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The Zambezi River Basin

A Multi-Sector Investment Opportunities Analysis

VOLUME 2

Basin Development Scenarios

THE WORLD BANK

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Basin Development Scenarios

June 2010

THE WORLD BANK
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Cover and interior design: The Word Express

Cover photos:
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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.

The World Bank peer reviewers for this work included Stephen Mink, Glenn Morgan, Daryl Fields, and Guy Alaerts. Francois Onimus also provided written comments. Their constructive inputs are very much appreciated. The team benefitted from the guidance of Rick Scobey, Acting Director for Regional Integration, Inger Andersen, Director for Sustainable Development, and Ashok K. Subramanian, Sector Manager for Water Resources Management, Africa Region.

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

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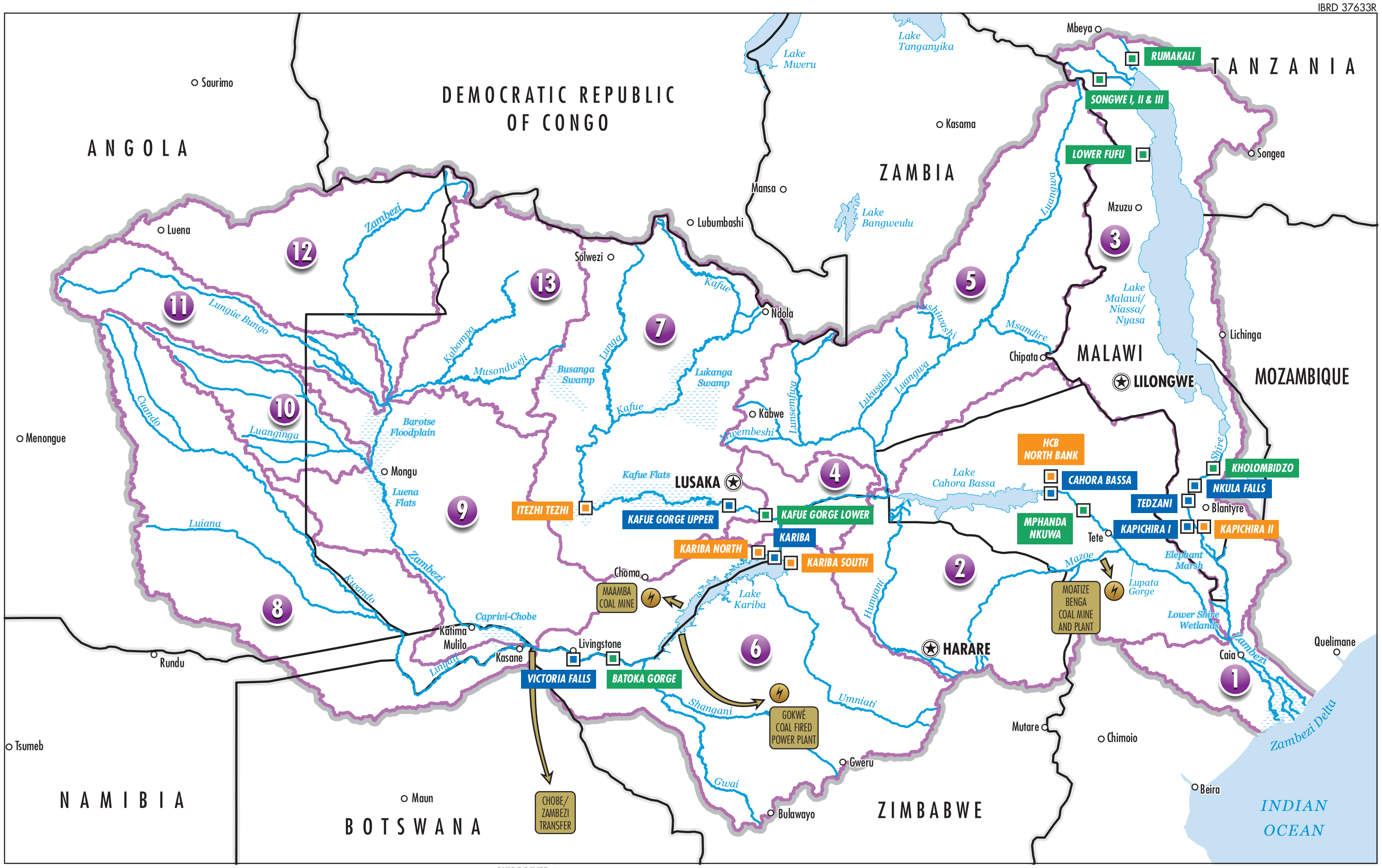

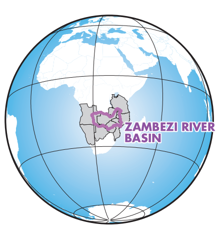

This map was produced by the Map Design Unit of The World Bank. The boundaries, colors, denominations and any other information shown on this map do not imply, on the part of The World Bank Group, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries.

	1 Zambezi Delta: Irrigated area (ha/year)	Equipped area (ha)	2 Tete: Irrigated area (ha/year)	Equipped area (ha)	3 Shire River & Lake Malawi/Niassa/Nyasa: Irrigated area (ha/year)	Equipped area (ha)	4 Mupata: Irrigated area (ha/year)	Equipped area (ha)	5 Luangwa: Irrigated area (ha/year)	Equipped area (ha)	6 Kariba: Irrigated area (ha/year)	Equipped area (ha)	7 Kafue: Irrigated area (ha/year)	Equipped area (ha)
Current situation (CS)	7,664	6,998	52,572	35,159	60,960	42,416	21,790	14,200	17,794	10,100	44,531	28,186	46,528	40,158
Identified projects (IP)	106,774	84,053	108,193	65,495	162,126	101,927	30,356	20,060	28,857	16,230	228,919	147,778	67,048	53,768
Upper limit potential (HLI)	231,774	184,053	508,193	265,495	766,755	451,927	30,356	20,060	73,814	41,230	948,825	591,578	104,448	78,768

	8 Cuando/Chobe: Irrigated area (ha/year)	Equipped area (ha)	9 Barotse: Irrigated area (ha/year)	Equipped area (ha)	10 Luanginga: Irrigated area (ha/year)	Equipped area (ha)	11 Lungúe Bungo: Irrigated area (ha/year)	Equipped area (ha)	12 Upper Zambezi: Irrigated area (ha/year)	Equipped area (ha)	13 Kabompo: Irrigated area (ha/year)	Equipped area (ha)
Current situation (CS)	765	620	340	200	1,000	750	1,250	1,000	3,250	2,500	595	350
Identified projects (IP)	1,215	920	12,753	7,208	6,000	5,750	1,875	1,500	8,250	7,500	11,314	6,650
Upper limit potential (HLI)	19,215	15,920	30,466	17,208	18,500	15,750	14,375	11,500	20,750	17,500	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.

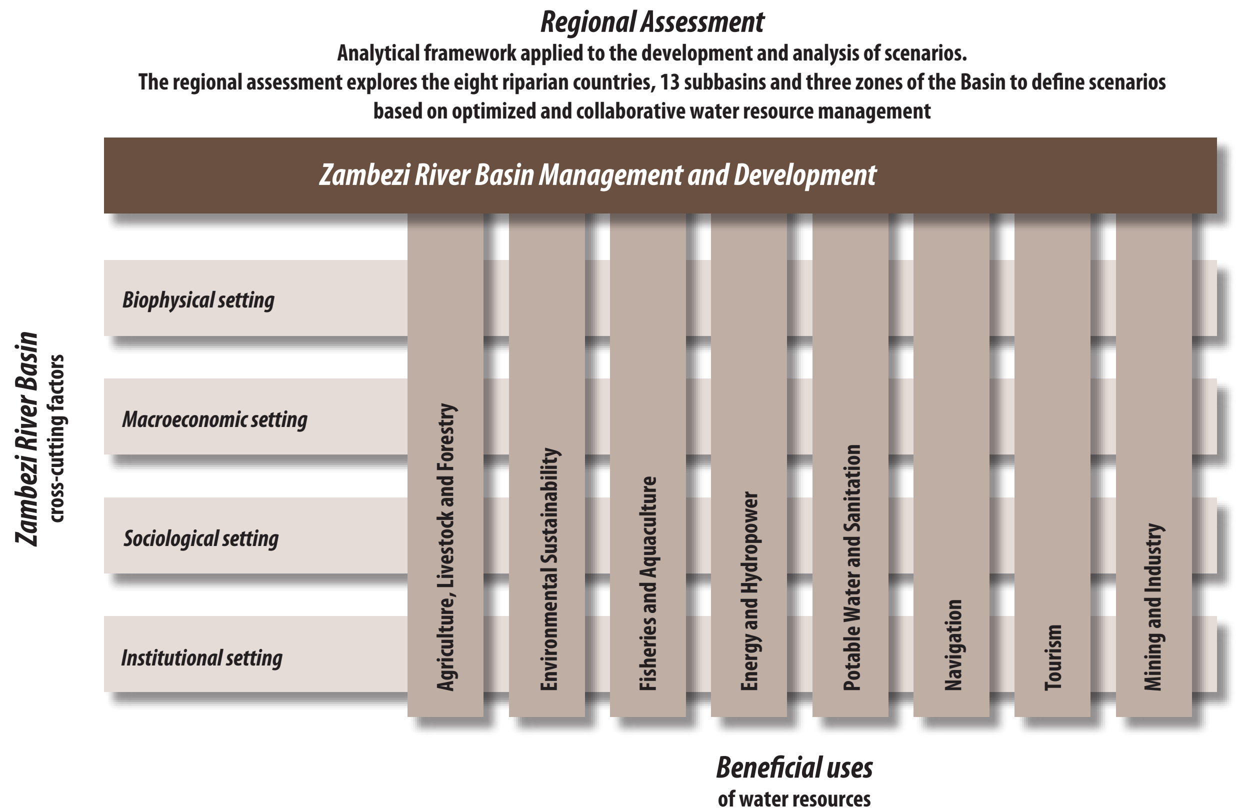
While the need to consider the details of the interaction among all stakeholders is acknowledged, the focus of this analysis is on major water-related investments being considered by the riparian countries in their national development plans. Development scenarios for other stakeholders can be superimposed 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.

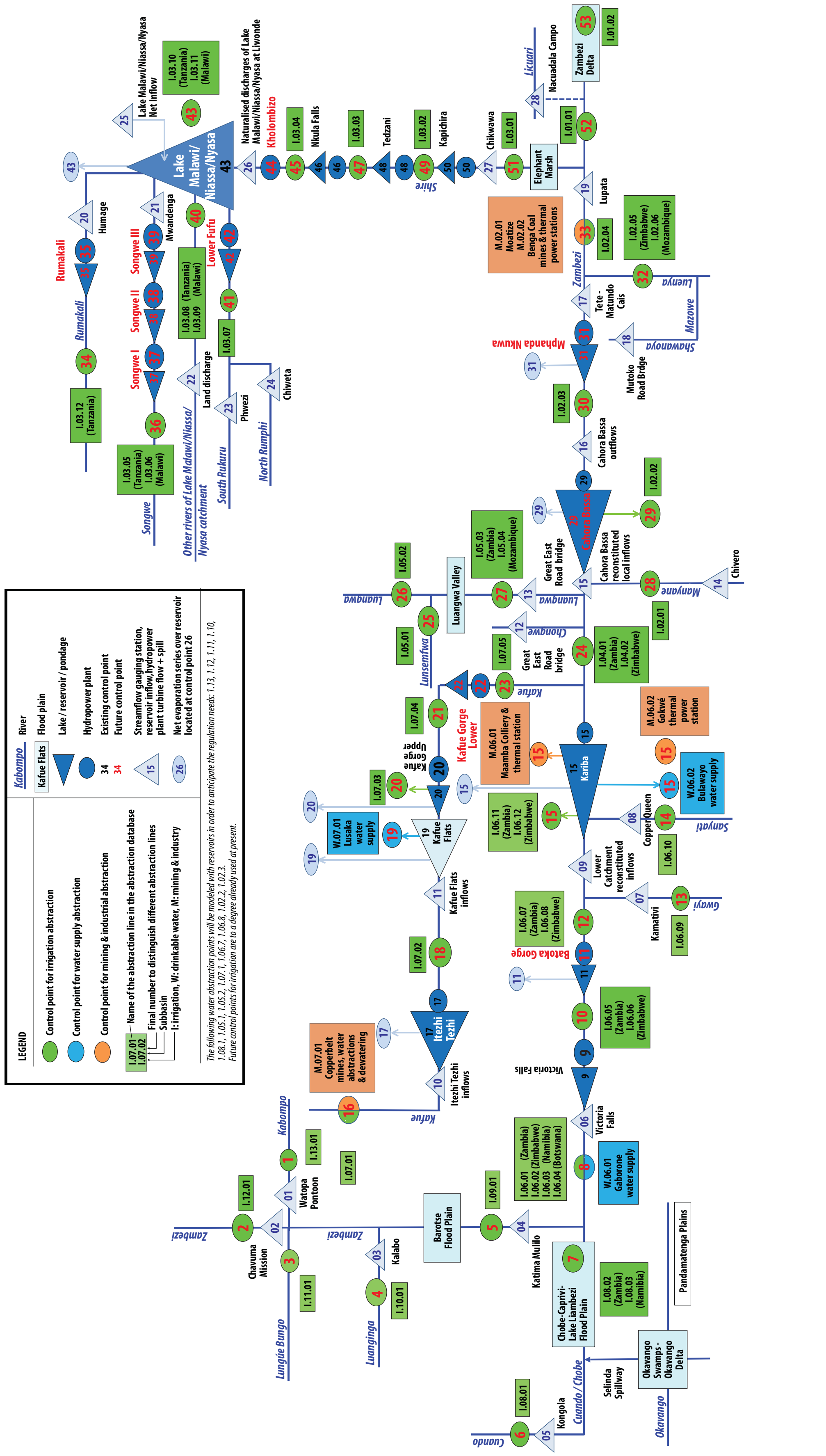
Specific attention is also given to the operational and investment options for reducing flood risks downstream of Cahora Bassa Dam and to the possibility of partial restoration of natural floods to manage the impact on the Zambezi Delta of existing dams on the Zambezi River. In this analysis, the impact 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.

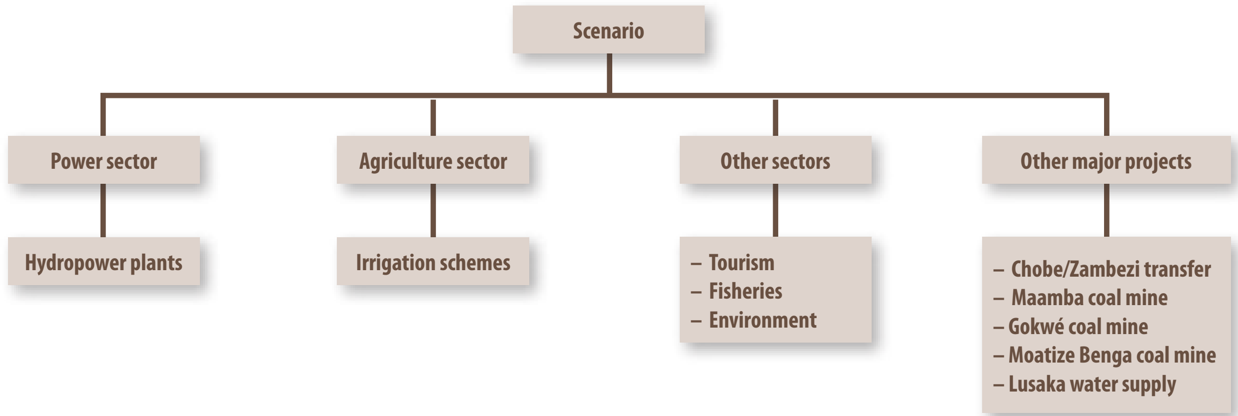
1.5.3 The Economic Assessment Tool

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 The Development Scenarios

In the Zambezi River Basin, there is vast potential for development and cooperation in hydropower and irrigation. In order to evaluate the associated benefits and costs of this potential, this study produced a set of 'scenarios'.

Using the analytical methodology described in section 1.5, these scenarios correspond to a set of different options. This chapter describes each scenario in terms of: objective, features and findings. The types of variables being considered across the scenarios essentially include:

- Production of firm and average energy (GWh per year);
- Total average of annually irrigated area and the equipped irrigated area (hectares);
- Net present value (US$ million); and
- Employment effect (number of jobs, person years).

The first scenario is called the 'Base Case – current situation' (Scenario 0), and reflects the present status of hydropower production and irrigation across the Basin. The subsequent scenarios represent a range of different levels developments in new hydropower projects and irrigation developments, as well as the impact of coordinated operation in each of these two sectors. As the set of scenarios was developed, some had to be divided into sub-scenarios to adequately capture different variables within, such as other water-using demands (e.g., partial restoration of natural floods). Certain scenarios also specifically addressed flood protection in the Lower Zambezi and in the Zambezi River Delta. When more water using activities are considered, in addition to hydropower and irrigation developments, a more balanced multi-sector approach is indicated in Scenario 8.

Building on Scenario 0, a total 28 scenarios (including sub-scenarios) were created and evaluated. A summary of the scenarios is reproduced in table 2.1. As the table indicates, provision for water supply for domestic use is included in all scenarios. Furthermore, minimum releases for environmental flows (e-flows) based on available data is included in Scenario 3 onwards. These two water users are given highest priority and demand is considered fully satisfied.

Table 2.1. Development scenarios

	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															

Table 2.1. Development scenarios *(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 m³/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 m³/s in lower Delta in February (4 weeks)
- AF2: 7,000 m³/s in lower Delta in February (4 weeks)
- AF3: 10,000 m³/s in lower Delta in February (4 weeks)
- AF4: 4,500 m³/s in lower Delta in December (4 weeks)
- AF5: 7,000 m³/s in lower Delta in December (4 weeks)
- AF6: 10,000 m³/s in lower Delta in December (4 weeks)

Flood protection:
- FP: Maximum of 10,000 m³/s D/S Lupata

2.1 SCENARIO 0: BASE CASE – CURRENT SITUATION

Objective: To assess the present energy generated by existing hydropower facilities (operated on stand-alone basis) and the present size of the irrigated area across the Basin.

Features: Scenario 0 is based on existing hydropower facilities across the Zambezi River Basin, operated on a stand-alone basis, and estimates the total equipped area for irrigation and the average annually total irrigated area.

Because of insufficient data and comparatively minimal abstractions, some facilities were not included in the HEC-3 model. These are the Mulungushi, the Lunsemfwa, and the Lusiwasi (all located in the headwaters of the Luangwa subbasin), as well as the Wovwe mini hydropower plant (HPP) in Malawi and the Victoria Falls HPP. These two latter facilities would not be impacted by upstream water-intensive developments when they operate during the wet season.

Scenario 0 incorporates abstraction for domestic water supply (included in all scenarios), but does not include releases for e-flows.

Findings: In total, an estimated 22,776 GWh per year of firm energy[2] and 30,287 GWh per year of average energy is generated by existing major hydropower facilities in the ZRB.

[2] In the model, firm energy is assumed at the 99% point on the duration curve. Unless inflows to all power plants are in perfect phase, the timing of firm energy at any hydropower plant does not necessarily coincide with the timing at other power plants. Hence, firm energy is non-additive. System firm energy does not necessarily equal the sum of each individual plant.

The equipped area for irrigation in the ZRB is estimated at 183,000 hectares. The average total irrigated area, however, is 259,000 hectares (i.e., the majority of the equipped area is farmed more than once per year).

2.2 SCENARIO 1: COORDINATED OPERATION OF EXISTING HYDROPOWER FACILITIES

Objective: To assess the potential of energy generation in the ZRB from conjunctive operation of existing hydropower facilities.

Features: Scenario 1 explores the effect of conjunctive operation of existing HPP facilities. The scenario also incorporates abstraction for domestic water supply (included in all scenarios), but does not include releases for e-flows.

Findings: If existing hydropower facilities across the Basin were operated as a 'common power pool', firm energy generation would increase from 22,776 to 24,397 GWh per year. The additional 1,621 GWh per year represents a 7.1 percent increase in production. With the assumption that distribution of firm energy is similar to the current situation in Scenario 0, the benefits of coordinating existing HPPs has a net present value (NPV) of $585 million (table 2.2.). Average energy production increases slightly in Scenario 1 with an additional 36 GWh per year, but remains practically constant at just over 30,000 GWh per year.

The gain in energy produced through conjunctive operation and cooperation may satisfy potential deficits in the base load. This could save costs to cover any delay in construction of new or upgraded hydropower plant. But the capacity of the hydropower system remains unchanged.[3]

The gains in energy production as predicted by the river/reservoir system model would be the maximum achievable under optimum conditions. This model is based on historical monthly flows, which do not necessarily provide sufficient indication of future conditions. Other determining factors also suggest that a realistic gain in energy production may be less than predicted by these optimal conditions assumed under the model. These factors include hydrological uncertainty, location of individual HPPs on different tributaries in the ZRB, and different operation and management of HPPs in riparian countries.

Achieving the potential gains predicted by the river/reservoir system model would depend on a

Table 2.2. Benefits of coordinated operation of existing HPPs

	Energy production (GWh/year)					Change in energy (%)	NPV
	Scenario 0			Scenario 1			
Hydropower plant	Firm	Secondary	Average	Firm	Average	Firm	(US$ m)
Kariba North	3,184	650	3,834		3,849		78
Kariba South	3,184	650	3,834		3,849		78
Kafue Gorge Upper	4,695	2,090	6,785		7,359		224
Cahora Bassa	11,922	1,613	13,535	24,397	13,028	7	181
Nkula Falls	462	555	1,017		989		11
Tedzani	300	422	722		691		1
Kapichira	455	105	560		558		12
Total	**22,776**	**7,511**	**30,287**	**24,397**	**30,323**	**7**	**585**

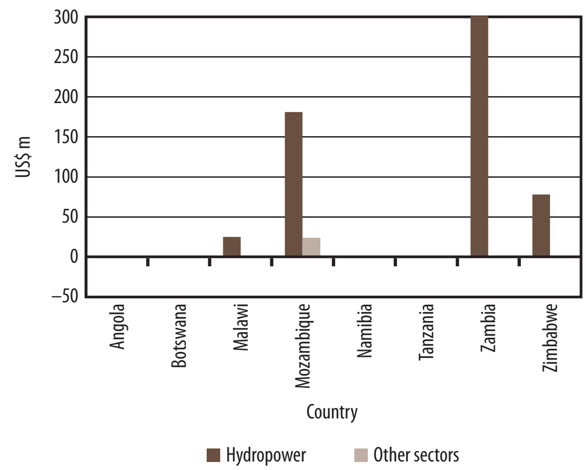
Note: The valuation of energy production is based on separate pricing of firm energy and secondary energy. Average energy may either increase or decrease as a result of differing operation modes in the reservoir, possibly modifying reservoir evaporation and spill at downstream run-of-the-river (RoR) plants. The marginal average increase of 36 GWh/year is well within the accuracy of the results.

[3] This would have to be confirmed within the framework of a generation-planning exercise.

fully interconnected transmission network. Such a network would moreover ensure both the efficiency and a more equitable sharing of gains. Although the current lack of interconnected networks may impede such developments, the income generated by improved efficiency could sustain substantial capital investments of approximately $100 million per year over five years and still yield an internal rate of return (IRR) of over 10 percent.

The modified flow from joint operation of HPPs could generate additional benefits in the Delta and, to a lesser degree, benefits to other sectors (including fisheries, the environment, and tourism). The summary of NPV estimates of hydropower and other sectors in each riparian country is listed in table 2.3. The table shows that benefits are primarily concentrated in downstream countries. This indicates that mechanisms for benefit sharing could be implemented in parallel to the conjunctive operations of existing HPPs.

Figure 2.1. Net present value by country (US$ m): Scenario 1 compared with Scenario 0



2.3 SCENARIO 2: DEVELOPMENT OF SAPP HYDROPOWER PLANS

Scenarios 2, 2A, 2B, 2C and 2D explore what happens when the system of hydropower plants across the Basin is expanded with upgrades, extensions and new constructions of HPPs listed in the Southern Africa Power Pool Regional Generation and Transmission Expansion Study (SAPP). From Scenario 2A onwards, releases for e-flows are incorporated. In Scenario 2B, 2C and 2D, the effects of coordinated operation of the HPPs in clusters are assessed.

Table 2.3. Net present value by country (US$ m): Scenario 1 compared with Scenario 0

Country	Hydropower	Other sectors	Total (US$ m)
Angola	0.00	0.00	0.00
Botswana	0.00	0.00	0.00
Malawi	25.00	–0.66	24.34
Mozambique	181.00	24.00	205.00
Namibia	0.00	0.00	0.00
Tanzania	0.00	0.00	0.00
Zambia	301.00	–0.14	300.86
Zimbabwe	78.00	–0.14	77.86
Total	585.00	23.24	609.00

Note: NPVs are based on separate pricing of firm and secondary energy

Objective: To assess potential energy generation from developing hydropower plants as envisaged under the Southern Africa Power Pool (SAPP) Expansion Study.

Features: Scenario 2 includes existing HPPs (Scenario 0) and adds HPPs identified in the SAPP Regional Generation and Transmission Expansion Plan Study up to 2025 (least cost alternatives). In the model, the upgraded HPPs are not operated in conjunction in Scenario 2. Table 2.4 lists the HPPs considered.

The model optimizes stand-alone firm energy for the HPPs served by a carry-over reservoir—that is, the Kariba, Cahora Bassa, Kafue Gorge, Rumakali, and the three Songwe reservoirs. Scenario 2 incorporates abstraction and allocation for domestic water supply (included in all scenarios), but does not include releases for e-flows.

In the SAPP, there are plans to extend many of the HPPs in the future (e.g., Kariba North and South, Cahora Bassa North, and Kapichira II). Some will be upgraded to provide extra energy (e.g., Kapichira II), and others will provide more operational capability such as peaking power (e.g., Kariba North and South and Cahora Bassa North). The amount of supplementary generation is estimated to be nine percent for Kariba, 11 percent for Cahora Bassa, and 90 percent for Kapichira HPPs.

The HPP system, as such, generates substantial additional benefits in terms of firm energy that cannot directly be attributed to individual HPPs. In this calculation, the firm energy produced by the system of HPPs is distributed according to individual HPPs.

Findings: Compared with the current situation in Scenario 0, firm energy production increases by 71 percent from 22,776 to 39,000 GWh per year when the future system of HPPs under SAPP is developed. Total average energy production doubles from 30,287 to 60,760 GWh per year.

The NPV of additional energy production is approximately one billion dollars.[4] The estimated employment effect is around 3,050 additional jobs[5] (or 92,000 person years).[6]

Table 2.4. SAPP HPPs development: Scenario 2 compared with Scenario 0

		Energy production (GWh/year)				% Change in energy production			
		Scenario 0		Scenario 2					
Hydropower plant		**Firm**	**Average**	**Firm**	**Average**	**Firm**	**Average**	**NPV (US$ m)**	**IRR (%)**
Batoka Gorge North	projected	0	0	954	4,819	0	0	–285	4
Batoka Gorge South	projected	0	0	954	4,819	0	0	–285	4
Kariba North	extension	3,184	3,834	3,167	4,179	–1	9	563	0
Kariba South	extension	3,184	3,834	3,167	4,179	–1	9	563	0
Itezhi Tezhi	extension	0	0	284	716	0	0	–19	8
Kafue Gorge Upper	refurbishment	4,695	6,785	4,687	6,784	0	0	733	0
Kafue Gorge Lower	projected	0	0	2,368	4,097	0	0	–545	4
Cahora Bassa	existing	11,922	13,535	11,826	15,024	–1	11	n.a.	0
Cahora Bassa North Bank	extension							562	20
Mphanda Nkuwa	projected	0	0	6,190	9,092	0	0	–272	8
Rumakali	projected	0	0	686	985	0	0	–147	2
Songwe I – Malawi	projected	0	0	21	45	0	0		
Songwe II – Malawi	projected	0	0	138	245	0	0	–48	2
Songwe III – Malawi	projected	0	0	114	207	0	0		
Songwe I – Tanzania	projected	0	0	21	45	0	0		
Songwe II – Tanzania	projected	0	0	138	245	0	0	–37	4
Songwe III – Tanzania	projected	0	0	114	207	0	0		
Lower Fufu	projected	0	0	134	645	0	0	–9	8
Kholombizo	projected	0	0	344	1,626	0	0	–32	7
Nkula Falls	existing	462	1,017	460	1,017	0	0	112	0
Tedzani	existing	300	721	299	721	0	0	47	0
Kapichira I	existing	542	560	541	1,063	0	90	85	0
Kapichira II	extension							18	15
Total		**22,776**	**30,286**	**39,000**	**60,760**	**71**	**101**	**1,003**	13

Note: NPV is based on separate pricing of firm energy and secondary energy. This applies to all subsequent tables that list NPV.

