stand-alone operation	Existing facilities: Coordinated operation	With new investments in hydropower sector: Stand-alone operation (without e-flows)	Stand-alone operation (with e-flows)	Four coord. clusters	Two coord. clusters	Full coordination
Scenario	**0**	**1**	**2**	**2A**	**2B**	**2C**	**2D**
Scenario for comparison		0		2	2A	2A	2A
Firm energy (GWh/year)	22,776	24,397	39,000	35,302	39,928	37,712	43,476
Loss/gain (GWh)		1 621		–3,697	4,626	2,410	8,173
Loss/gain (%)		*7*		*–9*	*13*	*7*	*23*
Average energy (GWh/year)	30,287	30,323	60,760	59,304	59,138	59,251	59,178
Loss/gain (GWh)		37		–1,456	–166	–53	–126
Loss/gain (%)		*0*		*–2*	*0*	*0*	*0*

ares of total irrigated area, firm energy production of the future power system would be approximately 32,400 GWh/year. This scenario provides for the creation of 250,000 employment opportunities.

Scenario 5A: Scenario 2A + coordinated identified irrigation projects

Objective: This is Scenario 5, plus cooperation among riparian countries in the development of identified irrigation projects. The variant is based on the observation that irrigation projects are generally located toward the lower part of the river basin so as to reduce abstraction for consumption in the upper part that would penalize other sectors of the economy—for example, high abstraction in the upper reaches would reduce flows for tourism and for hydropower at Victoria Falls, Kariba, Cahora Bassa, and other sites.

Findings: Relocating some new irrigation areas downstream (e.g., 28,000 hectares of sugarcane) would shift the points of consumption in the system and allow for additional energy generation. Firm energy production would increase by two percent to 33,107 GWh/year with cooperation, compared to without it. Average energy would increase by one percent.

The benefit of cooperative development (in terms of additional NPV) for this level of irrigation development is estimated at $140 million. Additional benefits could be generated by reducing water withdrawals from upstream reaches of the Zambezi River.

Scenario 6: Scenario 2A + high-level irrigation

Objective: To assess the impact of intense development of irrigation on Scenario 2A (development of hydropower under the SAPP and e-flows), but without any specific strategy for joint operation or cooperation among riparian countries.

Findings: Although intensive development of high-level irrigation would bring the estimated total irrigated area in the Basin to 2,800,000 hectares, such increase in water abstraction for irrigation would directly affect energy production levels of hydropower projects developed under SAPP (incorporating sufficient releases for e-flows). Compared to Scenario 2A (development of SAPP + e-flows), firm energy production decreases with 37 percent from 35,302 to 22,282 GWh/year, and average energy production by 18 percent from 59,304 to 48,504 GWh/year.

Scenario 6A: Scenario 2A + coordinated high-level irrigation

Objective: To assess the impact of intensive irrigation development combined with development of new hydropower plants, including cooperation among riparian countries in irrigation development.

Findings: In the presence of intensive development of irrigation (based on Scenario 4) that would yield some 2,800,000 hectares of irrigated area, firm energy production would be 22,917 GWh/year with cooperation in irrigation, compared with 22,282 GWh/year without it. Firm energy production would increase by three percent, average energy by one percent. Compared to Scenario 6, the benefit of cooperation (in terms of additional NPV) for this level of irrigation development is estimated at $265 million.

This scenario assumes transboundary cooperation in large-scale irrigated agriculture. It provides an opportunity for discussion of regional issues such as food self-sufficiency and food security, mechanisms for sharing benefits created from cooperative uses of water, and employment opportunities.

Scenario 7: Scenario 5 + other projects

Objective: To assess the effect on irrigation development and hydropower energy production of water withdrawals for other projects—transfers outside the basin, industrial withdrawals, and additional water supply.

Findings: Realization of industrial, domestic water, and interbasin water-transfer projects would reduce the annual production of firm energy to 32,024 GWh/year, compared with 32,358 GWh/year in Scenario 5. This one percent reduction appears to be a reasonable trade-off.

Scenario 8: Scenario 5 + flood protection

Objective: To assess the economic and environmental impact of balancing development of hydropower, irrigation, other water projects, flood protection, and restoration of natural flooding in the Lower Delta.