4 Please note that the benefits are calculated with separate pricing of firm and secondary energy.
5 Estimated employment impact is based on the size of the HPP.
6 This is the undiscounted sum of the calculated employment effect for the whole time horizon. It reflects the number

The way firm energy will be distributed in reality will depend on the stacking of energy production. A more accurate estimation would therefore involve generation planning for the system. Should this lead to a shift in firm energy production from one plant to another, there will also be a significant change in the viability of the power generated. The outcome of the economic analysis is extremely sensitive to the value assigned to the firm energy (see table 2.5.). If it drops below $0.05/kilowatt hour (KWh), the investment yields a negative NPV.

The HPP development envisaged in SAPP would more than triple the capacity of the existing system (Scenario 0), from approximately the current estimated capacity of 4,975 MW to a total of approximately 15,300 megawatt (MW).[7]

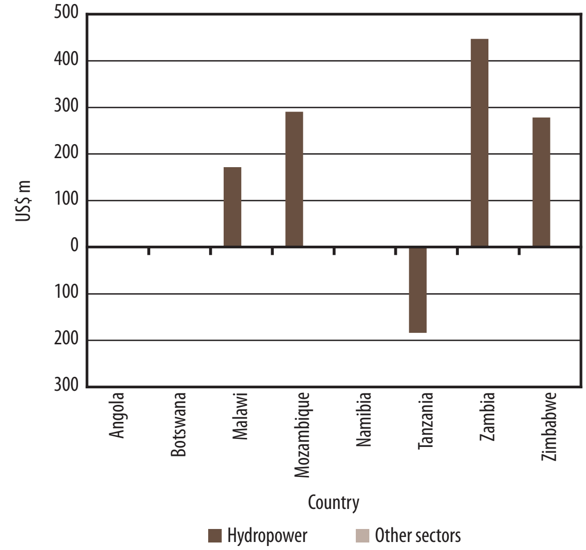
Table 2.5. Sensitivity to firm energy value

US$/KWh of firm energy	NPV (US$ million)	IRR (%)
0.02	–2,545	n/a
0.03	–1,559	6
0.04	–574	8
0.05	412	11
0.06	1,003	13
0.06	1,398	15

Table 2.6. Net present value by country (US$ m): Scenario 2 compared with Scenario 0

Country	Hydropower	Other sectors	Total
Angola	0.00	0.00	0.00
Botswana	0.00	0.00	0.00
Malawi	171.50	0.25	905.00
Mozambique	290.56	2.27	293.00
Namibia	0.00	0.00	0.00
Tanzania	–183.93	0.00	–184.00
Zambia	447.19	0.32	–286.00
Zimbabwe	278.18	0.32	279.00
Total	**1,004.00**	**3.00**	**1,007.00**

Figure 2.2. Net present value by country (US$ m): Scenario 2 compared with Scenario 0



2.4 SCENARIO 2A: SAPP WITH E-FLOWS

Objective: To assess the impact of e-flow releases on the system of HPPs developed under SAPP, without conjunctive operation.

Features: Scenario 2A is based on the upgrades, extensions and new construction of HPPs under SAPP (i.e., Scenario 2) but also includes vital e-flow releases (7,000 m^3 per second in the lower Delta in February). The HPPs in Scenario 2A are independently operated. Abstraction for domestic water supply is included (all scenarios).

Environmental flow requirements

In order to take into account e-flow requirements with due consideration to the amount of water available in the rivers, two flow regimes have been assessed for the entire Zambezi River Basin. These are:

of workplaces multiplied by number of years. It could therefore represent 92,000 staff in one year, or 47,000 in two years, or so on.

7 The HEC-3 model used for the MSIOA included a selection of the future potential HPP. See volume 3 and 4 for more details.

- Flow should never drop below any given value representing the current low-flow levels in dry years; and
- Average annual flow should not drop below 60 percent of the natural average annual flow (which is in fact equivalent to a minimum flood constraint because annual run-off is largely produced during flooding events).

These two rules have been translated in the river/reservoir system model as follows:

Table 2.7. Minimum flow levels in major tributaries of the Zambezi River Basin

Control point	Minimum flow level (m^3/s year round)
Barotse Flats	186
Zambezi River at Victoria Falls	145
Downstream of Lake Kariba	237
Lower Kafue	27
Lower Luangwa	11
Lower Shire	133
Zambezi Delta	7,000 (February)

Table 2.8. SAPP HPPs development with E-flow rules: Scenario 2A compared with Scenario 2 (energy) and compared with Scenario 0 (NPV)

<table>
<tr><th rowspan="3">Hydropower plant</th><th rowspan="3"></th><th colspan="4">Energy production (GWh/year)</th><th colspan="2" rowspan="2">% Change in energy production</th><th rowspan="3">NPV compared with Scenario 0 (US$ m)</th><th rowspan="3">IRR (%)</th></tr>
<tr><th colspan="2">Scenario 2</th><th colspan="2">Scenario 2A</th></tr>
<tr><th>Firm</th><th>Average</th><th>Firm</th><th>Average</th><th>Firm</th><th>Average</th></tr>
<tr><td>Batoka Gorge North</td><td>projected</td><td>954</td><td>4,819</td><td>954</td><td>4,819</td><td>0</td><td>0</td><td>–291</td><td>4</td></tr>
<tr><td>Batoka Gorge South</td><td>projected</td><td>954</td><td>4,819</td><td>954</td><td>4,819</td><td>0</td><td>0</td><td>–291</td><td>4</td></tr>
<tr><td>Kariba North</td><td>extension</td><td>3,167</td><td>4,179</td><td>3,184</td><td>4,180</td><td>1</td><td>0</td><td>493</td><td>0</td></tr>
<tr><td>Kariba South</td><td>extension</td><td>3,167</td><td>4,179</td><td>3,184</td><td>4,180</td><td>1</td><td>0</td><td>493</td><td>0</td></tr>
<tr><td>Itezhi Tezhi</td><td>extension</td><td>284</td><td>716</td><td>284</td><td>716</td><td>0</td><td>0</td><td>–22</td><td>8</td></tr>
<tr><td>Kafue Gorge Upper</td><td>refurbishment</td><td>4,687</td><td>6,784</td><td>4,542</td><td>6,766</td><td>–3</td><td>0</td><td>603</td><td>0</td></tr>
<tr><td>Kafue Gorge Lower</td><td>projected</td><td>2,368</td><td>4,097</td><td>2,301</td><td>4,092</td><td>–3</td><td>0</td><td>–577</td><td>4</td></tr>
<tr><td>Cahora Bassa</td><td>existing</td><td rowspan="2">11,826</td><td rowspan="2">15,024</td><td rowspan="2">9,680</td><td rowspan="2">14,204</td><td rowspan="2">–18</td><td rowspan="2">–5</td><td>0</td><td>0</td></tr>
<tr><td>Cahora Bassa North Bank</td><td>extension</td><td>211</td><td>14</td></tr>
<tr><td>Mphanda Nkuwa</td><td>projected</td><td>6,190</td><td>9,093</td><td>5,026</td><td>8,477</td><td>–19</td><td>–7</td><td>–434</td><td>7</td></tr>
<tr><td>Rumakali</td><td>projected</td><td>686</td><td>985</td><td>686</td><td>985</td><td>0</td><td>0</td><td>–151</td><td>2</td></tr>
<tr><td>Songwe I – Malawi</td><td>projected</td><td>21</td><td>45</td><td>21</td><td>45</td><td>0</td><td>0</td><td rowspan="3">–48</td><td rowspan="3">2</td></tr>
<tr><td>Songwe II – Malawi</td><td>projected</td><td>138</td><td>245</td><td>138</td><td>245</td><td>0</td><td>0</td></tr>
<tr><td>Songwe III – Malawi</td><td>projected</td><td>114</td><td>207</td><td>114</td><td>207</td><td>0</td><td>0</td></tr>
<tr><td>Songwe I – Tanzania</td><td>projected</td><td>21</td><td>45</td><td>21</td><td>45</td><td>0</td><td>0</td><td rowspan="3">–39</td><td rowspan="3">4</td></tr>
<tr><td>Songwe II – Tanzania</td><td>projected</td><td>138</td><td>245</td><td>138</td><td>245</td><td>0</td><td>0</td></tr>
<tr><td>Songwe III – Tanzania</td><td>projected</td><td>114</td><td>207</td><td>114</td><td>207</td><td>0</td><td>0</td></tr>
<tr><td>Lower Fufu</td><td>projected</td><td>134</td><td>645</td><td>134</td><td>645</td><td>0</td><td>0</td><td>–10</td><td>8</td></tr>
<tr><td>Kholombizo</td><td>projected</td><td>344</td><td>1,626</td><td>344</td><td>1,626</td><td>0</td><td>0</td><td>–34</td><td>7</td></tr>
<tr><td>Nkula Falls</td><td>existing</td><td>460</td><td>1,017</td><td>460</td><td>1,017</td><td>0</td><td>0</td><td>95</td><td>0</td></tr>
<tr><td>Tedzani</td><td>existing</td><td>299</td><td>720</td><td>299</td><td>721</td><td>0</td><td>0</td><td>40</td><td>0</td></tr>
<tr><td>Kapichira I</td><td>existing</td><td rowspan="2">541</td><td rowspan="2">1,063</td><td rowspan="2">541</td><td rowspan="2">1,063</td><td rowspan="2">0</td><td rowspan="2">0</td><td>72</td><td>0</td></tr>
<tr><td>Kapichira II</td><td>extension</td><td>18</td><td>15</td></tr>
<tr><td>Total</td><td></td><td>39,000</td><td>60,760</td><td>35,302</td><td>59,304</td><td>–9</td><td>–2</td><td>129</td><td>10</td></tr>
</table>

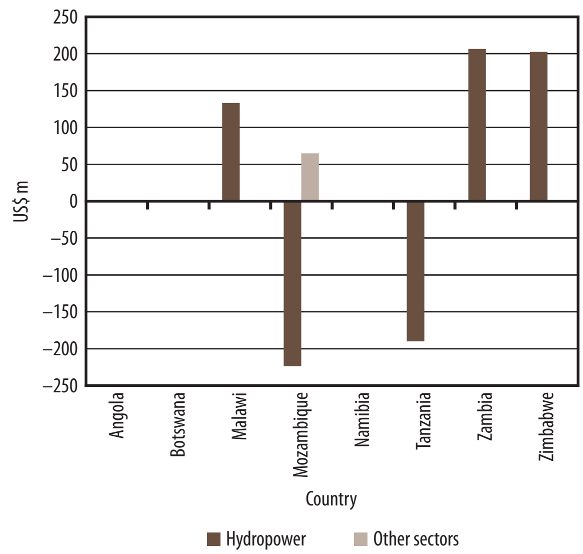
- When the flow drops below the 10-year low flow ("monthQ10 low-flow discharge"), abstractions are reduced, upstream regulation is increased, or dam management is modified in order to satisfy the flow rule. It may happen, though, that the 10-year low flow is not satisfied while there are no more abstractions or dams upstream. If it is null (on the Zimbabwean tributaries, for instance), then the five-year low flow is selected ("monthQ5 low-flow discharge"). If in turn this flow is also null (in rare instances), no minimum flow is considered.
- For the flood level of the rivers not regulated by any large dam, the maximum regulation volume upstream at any given point cannot be higher than 40 percent of the mean annual run-off of the five year dry-year flow ("yearQ5 low-flow discharge"). Consequently, at least 60 percent of the flood should be preserved during four years out of five.
- For the flood level downstream of Kariba Dam, minimum flows in the Delta should be 7,000 m^3 per second at least four years out of five. This rule also correspond to the rule implemented under the scenario AF2."

In terms of water abstractions, there is no prominent difference between Scenario 2 and Scenario 2A. Therefore, there will be no significant difference between low flows in relation to the yearQ5 low-flow discharge. But in drier years, Cahora Bassa Dam will need to release the minimum flow needed downstream and for the February flood of the lower Delta.

Table 2.9. Net present value by country (US$ m): Scenario 2A compared with Scenario 0

Country	Hydropower	Other sectors	Total
Angola	0.00	0.00	0.00
Botswana	0.00	0.00	0.00
Malawi	133.23	0.26	133.49
Mozambique	–223.80	64.77	–159.03
Namibia	0.00	0.00	0.00
Tanzania	–190.23	0.00	–190.23
Zambia	206.59	0.03	206.62
Zimbabwe	202.59	0.03	202.62
Total	**129.00**	**65.09**	**193.47**

Figure 2.3. Net present value by country (US$ m): Scenario 2A compared with Scenario 0



Findings: Incorporating releases for e-flows in Scenario 2A reduces the firm energy generation by nine percent to 35,302 GWh per year compared with Scenario 2. The total average energy production also falls, by two percent to 59,304 GWh per year compared with Scenario 2.

In economic terms, the reduction in firm energy generation (nine percent) is equivalent to approximately $207 million per year. The reduction in average energy is equivalent to approximately $69 million per year. In the absence of adequate economic assessment of the benefits derived from e-flows, the IRR of the investments drops by three percent compared with Scenario 0 (from 13 to 10 percent). The increase in secondary energy is 2,241 GWh, which would be equivalent to approximately $45 million. The employment effect, however, is assumed to be the same as for Scenario 2, approximately 3,050 additional jobs.

2.5 SCENARIO 2B: SAPP, E-FLOWS AND COORDINATION (4 CLUSTERS)

Objective: To assess the benefits of operating the system of HPPs under SAPP in four clusters (including e-flows).

Features: Scenario 2B assumes the upgrades, extensions and new construction of HPPs under SAPP and e-flow releases (7,000 m^3 per second in the lower Delta in February). The expanded system of HPPs are operated in conjunction in four clusters in Scenario 2B. Abstraction for domestic water supply is included.

The four clusters of conjunctive operation of HPPs are:

1. *Upper Zambezi River*: The Batoka Gorge (future) and Kariba (existing) dams are operated in conjunction. Given that the Batoka Gorge is proposed to be a run-of-the-river (RoR) plant and that both plants are on the same stem of the river, this is a likely operational mode potentially considered by the Zambezi River Authority (ZRA).
2. *Kafue River*: The Itezhi Tezhi reservoir is operated to consolidate energy of the system generated by the Itezhi Tezhi Dam (existing dam with plans for extension), and the HPPs Kafue Gorge Upper (existing) and Kafue Gorge Lower (new project).
3. *Middle Zambezi River:* The Cahora Bassa (existing) and Mphanda Nkuwa (new project) dams are operated in conjunction (for similar reasons as for the upper Zambezi River cluster). Extra consolidation of energy is comparatively marginal because the Kariba, Itezhi Tezhi, Kafue Gorge Upper, and Kafue Gorge Lower dams could regulate inflow into Lake Cahora Bassa; and the Cahora Bassa Dam could regulate inflow into the future reservoir behind the Mphanda Nkuwa Dam.
4. *Shire River and Lake Malawi/Nyasa/Niassa*: Energy generation in this cluster is assumed to be nearly identical to Scenario 2A (without coordination and e-flows) because the HPPs (existing and future) are either run-of-the-river or have relatively small reservoirs. This is the case of, for example, Songwe I, II, and III which are principally operated for flood mitigation.

Findings: Compared with Scenario 2A of independently operated HPPs, the conjunctive operation of HPPs (existing and future) in four clusters would increase firm energy production by 13 percent from 35,302 to 39,928 GWh per year. Average energy production in Scenario 2B, 59,138 GWh per year, remains practically unchanged compared with Scenario 2A.

Operating the system of HPPs in four clusters would increase the NPV with more than one billion dollars compared with Scenario 2A (table 2.11.). The benefits derived in Scenario 2B are primarily achieved through the conjunctive operation in the first cluster, i.e. the Batoka Gorge and Kariba dams (table 2.10.). These two hydropower plants would

Table 2.10. SAPP HPP development, E-flow rules and Coordination (4 clusters): Scenario 2B compared with Scenario 2A

		Energy production (GWh/year)				% Change in energy production		Change in NPV
		Scenario 2A		Scenario 2B				
Hydropower plant/ Cluster of operation		Firm	Average	Firm	Average	Firm	Average	(US$ m)
1. Upper Zambezi River								
Batoka Gorge North	projected	954	4,819	13,315	4,816	70	0	13
Batoka Gorge South	projected	954	4,819		4,816		0	13
Kariba North	extension	3,184	4,180		4,093		–2	162
Kariba South	extension	3,184	4,180		4,093		–2	162
	Subtotal	**7,816**	**17,998**	**13,315**	**17,818**	**70**	**–1**	**350**
2. Kafue River								
Itezhi Tezhi	extension	284	716	7,446	716	5	0	7
Kafue Gorge Upper	refurbishment	4,542	6,766		6,779		0	231

Continued on next page

Table 2.10. SAPP HPP development, E-flow rules and Coordination (4 clusters): Scenario 2B compared with Scenario 2A *(continued)*

<table>
<tr><th rowspan="3" colspan="2">Hydropower plant/ Cluster of operation</th><th colspan="4">Energy production (GWh/year)</th><th colspan="2" rowspan="2">% Change in energy production</th><th rowspan="2">Change in NPV</th></tr>
<tr><th colspan="2">Scenario 2A</th><th colspan="2">Scenario 2B</th></tr>
<tr><th>Firm</th><th>Average</th><th>Firm</th><th>Average</th><th>Firm</th><th>Average</th><th>(US$ m)</th></tr>
<tr><td>Kafue Gorge Lower</td><td>projected</td><td>2,301</td><td>4,092</td><td></td><td>4,088</td><td></td><td>0</td><td>58</td></tr>
<tr><td colspan="2">Subtotal</td><td>7,088</td><td>11,574</td><td>7,446</td><td>11,583</td><td>5</td><td>0</td><td>296</td></tr>
<tr><td colspan="9">3. Middle Zambezi River</td></tr>
<tr><td>Cahora Bassa</td><td>existing</td><td rowspan="2">9,680</td><td rowspan="2">14,204</td><td rowspan="3">15,006</td><td rowspan="2">14,117</td><td rowspan="3">2</td><td rowspan="2">–1</td><td></td></tr>
<tr><td>Cahora Bassa North Bank</td><td>extension</td><td>241</td></tr>
<tr><td>Mphanda Nkuwa</td><td>projected</td><td>5,026</td><td>8,477</td><td>8,575</td><td>1</td><td>100</td></tr>
<tr><td colspan="2">Subtotal</td><td>14,685</td><td>22,681</td><td>15,006</td><td>22,692</td><td>2</td><td>0</td><td>341</td></tr>
<tr><td colspan="9">4. Shire River and Lake Malawi/Niassa/Nyasa</td></tr>
<tr><td>Rumakali</td><td>projected</td><td>686</td><td>985</td><td rowspan="13">3,092</td><td>985</td><td rowspan="13">0</td><td>0</td><td>11</td></tr>
<tr><td>Songwe I – Malawi</td><td>projected</td><td>21</td><td>45</td><td>45</td><td>0</td><td rowspan="3">0</td></tr>
<tr><td>Songwe II – Malawi</td><td>projected</td><td>138</td><td>245</td><td>245</td><td>0</td></tr>
<tr><td>Songwe III – Malawi</td><td>projected</td><td>114</td><td>207</td><td>204</td><td>–1</td></tr>
<tr><td>Songwe I – Tanzania</td><td>projected</td><td>21</td><td>45</td><td>45</td><td>0</td><td rowspan="3">4</td></tr>
<tr><td>Songwe II – Tanzania</td><td>projected</td><td>138</td><td>245</td><td>245</td><td>0</td></tr>
<tr><td>Songwe III – Tanzania</td><td>projected</td><td>114</td><td>207</td><td>204</td><td>–1</td></tr>
<tr><td>Lower Fufu</td><td>projected</td><td>134</td><td>645</td><td>645</td><td>0</td><td>2</td></tr>
<tr><td>Kholombizo</td><td>projected</td><td>344</td><td>1,626</td><td>1,626</td><td>0</td><td>4</td></tr>
<tr><td>Nkula Falls</td><td>existing</td><td>460</td><td>1,017</td><td>1,017</td><td>0</td><td>36</td></tr>
<tr><td>Tedzani</td><td>existing</td><td>299</td><td>721</td><td>721</td><td>0</td><td>15</td></tr>
<tr><td>Kapichira I</td><td>existing</td><td rowspan="2">541</td><td rowspan="2">1,063</td><td rowspan="2">1,063</td><td rowspan="2">0</td><td>28</td></tr>
<tr><td>Kapichira II</td><td>extension</td><td>–35</td></tr>
<tr><td colspan="2">Subtotal</td><td>3,091</td><td>7,051</td><td>3,092</td><td>7,045</td><td>0</td><td>0</td><td>65</td></tr>
<tr><td colspan="2">Total</td><td>35,302</td><td>59,304</td><td>39,928</td><td>59,138</td><td>13</td><td>0</td><td>1,052</td></tr>
</table>

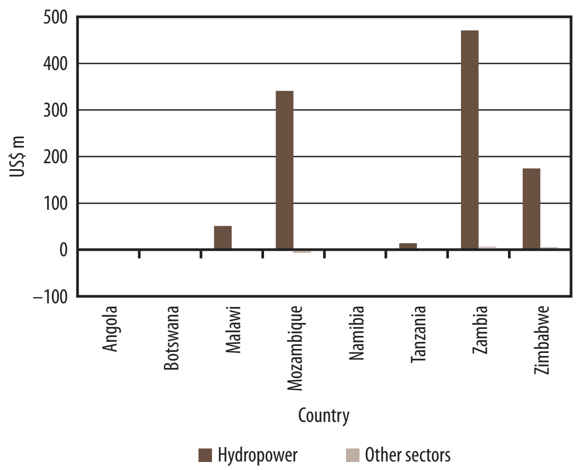
operate, not only in tandem, but also to compensate each other. During the dry season, when the production of Batoka Gorge Dam is down, most of the power is produced by the Kariba Dam. During the wet season, Batoka Gorge Dam carries the major portion of the load while the Kariba reservoir refills. Creation of the cluster to facilitate this type of co-operation would require no additional investments above those detailed under Scenario 2.

The employment effects are assumed to be the same as in Scenario 2, approximately 3,050 additional jobs. Conjunctive operation of HPPs in these four clusters would generate a small net increase in productivity of the other sectors (table 2.11.).

Table 2.11. Net present value by country (US$ m): Scenario 2B compared with Scenario 2A

Country	Hydropower	Other sectors	Total
Angola	0.00	0.00	0.00
Botswana	0.00	0.00	0.00
Malawi	51.27	–0.06	51.22
Mozambique	340.88	–3.26	337.61
Namibia	0.00	0.00	0.00
Tanzania	14.12	0.00	14.12
Zambia	470.69	2.29	472.98
Zimbabwe	174.60	2.29	176.89
Total	**1,052.00**	**1.00**	**1,053.00**

Figure 2.4. Net present value by country (US$ m): Scenario 2B compared with Scenario 2A



2.6 SCENARIO 2C: SAPP, E-FLOWS AND COORDINATION (2 CLUSTERS)

Objective: To assess the benefits of operating the system of HPPs under SAPP in two clusters (including e-flows).

Features: Scenario 2C assumes the upgrades, extensions and new construction of HPPs under SAPP, and vital e-flow releases (7,000 m^3 per second in the lower Delta in February). It considers further integration through the conjunctive operation of HPPs in two clusters. Abstraction for domestic water supply is included.

The two clusters of conjunctive operation of HPPs are:

- *Zambia and Zimbabwe*: HPPs in this extensive area is operated as one integrated aggregate of the Upper Zambezi and the Kafue River subbasins, primarily located in Zambia and Zimbabwe.
- *Mozambique and Malawi*: HPPs in this extensive area is operated as one integrated aggregate of the Lower Zambezi and the Shire River and Lake Malawi/Niassa/Nyasa subbasins.

Findings: Scenario 2C shows that conjunctive operation in two clusters will generate a seven percent increase to 37,712 GWh per year of firm energy production compared with Scenario 2A. Compared with the 13 percent increase in firm energy generation when operating the HPPs in four clusters (Scenario 2B), this smaller increase is caused by rearrangement in the energy generation of individual HPPs. An analysis of model output shows that low and high ranges of energy production are concurrent in Scenario 2C (table 2.12). Average energy

Table 2.12. SAPP HPP development, E-flow rules and Coordination (2 clusters): Scenario 2C compared with Scenario 2B

Hydropower plant/ Cluster of operation		Energy production (GWh/year) Scenario 2B Firm	Scenario 2B Average	Scenario 2C Firm	Scenario 2C Average	% change in energy production Firm	% change Average	Change in NPV (US$ m)
1. Zambia and Zimbabwe								
Batoka Gorge North	projected	18,957	4,816	19,570	4,818	3	0	–21
Batoka Gorge South	projected		4,816		4,818		0	–21
Kariba North	extension		4,093		4,069		–1	2
Kariba South	extension		4,093		4,069		–1	2
Itezhi Tezhi	extension		716		715		0	–13
Kafue Gorge Upper	refurbishment		6,779		7,147		5	16
Kafue Gorge Lower	projected		4,088		3,814		–7	–99
	Subtotal	**18,957**	**29,401**	**19,570**	**29,450**	**3**	**0**	**–134**

Continued on next page

Table 2.12. SAPP HPP development, E-flow rules and Coordination (2 clusters): Scenario 2C compared with Scenario 2B *(continued)*

Hydropower plant/ Cluster of operation		Energy production (GWh/year)				% change in energy production		Change in NPV (US$ m)
		Scenario 2B		Scenario 2C				
		Firm	Average	Firm	Average	Firm	Average	
2. Mozambique and Malawi								
Cahora Bassa	existing	18,913	14,117	19,894	14,201	5	1	0
Cahora Bassa North Bank	extension							100
Mphanda Nkuwa	projected		8,575		8,640		1	–172
Rumakali	projected		985		951		–3	–18
Songwe I – Malawi	projected		45		37		–19	0
Songwe II – Malawi	projected		245		262		7	
Songwe III – Malawi	projected		204		219		7	
Songwe I – Tanzania	projected		45		37		–19	–6
Songwe II – Tanzania	projected		245		262		7	
Songwe III – Tanzania	projected		204		219		7	
Lower Fufu	projected		645		645		0	–3
Kholombizo	projected		1,626		1,602		–1	–7
Nkula Falls	existing		1,017		992		–2	1
Tedzani	existing		721		693		–4	
Kapichira I	existing		1,063		1,041		–2	1
Kapichira II	extension							–35
	Subtotal	**18,913**	**29,737**	**19,894**	**29,801**	**5**	**0**	**–139**
Total		**39,928**	**59,138**	**37,712**	**59,251**	**–6**	**0**	**–273**

production in Scenario 2C of 59,251 GWh per year remains practically unchanged compared with Scenario 2A.

Conjunctive operation of HPPs in two clusters requires no additional investments above those detailed under Scenario 2. The employment effects are assumed to be the same as in Scenario 2, approximately 3,050 additional jobs.

2.7 SCENARIO 2D: SAPP, E-FLOWS AND COORDINATION (1 SYSTEM)

Objective: To assess the benefits of operating the SAPP HPP system as a fully integrated system of conjunctive operation of HPPs (including e-flows).

Features: Scenario 2D assumes the upgrades, extensions and new construction of HPPs under SAPP and e-flow releases (7,000 m^3 per second in the lower Delta in February). The HPPs in the ZRB are operated in conjunction as one fully integrated system. Abstraction for domestic water supply is included.

Findings: Conjunctive operation of the HPPs as one fully integrated system would increase firm energy production by 23 percent to a total of 43,476 GWh per year compared with Scenario 2A (independently operated system). Coordination and conjunctive operation would, in other terms, equate to 8,174 GWh per year (table 2.13). The average energy produced in Scenario 2D is practically unchanged compared with Scenario 2A.

Creation of the cluster to facilitate cooperation requires no additional investments above those detailed under Scenario 2. The employment effects are assumed to be the same as in Scenario 2, approximately additional 3,050 jobs.

Table 2.13. SAPP HPP development, E-flow rules and Full Coordination (1 cluster): Scenario 2D compared with Scenario 2C

Hydropower plant		Energy production (GWh/year)				% Change in energy production		Change in NPV (US$ m)
		Scenario 2C		Scenario 2D				
		Firm	Average	Firm	Average	Firm	Average	
Batoka Gorge North	projected		4,818		4,818		0	55
Batoka Gorge South	projected		4,818		4,818		0	55
Kariba North	extension		4,069		4,084		0	–1
Kariba South	extension		4,069		4,084		0	–1
Itezhi Tezhi	extension		715		716		0	31
Kafue Gorge Upper	refurbishment		7,147		7,206		1	–37
Kafue Gorge Lower	projected		3,814		3,830		0	258
Cahora Bassa	existing		14,201		14,004		15	0
Cahora Bassa North Bank	extension							–254
Mphanda Nkuwa	projected		8,640		8,658		0	450
Rumakali	projected		951		952		0	48
Songwe I – Malawi	projected	37,712	37	43,476	40	15	9	
Songwe II – Malawi	projected		262		262		0	0
Songwe III – Malawi	projected		219		216		–1	
Songwe I – Tanzania	projected		37		40		9	
Songwe II – Tanzania	projected		262		262		0	16
Songwe III – Tanzania	projected		219		216		–1	
Lower Fufu	projected		645		645		0	8
Kholombizo	projected		1,602		1,603		0	18
Nkula Falls	existing		992		991		0	–1
Tedzani	existing		693		693		0	0
Kapichira I	existing		1,041		1,040		15	–1
Kapichira II	extension							–35
Total		**37,712**	**59,251**	**43,476**	**59,178**	**15**	**0**	**609**

2.7.1 Benefits of coordinated operation of HPPs

Energy generation

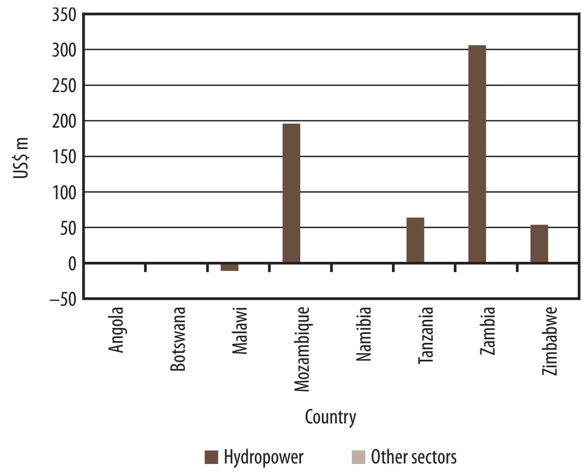
Implementing the SAPP involves the development of a series of prioritized HPPs with a planning horizon of 2025. Scenarios 2, 2A to 2D were developed to identify the benefits that would accrue from the inclusion of e-flows, and the progressive integration and coordinated management of the HPPs in the ZRB within a regional SAPP power grid.

Table 2.15. outlines the impact of introducing e-flows and then gradually incorporating different options for coordinating HPPs. The successive gain or loss in firm energy generation is also illustrated in figure 2.6. To put the additional firm energy generated from coordinated operation into context, this increase of over 8,174 GWh per year in Scenario 2D (compared with 2A without coordination) is equivalent to two percent of the firm energy demand increase forecasted in SAPP for the year 2025. This benefit represents an opportunity to offset energy deficits and a comparatively cost-effective way to

Table 2.14. Net present value by country (US$ m): Scenario 2D compared with Scenario 2C

Country	Hydropower	Other sectors	Total
Angola	0.00	0.00	0.00
Botswana	0.00	0.00	0.00
Malawi	–11.00	0.13	–48.00
Mozambique	196.00	–0.53	195.00
Namibia	0.00	0.00	0.00
Tanzania	64.00	0.00	64.00
Zambia	306.00	–0.20	344.00
Zimbabwe	54.00	–0.27	54.00
Total	**609.00**	**–0.87**	**608.00**

Figure 2.5. Net present value by country (US$ m): Scenario 2D compared with Scenario 2C



achieve growth in the energy production capacity of the ZRB.

Average energy production, on the other hand, was only marginally influenced by the introduction of e-flow requirements in the lower Delta (Scenario 2A – 59,304 GWh per year; Scenario 2B – 59,138 GWh per year; Scenario 2C – 59,251; and Scenario 2D – 59,178 GWh per year). This pattern was repeated at the individual HPP level.

In terms of NPV, increased coordination of HPPs (from Scenario 2A to 2D) would be equivalent to $1.4 billion and the IRR increases from 10 to 15 percent. There is a premium on firm energy production, and the expansion of that production yields very high benefits. In figure 2.7., the NPV of Scenarios 1–2D is presented. The results demonstrate that the optimization of firm energy production has a significant influence on the viability of the investments made. The NPV of Scenario 2D is substantially higher than that of Scenario 2 for example. The benefits from coordinated operation of the system of HPPs is also reflected in the IRR, where Scenario 2 yields an IRR of 13 percent and Scenarios 2A and 2D yield 10 percent and 15 percent respectively. With a discounting rate of 10 percent, an IRR of 10 percent yields an NPV equal to zero.

Table 2.15. Summary of energy generated in Scenario 0–Scenario 2D

	Existing facilities		SAPP HPPs development and investment				
	Scenario 0	Scenario 1	Scenario 2	Scenario 2A	Scenario 2B	Scenario 2C	Scenario 2D
Energy production	**Stand-alone operation**	**Coordinated operation (no e-flow)**	**Stand-alone operation (no e-flow)**	**Stand-alone operation (incl. e-flow)**	**4 clusters (incl. e-flow)**	**2 clusters (incl. e-flow)**	**Full coordination (incl. e-flow)**
Firm Energy (GWh/year)	22,776	24,397	39,000	35,302	39,928	37,712	43,476
gain/loss (GWh/year)		1,621		–3,697	4,626	2,410	8,173
gain/loss (%)		7%		–9%	13%	7%	23%
Average Energy (GWh/year)	30,287	30,323	60,760	59,304	59,138	59,251	59,178
gain/loss (GWh/year)		37		–1,456	–166	–53	–126
gain/loss (%)		0%		–2%	0%	0%	0%
Scenario for comparison		0		2	2A	2A	2A

Figure 2.6. Summary of firm energy generated in Scenario 0 – Scenario 2D

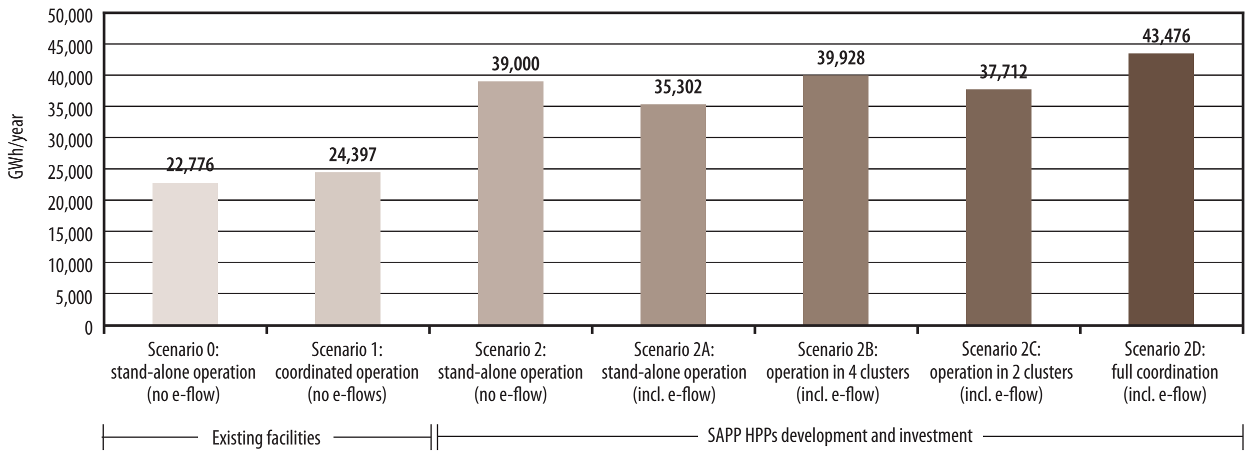
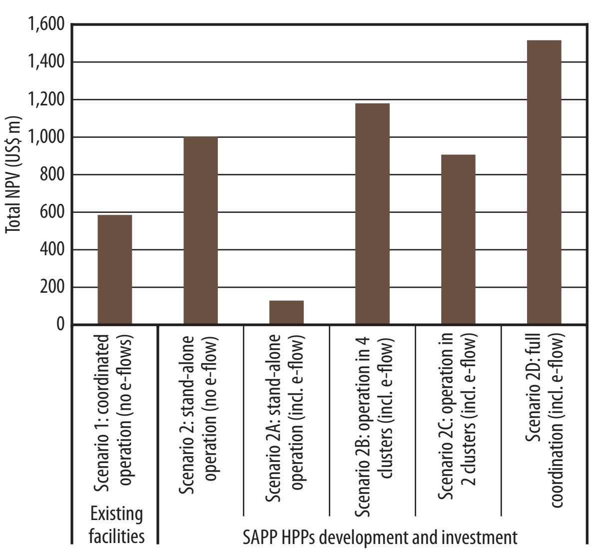


Figure 2.7. Total Net Present Value of hydropower: Scenario 1, 2, and 2A–2D



Operating HPPs in clusters

When the Batoka Gorge Dam would be constructed upstream of Lake Kariba and the Kariba Dam (existing), and if the HPPs of the two dams were operated in conjunction, their total generation of firm energy of both could increase from 7,816 to 17,819 GWh per year (i.e., additional 10,003 GWh per year). This represents a significant 70 percent potential increase in firm energy production. Batoka Gorge Dam would be situated on the same main stem of the Zambezi River as Kariba Dam, the stretch of the river that is equally shared by Zambia and Zimbabwe and under the management of ZRA. Coordinated operation could be achieved in practice by operating Lake Kariba to compensate for shortfalls in the energy production of Batoka Gorge during the dry season. The proposed design criteria for Batoka Gorge Dam provides limited storage capacity in relation to the installed capacity of its HPPs. This would firm up energy to serve the base load, especially in Zambia. But as Kariba would operate at higher reservoir levels on average in Scenario 2B than in Scenario 2A, surface evaporation could increase.

The Itezhi Tezhi reservoir cannot respond immediately to an increase in flow demand from the downstream HPPs due to the attenuating affect of the Kafue Flats. Meanwhile, the Kafue Gorge Upper reservoir located downstream of the Flats, could feed the two HPPs downstream in series. Considering that there is no significant inflow between the existing Kafue Gorge Upper Dam (KGU) and proposed future Kafue Gorge Lower (KGL), Scenario 2A already optimizes this subsystem. Hence, the subsequent scenarios 2B to 2D showed no significant improvement in the generation of firm energy.

The Cahora Bassa Dam in Mozambique currently exports 1,050 MW to Eskom in South Africa under a long-term contract (although more is exported on average). Coordinated operation of Cahora Bassa and the planned Mphanda Nkuwa

HPPs could therefore be influenced by the commitment to South Africa, and therefore, the firm energy production capacity in this proposed cluster may be maximized since inflows are already regulated.

The Shire River and Lake Malawi/Niassa/Nyasa subsystem would primarily be made up of existing and proposed run-of-the-river HPPs or dams with small reservoirs. Of these, only the generation from the proposed Kholombizo Dam can be forecasted with any accuracy as it would be located immediately downstream of the Lake and there is only a small intervening catchment. Outflows from the Lake are directly related to lake levels. All other existing or future HPPs are, or would be either located on relatively minor streams in the Lake Malawi/Niassa/Nyasa catchment or have a significant intervening catchment (if located on the Shire River downstream of Kholombidzo), thus impeding accurate inflow forecasting. In addition, the proposed Rumakali Dam would be managed by a different power utility than the other existing and proposed HPPs. Under these circumstances, this subsystem was not included in Scenarios 2C and 2D.

Quantifying more exact potential benefits from conjunctive operation of the HPPs as one fully integrated system necessitates a generation-planning analysis using such tools as the Web Analytics Solution Profiler (WASP) which is outside the scope of the MSIOA study.

Table 2.16. and 2.17, as well as figure 2.8. illustrate how energy production progresses with the development of scenarios 2, 2A to 2D. More information on the HPPs is outlined in volume 3.

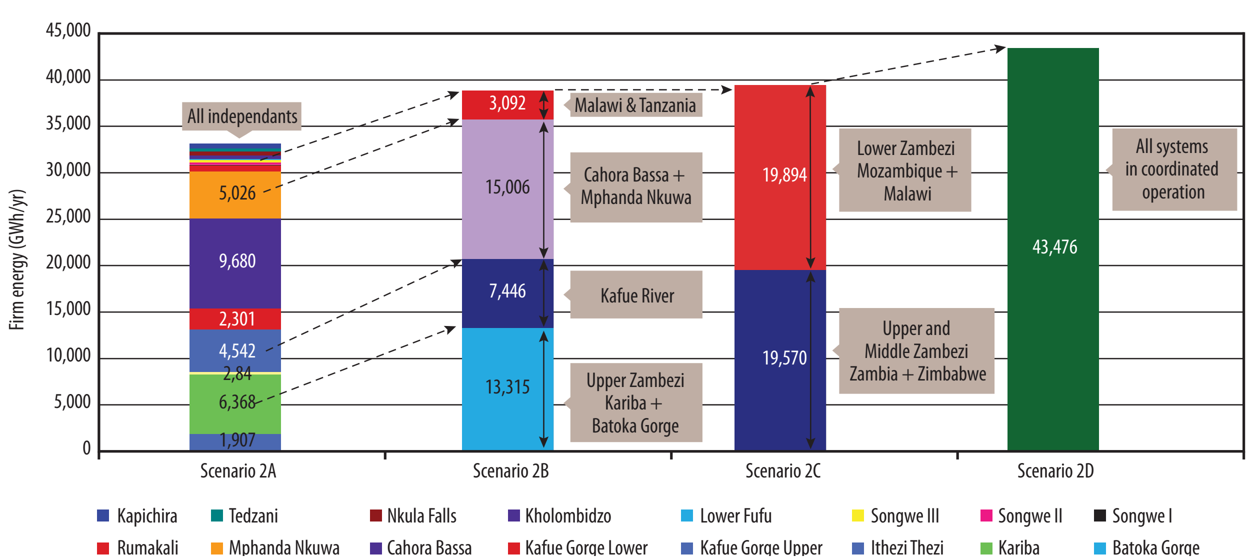
2.8 SCENARIO 3: IDENTIFIED IRRIGATION PROJECTS

Objective: To determine the impact of implementing identified irrigation projects on the energy production of existing system of independently operated HPPs.

Features: Scenario 3 represents the implementation and development of identified irrigation projects (IPs) in the ZRB. The impact of abstraction for IPs is assessed against the energy productivity of existing system of HPPs in Scenario 0 (not operated in conjunction). Releases for e-flows (7,000 m^3 per second in February in the lower Delta) are included as well as abstractions for domestic water supply.

At present, the total equipped irrigation area in the ZRB is approximately 183,000 hectares with a total annual irrigated area of around 260,000

Figure 2.8. Change in firm energy production: from Scenario 2A to 2D



<table>
<tr><th colspan="2" rowspan="3">Hydropower plant</th><th colspan="3">Scenario 2A: stand-alone operation (incl. e-flow)</th><th colspan="6">Scenario 2B: operation in 4 clusters (incl. e-flow)</th><th colspan="4">Scenario 2C: operation in 2 clusters (incl. e-flow)</th><th colspan="2">Scenario 2D: full coordination (incl. e-flow)</th></tr>
<tr><th colspan="3" rowspan="2">Firm Energy (GWh/year)</th><th colspan="6">Firm Energy (GWh/year)</th><th colspan="4">Firm Energy (GWh/year)</th><th colspan="2">Firm Energy (GWh/year)</th></tr>
<tr><th colspan="3"></th><th colspan="3">Increase</th><th colspan="2"></th><th colspan="2">Increase</th><th></th><th>Increase</th></tr>
<tr><td>Batoka Gorge</td><td>projected</td><td rowspan="2">7,816</td><td rowspan="5">15,056</td><td rowspan="16">35,302</td><td rowspan="2">13,315</td><td rowspan="5">18,957</td><td rowspan="16">39,928</td><td rowspan="2">5,499</td><td rowspan="5">3,901</td><td rowspan="16">4,626</td><td rowspan="5">19,570</td><td rowspan="16">37,712</td><td rowspan="5">613</td><td rowspan="16">−2,216</td><td rowspan="16">43,476</td><td rowspan="16">5,764</td></tr>
<tr><td>Kariba</td><td>existing & extension</td></tr>
<tr><td>Itezhi Tezhi</td><td>extension</td><td rowspan="3">7,088</td><td rowspan="3">7,446</td><td rowspan="3">358</td></tr>
<tr><td>Kafue Gorge Upper</td><td>refurbishment</td></tr>
<tr><td>Kafue Gorge Lower</td><td>projected</td></tr>
<tr><td>Cahora Bassa</td><td>existing & extension</td><td rowspan="2">14,685</td><td rowspan="11">18,556</td><td rowspan="2">15,006</td><td rowspan="11">18,913</td><td rowspan="2">321</td><td rowspan="11">357</td><td rowspan="11">19,894</td><td rowspan="11">981</td></tr>
<tr><td>Mphanda Nkuwa</td><td>projected</td></tr>
<tr><td>Rumakali</td><td>projected</td><td rowspan="9">3,091</td><td rowspan="9">3,092</td><td rowspan="9">1</td></tr>
<tr><td>Songwe I</td><td>projected</td></tr>
<tr><td>Songwe II</td><td>projected</td></tr>
<tr><td>Songwe III</td><td>projected</td></tr>
<tr><td>Lower Fufu</td><td>projected</td></tr>
<tr><td>Kholombizo</td><td>projected</td></tr>
<tr><td>Nkula Falls</td><td>existing</td></tr>
<tr><td>Tedzani</td><td>projected</td></tr>
<tr><td>Kapichira</td><td>existing & extension</td></tr>
</table>

Table 2.16. Future firm energy production by HPPs under SAPP in the Zambezi River Basin

Table 2.17. Future energy production in the Zambezi River Basin

Hydropower plant		Scenario 2A: stand-alone operation (incl. e-flow) HPP - GWh/year			Scenario 2B: operation in 4 clusters (incl. e-flow)				Scenario 2C: operation in 2 clusters (incl. e-flow)				Scenario 2D: full coordination (incl. e-flow)			
		Firm	Secondary	Average	HPP total	System of HPP - GWh/year Firm	Secondary	Average	HPP total	System of HPP - GWh/year Firm	Secondary	Average	HPP total	System of HPP - GWh/year Firm	Secondary	Average
Batoka Gorge	projected	1,908	7,730	9,638	9,633	13,315	4,504	17,819	1,927	19,570	9,880	29,450	9,635	43,476	15,702	59,178
Kariba	existing & extension	6,368	1,992	8,360	8,186				1,789				8,168			
Itezhi Tezhi	extension	284	432	716	716	7,446	4,137	11,583	76				716			
Kafue Gorge Upper	refurbishment	4,542	2,224	6,766	6,779				2,718				7,206			
Kafue Gorge Lower	projected	2,301	1,791	4,092	4,088				1,005				3,830			
Cahora Bassa	existing & extension	9,680	4,524	14,204	14,117	15,006	7,685	22,691	6,172	19,894	9,907	29,801	14,004			
Mphanda Nkuwa	projected	5,026	3,450	8,477	8,575				5,086				8,658			
Rumakali	projected	686	299	985	985	3,092	3,953	7,045	—				952			
Songwe I	projected	41	50	91	91				—				80			
Songwe II	projected	277	213	490	490				—				524			
Songwe III	projected	229	185	414	408				—				433			
Lower Fufu	projected	134	510	644	645				134				645			
Kholombizo	projected	344	1,282	1,626	1,626				326				1,603			
Nkula Falls	existing	460	557	1,017	1,017				384				991			
Tedzani	projected	299	423	721	721				221				695			
Kapichira	existing & extension	541	522	1,063	1,063				444				1,040			

hectares.[8] This includes 102,000 hectares of irrigated perennial crops (76 percent of which is used for sugarcane production) and represents around 56 percent of the total equipped area. Table 2.18 summarizes the areas under irrigation and further details on irrigation in the ZRB are outlined in volume 4.

Roughly 100 irrigation projects or programs[9] have been identified from various sources and in consultation with stakeholders in the riparian countries. In the process of data collection, the estimated additional area represented by identified IPs is 336,000 hectares of equipped irrigation area.

Findings: The results of Scenario 3 are compared with Scenario 0 (Base Case – Current Situation). The estimated total equipped irrigation area in the ZRB increases from 183,000 in Scenario 0 to approximately 519,000 hectares when IPs are included (Scenario 3). The additional 336,000 hectares is equivalent to a 184 percent increase in equipped irrigation area.

The estimated total average irrigated area in the ZRB (i.e., considering that one area can be cropped more than once a year), increases from approximately 260,000 to 774,000 hectares when IPs are included (i.e., sum of winter, summer, and perennially cropped areas). The additional 514,000 hectares is equivalent to a 199 percent increase in the equipped irrigation area. See section 2.8.1 for more details.

An increase in the total irrigated area would lead to substantial creation of employment, approximately 250,000 additional jobs (i.e., eight million person years) which would be geographically distributed with the expanded and newly irrigated areas. See section 2.8.2 for more details.

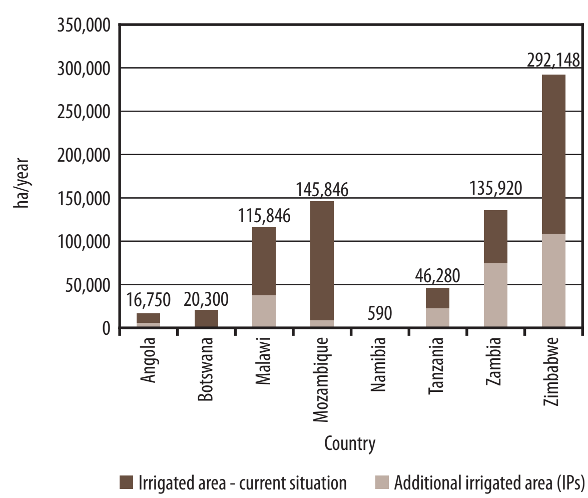
Scenario 3 has significant impact on the energy sector in the ZRB due to necessary water abstractions for the additional irrigation. Comparing Scenario 3 to the current situation in Scenario 0, the implementation of the identified IPs would decrease the production of firm energy in the Basin by 21 percent and total average energy by nine percent. The estimated value of this reduction in energy production is $234 million per year. See section 2.8.3 for more details.

2.8.1 Impact on total average irrigation area

The estimated total average irrigated area of 774,000 hectares when IPs have been implemented, includes 140,000 hectares of additional irrigated perennial crops (78 percent of which is planned for sugarcane), which is equivalent to roughly 42 percent of the total equipped area. Without the perennial crops, the projected irrigation areas have a mean cropping intensity of 196 percent. Winter wheat represents 38 percent of the projected irrigated winter crop areas (see tables 2.18. and 2.19. for details, including the percentage of increase compared with Scenario 0).

Figure 2.9. illustrates the distribution and extent of total average irrigated area under Scenario 3 (i.e., area irrigated in the current situation, plus the additional irrigated area of identified projects).

Figure 2.9. Estimated total average irrigated area per country: Scenario 3 with current irrigation area and Identified Projects



[8] The equipped area is the command area (irrigable area). The irrigated area is the one that is cropped; according to the intensity of use, an equipped area could be potentially used twice a year (intensity of 200 percent); for example one hectare of irrigated wheat in the dry season may also be irrigated with complementary irrigation with one hectare of maize in the wet season.

[9] A single identified irrigation program may include many smaller adjacent identified projects. For instance, "Rehabilitation/optimization of the use of reservoirs in the Luenha subbasin in Zimbabwe" is considered one program even though it includes several different irrigation schemes.

Table 2.18. Current irrigation areas in Zambezi River Basin, by subbasin and country: Scenario 0

	Irrigated (ha)	Equipped (ha)	Dry season (ha)	Wet season (ha)	Perennial (ha)
Subbasin					
Kabompo (13)	595	350	245	245	105
Upper Zambezi (12)	3,250	2,500	1,750	750	750
Lungúe Bungo (11)	1,250	1,000	750	250	250
Luanginga (10)	1,000	750	500	250	250
Barotse (9)	340	200	140	140	60
Cuando/Chobe (8)	765	620	495	145	125
Kafue (7)	46,528	40,158	6,370	6,370	33,788
Kariba (6)	44,531	28,186	16,325	16,345	11,861
Luangwa (5)	17,794	10,100	7,935	7,694	2,165
Mupata (4)	21,790	14,200	7,589	7,590	6,611
Shire River – Lake Malawi/Niassa/Nyasa (3)	60,960	42,416	18,606	18,544	23,810
Tete (2)	52,572	35,159	19,411	17,413	15,748
Zambezi Delta (1)	7,664	6,998	666	666	6,332
Total	**259,039**	**182,637**	**80,782**	**76,402**	**101,855**
Country					
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 2.19. Identified irrigation projects (additional hectares to current irrigated area)

	Irrigated (ha)	Increase (%)	Equipped (ha)	Increase (%)	Dry season (ha)	Wet season (ha)	Perennial (ha)
Subbasin							
Kabompo (13)	10,719	1,802	6,300	1,800	4,419	4,419	1,881
Upper Zambezi (12)	5,000	154	5,000	200	0	0	5,000
Lungúe Bungo (11)	625	50	500	50	375	125	125
Luanginga (10)	5,000	500	5,000	667	5,000	0	0
Barotse (9)	12,413	3,651	7,008	3,504	5,405	5,405	1,603
Cuando/Chobe (8)	450	59	300	48	300	150	0
Kafue (7)	20,520	44	13,610	34	6,910	6,910	6,700
Kariba (6)	184,388	414	119,592	424	64,796	69,096	50,496

Continued on next page

Table 2.19. Identified irrigation projects (additional hectares to current irrigated area) *(continued)*

	Irrigated (ha)	Increase (%)	Equipped (ha)	Increase (%)	Dry season (ha)	Wet season (ha)	Perennial (ha)
Luangwa (5)	11,063	62	6,130	61	4,933	4,933	1,197
Mupata (4)	8,566	39	5,860	41	2,706	2,706	3,154
Shire River - Lake Malawi/Niassa/Nyasa (3)	101,166	166	59,511	140	48,331	41,655	11,180
Tete (2)	55,621	106	30,336	86	25,285	25,285	5,051
Zambezi Delta (1)	99,110	1,293	77,055	1,101	22,055	22,055	55,000
Total	**514,641**	**199**	**336,202**	**184**	**190,515**	**182,738**	**141,387**
Country							
Angola	10,625	173	10,500	221	5,375	125	5,125
Botswana	20,300	0	13,800	0	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**

A number of IPs withdraw water from the Zambezi, Kafue, and Shire rivers which have sufficient water available all year round to satisfy the corresponding water demand. But other projects are located on tributaries where the flow is too low during the dry season to satisfy both irrigation demand and e-flows. There is also a need for additional regulation of flow in addition to the existing regulation that provides water for current irrigation schemes on the Kafue Flats (Itezhi Tezhi), downstream of Lake Malawi/Niassa/Nyasa, Kariba, and Cahora Bassa, including existing small reservoirs along some of the Zimbabwean tributaries.

This regulation need is estimated to around 254 million m^3 for all of the associated irrigation areas. The reservoirs listed in table 2.20. store water during the wet season for release during the irrigation season and have been included in the HEC model. The storage volume is the minimum regulation volume that meets the water demand of e-flows and irrigation at each control point of the system.