Findings: Under this scenario, 30,013 GWh/year of firm energy and 55,857 GWh/year of average energy would be generated. Identified irrigation projects would increase the total average irrigated area to some 774,000 hectares. Restoring natural flooding at the rate of 7,000 m^3/s could be achieved in February in the Zambezi Delta, and flood protection could be provided downstream from Lupata Gorge for up to 10,000 m^3/s peak flow. This scenario meets the e-flow requirements at all defined control points in the ZRB.

Scenario 9: Scenario 8 + impact of climate change

Objective: To assess the potential impact of climate change on the balanced approach represented in Scenario 8, as it includes all the water-using sectors.

Findings: The impact of climate change in this analysis was evaluated in terms of change in air temperature, basin yield (for natural flows), and irrigation water deficit (World Bank 2009). The preliminary indications are that some parts of the Basin would be affected more than others with potential reduction of up to 30 percent in hydropower generation. As noted, this will need further detailed analysis. Given the uncertainties associated with climate change projections, this finding should be viewed with caution.

Scenario 10: Flood restoration in the Lower Delta

Objective: To assess the effects of restoring natural flooding in the Lower Delta by modifying the operation of the Cahora Bassa reservoir in order to enhance environmental and economic benefits for fisheries, aquaculture and livestock production, and other uses, as well as to better protect downstream zones against flood damage. The following subscenarios are considered:

Scenario set 10-A, 10-B, and 10-C: To assess the effects of restoring natural flooding on the Lower Delta at three flooding levels; 4,500, 7,500, and 10,000 m^3/s in February of each year.

Scenario set 10-D, 10-E and 10-F: To assess the effects of restoring natural flooding on the Lower Delta at the same three flooding levels in December of each year.

Findings: The results of this series of scenario analysis show that:

- It is technically feasible to restore natural flooding with a high degree of success (from 100 percent for 4,500 m^3/s in February to 90 percent for 7,000 m^3/s in December). The probability of success in restoring a 10,000 m^3/s flood in December would only be 50 percent.
- Flood restoration would reduce energy generation from three to 33 percent at Cahora Bassa and from four to 34 percent at the planned Mphanda Nkuwa Dam, compared with energy production under the base case (Scenario 2A). This reduction in generation is significant.

- The economic trade-offs between power production and restored flooding benefits are not favorable to flood restoration. The price of energy is critical in this regard. The break-even point is at an electricity price of $0.02/KWh, with the value of hydropower increasing at higher unit prices.

Scenario 11: Flood protection downstream of Lupata Gorge (to a maximum of 10,000 m^3/s)

Objective: This scenario combines two different objectives: restoring natural flooding (as in Scenario 10) and flood protection to a maximum of 10,000 m^3/s downstream from Lupata Gorge.

Findings: The results of this set of scenarios show that:

- It is technically feasible to combine part restoration of natural flooding of 4,500 or 7,000 m^3/s in February and December with flood protection downstream from Lupata Gorge.
- Depending on the scenario set considered, energy production could be curtailed from 10 percent to 40 percent for firm energy and from one percent to 37 percent for average energy, compared with Scenario 2A.

It should be noted that although it is theoretically possible to modify the operation of Cahora Bassa to mitigate most of the flooding at the monthly scale specified in this scenario, in practice, a sizeable portion of floods originate from flash streams, making their management difficult. In the absence of a comprehensive early warning system, the capability of Cahora Bassa Dam to mitigate floods downstream is limited, and the level of flood protection will be lower in practice than in theory. Nonetheless, this analysis provides some insight into the trade-off among storage, power generation, and flood mitigation.

The economic value of flood protection is based on the costs from loss and damage caused by hazardous floods. The NPV of the projected avoided costs is $72 million over the period (2010–60). At an assumed firm energy price of $.056/KWh, this averted damage is equivalent to about 130 GWh of generation. The production loss of averting damages, therefore, is between 750 and 2,200 GWh in the Cahora Bassa Dam and the planned Mphanda Nkuwa Dam. In economic terms, protection is justifiable if the economic price of energy is much lower.

4 Conclusions and Next Steps

4.1 CONCLUSIONS

This report has analyzed a set of development scenarios for growth-oriented investments in water and power in the Zambezi River Basin. The scenarios represent a range of options that may be considered by the eight riparian countries in the course of deliberations over cooperative development and management of the water resources of the Basin. The analysis focused on hydropower and irrigation as key investment areas. The water needs of closely related sectors and topics—water and sanitation, flood management, environment, tourism, wetlands—were also taken into account. Water users in these sectors were considered to be legitimate stakeholders with first-priority claims on water allocation.

The main findings of the analysis are:

- The ZRB and its rich resources present ample opportunities for sustainable, cooperative investment in hydropower and irrigated agriculture.
- With cooperation and coordinated operation of the existing hydropower facilities found in the Basin, firm energy generation can potentially increase by seven percent, adding a value of $585 million over 30 years with essentially no major infrastructure investment.
- Development of the hydropower sector according to the generation plan of the SAPP (NEXANT 2007) will require an investment of $10.7 billion over an estimated 15 years. That degree of development will result in estimated firm energy production of approximately 35,300 GWh/year and average energy production of approximately 60,000 GWh/year, thereby meeting all or most of the estimated 48,000 GWh/year demand of the riparian countries.
- With the SAPP plan in place, coordinated operation of the system of hydropower facilities can provide an additional 23 percent generation over uncoordinated (unilateral) operation. The value of cooperative generation therefore appears to be quite significant.
- Implementation of all presently identified national irrigation projects would expand the equipped area by some 184 percent

(including double cropping in some areas) for a total required investment of around $2.5 billion. However, this degree of development of the irrigation sector, without further development of hydropower, would reduce hydropower generation of firm energy by 21 percent and average energy by nine percent. If identified irrigation projects were developed alongside current SAPP plans, the resulting reduction in generation would be about eight percent for firm energy and four percent for average energy.

- Cooperative irrigation development (such as moving 28,000 hectares of large infrastructure downstream) could increase firm energy generation by two percent, with a net present value of $140 million. But complexities associated with food security and self-sufficiency warrant closer examination of this scenario.
- Other water-using projects (such as transfers out of the Basin and for other industrial uses within the Basin) would not have a significant effect on productive (economic) use of the water in the system at this time. But they might affect other sectors and topics, such as tourism and the environment, especially during periods of low flow. A more detailed study is warranted. Similarly additional detailed analysis is needed for assessing the impact of climate change.
- For the Lower Zambezi, restoration of natural flooding (for beneficial uses in the Delta, including fisheries, agriculture, and environmental sustainability) and better flood protection could be assured by modifying reservoir operating guidelines at Cahora Bassa Dam. Depending on the natural flooding scenario selected, these changes could cause reduction in hydropower production (between three and 33 percent for Cahora Bassa Dam and between four and 34 percent for the planned Mphanda Nkuwa Dam). More detailed studies are warranted.
- Based on the findings for Scenario 8, a reasonable balance between hydropower and irrigation investment could result in firm hydropower generation of 30,000 GWh/year and some 774,000 hectares of irrigated land. Those goals could be achieved while providing some level of flood protection and natural flooding in the Lower Zambezi.

4.2 NEXT STEPS

Explore and exploit the benefits of cooperative investments and coordinated operations. The analysis has demonstrated that the riparian countries could achieve short- and long-term benefits through coordinated operation of existing and planned hydropower facilities, cooperative flood management, and cooperative irrigation development. This is particularly true at the subbasin level and when cooperation takes place between two or more countries, in 'clusters'. Engagement in the basin will depend on opportunities to build confidence in cooperation at these different levels, and will depend on political and socioeconomic conditions. A detailed study of the benefits of cooperation and joint investment, and of how those benefits might be shared, is recommended.

Strengthen the knowledge base and the regional capacity for river basin modeling and planning. This analysis consolidated data and information from both the basin-wide and national perspectives. The consolidated information will be provided to the riparian countries, the SADC, and international development partners, as well as other interested parties. It can also inform other basin-wide initiatives taken by the countries and the donor community. Development of comprehensive planning, and eventually of an operational model for the Zambezi River Basin (with a more refined operational time scale), is recommended. The region would also benefit from better flood forecasting and more sensitive and dependable early warning capabilities, both of which would improve reservoir management and thereby maximize power generation, irrigation supply, and flood management (both to release floods for beneficial uses and to mitigate high flows). The modeling effort should benefit from ongoing activities related to flood management, early warning systems, synchronized operation of hydropower facilities, and other activities.