Table 2.20. Supplementary regulation requirements for identified projects in Scenario 3

Subbasin	Supplementary regulation (million m^3)
Kabompo (13)	10
Upper Zambezi (12)	15
Lungúe Bungo (11)	0
Luanginga (10)	30
Barotse (9)	0
Cuando/Chobe (8)	0
Kafue (7)	0
Kariba (6)	20
Luangwa (5)	39
Mupata (4)	0
Shire River – Lake Malawi/Niassa/Nyasa (3)	102
Tete (2)	38
Zambezi Delta (1)	0
Total	**254**

2.8.2 Impact on employment

Implementing the IPs included in Scenario 3 could have significant impact on employment creation. An estimated 250,000 additional jobs could be created (i.e., eight million person years). This accrues proportionally to the investment in irrigation development across countries (table 2.21. and figure 2.10.), with Zimbabwe and Mozambique experiencing the highest gains.

2.8.3 Impact on energy production

The development of all IPs included under Scenario 3 results in a 21 percent decrease in firm energy production compared with Scenario 0. The reductions vary among the individual HPP, and is illustrated in table 2.22. (e.g., 27 percent reduction at Kapichira, 26 percent reduction at Cahora Bassa and 11 percent reduction at Kariba).

Total average energy production decreases by nine percent from 30,287 to 27,629 GWh per year compared with Scenario 0. The fall in average energy is not as large as that of firm energy, indicating a shift from firm to secondary energy, which lowers the overall economic benefits generated in the hydropower sector.

2.8.4 Impact on NPV

The annual economic impact of the reduction in hydropower is estimated to be $234 million when the identified irrigation projects are fully implemented.

Table 2.21. Impact on employment by country (person years): Scenario 3

Country	Person years
Angola	271
Botswana	486
Malawi	1,338
Mozambique	2,009
Namibia	8
Tanzania	416
Zambia	918
Zimbabwe	2,634
Total	**8,080**

Figure 2.10. Impact on employment by country (person years): Scenario 3

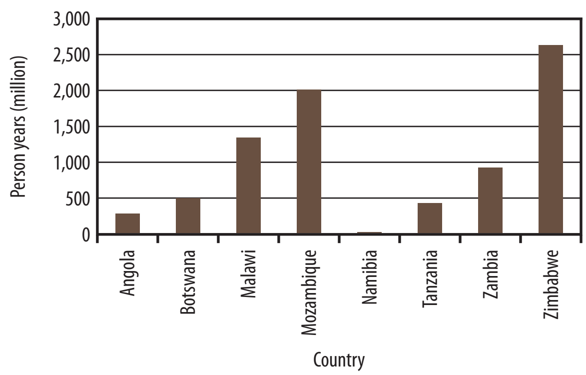


Table 2.22. Impact on energy production: Scenario 3 compared with Scenario 0

	Energy production (GWh/year)				Energy loss (%)	
	Scenario 0		Scenario 3			
Hydropower plant	Firm	Average	Firm	Average	Firm	Average
Kariba	6,369	7,668	5,694	7,059	11	8
Kafue Gorge Upper	4,695	6,785	4,424	6,677	6	2
Cahora Bassa	11,922	13,536	8,804	11,609	26	14
Nkula Falls	462	1,017	442	1,011	4	1
Tedzani	300	721	282	716	6	1
Kapichira	542	560	395	557	27	1
System	**22,776**	**30,287**	**18,052**	**27,629**	**21**	**9**

The reduction in energy production is particularly high for Cahora Bassa HPP (figure 2.11.), whereas the gains in irrigation are centered on the irrigation expansion plans identified in Zimbabwe. In determining the NPV (table 2.23), the numbers for the HPPs are given as yearly productions. The introduction of irrigation is, however, gradual and the fall in hydropower production has therefore been proportioned according to the estimated implementation rate of irrigation projects. The total NPV for hydropower is estimated at being negative $873 million, and for agriculture, a positive $527 million. This type of calculation is done for all scenarios involving irrigation. The economics of irrigation are based on a number of farm models, which are distributed across the Basin and relate to the planned increase in irrigation expansion (hectares). The input from the farm models were integrated into the HEC-3 model. See volume 4 for further details.

Figure 2.11. Net present value by subbasin (US$ m): Scenario 3 compared with Scenario 0

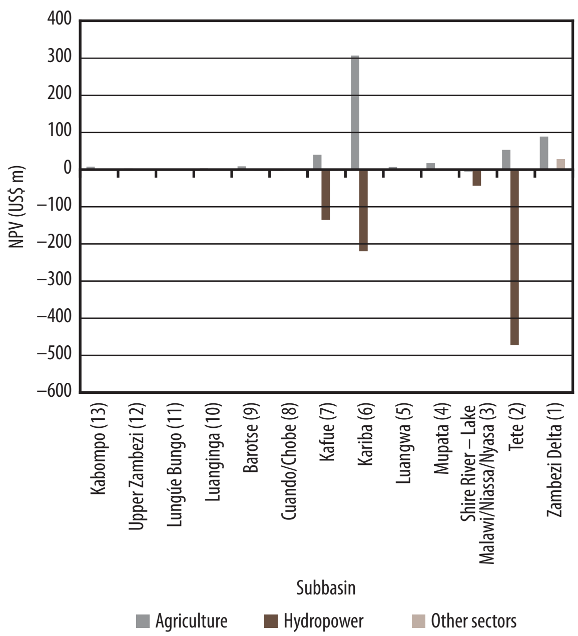
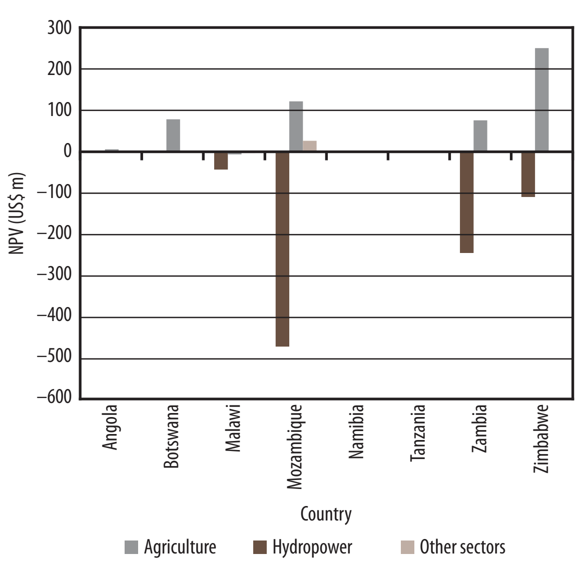


Figure 2.12. Net present value by country (US$ m): Scenario 3 compared with Scenario 0



2.9 SCENARIO 4: HIGH-LEVEL IRRIGATION DEVELOPMENT

Objective: To determine the impact of implementing a set of ambitious high-level irrigation projects on the energy production of the existing system of independently operated HPPs.

Features: Scenario 4 represents the implementation and development of high-level national irrigation projects (HLI) and the identified projects (IPs) concurrently. The total estimated irrigated areas in Scenario 4 are thus the sum of areas of currently irrigated, IPs and HLI. The impact is assessed against the energy production of existing system of HPPs in Scenario 0 (without conjunctive operation). Releases for e-flows (7,000 m^3 per second in February in the lower Delta) are included as well as abstractions for domestic water supply.

Scenario 4 is based on the information provided by riparian countries related to their not yet formalized, long-term and particularly ambitious irrigation expansion strategies. The model shows that the water abstractions needed to realize these strategies may jeopardize water availability for other users, raising questions about feasibility. The assumptions in Scenario 4 are detailed in volume 4.

Findings: The estimated additional equipped irrigated area from implementing the high-level irrigation in Scenario 4 would increase the total equipped irrigation area to approximately 1.73 mil-

Table 2.23. Net present value by subbasin and country (US$ m): Scenario 3 compared with Scenario 0

	Hydropower	Agriculture	Other sectors	Total
Subbasin				
Kabompo (13)	0.00	7.60	0.00	7.60
Upper Zambezi (12)	0.00	2.40	0.00	2.40
Lungúe Bungo (11)	0.00	0.50	0.00	0.50
Luanginga (10)	0.00	2.70	0.00	2.70
Barotse (9)	0.00	8.40	–0.09	8.30
Cuando/Chobe (8)	0.00	0.10	0.00	0.10
Kafue (7)	–135.80	39.60	–0.010	–96.20
Kariba (6)	–220.10	306.40	0.40	86.70
Luangwa (5)	0.00	6.60	0.00	6.60
Mupata (4)	0.00	16.90	0.00	16.90
Shire River – Lake Malawi/Niassa/Nyasa (3)	–43.60	–5.70	–3.57	–52.90
Tete (2)	–472.90	52.70	–1.62	–421.80
Zambezi Delta (1)	0.00	88.50	27.78	116.20
Total	**–872.50**	**526.80**	**22.90**	**–322.80**
Country				
Angola	0.00	5.60	0.00	5.60
Botswana	0.00	78.30	0.00	78.30
Malawi	–43.60	–6.80	–3.60	–54.00
Mozambique	–472.90	121.80	26.20	–324.90
Namibia	0.00	0.10	0.00	0.10
Tanzania	0.00	1.10	0.00	1.10
Zambia	–245.90	75.80	0.10	–170.00
Zimbabwe	–110.10	250.90	0.20	141.00
Total	**–872.50**	**526.80**	**22.90**	**–322.80**

lion hectares. This tremendous increase is equivalent to almost a tenfold increase of the equipped area in the current situation of Scenario 0, and, a 230 percent increase of the total equipped area of Scenario 3 (table 2.24.).

The implementation of the high-level irrigation scenario would increase the total irrigated area to approximately 2.8 million hectares. Similarly to the increase in the equipped area, this is equivalent to more than a tenfold increase compared with the current situation (Scenario 0), and roughly, a two million additional hectares to when identified projects of Scenario 3 are implemented (table 2.24). See section 2.9.1 for more details.

The high-level irrigation Scenario 4 would lead to substantial new employment, potentially creating more than one million jobs (i.e., 34 million person years). These jobs would be geographically distributed across the expanded and new irrigated areas. See section 2.9.2 for more details.

Due to the necessary water abstractions for the HLI in Scenario 4, energy productivity in the ZRB is significantly curtailed. Compared with energy generation in the current situation of Scenario 0 (i.e., existing system of HPPs without conjunctive operation) firm energy under Scenario 4 is reduced by 49 percent to 11,600 GWh per year, and, total average energy is reduced by 28 percent to 21,907

GWh per year. The estimated value of the energy losses is $234 million per year. See section 2.9.3 for more details.

2.9.1 Impact on total irrigation area

Scenario 4 includes 360,000 hectares of additional irrigated perennial crops (65 percent of sugarcane), equivalent to around 30 percent of the total equipped area. Without the perennial crops, the projected irrigation areas have a mean cropping intensity of 197 percent. Winter wheat represents 36 percent of the projected irrigated winter crop areas.

Figure 2.13. illustrates the distribution and extent of total irrigated area under Scenario 4 (i.e., area irrigated in the current situation, plus the additional irrigated area under IPs, plus the high-level irrigation predictions).

The supplementary regulation requirements in Scenario 4 is estimated at approximately 3,000 million m^3 across the Basin (table 2.25.), representing around 12 times the regulation needs of the IPs.

Table 2.24. Additional high-level irrigation areas (ha) compared with IPs by subbasin and country

	Additional irrigated area (ha)	Increase (%)	Additional equipped area (ha)	Increase (%)	Additional dry season (ha)	Additional wet season (ha)	Additional perennial (ha)
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	2,000	10,000	2,000	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	4,000	15,000	5,000	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)	604,630	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 (1)	125,000	126	100,000	130	25,000	25,000	75,000
Total	**2,022,120**	**393**	**1,208,800**	**360**	**846,800**	**817,620**	**357,700**
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	4,000	15,000	5,000	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	**2,022,119**	**393**	**1,208,800**	**360**	**846,800**	**817,619**	**357,700**

2.9.2 Impact on employment

The ambitious development of the irrigation sector in Scenario 4 generates large agricultural benefits and employment. The impact on employment creation for this scenario is estimated at approximately 1,131,000 additional jobs (i.e., 34 million person years). The geographic distributions of these job opportunities are detailed in table 2.26. and figure 2.14.

Figure 2.13. Estimated additional total average irrigated area in Scenario 4: current situation, identified projects and high-level irrigation development

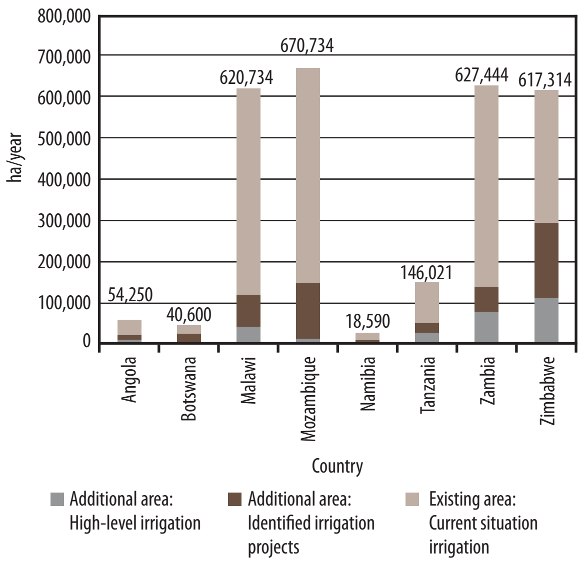


Table 2.25. Supplementary regulation requirements for high-level irrigation projects in Scenario 4

Subbasin	Supplementary regulation (million m³)
Kabompo (13)	35
Upper Zambezi (12)	40
Lungúe Bungo (11)	35
Luanginga (10)	160
Barotse (9)	10
Cuando/Chobe (8)	200
Kafue (7)	0
Kariba (6)	40
Luangwa (5)	70
Mupata (4)	0
Shire River – Lake Malawi/ Niassa/Nyasa (3)	2,450
Tete (2)	38
Zambezi Delta (1)	0
Total	**3,078**

2.9.3 Impact on energy production

The effect of HLI on hydropower production in Scenario 4 is detailed in table 2.27. Compared with the current situation in Scenario 0, the production of firm energy falls with 49 percent, from 22,776 to 11,600 GWh per year. The drop is mainly driven by the fall in energy production of HPPs with carry-over reservoirs, namely Kariba and Cahora Bassa. The average energy production in Scenario 4 is 21,907 GWh per year, which is equivalent to a 28

Table 2.26. Impact on employment by subbasin (person years): Scenario 4

Country	Person years
Angola	844
Botswana	0
Malawi	9,577
Mozambique	6,102
Namibia	177
Tanzania	2,209
Zambia	7,567
Zimbabwe	7,473
Total	**33,950**

Figure 2.14. Impact on employment by country (person years): Scenario 4

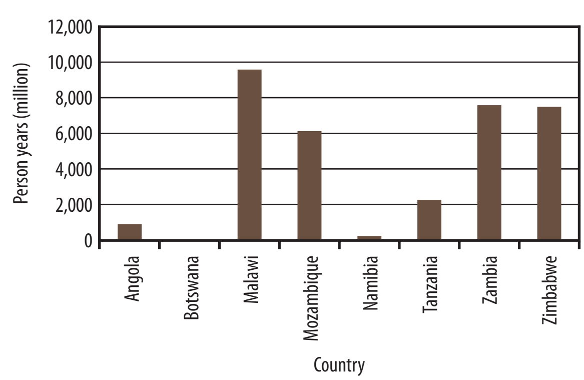


Table 2.27. Impact on energy production: Scenario 4 compared to Scenario 0

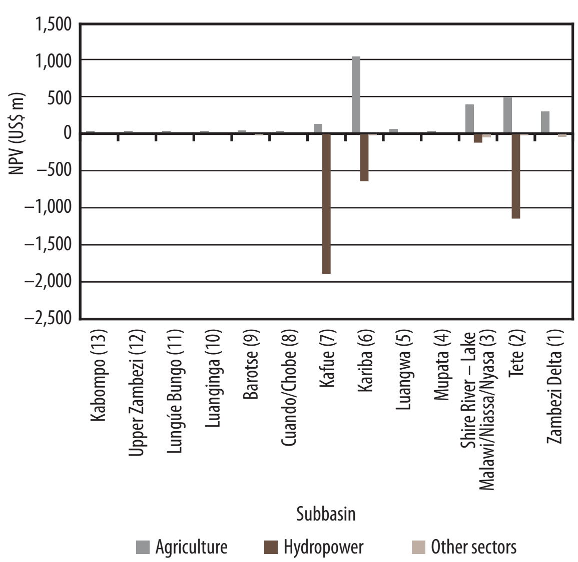
	Energy production (GWh/year)				Energy loss (%)	
	Scenario 0		Scenario 4			
Hydropower plant	Firm	Average	Firm	Average	Firm	Average
Kariba	6,369	7,668	3,171	4,701	50	39
Kafue Gorge Upper	4,695	6,785	3,819	6,460	19	5
Cahora Bassa	11,922	13,536	4,949	8,622	58	36
Nkula Falls	462	1,017	272	936	41	8
Tedzani	300	721	173	651	42	10
Kapichira	542	560	102	537	81	4
System	**22,776**	**30,287**	**11,600**	**21,907**	**49**	**28**

percent decrease compared with the 30,287 GWh per year of energy produced in Scenario 0.

2.9.4 Impact on NPV

The total economic loss due to the enormous drop in the HPP system's energy production under Scenario 4 would exceeds the benefits gained from the high-level expansion in irrigation. The yearly economic loss compared to Scenario 0 is estimated at $597 million and the break-even point is at a firm energy price of approximately $0.04.

Figure 2.15. Net present value by subbasin (US$ m): Scenario 4 compared to Scenario 0



2.10 SCENARIO 5: SAPP HYDROPOWER PLANS AND IDENTIFIED IRRIGATION PROJECTS

Objective: To assess the impact of parallel implementation of the system of HPPs envisaged under SAPP and identified irrigation projects, without any basin-level coordination in either sector.

Features: Scenario 5 incorporates the development of identified irrigation projects (IPs) and the system of independently operated HPP facilities under SAPP (the latter equivalent to Scenario 2A). Releases for e-flows (7,000 m^3 per second in February in the

Figure 2.16. Net present value by country (US$ m): Scenario 4 compared to Scenario 0

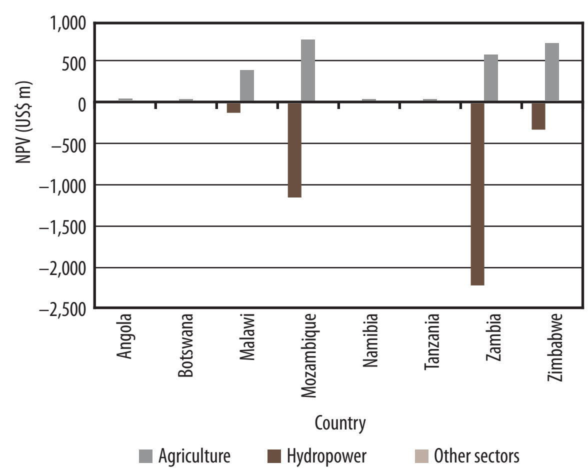


Table 2.28. Net present value by subbasin and country (US$ m): Scenario 4 compared to Scenario 0

	Hydropower	Agriculture	Other sectors	Total
Subbasin				
Kabompo (13)	0.00	19.30	0.00	19.30
Upper Zambezi (12)	0.00	10.70	0.00	10.70
Lungúe Bungo (11)	0.00	9.20	0.00	9.20
Luanginga (10)	0.00	6.00	0.00	6.00
Barotse (9)	0.00	19.90	–0.20	19.70
Cuando/Chobe (8)	0.00	–3.60	0.00	–3.60
Kafue (7)	–1,899.40	113.70	0.00	–1,785.70
Kariba (6)	–639.10	1,026.00	–1.20	385.70
Luangwa (5)	0.00	42.00	0.00	42.00
Mupata (4)	0.00	16.90	0.00	16.90
Shire River – Lake Malawi/Niassa/Nyasa (3)	–113.80	376.40	–37.50	225.10
Tete (2)	–1,146.60	477.30	–2.10	–671.40
Zambezi Delta (1)	0.00	283.20	28.10	311.30
Total	**–3,798.80**	**2,397.00**	**–13.00**	**–1,414.80**
Country				
Angola	0.00	26.00	0.00	26.00
Botswana	0.00	–2.30	0.00	–2.30
Malawi	–113.80	369.00	–37.50	217.70
Mozambique	–1,146.60	741.10	26.00	–379.50
Namibia	0.00	–3.60	0.00	–3.60
Tanzania	0.00	7.30	0.00	7.30
Zambia	–2,219.00	557.90	–0.90	–1,662.00
Zimbabwe	–319.50	701.60	–0.60	381.50
Total	**–3,798.90**	**2,397.00**	**–13.00**	**–1,414.90**

lower Delta) are included as well as abstractions for domestic water supply.

Findings: The effect of adding IPs to the energy production of the system of HPP under SAPP is detailed in table 2.29. At the basin-level, abstracting additional water for the identified IPs would reduce firm energy production by eight percent, from 35,302 to 32,358 GWh per year. The decrease in firm energy production varies between HPPs, where firm energy production diminishes drastically in the case of Songwe I and II, and Kapichira, for example. But firm energy is selected at the 99 percent point of the energy production duration curve, the zone where power generation drops off rapidly. Such results are to be expected, especially for run-of-the-river HPPs.

Overall average energy production also decreases in Scenario 5, by four percent from 59,304 to 56,993 GWh per year. Average energy loss is marginal for HPPs located in the Kafue subbasin, but rather significant for the HPPs located on the main stem of the Zambezi River (with the exception of the proposed Batoka Gorge Dam). The impact on energy in Scenario 5 is detailed in table 2.29.

The decrease in energy production when water is abstracted from the system for the additional IPs, leads to a negative NPV (table 2.31.). The absolute

Table 2.29. Impact of IPs on HPP energy generation under SAPP: Scenario 5 compared with Scenario 2A

Hydropower plant		Energy production (GWh/year)				% Change in energy production	
		Scenario 2A		Scenario 5			
		Firm	Average	Firm	Average	Firm	Average
Batoka Gorge	projected	1,907	9,638	1,660	9,479	–13	–2
Kariba	existing and extension	6,369	8,360	5,694	7,709	–11	–8
Itezhi Tezhi	extension	284	716	258	712	–9	0
Kafue Gorge Upper	refurbishment	4,542	6,766	4,424	6,677	–3	0
Kafue Gorge Lower	projected	2,301	4,092	2,239	4,036	–3	0
Cahora Bassa	existing and extension	9,680	14,204	8,804	13,449	–9	–5
Mphanda Nkuwa	projected	5,026	8,477	4,554	8,063	–9	–5
Rumakali	projected	686	985	670	966	–2	–2
Songwe I	projected	41	90	29	75	–29	–17
Songwe II	projected	277	490	228	436	–18	–11
Songwe III	projected	229	414	197	378	–14	–9
Lower Fufu	projected	134	645	134	645	0	0
Kholombizo	projected	344	1,626	318	1,603	–8	0
Nkula Falls	existing	460	1,017	440	1,010	–4	0
Tedzani	existing	299	721	281	714	–6	0
Kapichira	existing and extension	541	1,063	394	1,041	–27	–2
Total		**35,302**	**59,304**	**32,358**	**56,993**	**–8**	**–4**

and relative fall in energy production, however, is not as significant as in Scenario 3. Similar to Scenario 3, the development of IPs would provide substantial employment benefits, estimated at approximately 250,000 additional jobs (i.e., eight million person years).

The regulation needs for Scenarios 5 is detailed in table 2.30. (the same supplementary requirements apply to Scenario 5A). The table shows an overall reduction in requirement, because there are no supplementary requirements in the Upper Zambezi and Kariba subbasins.

2.11 SCENARIO 5A: SAPP HYDROPOWER PLANS AND COORDINATED IDENTIFIED IRRIGATION PROJECTS

Objective: To assess the impact of parallel implementation of a system of independently operated

Table 2.30. Supplementary regulation requirements in Scenarios 5 and 5A

Subbasin	Supplementary regulation (million m³)	
	Scenario 5	Scenario 5A
Kabompo (13)	10	10
Upper Zambezi (12)	15	0
Lungúe Bungo (11)	0	0
Luanginga (10)	30	30
Barotse (9)	0	0
Cuando/Chobe (8)	0	0
Kafue (7)	0	0
Kariba (6)	20	0
Luangwa (5)	39	39
Mupata (4)	0	0
Shire River – Lake Malawi/Niassa/Nyasa (3)	102	102
Tete (2)	38	38
Zambezi Delta (1)	0	0
Basin total	**254**	**219**

Figure 2.17. Net present value by subbasin (US$ m): Scenario 5 compared with Scenario 2A

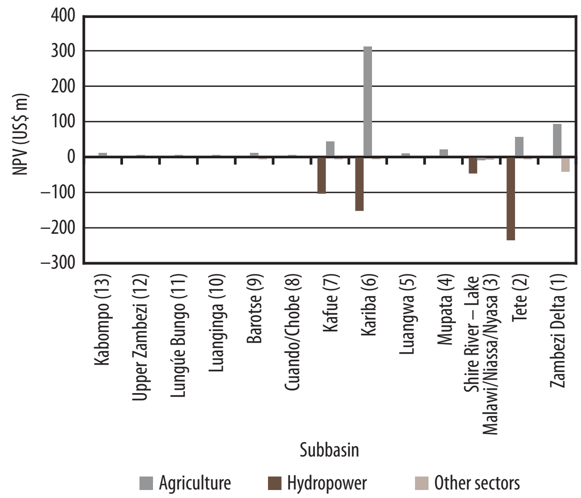


Figure 2.18. Net present value by country (US$ m): Scenario 5 compared with Scenario 2A

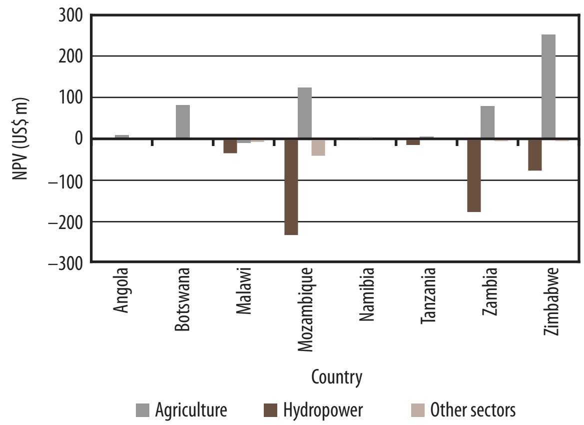


Table 2.31. Net present value by subbasin and country (US$ m): Scenario 5 compared with Scenario 2A

	Hydropower	Agriculture	Other sectors	Total change
Subbasin				
Kabompo (13)	0.00	7.60	0.00	7.60
Upper Zambezi (12)	0.00	2.40	0.00	2.40
Lungúe Bungo (11)	0.00	0.50	0.00	0.50
Luanginga (10)	0.00	2.70	0.00	2.70
Barotse (9)	0.00	8.40	–0.10	8.30
Cuando/Chobe (8)	0.00	0.10	0.00	0.10
Kafue (7)	–101.10	39.60	–0.00	–61.50
Kariba (6)	–149.40	306.40	0.40	157.40
Luangwa (5)	0.00	6.6	0.00	6.60
Mupata (4)	0.00	16.9	0.00	16.90
Shire River – Lake Malawi/Niassa/Nyasa (3)	–44.30	–5.70	–3.80	–53.80
Tete (2)	–232.00	52.70	–0.30	–179.50
Zambezi Delta (1)	0.00	88.50	–37.50	51.00
Total	**–526.80**	**526.80**	**–41.20**	**–41.20**
Country				
Angola	0.00	5.60	0.00	5.60
Botswana	0.00	78.30	0.00	78.30
Malawi	–32.20	–6.80	–3.80	–109.60
Mozambique	–232.00	121.80	–37.80	–147.90
Namibia	0.00	0.10	0.00	0.10
Tanzania	–12.10	1.10	0.00	–11.00
Zambia	–175.80	75.80	0.10	–33.10
Zimbabwe	–74.70	250.90	0.20	176.40
Total	**–526.80**	**526.80**	**–41.20**	**–41.20**

HPPs envisaged under SAPP, and identified irrigation projects which are coordinated at basin level.

Features: Scenario 5A is based on the development of coordinated identified IPs for sector optimization (i.e., moving irrigated area from upstream to downstream), as well as the development of the system of independently operated hydropower facilities under SAPP (i.e., Scenario 2A). Releases for e-flows (7,000 m^3 per second in February in the lower Delta) are included as well as abstractions for domestic water supply.

Coordination in the irrigation sector in Scenario 5A implies relocating 70 percent of the identified sugar irrigation projects in the Upper Zambezi, Kafue, and Kariba (upstream of Lake Kariba) subbasins downstream to the Zambezi Delta subbasin (approximately 28,000 hectares of sugarcane).[10]

Findings: In Scenario 5A, the production of firm energy in the system of HPPs envisaged under SAPP increases as a result of optimized IPs (i.e., due to increased water availability), with two percent from 32,358 to 33,107 GWh per year. The average energy production also increases compared with Scenario 5, by one percent to 57,468 GWh per year. Details are provided in table 2.35.

The total equipped irrigation area in the ZRB increases by 1.5 percent in Scenario 5A compared with Scenario 5 (from 518,839 to 526,336 hectares). The increase in total average irrigated area is slightly higher, approximately two percent (from 773,680 to 788,680 hectares). The impact is detailed in table 2.32., table 2.33. and table 2.34.

Compared with Scenario 5, introducing optimization in irrigation leads to increased energy production. This increase would equate to a positive

Table 2.32. Total additional irrigated and equipped area (ha) from IPs: Scenario 5A compared with Scenario 5

	Scenario 5		Scenario 5A		Change in area (ha)	
Subbasin	Additional equipped area (ha)	Additional irrigated area (ha)	Additional equipped area (ha)	Additional irrigated area (ha)	Equipped area (ha)	Irrigated area (ha)
Kabompo (13)	6,300	10,719	6,300	10,719	0	0
Upper Zambezi (12)	5,000	5,000	1,500	1,500	–3,500	–3,500
Lungúe Bungo (11)	500	625	500	625	0	0
Luanginga (10)	5,000	5,000	5,000	5,000	0	0
Barotse (9)	7,008	12,413	7,008	12,413	0	0
Cuando/Chobe (8)	300	450	300	450	0	0
Kafue (7)	13,610	20,520	9,011	15,921	–4,599	–4,599
Kariba (6)	119,592	184,388	99,643	164,438	–19,949	–19,950
Luangwa (5)	6,130	11,063	6,130	11,063	0	0
Mupata (4)	5,860	8,566	5,860	8,566	0	0
Shire River – Lake Malawi/ Niassa/Nyasa (3)	59,511	101,166	59,511	101,166	0	0
Tete (2)	30,336	55,621	30,336	55,621	0	0
Zambezi Delta (1)	77,055	99,110	105,104	127,159	28,049	28,049
Total additional area (IPs)	**336,202**	**514,641**	**336,203**	**514,641**	**1**	**0**
Total existing area	**182,637**	**259,039**	**182,637**	**259,039**	**0**	**0**
TOTAL (current situation + IPs)	**518,839**	**773,680**	**518,840**	**773,680**	**1**	**0**

[10] In Scenarios 3 and 5 (i.e., implementation of IPs with existing system of HPPs, and with implementation of HPPs under SAPP, respectively), irrigation projects are included in the water allocation model at the sites identified in existing feasibility or prefeasibility studies.

Table 2.33. Dry season, Perennial and Wet season crops per subbasin: Scenario 5A compared with Scenario 5

	Dry season crops							Perennial crops						Wet season crops					
Subbasin	Winter Wheat	Winter rice	Winter maize	Vegetables	Beans	Winter cotton	Other	Sugar	Tea	Coffee	Citrus	Bananas	Pasture	Maize	Soy-beans	Sor-ghum	Cotton	Tobacco	Rice
Scenario 5																			
Kabompo (13)	2,455	0	0	1,145	0	0	819	0	0	0	409	0	1,472	1,596	0	0	0	859	0
Upper Zambezi (12)	0	0	0	0	0	0	0	5,000	0	0	0	0	0	0	0	0	0	0	0
Lungúe Bungo (11)	0	250	0	125	0	0	0	0	0	0	125	0	0	0	0	0	0	0	0
Luanginga (10)	0	5,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barotse (9)	1,603	0	0	3,801	0	0	1	0	0	0	1,601	0	2	1,042	0	0	0	561	0
Cuando/Chobe (8)	0	150	0	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kafue (7)	6,710	0	0	120	0	80	0	6,570	0	0	120	10	0	0	6,710	0	80	0	0
Kariba (6)	40,960	0	5,000	8,541	0	0	10,295	28,499	3,356	5,033	6,472	0	7,136	15,120	12,466	2,300	13,686	6,688	0
Luangwa (5)	4,258	0	0	370	235	0	70	0	0	0	584	0	613	3,019	0	0	0	1,474	0
Mupata (4)	1,610	0	0	777	0	0	319	905	107	1,260	670	0	213	523	332	0	434	321	0
Shire River – Lake Malawi/Niassa/Nyasa (3)	0	15,950	20,070	1,928	942	6,676	2,765	11,120	60	0	0	0	0	12,080	5,356	1,439	2,136	0	15,950
Tete (2)	15,330	0	75	4,722	4,075	0	1,082	3,066	361	542	361	0	722	8,614	3,853	1,212	5,108	693	0
Zambezi Delta (1)	0	22,055	0	0	0	0	0	55,000	0	0	0	0	0	0	0	0	0	0	22,055
Total	**72,926**	**43,405**	**25,145**	**21,680**	**5,252**	**6,756**	**15,352**	**110,160**	**3,883**	**6,835**	**10,341**	**10**	**10,158**	**41,994**	**28,717**	**4,951**	**21,444**	**10,596**	**38,005**
% of winter crops	38%	23%	13%	11%	3%	4%	8%												
% of summer crops				12%			8%							23%	16%	3%	12%	6%	21%
% of perennial crops								78%	3%	5%	7%	0%	7%						
SCENARIO 5A																			
Kabompo (13)	2,455	0	0	1,145	0	0	819	0	0	0	409	0	1,472	1,596	0	0	0	859	0
Upper Zambezi (12)	0	0	0	0	0	0	0	1,500	0	0	0	0	0	0	0	0	0	0	0
Lungúe Bungo (11)	0	250	0	125	0	0	0	0	0	0	125	0	0	0	0	0	0	0	0
Luanginga (10)	0	5,000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Barotse (9)	1,603	0	0	3,801	0	0	1	0	0	0	1,601	0	2	1,042	0	0	0	561	0
Cuando/Chobe (8)	0	150	0	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kafue (7)	6,710	0	0	120	0	80	0	1,971	0	0	120	10	0	0	6,710	0	80	0	0
Kariba (6)	40,960	0	5,000	8,541	0	0	10,295	8,550	3,356	5,033	6,472	0	7,136	15,120	12,466	2,300	13,686	6,688	0
Luangwa (5)	4,258	0	0	370	235	0	70	0	0	0	584	0	613	3,019	0	0	0	1,474	0
Mupata (4)	1,610	0	0	777	0	0	319	905	107	1,260	670	0	213	523	332	0	434	321	0
Shire River – Lake Malawi/Niassa/Nyasa (3)	0	15,950	20,070	1,928	942	6,676	2,765	11,120	60	0	0	0	0	12,080	5,356	1,439	2,136	0	15,950
Tete (2)	15,330	0	75	4,722	4,075	0	1,082	3,066	361	542	361	0	722	8,614	3,853	1,212	5,108	693	0
Zambezi Delta (1)	0	22,055	0	0	0	0	0	83,049	0	0	0	0	0	0	0	0	0	0	22,055
Total	**72,926**	**43,405**	**25,145**	**21,680**	**5,252**	**6,756**	**15,352**	**110,160**	**3,883**	**6,835**	**10,341**	**10**	**10,158**	**41,994**	**28,717**	**4,951**	**21,444**	**10,596**	**38,005**
% of winter crops	38%	23%	13%	11%	3%	4%	8%												
% of summer crops				12%			8%							23%	16%	3%	12%	6%	21%
% of perennial crops								78%	3%	5%	7%	0%	7%						

Note: Shaded fields indicate change between Scenario 5 and Scenario 5A.

Table 2.34. Dry season, Perennial and Wet season crops per country: Scenario 5A compared with Scenario 5

	Dry season crops							Perennial crops						Wet season crops					
Country	**Winter wheat**	**Winter rice**	**Winter maize**	**Vegetables**	**Beans**	**Winter cotton**	**Other**	**Sugar**	**Tea**	**Coffee**	**Citrus**	**Bananas**	**Pasture**	**Maize**	**Soybeans**	**Sorghum**	**Cotton**	**Tobacco**	**Rice**
SCENARIO 5																			
Angola	0	5,250	0	125	0	0	0	5,000	0	0	125	0	0	0	0	0	0	0	0
Botswana	0	0	5,000	1,500	0	0	0	0	0	0	3,000	0	0	5,000	2,000	2,300	0	0	0
Malawi	0	6,141	18,916	1,351	942	6,676	2,765	11,120	0	0	0	0	0	11,503	5,149	1,346	1,859	0	6,141
Mozambique	11,000	22,055	75	4,000	4,075	0	0	55,000	0	0	0	0	0	7,575	2,727	1,212	3,636	0	22,055
Namibia	0	150	0	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanzania	0	9,809	1,154	577	0	0	0	0	60	0	0	0	0	577	208	92	277	0	9,809
Zambia	16,066	0	0	6,330	235	80	1,126	6,570	0	1,101	3,393	10	2,511	6,333	6,710	0	80	3,258	0
Zimbabwe	45,860	0	0	7,646	0	0	11,460	32,470	3,823	5,735	3,823	0	7,646	11,006	11,924	0	15,592	7,338	0
Total	**72,926**	**43,405**	**25,145**	**21,680**	**5,252**	**6,756**	**15,352**	**110,160**	**3,883**	**6,835**	**10,341**	**10**	**10,158**	**41,994**	**28,717**	**4,951**	**21,444**	**10,596**	**38,005**
SCENARIO 5A																			
Angola	0	5,250	0	125	0	0	0	1,500	0	0	125	0	0	0	0	0	0	0	0
Botswana	0	0	5,000	1,500	0	0	0	0	0	0	3,000	0	0	5,000	2,000	2,300	0	0	0
Malawi	0	6,141	18,916	1,351	942	6,676	2,765	11,120	0	0	0	0	0	11,503	5,149	1,346	1,859	0	6,141
Mozambique	11,000	22,055	75	4,000	4,075	0	0	83,049	0	0	0	0	0	7,575	2,727	1,212	3,636	0	22,055
Namibia	0	150	0	150	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanzania	0	9,809	1,154	577	0	0	0	0	60	0	0	0	0	577	208	92	277	0	9,809
Zambia	16,066	0	0	6,330	235	80	1,126	1,971	0	1,101	3,393	10	2,511	6,333	6,710	0	80	3,258	0
Zimbabwe	45,860	0	0	7,646	0	0	11,460	12,520	3,823	5,735	3,823	0	7,646	11,006	11,924	0	15,592	7,338	0
Total	**72,926**	**43,405**	**25,145**	**21,680**	**5,252**	**6,756**	**15,352**	**110,160**	**3,883**	**6,835**	**10,341**	**10**	**10,158**	**41,994**	**28,717**	**4,951**	**21,444**	**10,596**	**38,005**

Note: Shaded fields indicate change between Scenario 5 and Scenario 5A.

change in NPV by $140 million (table 2.36.). This indicates that coordinated development of irrigation projects would improve the economic viability of water resources development investments in the ZRB. The distribution of NPV by country and by subbasin are illustrated in figure 2.19. and figure 2.20. The regulation requirements for Scenario 5A are the same as for Scenario 5 (table 2.30.).

Table 2.35. Impact of IPs with coordination on HPP energy generation under SAPP: Scenario 5A compared with Scenario 5

		Energy production (GWh/year)				% Change in energy production	
		Scenario 5		Scenario 5A			
Hydropower plant		**Firm**	**Average**	**Firm**	**Average**	**Firm**	**Average**
Batoka Gorge	projected	1,660	9,479	1,696	9,495	2	0
Kariba	existing & extension	5,694	7,709	5,825	7,850	2	2
Itezhi Tezhi	extension	258	712	258	712	0	0
Kafue Gorge Upper	refurbishment	4,424	6,677	4,459	6,714	1	1
Kafue Gorge Lower	projected	2,239	4,036	2,252	4,061	1	1
Cahora Bassa	existing & extension	8,804	13,449	8,970	13,613	2	1
Mphanda Nkuwa	projected	4,554	8,063	4,643	8,154	2	1
Rumakali	projected	670	966	670	966	0	0
Songwe I	projected	29	75	29	75	0	0
Songwe II	projected	228	436	228	436	0	0
Songwe III	projected	197	378	197	378	0	0
Lower Fufu	projected	134	645	134	645	0	0
Kholombizo	projected	318	1,603	318	1,603	0	0
Nkula Falls	existing	440	1,010	440	1,010	0	0
Tedzani	projected	281	714	281	715	0	0
Kapichira	existing & extension	394	1,041	394	1,041	0	0
Total		**32,358**	**56,993**	**33,107**	**57,468**	**2**	**1**

Figure 2.19. Net present value by subbasin (US$ m): Scenario 5A compared with Scenario 5

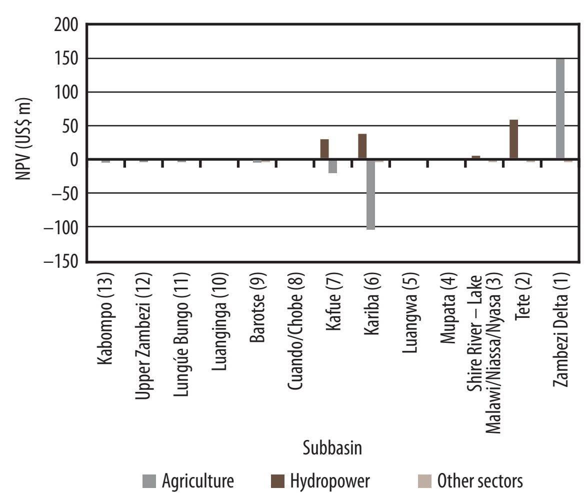


Figure 2.20. Net present value by country (US$ m): Scenario 5A compared with Scenario 5

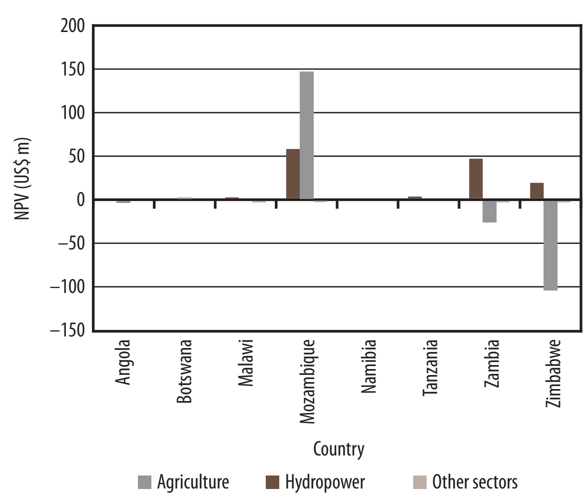


Table 2.36. Net present value by subbasin and country (US$ m): Scenario 5A compared with Scenario 5

	Hydropower	Agriculture	Other sectors	Total change
Subbasin				
Kabompo (13)	0.00	–2.60	0.00	–2.60
Upper Zambezi (12)	0.00	–1.40	0.00	–1.40
Lungúe Bungo (11)	0.00	–0.30	0.00	–0.30
Luanginga (10)	0.00	0.00	0.00	0.00
Barotse (9)	0.00	–3.00	0.0	–3.00
Cuando/Chobe (8)	0.00	0.00	0.00	0.00
Kafue (7)	27.70	–18.10	0.00	9.60
Kariba (6)	35.60	–101.70	0.10	–66.00
Luangwa (5)	0.00	0.00	0.00	0.00
Mupata (4)	0.00	0.00	0.00	0.00
Shire River – Lake Malawi/Niassa/Nyasa (3)	3.30	0.00	–0.00	3.30
Tete (2)	56.50	0.00	0.10	56.60
Zambezi Delta (1)	0.00	145.80	0.40	146.20
Total	**123.10**	**18.70**	**0.50**	**142.10**
Country				
Angola	0.00	–1.80	0.00	–1.80
Botswana	0.00	0.90	0.00	0.90
Malawi	1.20	0.00	–0.00	1.10
Mozambique	56.50	145.80	0.40	202.70
Namibia	0.00	0.00	0.00	0.00
Tanzania	2.10	0.00	0.00	2.10
Zambia	45.50	–24.50	0.10	21.00
Zimbabwe	17.80	–101.90	0.10	–84.00
Total	**123.10**	**18.50**	**0.50**	**142.10**

2.12 SCENARIO 6: SAPP HYDROPOWER PLANS AND HIGH-LEVEL IRRIGATION DEVELOPMENT

Objective: To assess the impact of parallel implementation of the system of HPPs envisaged under SAPP and a high-level of irrigation development (HLI), without any basin-level coordination in either sector.

Features: Scenario 6 is based on high-level irrigation development as in Scenario 4 (i.e., the sum of current irrigated area, plus IPs, plus additional high-level potential irrigation). Scenario 6 is also based on implementing independently operated HPPs facilities under SAPP (Scenario 2A). Releases for e-flows (7,000 m^3 per second in February in the lower Delta) are included as well as abstractions for domestic water supply.

Findings: The large water abstractions needed for implementing the HLI projects reduces the energy productivity of the system of HPPs under SAPP. Firm energy production decreases by 37 percent to 22,282 GWh per year compared with 35,302 GWh per year in Scenario 2A (i.e., the system of HPPs under SAPP without any superimposed additional

Table 2.37. Impact of high-level irrigation on HPP energy generation under SAPP without any coordination: Scenario 6 compared with Scenario 2A

		Energy production (GWh/year)				% Change in energy production	
		Scenario 2A		Scenario 6			
Hydropower plant		**Firm**	**Average**	**Firm**	**Average**	**Firm**	**Average**
Batoka Gorge	projected	1,907	9,637	1,099	9,123	–42	–5
Kariba	existing & extension	6,369	8,361	3,171	5,255	–50	–37
Itezhi Tezhi	extension	284	716	208	705	–27	–2
Kafue Gorge Upper	refurbishment	4,542	6,766	3,811	6,460	–16	–5
Kafue Gorge Lower	projected	2,301	4,092	1,924	3,913	–16	–4
Cahora Bassa	existing & extension	9,680	14,204	4,967	10,361	–49	–27
Mphanda Nkuwa	projected	5,026	8,476	2,511	6,347	–50	–25
Rumakali	projected	686	985	670	966	–2	–2
Songwe I	projected	41	91	32	75	–23	–18
Songwe II	projected	277	490	237	439	–15	–10
Songwe III	projected	229	414	201	381	–12	–8
Lower Fufu	projected	134	645	134	645	0	0
Kholombizo	projected	344	1,626	152	1,371	–56	–16
Nkula Falls	existing	460	1,017	271	935	–41	–8
Tedzani	projected	299	721	172	648	–42	–10
Kapichira	existing & extension	541	1,063	103	880	–81	–17
Total		**35,302**	**59,304**	**22,282**	**48,504**	**–37**	**–18**

irrigation in the Basin). Average energy production also decreases, by 18 percent to 48,504 GWh per year compared with Scenario 2A which has an average energy of 59,304 GWh per year. The results are detailed in table 2.37. The dramatic fall in hydropower productivity and the negative impact on other sectors suggests that Scenario 6 may not be an economically viable option for water resources investments in the Basin, despite the substantial impact in terms of additional employment.[11]

The necessary regulation requirements in Scenario 6 (and Scenario 6A) is slightly higher than the one required for Scenario 4, because of the new hydropower stations in the Shire River Basin are not negligible. The reallocation of planned irrigation schemes from upstream to downstream decreases regulation requirements as more water is available year-round downstream (table 2.38.). Should more planned irrigated area be transferred to downstream areas in the Basin, then regulation needs would reduce further.

Table 2.38. Supplementary regulation requirements in Scenarios 6 and Scenario 6A

	Supplementary regulation	
	Scenario 6 (million m^3)	**Scenario 6A (million m^3)**
Subbasin		
Kabompo (13)	35	35
Upper Zambezi (12)	40	0
Lungúe Bungo (11)	35	35
Luanginga (10)	160	160
Barotse (9)	10	10
Cuando/Chobe (8)	200	200
Kafue (7)	0	0
Kariba (6)	40	0
Luangwa (5)	70	70
Mupata (4)	0	0
Shire River – Lake Malawi/ Niassa/Nyasa (3)	2,700	2,700
Tete (2)	38	38
Zambezi Delta (1)	0	0
Total	**3,328**	**3,248**

11 A detailed cost-benefit analysis of Scenario 6 is warranted.

Figure 2.21. Net present value by subbasin (US$ m): Scenario 6 compared with Scenario 2A

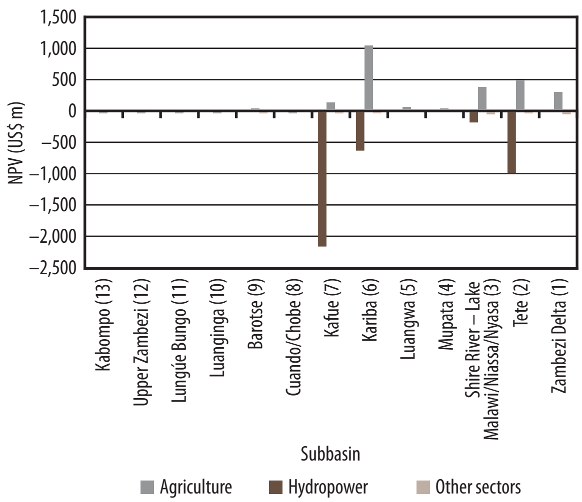


Figure 2.22. Net present value by country (US$ m): Scenario 6 compared with Scenario 2A

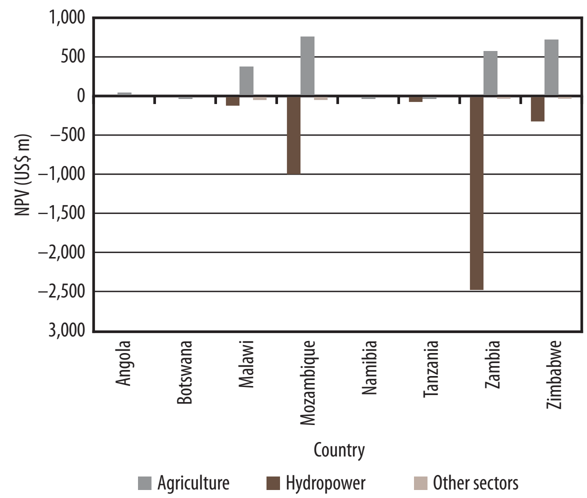


Table 2.39. Net present value by subbasin and country (US$ m): Scenario 6 compared with Scenario 2A

	Hydropower	Agriculture	Other sectors	Total change
Subbasin				
Kabompo (13)	0.00	19.30	0.00	19.30
Upper Zambezi (12)	0.00	10.70	0.00	10.70
Lungúe Bungo (11)	0.00	9.20	0.00	9.20
Luanginga (10)	0.00	6.00	0.00	6.00
Barotse (9)	0.00	19.90	−0.23	19.60
Cuando/Chobe (8)	0.00	−3.60	0.00	−3.60
Kafue (7)	−2,156.60	113.70	−0.03	−2,042.90
Kariba (6)	−622.20	1,026.00	1.72	405.50
Luangwa (5)	0.00	42.00	0.00	42.00
Mupata (4)	0.00	16.90	0.00	16.90
Shire River – Lake Malawi/Niassa/Nyasa (3)	−171.40	365.70	−38.42	155.80
Tete (2)	−986.30	477.30	−0.75	−509.70
Zambezi Delta (1)	0.00	283.20	−37.15	246.00
Total	**−3,936.50**	**2,386.30**	**−74.86**	**−1,625.20**
Country				
Angola	0.00	26.00	0.00	26.00
Botswana	0.00	−2.30	0.00	−2.30
Malawi	−109.78	358.30	−38.42	−1,758.10
Mozambique	−986.30	741.10	−37.90	−283.10
Namibia	0.00	−3.60	0.00	−3.60
Tanzania	−61.70	7.30	0.00	−54.30
Zambia	−2,467.68	557.90	0.61	59.10
Zimbabwe	−311.10	701.60	0.86	391.40
Total	**−3,936.56**	**2,386.30**	**−74.85**	**−1,624.90**

2.13 SCENARIO 6A: SAPP HYDROPOWER PLANS AND COORDINATED HIGH-LEVEL IRRIGATION DEVELOPMENT

Objective: To assess the impact of parallel implementation of the system of HPPs envisaged under SAPP and basin-level coordinated high-level of irrigation development (HLI).

Features: Scenario 6A is based on the coordinated development of high-level irrigation projects for sector optimization (i.e., rellocating irrigated area from upstream to downstream), as well as the development of the system of independently operated HPP facilities under SAPP (i.e., Scenario 2A). Releases for e-flows (7,000 m^3 per second in February in the lower Delta) are included as well as abstractions for domestic water supply.

Essentially, the high-level irrigation projects considered in Scenario 6 is retained but the same 28,000 hectares of sugarcane production is relocated from upstream subbasins to the Zambezi Delta subbasin (as with the relocated IPs in Scenario 5A).

Findings: The substantial water abstraction needed for HLI reduces energy production in the system of HPPs under SAPP, similarly to Scenario 6. However, the optimized HLI development when relocating irrigated areas from upstream to downstream increases both firm and average energy production. Compared with Scenario 6, firm energy production increases by three percent from 22,828 to 22,917 GWh per year. Average energy production increases by one percent from 48,504 to 49,020 GWh per year. Details are provided in table 2.40.

The benefit of cooperation (additional NPV compared with Scenario 6) for this level of irrigation development is estimated at $264 million. Coopera-

Table 2.40. Impact of coordinated high-level irrigation on HPP energy generation under SAPP: Scenario 6A compared with Scenario 6

Hydropower plant		Energy production (GWh/year)				% Change in energy production	
		Scenario 6		Scenario 6A			
		Firm	Average	Firm	Average	Firm	Average
Batoka Gorge	projected	1,099	9,123	1,125	9,140	2	0
Kariba	existing & extension	3,171	5,255	3,311	5,396	4	3
Itezhi Tezhi	extension	208	705	208	705	0	0
Kafue Gorge Upper	refurbishment	3,811	6,460	4,030	6,518	6	1
Kafue Gorge Lower	projected	1,924	3,913	2,035	3,944	6	1
Cahora Bassa	existing & extension	4,967	10,361	5,151	10,535	4	2
Mphanda Nkuwa	projected	2,511	6,347	2,608	6,440	4	1
Rumakali	projected	670	966	670	966	0	0
Songwe I	projected	32	75	32	75	0	0
Songwe II	projected	237	439	237	439	0	0
Songwe III	projected	201	381	203	381	1	0
Lower Fufu	projected	134	645	134	645	0	0
Kholombizo	projected	152	1,371	152	1,371	0	0
Nkula Falls	existing	271	935	271	935	0	0
Tedzani	projected	172	648	172	652	0	0
Kapichira	existing & extension	103	880	103	880	0	0
Total		**22,282**	**48,504**	**22,917**	**49,022**	**3**	**1**

Figure 2.23. Net present value by subbasin (US$ m): Scenario 6A compared with Scenario 6

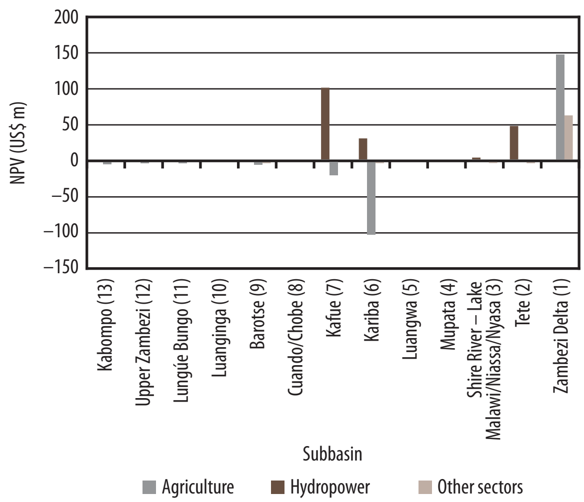
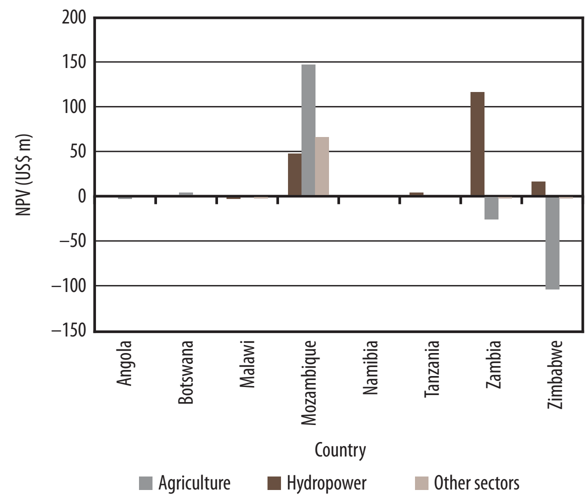


Figure 2.24. Net present value by country (US$ m): Scenario 6A compared with Scenario 6



tion introduces substantial economic benefits, albeit under the very ambitious irrigation expansion. However, these benefits in terms of estimated NPV are not enough to compensate for the loss in energy production detailed in Scenario 6 (see table 3.4.) and the investment options may not be viable.[12] In less ambitious expansion plans, this kind of cooperation can be very beneficial, as illustrated in Scenarios 5 and 5A. Regulation needs for Scenario 6A is the same as for Scenario 6 (table 2.38.).