Improve the hydrometric data system. In the course of the analysis, it became evident that significant gaps exist in the geographic extent and density of the region's hydrometric network. Some stations have been discontinued and need to be rehabilitated or replaced altogether. Future detailed analyses will depend on the availability and accuracy of data and information on water resources and other related sectors.

Conduct specific studies on select topics. Future detailed planning of water resources development and management would benefit from studies such as: benefit- and cost-sharing approaches applied to specific cases; determination of e-flows, particularly for tributaries; acceleration of power transmission interconnections; and other studies deemed essential for project preparation and decision making. Such studies would provide a good starting point for ZAMCOM when it becomes fully operational.

Build institutional capacity. During the national consultations organized as part of the MSIOA, it became apparent that riparian countries varied widely in their institutional approach to water resources management. Effective engagement in cooperative water resources development and management on a regional scale would require greater institutional capability at both the regional and country levels.

Box 4.1. The Zambezi River Watercourse Commission (ZAMCOM)

Establishment of a Watercourse Commission for the Zambezi River has been under discussion for more than two decades. In 1987 the SADC developed the "Action Plan for the Environmentally Sound Management of the Common Zambezi River System" and launched the Zambezi River Action Plan (ZACPLAN) to promote joint management of the water resources of the Zambezi River. This addressed both technical and political initiatives, including support to preparation of a Zambezi River Watercourse Commission (ZAMCOM). A draft ZAMCOM agreement was subsequently produced and the first detailed negotiations among the riparian countries took place in 1998.

The negotiations were terminated later in the same year. It was agreed that the process should meet the needs of all SADC Member States and this resulted in development of the SADC Protocol on Shared Water Courses. A revised version of the protocol was agreed in 2000 which was signed and ratified by all of the then 14 SADC Member States and is now in force.

The ZACPLAN process, including negotiations on establishment of the ZAMCOM, was initiated again in October 2001 through the launch of the ZACPRO 6, Phase II Project with the assistance of the governments of Sweden, Norway and Denmark. The immediate objectives of ZACPRO 6.2 were (i) to setup the regional and national enabling environment necessary for strategic water resources management through ZAMCOM; (ii) to establish water resources management systems including models, tools and guidelines; and (iii) to develop an integrated water resources management strategy.

The Zambezi Water Information System (ZAMWIS) has been established and the Integrated Water Resources Management Strategy and Implementation Plan for the Zambezi River Basin was finalized in April, 2008. This acknowledges gaps and weaknesses in the approach to ZAMCOM and makes recommendations on how to address these, as detailed at the end of volume 3 of this study. These are identified in the following broad areas:

- Integrated and coordinated water resources development
- Environmental management and sustainable development
- Adaptation to climate variability and climate change
- Basin-wide cooperation and integration

An updated version of the draft ZAMCOM Agreement facilitated under ZACPRO 6.2 was signed by seven of the eight riparian countries on July 13, 2004. The agreement will come into force with ratification by six of the riparian countries, with five having ratified to date. Zambia still has not signed and is awaiting conclusion of the policy reform process and institutional alignments.

ZAMCOM was designed to assume the functions of the ZACPRO and continue to provide an enabling environment for the development of integrated water resources management of the Zambezi River Basin. ZACPRO 6.2 came to an end on April 30, 2009 and was supposed to cede its functions to ZAMCOM. In July 2009, in the absence of a ratified agreement, the riparian Ministers responsible for water adopted an Interim ZAMCOM Governance Structure. A Council of Ministers is responsible for overall guidance, strategic planning supervision, financial overview and decisions, connecting with institutions outside the Zambezi River Basin, and evaluation of programs. Its Technical Committee implements policies and decisions of the Council, develops the strategic plan, develops hydrometric data and early warning systems, and monitors water abstraction. The Committee also makes legal, political, and technical recommendations to the Council and is intended to supervise the ZAMCOM secretariat (ZAMSEC). In the absence of the ratified agreement all riparian countries have agreed on the establishment of an interim secretariat to be established in Gaborone, Botswana.

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