2.14 SCENARIO 7: SAPP HYDROPOWER, IDENTIFIED IRRIGATION PROJECTS AND OTHER PROJECTS

Objective: To assess the impact of parallel implementation of the system of HPPs envisaged under SAPP, identified irrigation projects, and other projects abstracting water from the system.

Features: Scenario 7 introduces other projects with water abstraction requirements to the model, in addition to the development of the system of HPPs envisaged under SAPP and the identified IPs (without any coordinated operation in either sector). Releases for e-flows (7,000 m^3 per second in February in the lower Delta) are included as well as abstractions for domestic water supply. The other projects fall into two categories elaborated below in section 2.14.1.

Findings: The effect of the additional water withdrawals for other projects is comparatively limited. In Scenario 7, firm energy is 32,024 GWh per year and average energy is 56,596. Compared to Scenario 5, which did not incorporate other projects, this is equivalent to a one percent reduction in both (table 2.43.).

The total employment effect is estimated at approximately 275,000 additional jobs (i.e., eight million person years). The majority of new jobs are created in the agricultural sector as a result of expanded irrigation and agricultural productivity.

2.14.1 Other projects: water abstraction for urban water supply and mining

The other projects considered in Scenario 7 broadly falls into two categories: firstly, water transfer for primarily urban water supply (and agriculture in the case of the Chobe/Zambezi Transfer Scheme in Botswana); and secondly, for water transfer for coal-fired thermal plants and associated mines.

12 A detailed cost-benefit analysis is warranted.

Table 2.41. Net present value by subbasin and country (US$ m): Scenario 6A compared with Scenario 6				
	Hydropower	**Agriculture**	**Other sectors**	**Total change**
Subbasin				
Kabompo (13)	0.00	–2.60	0.00	–2.60
Upper Zambezi (12)	0.00	–0.20	0.00	–0.20
Lungúe Bungo (11)	0.00	–0.30	0.00	–0.30
Luanginga (10)	0.00	0.00	0.00	0.00
Barotse (9)	0.00	–3.00	0.00	–3.00
Cuando/Chobe (8)	0.00	0.00	0.00	0.00
Kafue (7)	99.70	–18.10	0.00	81.60
Kariba (6)	29.10	–100.40	0.10	–71.20
Luangwa (5)	0.00	0.00	0.00	0.00
Mupata (4)	0.00	0.00	0.00	0.00
Shire River – Lake Malawi/Niassa/Nyasa (3)	2.50	0.00	0.30	2.70
Tete (2)	46.40	0.00	–0.50	46.00
Zambezi Delta (1)	0.00	145.80	65.30	211.10
Total	**178.00**	**21.00**	**65.00**	**264.00**
Country				
Angola	0.00	–0.60	0.00	–0.60
Botswana	0.00	2.30	0.00	2.30
Malawi	–0.30	0.00	0.30	0.00
Mozambique	46.40	145.80	64.80	257.00
Namibia	0.00	0.00	0.00	0.00
Tanzania	2.70	0.00	0.00	2.70
Zambia	114.30	–24.60	0.10	89.80
Zimbabwe	14.60	–101.90	0.00	–87.30
Total	**178.00**	**21.00**	**65.00**	**264.00**

Water transfer for urban water supply and agriculture:

- *The Chobe/Zambezi Transfer Scheme* in Botswana plans to abstract water from the Zambezi River via a pipeline and transport water to the Dikgatlhong reservoir (in connection with the North-South Carrier Water Project). An estimated 800 million m^3 per year of water would be made available to meet water demands by the year 2020 for domestic, industrial, mining, and agricultural use (Zambezi Integrated Agro-Commercial Development Project).
- *Water transfer to the City of Bulawayo* in Southern Zimbabwe, to which water would be supplied to a dam on the Munyati River near its confluence with the Sanyati River (a project has been proposed to pump 1.4 m^3 per second from the Zambezi River to meet the growing water demand [SWECO 1996]); and
- *Water transfer to the City of Lusaka* from the Kafue River, upstream of the Kafue Gorge Upper reservoir, to supplement the existing pipeline by

[13] In addition to the coal-fired thermal plants and mines listed, there is a number of copper mines in the Copperbelt (Kafue River subbasin in Zambia) that operate, withdrawing and (through mine dewatering) restitute water to the watershed. The

a second one whose capacity will be six m^3 per second (Lusaka City Master Plan, 2009).

Water abstraction for coal-fired thermal plants and associated mines:[13]

- *Maamba* in Zambia
- *Gokwe* in Zimbabwe
- *Moatize and Benga* in Mozambique

Although thermal power stations have varying cooling water requirements depending on whether they use once-through cooling or cooling towers, it is not quantity of water per se but water consumption through associated evaporation that has most impact on water consumption by the plants. Most of the water processed using once-through cooling will go back to the river; thus, the water requirement is in the range of 80–240 m^3 per megawatt hour (MWh) produced, provided that the power plant is close to the river. The power plants that are located further away from the river adopt cooling towers and, hence, their water requirements and consumption decrease considerably, to two to three m^3 of water per MWh produced. This is the case for Gokwe, for example, where water will be drawn from Lake Kariba through an 85 km long canal to cool the turbines. Yet water consumption is only in the order of 1.2–2.0 m^3 per MWh produced (Freedman and Wolfe 2007, World Nuclear Association).

In addition to water consumption during the cooling process, water is also consumed during the coal-extraction process, and the volume consumed can vary considerably depending on whether water is used to control dust or for other purposes. In comparison, studies of water consumption in Australian mines indicate that water consumption varies in the range of 200–800 liter per ton of extracted coal. Vale, the owner of the Moatize complex in the Lower Zambezi in Mozambique, indicated that the average water consumption of the mining complex would be 320 liters per second. It is estimated that the mine would extract 8.9 million tons of coal per year to supply the thermal power station; hence, water consumption of 1,140 liters per second is on the high side.

Since data and information obtained on water consumption from the owners of mine-cum-thermal-power-station complexes were insufficient, estimates are based on the information provided in available publications and presentations.[14]

Table 2.42. presents water withdrawal estimates based on available information and the following assumptions:

- Plant factor of 0.88;
- Coal consumption of 480 tons/GWh;
- Water consumption of one m^3 per ton for coal extraction; and
- Water consumption for power plant cooling of 1.85 m^3/MWh.

Table 2.42. Water consumption at mines and thermal power stations

Project	Installed capacity (MW)	Coal input (million tons/year)	Mine consumption (m^3/s)	Plant cooling consumption (m^3/s)	Total consumption (m^3/s)
Maamba	200	0.7	0	0.1	0.1
Gokwe	1,400	5.2	0.2	0.6	0.8
Moatize	2,400	8.9	0.3	1.1	1.4
Benga	2,000	7.4	0.2	0.9	1.1

current and future situation of mining development or mine closure has not been determined for the purpose of this study. Yet the water transfer amounts are relatively large. For example, in 1992–93, the Zambia Consolidated Copper Mines Ltd (ZCCM) pumped on average, 8.5 m^3/s (Naish 1993), most of which probably came from dewatering the Konkola mine.

14 Freedman and Wolfe 2007; Naish 1993; presentation on power generation options given by Mr. O. Nyatanga, general manager, Corporate Affairs of ZESA Holdings (Pvt) Ltd (for information on Gokwe thermal plant in Zimbabwe), and Chubu Electric Power Co., July 2009 report and the Generation Planning Seminar held in Lusaka on October 22, 2009 (for information on Maamba coal mine in Zambia).

2.14.2 Impact on energy production

As table 2.43. outlines, introducing the abstractions for other projects results in a one percent reduction for both firm and average energy production. Compared to Scenario 2A, where only the system of HPP under SAPP is developed (i.e., it does not include IPs or other projects), the loss in energy

Table 2.43. Impact on energy production by other projects: Scenario 7 compared with Scenario 5

		Energy production (GWh/year)				% Change in energy production	
		Scenario 5		Scenario 7			
Hydropower plant		Firm	Average	Firm	Average	Firm	Average
Batoka Gorge	projected	1,660	9,479	1,618	9,453	–3	0
Kariba	existing & extension	5,694	7,709	5,624	7,668	–1	–1
Itezhi Tezhi	extension	258	712	258	712	0	0
Kafue Gorge Upper	refurbishment	4,424	6,677	4,292	6,581	–3	–1
Kafue Gorge Lower	projected	2,239	4,036	2,168	3,974	–3	–2
Cahora Bassa	existing & extension	8,804	13,449	8,585	13,344	–2	–1
Mphanda Nkuwa	projected	4,554	8,064	4,457	7,996	–2	–1
Rumakali	projected	670	966	670	966	0	0
Songwe I	projected	29	75	29	75	0	0
Songwe II	projected	228	436	228	436	0	0
Songwe III	projected	197	378	197	378	0	0
Lower Fufu	projected	134	645	134	645	0	0
Kholombizo	projected	318	1,603	318	1,603	0	0
Nkula Falls	existing	440	1,010	440	1,010	0	0
Tedzani	projected	281	713	281	714	0	0
Kapichira	existing & extension	394	1,041	394	1,041	0	0
Total		**32,358**	**56,993**	**32,024**	**56,596**	**–1**	**–1**

Table 2.44. Impact on energy production by other projects and IPs: Scenario 7 compared with Scenario 2A

		Energy production (GWh/year)				% Change in energy production	
		Scenario 2A		Scenario 7			
Hydropower plant		Firm	Average	Firm	Average	Firm	Average
Batoka Gorge	projected	1,908	9,637	1,618	9,453	–15	–2
Kariba	existing & extension	6,368	8,360	5,624	7,668	–12	–8
Itezhi Tezhi	extension	284	716	258	712	–9	0
Kafue Gorge Upper	refurbishment	4,542	6,766	4,292	6,581	–5	–3
Kafue Gorge Lower	projected	2,301	4,092	2,168	3,974	–6	–3
Cahora Bassa	existing & extension	9,680	14,204	8,585	13,344	–11	–6
Mphanda Nkuwa	projected	5,026	8,477	4,457	7,996	–11	–6
Rumakali	projected	686	985	670	966	–2	–2
Songwe I	projected	42	91	29	75	–29	–17

Continued on next page

Table 2.44. Impact on energy production by other projects and IPs: Scenario 7 compared with Scenario 2A *(continued)*

Hydropower plant		Energy production (GWh/year)				% Change in energy production	
		Scenario 2A		Scenario 7			
		Firm	Average	Firm	Average	Firm	Average
Songwe II	projected	276	490	228	436	–18	–11
Songwe III	projected	228	414	197	378	–14	–9
Lower Fufu	projected	134	645	134	645	0	0
Kholombizo	projected	344	1,626	318	1,603	–8	–1
Nkula Falls	existing	460	1,017	440	1,010	–4	–1
Tedzani	projected	299	721	281	714	–6	–1
Kapichira	existing & extension	541	1,063	394	1,041	–27	–2
Total		**35,302**	**59,304**	**32,024**	**56,596**	**–9**	**–5**

productivity is greater. Specifically, firm energy falls by nine percent and average energy by five percent as presented in table 2.44.

2.14.3 Impact on NPV

The fall in energy production results in a corresponding decrease in NPV in Scenario 7 compared with Scenario 2A according to the model (table 2.45.). The other water transfer projects yield a positive NPV under the given assumptions.[15] However, Scenario 7 still has a positive NPV if compared with the current situation in Scenario 0 ($116 million), suggesting viability in the associated investments. More detailed assessment of the economic and social benefits of the water transferring projects in Scenario

Figure 2.25. Net present value by subbasin (US$ m): Scenario 7 compared with Scenario 2A

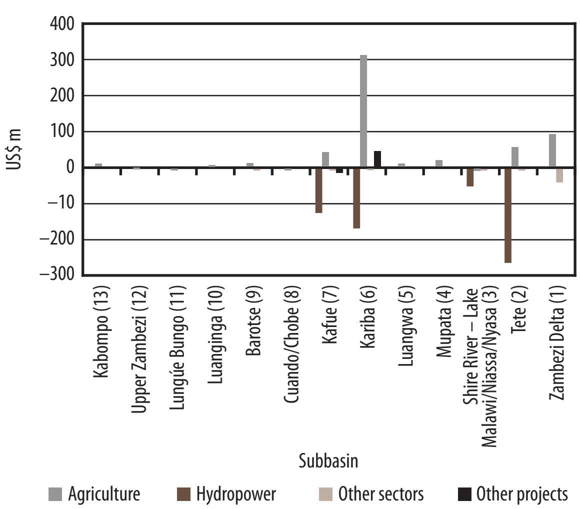
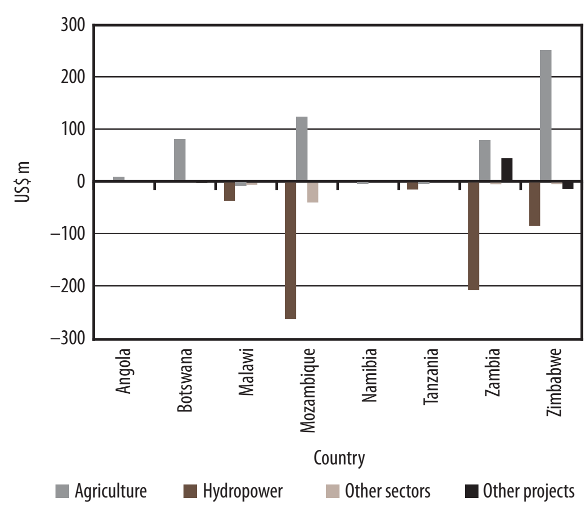


Figure 2.26. Net present value by country (US$ m): Scenario 7 compared with Scenario 2A



15 The price for water supplied is particularly important for economic evaluation of the projects. In the case of the transfer to Bulawayo in Zimbabwe, two dollars per m3 was applied on the basis of the range of values given in the feasibility study. In the Chobe/Zambezi transfer in Botswana, a long-run marginal cost (LRMC) price of $0.68 per m^3 was used.

Table 2.45. Net present value by subbasin and country (US$ m): Scenario 7 compared with Scenario 2A

	Hydropower	Agriculture	Other sectors	Other projects	Total change
Subbasin					
Kabompo (13)	0.00	7.60	0.00	0.00	7.60
Upper Zambezi (12)	0.00	2.40	0.00	0.00	2.40
Lungúe Bungo (11)	0.00	0.50	0.00	0.00	0.50
Luanginga (10)	0.00	2.70	0.00	0.00	2.70
Barotse (9)	0.00	8.40	–0.09	0.00	8.30
Cuando/Chobe (8)	0.00	0.10	0.00	0.00	0.10
Kafue (7)	–122.20	39.60	–0.01	–10.10	–92.70
Kariba (6)	–164.80	306.40	0.84	42.70	185.20
Luangwa (5)	0.00	6.60	0.00	0.00	6.60
Mupata (4)	0.00	16.90	0.00	0.00	16.90
Shire River – Lake Malawi/Niassa/Nyasa (3)	–48.50	–5.70	–3.75	0.00	–58.00
Tete (2)	–260.40	52.70	–0.11	0.00	–207.80
Zambezi Delta (1)	0.00	88.50	–37.50	0.00	51.00
Total	**–595.90**	**526.70**	**–40.62**	**32.60**	**–77.20**
Country					
Angola	0.00	5.60	0.00	0.00	5.60
Botswana	0.00	78.30	0.00	1.30	79.60
Malawi	–35.24	–6.80	–3.75	0.00	–126.30
Mozambique	–260.00	121.80	–37.62	0.00	–176.20
Namibia	0.00	0.10	0.00	0.00	0.10
Tanzania	–13.30	1.10	0.00	0.00	–12.20
Zambia	–204.62	75.80	0.33	45.20	–2.80
Zimbabwe	–82.40	250.90	0.42	–13.80	155.00
Total	**–595.56**	**526.80**	**–40.62**	**32.70**	**–77.20**

7, and their economic viability would require more complete analysis and full feasibility studies.

2.15 SCENARIO 8: MULTI-SECTOR DEVELOPMENT

Due consideration to the importance of water for economic, social and environmental development, requires a multi-sector approach when analysing the Basin's water resources. The approach shown in Scenario 8 represents the attempt to meet multiple objectives, whilst at the same time, illustrating potentials of benefit sharing as well as inherent issues of trade-off between sectors.

Objective: To assess the impact of balancing multi-sector development projects. The water-using activities considered in Scenario 8 include: the system of HPPs envisaged under SAPP, identified irrigation projects, other projects (per Scenario 7), and, flood protection in the Lower Zambezi.

Features: Scenario 8 represents a more balanced approach to development of the Basin's water resources by incorporating multi-sector development objectives and options. The scenario is based on the system of HPPs envisaged under SAPP, identified IPs, other projects as outlined in Scenario 7 and, flood protection downstream of Lupata Gorge at the confluence of the Shire and Zambezi River. As with previous scenarios, releases for e-flows (7,000 m^3 per second in the lower Delta in February) and abstractions for domestic water supply are included.

Findings: To impact of introducing multi-sector water users on the production of hydropower generated by the system of HPPs under SAPP is presented in table 2.47. (Scenario 8 compared with Scenario 2A). Firm energy production in Scenario 8 is 30,013 GWh per year and average energy production is 55,857 GWh per year. Compared with Scenario 2A, which does not include multi-sector water use, these are equivalent to seven and six percent reduction respectively. At the same time, Scenario 8 yields considerable employment benefits with an estimated 275,000 additional jobs (i.e., eight million person years). The approach of considering multiple sectors and objectives also indicates higher agricultural productivity through the expansion in irrigated areas. Possible trade-offs between sector need further analysis and involve decision making in the spirit of cooperation and agreed solutions.

Table 2.46. Supplementary regulation requirements in Scenarios 8 and Scenario 9

	Supplementary regulation	
	Scenario 8 (million m^3)	Scenario 9 (million m^3)
Subbasin		
Kabompo (13)	10	50
Upper Zambezi (12)	15	15
Lungúe Bungo (11)	0	10
Luanginga (10)	30	45
Barotse (9)	0	5
Cuando/Chobe (8)	0	0
Kafue (7)	0	20
Kariba (6)	20	20
Luangwa (5)	39	39
Mupata (4)	0	0
Shire River - Lake Malawi/ Niassa/Nyasa (3)	102	83
Tete (2)	38	38
Zambezi Delta (1)	0	0
Total	**254**	**325**

Table 2.47. Impact on energy production in a multi-sector development context: Scenario 8 compared with Scenario 2A

		Energy production (GWh/year)				% Change in energy production	
		Scenario 2A		Scenario 8			
Hydropower plant		**Firm**	**Average**	**Firm**	**Average**	**Firm**	**Average**
Batoka Gorge	projected	1,908	9,637	1,618	9,453	–15	–2
Kariba	existing & extension	6,368	8,360	5,624	7,668	–12	–8
Itezhi Tezhi	extension	284	716	258	712	–9	0
Kafue Gorge Upper	refurbishment	4,542	6,766	4,292	6,581	–5	–3
Kafue Gorge Lower	projected	2,301	4,092	2,168	3,974	–6	–3
Cahora Bassa	existing & extension	9,680	14,204	7,420	12,725	–23	–10
Mphanda Nkuwa	projected	5,026	8,477	3,867	7,876	–23	–7
Rumakali	projected	686	985	670	966	–2	–2
Songwe I	projected	42	91	29	75	–29	–17
Songwe II	projected	276	490	228	436	–18	–11
Songwe III	projected	228	414	197	378	–14	–9
Lower Fufu	projected	134	645	134	645	0	0
Kholombizo	projected	344	1,626	318	1,603	–8	–1
Nkula Falls	existing	460	1,017	440	1,010	–4	–1
Tedzani	projected	299	721	281	714	–6	–1
Kapichira	existing & extension	541	1,063	394	1,041	–27	–2
Total		**35,302**	**59,304**	**30,013**	**55,857**	**–7**	**–6**

Figure 2.27. Net present value by subbasin (US$ m): Scenario 8 compared with Scenario 2A

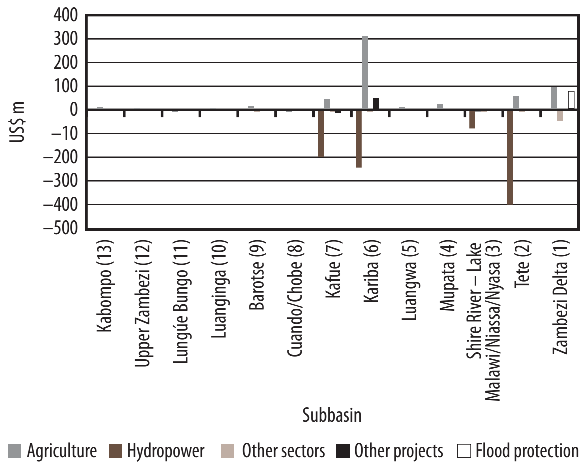
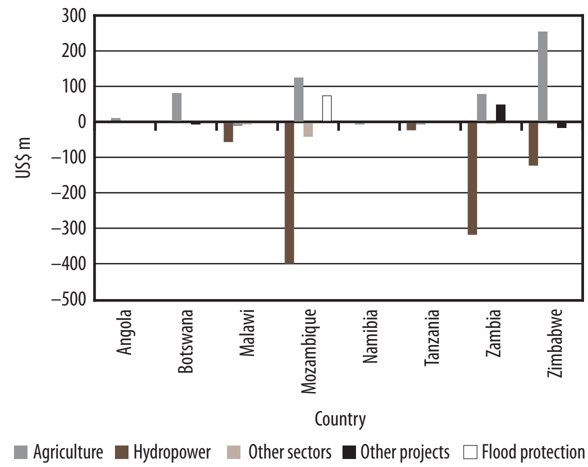


Figure 2.28. Net present value by country (US$ m): Scenario 8 compared with Scenario 2A



The flood protection regime estimated for the lower Delta could bring a number of significant socio-economic and environmental benefits. The "unpredictable" nature of the current flooding regime in the Lower Zambezi has profound effect on subsistence production systems, and by preventing hazardous floods, a protection regime would improve livelihoods, economic activities and ecosystem sustainability across the Delta. The value of such benefits has only partially been estimated in the model by estimating avoided losses in agricultural production and infrastructure. The substantial scope of social and environmental benefits have not been quantified in the analysis and therefore not included explicitly in the NPV calculations detailed in Table 2.48.

Supplementary regulation requirements for Scenario 8 (and Scenario 9) increases in some of the upstream subbasins but decreases in the downstream ones (table 2.46.).

2.16 SCENARIO 9: POTENTIAL IMPACT OF CLIMATE CHANGE

Objective: To assess the potential impact of climate change on the balanced multi-sector development Scenario 8.

Features: Scenario 9 applies a set of simulated parameters of potential climate change onto Scenario 8, the more balanced multi-sector development scenario. These development activities include: the system of HPPs envisaged under SAPP, identified IPs, other projects as outlined in Scenario 7, and, flood protection downstream of Lupata Gorge at the confluence of the Shire and Zambezi River. Releases for e-flows (7,000 m^3 per second in the lower Delta in February) and abstractions for domestic water supply are included.

The basic parameters of climate change in Scenario 9 are change in mean air temperature and estimated evaporation rates. These are used to assess the percentage change in basin yield and irrigation deficits for the year 2030. The climate change scenario has been simulated with one of the global climate simulation models. The results are presented in table 2.49. and further detail can be found in volume 4.

The findings of Scenario 9 should be treated with caution due to the limitations with the model and available data. More detailed analysis and studies are warranted and would benefit the riparian countries in their adaptation and mitigation planning.

Findings: When the impact of climate change on water resources in the ZRB are modeled according to the selected broad parameters, the impact on energy productivity is substantial. Compared to Scenario 8, firm energy falls by 32 percent from 30,013 to 20,270 GWh per year. Similarly, a significant reduction is

Table 2.48. Net present value by subbasin and country: Scenario 8 compared with Scenario 2A

	Hydropower	Agriculture	Other sectors	Other projects	Flood protection	Total change
Subbasin						
Kabompo (13)	0.00	7.65	0.00	0.00	0.00	7.65
Upper Zambezi (12)	0.00	2.37	0.00	0.00	0.00	2.37
Lungúe Bungo (11)	0.00	0.53	0.00	0.00	0.00	0.53
Luanginga (10)	0.00	2.69	0.00	0.00	0.00	2.69
Barotse (9)	0.00	8.42	0.00	0.00	0.00	8.42
Cuando/Chobe (8)	0.00	0.08	0.00	0.00	0.00	0.08
Kafue (7)	–193.25	39.60	0.00	–10.11	0.00	–163.76
Kariba (6)	–237.90	306.43	0.28	42.71	0.00	111.52
Luangwa (5)	0.00	6.58	0.00	0.00	0.00	6.58
Mupata (4)	0.00	16.91	0.00	0.00	0.00	16.91
Shire River – Lake Malawi/Niassa/Nyasa (3)	–73.32	–5.68	–0.35	0.00	0.00	–79.35
Tete (2)	–393.55	52.75	0.99	0.00	0.00	–339.81
Zambezi Delta (1)	0.00	88.46	–39.28	0.00	72.67	121.85
Total	**–898.01**	**526.78**	**–38.36**	**32.59**	**72.67**	**–304.33**
Country						
Angola	0.00	5.59	0.00	0.00	0.00	5.59
Botswana	0.00	78.32	0.00	1.28	0.00	79.61
Malawi	–53.16	–6.77	–0.35	0.00	0.00	–60.28
Mozambique	–393.55	121.83	–38.29	0.00	72.67	–237.34
Namibia	0.00	0.08	0.00	0.00	0.00	0.08
Tanzania	–20.16	1.08	0.00	0.00	0.00	–19.07
Zambia	–312.19	75.78	0.14	45.16	0.00	–191.11
Zimbabwe	–118.95	250.87	0.14	–13.85	0.00	118.21
Total	**–898.01**	**526.78**	**–38.36**	**32.59**	**72.67**	**–304.33**

Table 2.49. Estimated impact of climate change in the Zambezi River Basin by 2030

	% change in 2030	
Subregion	**Basin yield**	**Irrigation deficit**
Upper Zambezi	–16	13
Kafue subbasin	–34	21
Lower Zambezi	–24	17
Shire River and Lake Malawi/Niassa/Nyasa	–14	15
Zambezi Delta	–13	27
Assumptions and definitions	**data assumption**	**Source**
Parameter	% change from historic data	Climate Research Unit (CRU): 19610 - 90
Method	Weighted average	U.S. Geological Survey (USGS): class 4 catchment area
Emission scenario	A1B	
Global Circulation Model	Midrange of 23 models	
Air temperature	1.5 degree Celcius (for evaporation estimates)	

Source: World Bank 2009.

seen in the average energy production which falls by 21 percent to from 55,857 to 44,189 GWh per year. Details are provided in table 2.50. If Scenario 9 is compared with Scenario 2A, the reduction in firm and average energy is greater, 43 and 25 percent respectively. The supplementary requirements for Scenario 9 are the same as for Scenario 8 (table 2.46.)

2.17 SCENARIOS 10A–10F: PARTIAL RESTORATION OF NATURAL FLOODS IN LOWER ZAMBEZI

Objective: To assess the impact of partially restoring natural floods in the lower Zambezi Delta for the environmental and economic benefit of multiple sectors (i.e., fisheries, recession farming, livestock, ecosystem sustainability etc.).

Features: Scenarios 10A to 10F are based on different levels of flooding in the lower Zambezi Delta and estimates the impact if these occur in February or in December (based on the work of Beilfuss and Brown, 2006). These six different options for partial restoration of natural floods can be achieved through modifying the operation of Lake Cahora Bassa. The details of the scenarios are listed in figure 2.31.

Scenarios 10A to 10F are based on the system of HPPs envisaged under SAPP, the existing irrigation projects, and abstractions for domestic water supply. They do not include IPs or HLI projects, or other projects. Note than scenario 10B is the same as scenario 2A.

Partial restoration of natural floods in the lower Zambezi Delta is imperative for the viability of ecosystem processes, the sustainability of aquatic and marine life, sustaining livelihoods and ensuring economic development from its resources. The construction of Kariba and Cahora Bassa dams altered the regime of the Zambezi River, drastically reducing the frequency and magnitude of floods as well as the River's ability to sustain a level of low flows.

Findings: Releasing water for partial restoration of natural floods would impact the potential energy

Table 2.50. Impact on energy production by potential climate change in 2030: Scenario 9 compared with Scenario 8

Hydropower plant		Energy production (GWh/year)				% Change in energy production	
		Scenario 8		Scenario 9			
		Firm	Average	Firm	Average	Firm	Average
Batoka Gorge	projected	1,618	9,453	1,353	8,640	–16	–9
Kariba	existing & extension	5,624	7,668	4,380	6,151	–22	–20
Itezhi Tezhi	extension	258	712	206	540	–20	–24
Kafue Gorge Upper	refurbishment	4,292	6,581	2,655	4,866	–38	–26
Kafue Gorge Lower	projected	2,168	3,974	1,354	2,747	–38	–31
Cahora Bassa	existing & extension	7,420	12,725	4,949	9,686	–33	–24
Mphanda Nkuwa	projected	3,867	7,876	2,571	6,171	–34	–22
Rumakali	projected	670	966	587	865	–12	–10
Songwe I	projected	29	75	26	61	–11	–18
Songwe II	projected	228	436	200	377	–12	–13
Songwe III	projected	197	378	171	329	–13	–13
Lower Fufu	projected	134	645	114	607	–15	–6
Kholombizo	projected	318	1,603	48	1,009	–85	–37
Nkula Falls	existing	440	1,010	160	780	–64	–23
Tedzani	projected	281	714	103	528	–63	–26
Kapichira	existing & extension	394	1,041	211	832	–46	–20
Total		**30,013**	**55,857**	**20,270**	**44,189**	**–32**	**–21**

Figure 2.29. Net present value by subbasin (US$ m): Scenario 9 compared with Scenario 2A

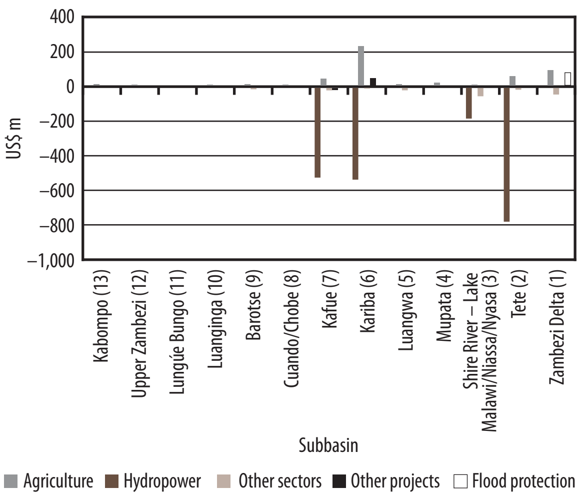
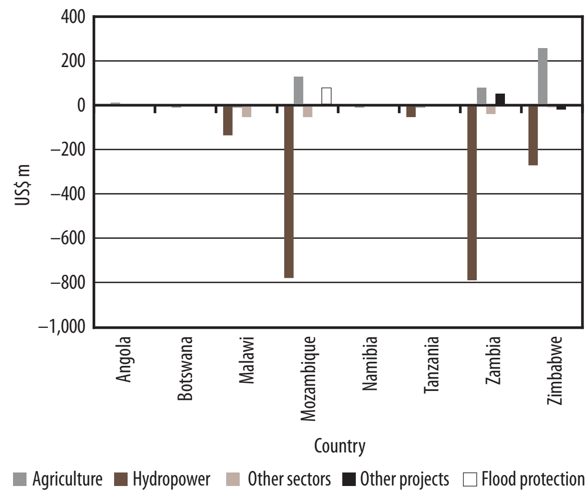


Figure 2.30. Net present value by country (US$ m): Scenario 9 compared with Scenario 2A



generation of Cahora Bassa Dam and the planned Mphanda Nkuwa Dam. Estimated corresponding levels of impact are detailed in table 2.53. These are also illustrated in figure 2.32. for firm energy production and figure 2.33. for average energy production.

Reestablishing natural flooding to various levels is technically feasible and creates substantial benefits to the Delta. The cost in hydropower production losses are, however, higher at the present assumed prices. The results are very sensitive

Table 2.51. Impact on energy production by potential climate change in 2030: Scenario 9 compared with Scenario 2A

Hydropower plant		Energy production (GWh/year) Scenario 2A Firm	Scenario 2A Average	Scenario 9 Firm	Scenario 9 Average	% Change in energy production Firm	% Change in energy production Average
Batoka Gorge	projected	1,908	9,637	1,353	8,640	−29	−10
Kariba	existing & extension	6,368	8,360	4,380	6,151	−31	−26
Itezhi Tezhi	extension	284	716	206	540	−28	−25
Kafue Gorge Upper	refurbishment	4,542	6,766	2,655	4,866	−42	−28
Kafue Gorge Lower	projected	2,301	4,092	1,354	2,747	−41	−33
Cahora Bassa	existing & extension	9,680	14,204	4,949	9,686	−49	−32
Mphanda Nkuwa	projected	5,026	8,477	2,571	6,171	−49	−27
Rumakali	projected	686	985	587	865	−14	−12
Songwe I	projected	42	91	26	61	−37	−33
Songwe II	projected	276	490	200	377	−28	−23
Songwe III	projected	228	414	171	329	−25	−20
Lower Fufu	projected	134	645	114	607	−15	−6
Kholombizo	projected	344	1,626	48	1,009	−86	−38
Nkula Falls	existing	460	1,017	160	780	−65	−23
Tedzani	projected	299	721	103	528	−65	−27
Kapichira	existing & extension	541	1,063	211	832	−61	−22
Total		**35,302**	**59,304**	**20,270**	**44,189**	**−43**	**−25**

Table 2.52. Net present value by subbasin and country (US$ m): Scenario 9 compared with Scenario 2A

	Hydropower	Agriculture	Other sectors	Other projects	Flood protection	Total change
Subbasin						
Kabompo (13)	0.00	5.50	0.00	0.00	0.00	5.50
Upper Zambezi (12)	0.00	2.40	0.00	0.00	0.00	2.40
Lungúe Bungo (11)	0.00	0.00	0.00	0.00	0.00	0.00
Luanginga (10)	0.00	2.00	0.00	0.00	0.00	2.00
Barotse (9)	0.00	8.10	–7.41	0.00	0.00	0.69
Cuando/Chobe (8)	0.00	0.10	0.00	0.00	0.00	0.10
Kafue (7)	–517.40	38.90	–13.52	–10.10	0.00	–502.12
Kariba (6)	–529.20	227.20	0.77	42.70	0.00	–258.53
Luangwa (5)	0.00	6.60	–13.18	0.00	0.00	–6.58
Mupata (4)	0.00	16.90	0.00	0.00	0.00	16.90
Shire River - Lake Malawi/ Niassa/Nyasa (3)	–177.00	1.10	–47.57	0.00	0.00	–223.47
Tete (2)	–771.70	52.70	–10.08	0.00	0.00	–729.08
Zambezi Delta (1)	0.00	88.50	–37.50	0.00	72.70	123.70
Total	**–1,995.30**	**450.00**	**–128.49**	**32.60**	**72.70**	**–1,568.49**
Country						
Angola	0.00	4.30	0.00	0.00	0.00	4.30
Botswana	0.00	–0.90	0.00	1.30	0.00	0.40
Malawi	–129.56	0.90	–47.57	0.00	0.00	–176.23
Mozambique	–771.70	121.80	–47.58	0.00	72.70	–624.78
Namibia	0.00	0.10	0.00	0.00	0.00	0.10
Tanzania	–47.50	0.20	0.00	0.00	0.00	–47.30
Zambia	–781.97	72.70	–33.72	45.20	0.00	–697.79
Zimbabwe	–264.60	250.90	0.38	–13.80	0.00	–27.12
Total	**–1,995.33**	**450.00**	**–128.49**	**32.70**	**72.70**	**–1,568.42**

to changes in prices as a number of scenarios can become positive at relatively small changes in price assumptions.

Figure 2.31. Scenario 10A–10F: Flooding characteristics

Scenario	Zambezi Delta flow (m^3/s)	Timing	Duration
10A	4,500	February	4 weeks
10B	7,000	February	4 weeks
10C	10,000	February	4 weeks
10D	4,500	December	4 weeks
10E	7,000	December	4 weeks
10F	10,000	December	4 weeks

Source: Beilfuss and Brown, 2006.

For effects to be comparable in Scenario 10C, the price per KWh should be between $0.10 and $0.20. This is not far from present prices, but quite far from the prices used in this analysis. In Scenario 10D a slight reduction of the firm energy price from $0.58 to $0.50 would balance the NPVs.

The results of scenarios 10A to 10F show that:

- It is technically feasible to restore natural flooding with a high percentage of success (from 100 percent for 4,500 m^3 per second in February to 90 percent for 7,000 m^3 per second in December), with the exception of the release of 10,000 m^3 per second in December (50 percent of occurrence).
- This will cause a reduction in generation at Cahora Bassa and Mphanda Nkuwa HPPs,

Table 2.53. Impact on energy production of Cahora Bassa Dam and the future Mphanda Nkuwa Dam: Scenario 2, Scenario 10A–F

Scenario	2	10A	10B	10C	10D	10E	10F
timing		February			December		
flood level	—	4,500 m³/s	7,000 m³/s	10,000 m³/s	4,500 m³/s	7,000 m³/s	10,000 m³/s
				Cahora Bassa Dam (existing)			
Firm energy (GWh/year)	11,826	11,432	9,680	7,577	10,862	9,373	7,972
Loss (GWh/year)	—	*394*	*2,146*	*4,249*	*964*	*2,453*	*3,854*
Loss (%)	—	*3*	*18*	*36*	*8*	*21*	*33*
Average energy (GWh/year)	15,024	15,062	14,204	12,771	14,961	14,135	13,059
Loss (GWh/year)	—	*–38*	*820*	*2,253*	*64*	*889*	*1,965*
Loss (%)	—	*0*	*5*	*15*	*0*	*6*	*13*
				Mphanda Nkuwa Dam (planned)			
Firm energy (GWh/year)	6,190	5,970	5,026	3,916	5,654	4,859	4,096
Loss (GWh/year)	—	*220*	*1,164*	*2,274*	*536*	*1,331*	*2,094*
Loss (%)	—	*4*	*19*	*37*	*9*	*22*	*34*
Average energy (GWh/year)	9,092	9,059	8,476	7,705	8,949	8,479	7,977
Loss (GWh/year)	—	*33*	*617*	*1,388*	*144*	*614*	*1,116*
Loss (%)	—	*0*	*7*	*15*	*2*	*7*	*12*
Delta flood occurence (% time)	**—**	**100**	**98**	**98**	**98**	**95**	**90**

Figure 2.32. Impact on the energy production of Cahora Bassa HPP: Scenario 2, 10A–10F

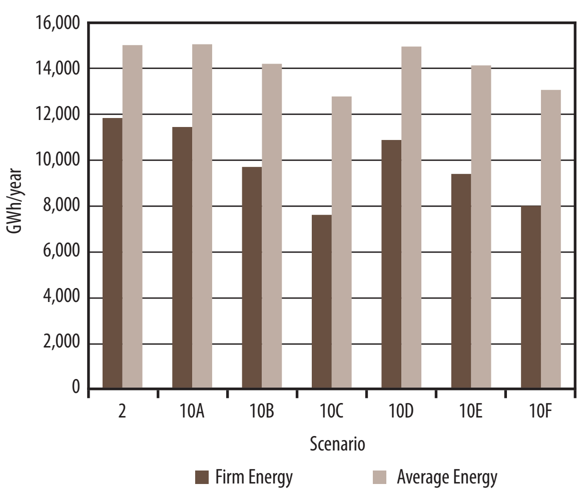
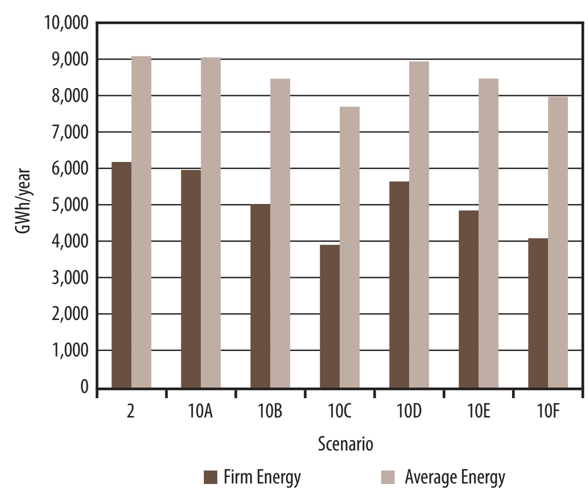


Figure 2.33. Impact on the energy production of the planned Mphanda Nkuwa HPP: Scenario 2, 10A–10F



between three percent and 33 percent for Cahora Bassa and four percent and 34 percent for Mphanda Nkuwa (a firm energy reduction when compared with the base case).

- The economic trade-offs between power and benefits do not favor flooding under the given assumptions. The price of energy is critical in this regard. If one assumes the present bus bar

Table 2.54. Net present value by flooding level (US$ m): Scenarios 10A–10F compared with Scenario 2

Scenario	Zambezi Delta flow (m^3/s)	Timing	Duration	Hydropower	Other sectors
10A	4,500	February	4 weeks	245.66	47.35
10B	7,000	February	4 weeks	−874.95	61.93
10C	10,000	February	4 weeks	−1,848.36	49.65
10D	4,500	December	4 weeks	−331.2	53.49
10E	7,000	December	4 weeks	−988.35	67.26
10F	10,000	December	4 weeks	−1,657.12	58.28

prices ($0.02/KWh) the situation would be reversed for most of the scenarios.

Discharging 4,500m^3 per second in February, as presented in Scenario 10A, would meet the objective at all times as presented in historical flow series. For the other scenarios, however, it would only be partly met. The success of Scenario 10A would depend on the availability and effectiveness of hydrometric information network and system that especially covered the Lower Shire and Zambezi rivers as well as tributaries.

The restoration of natural floods means that the hydropower production will be affected either positively (where flooding level signifies less restriction on operations such as Scenario 10A) or negatively where the changed flooding level imposes more restrictions on operation. The corresponding impact on NPV is presented in table 2.54.

2.18 SCENARIOS 11A–11G: FLOOD PROTECTION IN LOWER ZAMBEZI

Objective: To assess the impact of both restoring different levels of natural floods (Scenario 10A–10F) and flood protection to a maximum of 10,000 m^3 per second downstream of Lupata Gorge in the Lower Zambezi.

Features: Scenarios 11A to 11G introduces flood protection to a maximum of 10,000 m^3 per second downstream of Lupata Gorge in the Lower Zambezi (see map in figure 1.1.). This level of flood protection is firstly introduced to a situation where no releases are made for restoring natural floods (Scenario 11A). The subsequent scenarios (scenario 11B to 11G) introduce the six levels of natural floods as established in scenarios 10A to 10F (section 2.17.). The features of Scenario 11A–11G are outlined in figure 2.34.

Scenarios 11A to 11G are based on the system of HPPs envisaged under SAPP, the existing irrigation projects, and abstractions for domestic water supply. They do not include IPs or HLI projects, or other projects.

Floods occur regularly in the Lower Zambezi downstream of Lupata Gorge in Mozambique, in the reaches of the Zambezi River both upstream and downstream of the confluence with the Shire River, as well as on the Lower Shire itself. According to information obtained from HidroEléctrica de Cahora Bassa (HCB), flooding in these reaches start when the Zambezi River discharge exceeds 10,000 m^3 per second.

In the historical period of the model, the Zambezi River monthly discharge downstream of the Lupata Gorge exceed the threshold of 10,000 m^3 per second between December and mid-March in any ten separate years, causing potential flood

Figure 2.34. Scenario 11A–11G: flood protection characteristics

Scenario	Flood protection –maximum m^3/s	Zambezi Delta flow (m^3/s)	Timing	Duration
11A	10,000	—	—	—
11B	10,000	4,500	February	4 weeks
11C	10,000	7,000	February	4 weeks
11D	10,000	10,000	February	4 weeks
11E	10,000	4,500	December	4 weeks
11F	10,000	7,000	December	4 weeks
11G	10,000	10,000	December	4 weeks

related disasters. In order to limit the discharge to 10,000 m^3 per second, the Cahora Bassa flood rule curve is modified to provide supplementary storage equal to the volume required to meet the maximum permissible flow criterion downstream. Modifying the flood rule curve of Cahora Bassa in the months of October to February provides the desired results for all months, except January and March 1978. Whereas in the original time series, only 75 percent of the years do not experience flooding, with the rule curve developed at Cahora Bassa to limit downstream flooding, 98 percent of the years do not experience downstream flooding. It is, however, important to note that it would be next to impossible to manage the Cahora Bassa reservoir to counter all flooding situations. In conclusion, managing the Cahora Bassa reservoir to protect the Lupata Floodplain against flooding does not promise to be consistently effective.

It should also be noted that if, theoretically, modified operation of Cahora Bassa reservoir could mitigate most flooding at the monthly level, the a sizeable portion of floods originate from flash floods in major and minor tributaries. In the absence of a comprehensive early warning system, the capability to mitigate is limited and the level of flood protection achieved in the simulation would not be achieved in practice.

Findings: Scenarios 11A to 11G demonstrate that it is theoretically possible to operate Cahora Bassa reservoir to both reduce floods in the Zambezi Floodplain near Lupata Gorge and to restore flooding in the Lower Delta—two apparently contradictory objectives. But as shown in table 2.55., the objective of restoring natural flooding cannot be met at all times. In particular, Scenario 11G shows that flood restoration in the Lower Delta is effective only in 50 percent of the years modeled. Yet, out of the 20 years where the 10,000 m^3 per second cannot be met, in 11 years the flood restoration level is above 9,000 m^3 per second, while in the other nine years it varies from 3,600 to 8,000 m^3 per second.

The impact on energy production by flood protection outlined in Scenarios 11A and 11B is detailed in table 2.55. Contrary to scenarios 10A to 10F, production rates are higher. Reestablishing natural flooding and flood protection is technically feasible and creates substantial benefits. But, in economic terms and under the given assumptions, introduction of flood protection has a substantial cost in losses of hydropower production over and above the avoided costs.

The NPV reduction of hydropower production outweighs the calculated effects from other sectors and the value of adding flood protection to scenarios 10A to 10F. Reducing the firm energy

Figure 2.35. Impact on the energy production of Cahora Bassa HPP: Scenario 11A–11G compared with Scenario 10A–10F

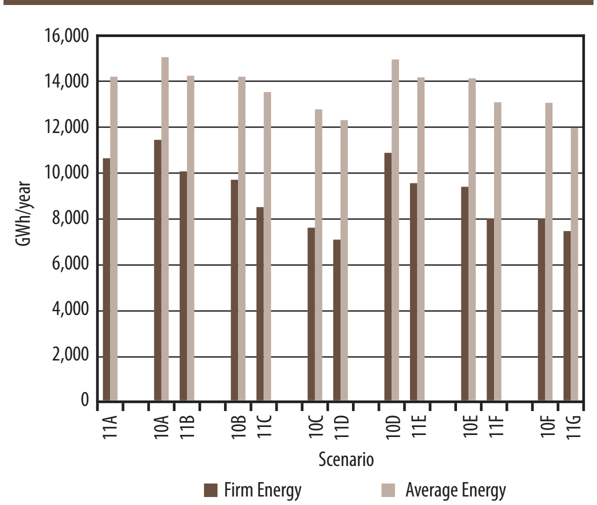


Figure 2.36. Impact on the energy production of the planned Mphanda Nkuwa HPP: Scenario 11A–11G compared with Scenario 10A–10F

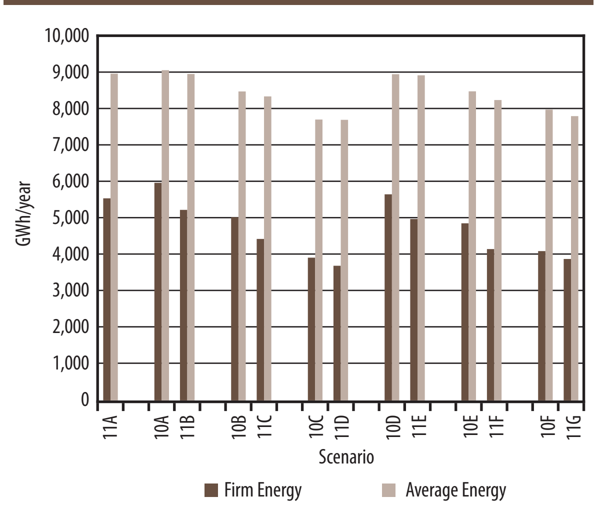


Table 2.55. Impact on energy production of Cahora Bassa Dam and the future Mphanda Nkuwa Dam: Scenario 2, Scenario 10A–10F, 11A–11G

Scenario	2	11A	10A	11B	10B	11C	10C	11D	10D	11E	10E	11F	10F	11G
timing	—	February							December					
flood protection, max (m^3/s)	—	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
flood level (m^3/s)	—	—	4,500	4,500	7,000	7,000	10,000	10,000	4,500	4,500	7,000	7,000	10,000	10,000
Cahora Bassa Dam (existing)														
Firm energy (GWh/year)	11,826	10,626	11,432	10,048	9,680	8,480	7,577	7,052	10,862	9,531	9,373	7,972	7,972	7,428
Loss (GWh/year)		*1,200*	*394*	*1,778*	*2,146*	*3,346*	*4,249*	*4,774*	*964*	*2,295*	*2,453*	*3,854*	*3,854*	*4,398*
Loss (%)		*10*	*3*	*15*	*18*	*28*	*36*	*40*	*8*	*19*	*21*	*33*	*33*	*37*
Average energy (GWh/year)	15,024	14,204	15,062	14,247	14,204	13,529	12,771	12,299	14,961	14,175	14,135	13,083	13,059	11,948
Loss (GWh/year)		*821*	*−38*	*777*	*820*	*1,495*	*2,253*	*2,725*	*64*	*849*	*889*	*1,941*	*1,965*	*3,077*
Loss (%)		*5*	*0*	*5*	*5*	*10*	*15*	*18*	*0*	*6*	*6*	*13*	*13*	*20*
Mphanda Nkuwa Dam (planned)														
Firm energy (GWh/year)	6,190	5,544	5,970	5,227	5,026	4,430	3,916	3,694	5,654	4,976	4,859	4,152	4,096	3,880
Loss (GWh/year)		*646*	*220*	*963*	*1,164*	*1,760*	*2,274*	*2,496*	*536*	*1,214*	*1,331*	*2,038*	*2,094*	*2,310*
Loss (%)		*10*	*4*	*16*	*19*	*28*	*37*	*40*	*9*	*20*	*22*	*33*	*34*	*37*
Average energy (GWh/year)	9,092	8,963	9,059	8,954	8,476	8,340	7,705	7,697	8,949	8,919	8,479	8,240	7,977	7,799
Loss (GWh/year)		*130*	*33*	*139*	*617*	*752*	*1,388*	*1,396*	*144*	*173*	*614*	*853*	*1,116*	*1,294*
Loss (%)		*1*	*0*	*2*	*7*	*8*	*15*	*15*	*2*	*2*	*7*	*9*	*12*	*14*
Delta flood occurence (% time)		*93*	*100*	*100*	*98*	*98*	*98*	*93*	*98*	*95*	*95*	*90*	*90*	*50*
Flood protection occurance (% time)		*93*		*93*		*93*		*95*		*95*		*95*		*95*

Table 2.56. Net present value of flood protection levels (US$ m): Scenarios 11A–11G compared with Scenario 2A and 10A–10F

Scenario	Compared with Scenario	Flood protection –maximum m³/s	Zambezi Delta flow (m³/s)	Timing	Duration	Hydropower	Other sectors	Flood protection	Total
11A	2A	10,000	—	—	—	482	–94	73	461
11B	10A	10,000	4,500	February	4 weeks	–593	2	73	–518
11C	10B	10,000	7,000	February	4 weeks	–506	65	73	–368
11D	10C	10,000	10,000	February	4 weeks	–238	65	73	–101
11E	10D	10,000	4,500	December	4 weeks	–576	65	73	–439
11F	10E	10,000	7,000	December	4 weeks	–637	65	73	–500
11G	10F	10,000	10,000	December	4 weeks	–348	65	73	–211

price in Scenario 11D to $0.03/KWh would balance the NPVs.

The economic value of flood protection is based on the avoided economic costs from disasters. The losses are calculated on housing, infrastructure, and agriculture assets. The NPV of the projected avoided costs is $72 million. This could be at the assumed price of firm energy of $0.58, which offsets a loss of 130 GWh in firm energy and is much less than in the scenarios envisaged.

The results of scenarios 11A to 11G that:

- Partial restoration of natural flooding of 4,500 m³ per second or 7,000 m³ per second in February and December and flood protection downstream of the Lupata Gorge can be combined;
- Partially restoring natural flooding with 10,000 m³ per second in February has a high percentage of success except during December (50 percent); and
- Compared with the base scenario, energy production is significantly reduced with between 10 to 40 percent for firm energy and one to 37 percent for average energy.

2.19 INFLOW SENSITIVITY ANALYSIS

A sensitivity analysis was undertaken to assess the implications of inaccuracies and variability in the inflows to the reservoir operation model. Variability in the range of plus and minus ten percent was considered in the results of Scenario 8, the balanced multi-sector development scenario.

The impact of variability in inflow on firm and average energy productivity of Scenario 8 is detailed in table 2.57. With a ten percent reduction in inflows, firm energy decreases by 17 percent and average energy by eight percent. With a ten percent increase in inflows, the increases are 12 and eight percent respectively.

Table 2.57. Sensitivity analysis on energy production: Scenario 8

Hydropower plant		Energy production (GWh/year): Firm energy: 10% reduced inflows	Firm energy: Scenario 8	Firm energy: 10% increased inflow	Average energy: 10% reduced inflows	Average energy: Scenario 8	Average energy: 10% increased inflow	% Change in energy production: 10% reduced inflows: Firm	10% reduced inflows: Average	10% increased inflows: Firm	10% increased inflows: Average
Batoka Gorge	projected	1,444	1,618	1,790	8,975	9,453	9,881	–11	–5	11	5
Kariba	existing & extension	4,949	5,624	6,325	6,825	7,668	8,505	–12	–11	12	11
Itezhi Tezhi	extension	80	258	316	673	712	747	–69	–6	23	5
Kafue Gorge Upper	refurbishment	3,376	4,292	4,468	6,153	6,581	6,899	–21	–6	4	5
Kafue Gorge Lower	projected	1,708	2,168	2,257	3,661	3,974	4,234	–21	–8	4	7
Cahora Bassa	existing & extension	6,106	7,420	8,453	11,381	12,725	13,972	–18	–11	14	10
Mphanda Nkuwa	projected	3,165	3,867	4,391	7,051	7,876	8,695	–18	–10	14	10
Rumakali	projected	118	670	718	909	966	1,027	–82	–6	7	6
Songwe I	projected	27	29	36	66	75	84	–7	–12	22	12
Songwe II	projected	206	228	266	395	436	485	–10	–9	17	11
Songwe III	projected	177	197	225	344	378	417	–10	–9	14	10
Lower Fufu	projected	122	134	147	618	645	668	–9	–4	9	4
Kholombizo	projected	208	318	417	1,453	1,603	1,721	–34	–9	31	7
Nkula Falls	existing	307	440	528	961	1,010	1,038	–30	–5	20	3
Tedzani	projected	195	281	338	670	714	738	–31	–6	20	4
Kapichira	existing & extension	314	394	495	983	1,041	1,071	–20	–6	26	3
Total		**25,020**	**30,013**	**33,519**	**51,120**	**55,857**	**60,182**	**–17**	**–8**	**12**	**8**

3 Summary of Findings

In table 3.1. a summary of the scenario results in each sector is provided. The subsequent sections of this chapter look at water-using activities individually to illustrate relative impact and summary of results.

3.1 ENERGY PRODUCTION

The estimated levels of firm and average energy production from Scenario 0 to Scenario 8 are presented in figure 3.1. and figure 3.2. respectively. The result shows that the generation of firm energy ranges from 43,476 GWh per year in Scenario 2D to 11,600 GWh per year in Scenario 4. For average energy, the equivalent range is from 60,760 GWh per year in Scenario 2 to 21, 907 GWh per year in Scenario 4. In the figures, the lighter shaded data labels indicate the existing system of HPPs, and the darker indicate the potential HPPs envisaged under SAPP.

3.2 IRRIGATION

The model evaluates three different levels of irrigation in the ZRB. Firstly, the existing areas that are equipped and the total average annually irrigated area. Secondly, estimates were made for how these two categories of irrigation areas would increase with the development and implementation of identified irrigation projects (IPs). Lastly, the model also considered the potential of a much higher level of irrigation (HLI) on two previous levels of irrigation.

In addition to estimating the potential of these two latter categories of expansion (IPs and HLI), the model evaluated what would happen if there was coordination in the basin, by moving upstream irrigated areas to downstream location (see Scenario 5A and Scenario 6A).

The expansion of irrigated area (both total average and equipped area) is detailed in table 3.2. The results indicate that the increase is concentrated to the middle and lower parts of the ZRB: in the Kafue subbasin with no potential for significant increase in irrigated area; in the Kariba subbasin where Zimbabwe plans a major initiative to

Table 3.1. Summary of findings: Scenario 0 – Scenario 8

Scenario		0	1	2	2A	2B	2C	2D	3	4	5	5A	6	6A	7	8
Hydropower		Current Situation - No coordinated operation	Current Situation - No coordinated operation	SAPP Development - no coordinated operation	SAPP Development - no coordinated operation	SAPP Development - 4 clusters	SAPP Development - 2 clusters	SAPP Development - 1 system	Current Situation - no coordinated operation	Current Situation - no coordinated operation	SAPP Development - no coordinated operation	SAPP Development - no coordinated operation	SAPP Development - no coordinated operation	SAPP Development - no coordinated operation	SAPP Development - no coordinated operation	SAPP Development - no coordinated operation
Irrigation		Current Situation	Current Situation	Current Situation	Current Situation	Current Situation	Current Situation	Current Situation	IPs - no coordination	HLI - no coordination	IPs - no coordination	IPs - coordinated	HLI - no coordination	HLI - coordinated	IPs - no coordination	IPs - no coordination
Restoration of natural flooding in Delta		No artificial flooding	No artificial flooding	No artificial flooding	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)	AF2 (7,000 m^3/s in February)
Flood protection		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	FP (max 10,000 m^3/s at Lupata)
E-Flows		n/a	n/a	n/a	e-flows	e-flows	e-flows	e-flows	e-flows	e-flows	e-flows	e-flows	e-flows	e-flows	e-flows	e-flows
Other projects		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	No	n/a	n/a	Other Projects	Other Projects
Domestic water supply		domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply	domestic water supply
HYDROPOWER																
Firm energy production - change G																
Batoka Gorge	projected	—		1,907	1,907	13,315			—	—	1,660	1,696	1,099	1,125	1,618	1,618
Kariba	existing & extension	6,369		6,333	6,369				5,694	3,171	5,694	5,825	3,171	3,311	5,624	5,624
Itezhi Tezhi	extension	—		284	284		19,570		—	—	258	258	208	208	258	258
Kafue Gorge Upper	refurbishment	4,695		4,687	4,542	7,446			4,424	3,819	4,424	4,459	3,811	4,030	4,292	4,292
Kafue Gorge Lower	projected	—	24,397	2,368	2,301			43,476	—		2,239	2,252	1,924	2,035	2,168	2,168
Cahora Bassa	existing & extension	11,922		11,826	9,680	15,006			8,804	4,949	8,804	8,970	4,967	5,151	8,585	7,420
Mphanda Nkuwa	projected	—		6,190	5,026		19,894		—	—	4,554	4,643	2,511	2,608	4,457	3,867
Rumakali	projected	—		686	686				—	—	670	670	670	670	670	670
Songwe I	projected	—		41	41	3,092			—	—	29	29	32	32	29	29
Songwe II	projected	—		277	277				—	—	228	228	237	237	228	228

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Table 3.1. Summary of findings: Scenario 0 – Scenario 8 *(continued)*

Scenario		0	1	2	2A	2B	2C	2D	3	4	5	5A	6	6A	7	8
Songwe III	projected	—		229	229				—	—	197	197	201	203	197	197
Lower Fufu	projected	—		134	134				—	—	134	134	134	134	134	134
Kholombizo	projected	—		344	344				—	—	318	318	152	152	318	318
Nkula Falls	existing	462	24,397	460	460	3,092	19,894	43,476	442	272	440	440	271	271	440	440
Tedzani	projected	300		299	299				282	173	281	281	172	172	281	281
Kapichira	existing & extension	542		541	541				395	102	394	394	103	103	394	394
Total		**22,776**	**24,397**	**39,000**	**35,302**	**39,928**	**37,712**	**43,476**	**18,052**	**11,600**	**32,358**	**33,107**	**22,282**	**22,917**	**32,024**	**30,013**
Change in firm energy production (GWh/year)																
Compared with Scenario:			*0*	*0*	*0*	*2A*	*2B*	*2C*	*0*	*0*	*2A*	*5*	*2A*	*6*	*2A*	*2A*
Batoka Gorge	projected			1,907	1,907	5,499			–	–	–247	37	–808	26	–290	–290
Kariba	existing & extension			–35	0				–675	–3,197	–675	131	–3,197	140	–745	–745
Itezhi Tezhi	extension			284	284		613		–	–	–26	0	–76	0	–26	–26
Kafue Gorge Upper	refurbishment			–9	–153	358			–271	–876	–118	34	–731	219	–250	–250
Kafue Gorge Lower	projected			2,368	2,301				–	–	–62	13	–377	111	–133	–133
Cahora Bassa	existing & extension			–96	–2,243	321			–3,119	–6,973	–876	166	–4,713	184	–1,095	–2,260
Mphanda Nkuwa	projected	n/a	1,621	6,190	5,026			5,764	–	–	–473	90	–2,515	96	–569	–1,159
Rumakali	projected			686	686				–	–	–16	0	–16	0	–16	–16
Songwe I	projected			41	41				–	–	–12	0	–10	0	–12	–12
Songwe II	projected			277	277				–	–	–49	0	–40	0	–49	–49
Songwe III	projected			229	229		981		–	–	–32	0	–27	2	–32	–32
Lower Fufu	projected			134	134	1			–	–	0	0	0	0	0	0
Kholombizo	projected			344	344				–	–	–26	0	–192	0	–26	–26
Nkula Falls	existing			–2	–2				–20	–191	–20	0	–189	0	–20	–20
Tedzani	projected								–18	–127	–18	0	–126	0	–18	–18
Kapichira	existing & extension								–147	–441	–147	0	–439	0	–147	–147
Total			1,621	16,224	12,526	4,626	–2,216	5,764	–4,724	–11,176	–2,944	749	–13,020	635	–3,279	–5,290

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Table 3.1. Summary of findings: Scenario 0 – Scenario 8 *(continued)*

Scenario		0	1	2	2A	2B	2C	2D	3	4	5	5A	6	6A	7	8
% change		*n/a*	*7%*	*42%*	*35%*	*12%*	*–6%*	*13%*	*–26%*	*–96%*	*–9%*	*2%*	*–58%*	*3%*	*–10%*	*–18%*
Average energy production (GWh/year)																
Batoka Gorge	projected	0	0	9,638	9,638	17,819	30,094	59,178	0	0	9,479	9,495	9,123	9,140	9,453	9,453
Kariba	existing & extension	7,668	7697	8,358	8,361				7,059	4,701	7,709	7,850	5,255	5,396	7,668	7,668
Itezhi Tezhi	extension	0	0	716	716	11,583			0	0	712	712	705	705	712	712
Kafue Gorge Upper	refurbishment	6,785	7359	6,784	6,766				6,677	6,460	6,677	6,714	6,460	6,518	6,581	6,581
Kafue Gorge Lower	projected	0	0	4,097	4,092				0	0	4,036	4,061	3,913	3,944	3,974	3,974
Cahora Bassa	existing & extension	13,535	13028	15,024	14,204	22,691	29,157		11,609	8,622	13,449	13,613	10,361	10,535	13,344	12,725
Mphanda Nkuwa	projected	0	0	9,093	8,476				0	0	8,063	8,154	6,347	6,440	7,996	7,876
Rumakali	projected	0	0	985	985	7,045			0	0	966	966	966	966	966	966
Songwe I	projected	0	0	90	91				0	0	75	75	75	75	75	75
Songwe II	projected	0	0	490	490				0	0	436	436	439	439	436	436
Songwe III	projected	0	0	414	414				0	0	378	378	381	381	378	378
Lower Fufu	projected	0	0	645	645				0	0	645	645	645	645	645	645
Kholombizo	projected	0	0	1,626	1,626				0	0	1,603	1,603	1,371	1,371	1,603	1,603
Nkula Falls	existing	1,017	989	1,017	1,017				1,011	936	1,010	1,010	935	935	1,010	1,010
Tedzani	projected	722	692	720	720				716	651	714	715	648	650	714	714
Kapichira	existing & extension	560	558	1,063	1,063				557	537	1,041	1,041	880	880	1,041	1,041
Total		**30,287**	**30,232**	**60,760**	**59,304**	**59,138**	**59,251**	**59,178**	**27,629**	**21,907**	**56,993**	**57,468**	**48,504**	**49,020**	**56,596**	**55,857**
Change in average energy production (GWh/year)																
Compared with Scenario:			*0*	*0*	*0*	*2A*	*2B*	*2C*	*0*	*0*	*2A*	*5*	*2A*	*6*	*2A*	*2A*
Batoka Gorge	projected	n/a	0	9,638	9,638	–179	692	–73	0	0	–159	16	–515	17	–185	–185
Kariba	existing & extension		29	690	693				–609	–2967	–652	141	–3,106	141	–693	–693
Itezhi Tezhi	extension		0	716	716	8			0	0	–4	0	–11	0	–4	–4
Kafue Gorge Upper	refurbishment		574		–19				–108	–325	–89	37	–306	58	–185	–185

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Table 3.1. Summary of findings: Scenario 0 – Scenario 8 *(continued)*

Scenario		0	1	2	2A	2B	2C	2D	3	4	5	5A	6	6A	7	8
Kafue Gorge Lower	projected		0	4,097	4,092	8	692		0	0	–56	25	–179	31	–118	–118
Cahora Bassa	existing & extension		–507	1,489	669	12			–1926	–4913	–755	164	–3,843	174	–860	–1,479
Mphanda Nkuwa	projected		0	9,093	8,476				0	0	–413	91	–2,129	93	–480	–600
Rumakali	projected		0	985	985				0	0	–19	0	–19	0	–19	–19
Songwe I	projected		0	90	91				0	0	–16	0	–16	0	–16	–16
Songwe II	projected	n/a	0	490	490			–73	0	0	–54	0	–51	0	–54	–54
Songwe III	projected		0	414	414		–579		0	0	–36	0	–33	0	–36	–36
Lower Fufu	projected		0	645	645	483			0	0	0	0	0	0	0	0
Kholombizo	projected		0	1,626	1,626				0	0	–23	0	–255	0	–23	–23
Nkula Falls	existing		–28	0	0				–6	–81	–7	0	–82	0	–7	–7
Tedzani	projected		–30	–2	–2				–6	–71	–6	1	–72	2	–6	–6
Kapichira	existing & extension		–2	503	503				–3	–23	–22	0	–183	0	–22	–22
Total		**n/a**	**36**	**30473**	**29,017**	**324**	**113**	**–73**	**–2658**	**–8380**	**–2311**	**475**	**–10800**	**516**	**–2708**	**–3447**
% change		*n/a*	*0%*	*50%*	*49%*	*1%*	*0%*	*0%*	*–10%*	*–38%*	*–4%*	*1%*	*–22%*	*1%*	*–5%*	*–6%*
IRRIGATION																
Total equipped area (ha)																
Angola		4,750	4,750	4,750	4,750	4,750	4,750	4,750	15,250	45,250	15,250	15,250	45,250	45,250	15,250	15,250
Botswana		0	0	0	0	0	0	0	13,800	27,600	13,800	13,800	27,600	27,600	13,800	13,800
Malawi		30,816	30,816	30,816	30,816	30,816	30,816	30,816	78,727	378,727	78,727	78,727	378,727	378,727	78,727	78,727
Mozambique		7,413	7,413	7,413	7,413	7,413	7,413	7,413	103,618	403,618	103,618	103,618	403,618	403,618	103,618	103,618
Namibia		120	120	120	120	120	120	120	420	15,420	420	420	15,420	15,420	420	420
Tanzania		11,600	11,600	11,600	11,600	11,600	11,600	11,600	23,200	73,200	23,200	23,200	73,200	73,200	23,200	23,200
Zambia		56,452	56,452	56,452	56,452	56,452	56,452	56,452	93,874	383,874	93,874	93,874	383,874	383,874	93,874	93,874
Zimbabwe		71,486	71,486	71,486	71,486	71,486	71,486	71,486	189,950	399,950	189,950	189,950	399,950	399,950	189,950	189,950
Total		**182,637**	**182,637**	**182,637**	**182,637**	**182,637**	**182,637**	**182,637**	**518,839**	**1,727,639**	**518,839**	**518,839**	**1,727,639**	**1,727,639**	**518,839**	**518,839**
Change in equipped area (ha)																
Angola			0	0	0	0	0	0	10,500	40,500	10,500	10,500	40,500	40,500	10,500	10,500
Botswana		n/a	0	0	0	0	0	0	13,800	27,600	13,800	13,800	27,600	27,600	13,800	13,800
Malawi			0	0	0	0	0	0	47,911	347,911	47,911	47,911	347,911	347,911	47,911	47,911

Continued on next page

Table 3.1. Summary of findings: Scenario 0 – Scenario 8 *(continued)*

Scenario	0	1	2	2A	2B	2C	2D	3	4	5	5A	6	6A	7	8
Mozambique	n/a	0	0	0	0	0	0	96,205	396,205	96,205	96,205	396,205	396,205	96,205	96,205
Namibia		0	0	0	0	0	0	300	15,300	300	300	15,300	15,300	300	300
Tanzania		0	0	0	0	0	0	11,600	61,600	11,600	11,600	61,600	61,600	11,600	11,600
Zambia		0	0	0	0	0	0	37,422	327,422	37,422	37,422	327,422	327,422	37,422	37,422
Zimbabwe		0	0	0	0	0	0	118,464	328,464	118,464	118,464	328,464	328,464	118,464	118,464
Total		**0**	**0**	**0**	**0**	**0**	**0**	**336,202**	**1,545,002**	**336,202**	**336,202**	**1,545,002**	**1,545,002**	**336,202**	**336,202**
% change		*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*65%*	*89%*	*65%*	*65%*	*89%*	*89%*	*65%*	*65%*
Total average irrigated area (ha)															
Angola	6,125	6,125	6,125	6,125	6,125	6,125	6,125	16,750	54,250	16,750	16,750	54,250	54,250	16,750	16,750
Botswana	0	0	0	0	0	0	0	20,300	40,600	20,300	20,300	40,600	40,600	20,300	20,300
Malawi	37,820	37,820	37,820	37,820	37,820	37,820	37,820	115,846	620,734	115,846	115,846	620,734	620,734	115,846	115,846
Mozambique	8,436	8,436	8,436	8,436	8,436	8,436	8,436	145,846	670,846	145,846	145,846	670,846	670,846	145,846	145,846
Namibia	140	140	140	140	140	140	140	590	18,590	590	590	18,590	18,590	590	590
Tanzania	23,140	23,140	23,140	23,140	23,140	23,140	23,140	46,280	146,021	46,280	46,280	146,021	146,021	46,280	46,280
Zambia	74,661	74,661	74,661	74,661	74,661	74,661	74,661	135,920	627,444	135,920	135,920	627,444	627,444	135,920	135,920
Zimbabwe	108,717	108,717	108,717	108,717	108,717	108,717	108,717	292,148	617,314	292,148	292,148	617,314	617,314	292,148	292,148
Total	**259,039**	**259,039**	**259,039**	**259,039**	**259,039**	**259,039**	**259,039**	**773,680**	**2,795,799**	**773,680**	**773,680**	**2,795,799**	**2,795,799**	**773,680**	**773,680**
Change in total average irrigated area (ha)															
Angola	n/a	0	0	0	0	0	0	10,625	48,125	10,625	10,625	48,125	48,125	10,625	10,625
Botswana		0	0	0	0	0	0	20,300	40,600	20,300	20,300	40,600	40,600	20,300	20,300
Malawi		0	0	0	0	0	0	78,026	582,914	78,026	78,026	582,914	582,914	78,026	78,026
Mozambique		0	0	0	0	0	0	137,410	662,410	137,410	137,410	662,410	662,410	137,410	137,410
Namibia		0	0	0	0	0	0	450	18,450	450	450	18,450	18,450	450	450
Tanzania		0	0	0	0	0	0	23,140	122,881	23,140	23,140	122,881	122,881	23,140	23,140
Zambia		0	0	0	0	0	0	61,259	552,783	61,259	61,259	552,783	552,783	61,259	61,259
Zimbabwe		0	0	0	0	0	0	183,431	508,597	183,431	183,431	508,597	508,597	183,431	183,431
Total		**0**	**0**	**0**	**0**	**0**	**0**	**514,641**	**2,536,760**	**514,641**	**514,641**	**2,536,760**	**2,536,760**	**514,641**	**514,641**
% change		*0%*	*0%*	*0%*	*0%*	*0%*	*0%*	*67%*	*91%*	*67%*	*67%*	*91%*	*91%*	*67%*	*67%*
OTHER ABSTRACTIONS AND SUPPLEMENTARY REGULATION															
Additional regulation requirements compared with Scenario 0															
million m^3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	254	3,078	254	219	3,328	3,248	254	254

Continued on next page

Table 3.1. Summary of findings: Scenario 0 – Scenario 8 *(continued)*

Scenario	0	1	2	2A	2B	2C	2D	3	4	5	5A	6	6A	7	8
Irrigation															
million m^3	3,234	3,234	3,234	3,234	3,234	3,234	3,234	9,119	29,326	9,119	8,840	29,326	29,047	9,119	9,119
% run-off	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	2.5%	7.0%	22.6%	7.0%	6.8%	22.6%	22.4%	7.0%	7.0%
Mining and water supply															
million m^3	344	344	344	344	344	344	344	344	344	344	344	344	344	786	786
% run-off	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.6%	0.6%
Evaporation															
million m^3	9,054	8,963	9,357	9,262	9,240	9,048	9,007	8,985	9,070	9,237	9,250	9,338	9,328	9,237	8,953
% run-off	7.0%	6.9%	7.2%	7.1%	7.1%	7.0%	6.9%	6.9%	7.0%	7.1%	7.1%	7.2%	7.2%	7.1%	6.9%

Figure 3.1. Firm energy production: Scenario 0–Scenario 8

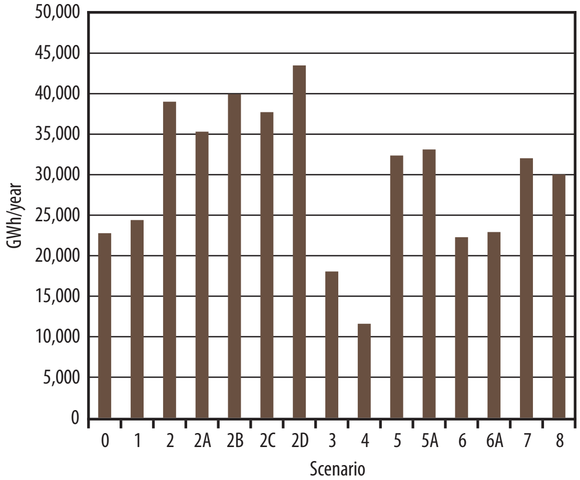
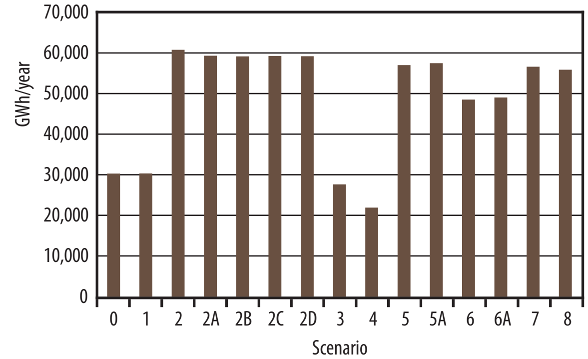


Figure 3.2. Average energy production: Scenario 0 – Scenario 8



develop agriculture; and the Tete, the Shire River and Lake Malawi/Niassa/Nyasa, and the Zambezi Delta subbasins.

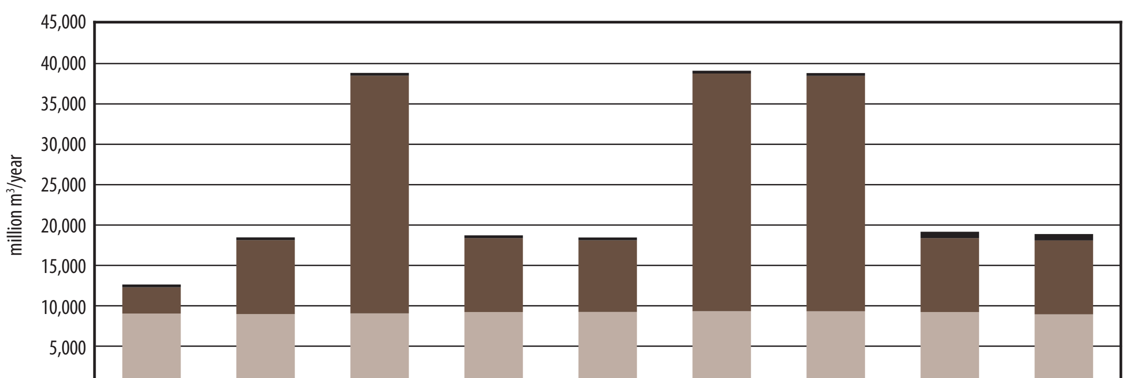
3.3 OTHER ABSTRACTIONS AND SUPPLEMENTARY REGULATION

Evaporation from reservoirs in the ZRB equates to approximately seven percent of the total annual run-off (130,000 million m^3 per year) and approximately 72 percent of total water abstractions (figure 3.3.). In the modeled scenarios, evaporation rates vary from 23 percent to 50 percent depending on levels of water withdrawal for other uses.

In the Base Case (Scenario 0), irrigation abstractions are comparable to 2.5 percent of annual run-off and 26 percent of total abstractions. When the identified irrigation projects are introduced, abstraction doubles to approximately 50 percent of the total abstractions, and triples in the high-level irrigation scenarios.

When multi-sector development is considered in Scenario 7 and Scenario 8, water withdrawals equate to approximately 15 percent of the annual

Figure 3.3. Water abstractions (million m^3/year): Scenario 0, Scenario 3 to 8



	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Mining and water supply	344	344	344	344	344	344	344	786	786
Irrigation	3,234	9,119	29,326	9,119	8,840	29,326	29,047	9,119	9,119
Evaporation	9,054	8,985	9,070	9,237	9,250	9,338	9,328	9,237	8,953

Table 3.2. Total average irrigated area and total equipped area (ha/year): Scenario 0–8

	Average annual irrigated area (ha)					Equipped irrigation area (ha)				
	Scenario 0, 2 & 2A–2D	Scenario 3, 5, 7 & 8	Scenario 5A	Scenario 4 & 6	Scenario 6A	Scenario 0, 2 & 2A–2D	Scenario 3, 5, 7 & 8	Scenario 5A	Scenario 4 & 6	Scenario 6A
	Current situation	IPs without cooperation	IPs with cooperation	HLI without cooperation	HLI with cooperation	Current situation	IPs without cooperation	IPs with cooperation	HLI without cooperation	HLI with cooperation
Subbasins										
Kabompo (13)	595	11,314	11,314	28,328	28,328	350	6,650	6,650	16,650	16,650
Upper Zambezi (12)	3,250	8,250	4,750	20,750	17,250	2,500	7,500	4,000	17,500	14,000
Lungúe Bungo (11)	1,250	1,875	1,875	14,375	14,375	1,000	1,500	1,500	11,500	11,500
Luanginga (10)	1,000	6,000	6,000	18,500	18,500	750	5,750	5,750	15,750	15,750
Barotse (9)	340	12,753	12,753	30,466	30,466	200	7,208	7,208	17,208	17,208
Cuando/Chobe (8)	765	1,215	1,215	19,215	19,215	620	920	920	15,920	15,920
Kafue (7)	46,528	67,048	62,449	104,448	99,849	40,158	53,768	49,169	78,768	74,169
Kariba (6)	44,531	228,919	208,969	948,825	928,875	28,186	147,778	127,828	591,578	571,628
Luangwa (5)	17,794	28,857	28,857	73,814	73,814	10,100	16,230	16,230	41,230	41,230
Mupata (4)	21,790	30,356	30,356	30,356	30,356	14,200	20,060	20,060	20,060	20,060
Shire River - Lake Malawi/Niassa/Nyasa (3)	60,960	162,126	162,126	766,755	766,755	42,416	101,927	101,927	451,927	451,927
Tete (2)	52,572	108,193	108,193	508,193	508,193	35,159	65,495	65,495	265,495	265,495
Zambezi Delta (1)	7,664	106,774	134,823	231,774	259,823	6,998	84,053	112,102	184,053	212,102
Total	**259,039**	**773,680**	**773,680**	**2,795,799**	**2,795,799**	**182,637**	**518,839**	**518,839**	**1,727,639**	**1,727,639**
Countries										
Angola	6,125	16,750	13,250	54,250	50,750	4,750	15,250	11,750	45,250	41,750
Botswana	0	20,300	20,300	40,600	40,600	0	13,800	13,800	27,600	27,600
Malawi	37,820	115,846	115,846	620,734	620,734	30,816	78,727	78,727	378,727	378,727
Mozambique	8,436	145,846	173,895	670,846	698,895	7,413	103,618	131,667	403,618	431,667
Namibia	140	590	590	18,590	18,590	120	420	420	15,420	15,420
Tanzania	23,140	46,280	46,280	146,021	146,021	11,600	23,200	23,200	73,200	73,200
Zambia	74,661	135,920	131,321	627,444	622,845	56,452	93,874	89,275	383,874	379,275
Zimbabwe	108,717	292,148	272,198	617,314	597,364	71,486	189,950	170,000	399,950	380,000
Total	**259,039**	**773,680**	**773,680**	**2,795,799**	**2,795,799**	**182,637**	**518,839**	**518,839**	**1,727,639**	**1,727,639**

run-off. In the high-level irrigation scenarios, however, withdrawals increase to 30 percent of the annual run-off (table 3.3.).

3.4 ECONOMIC ASSESSMENT

The simulated scenarios primarily explore how hydropower and irrigation sectors can be optimized and with what economic benefits (i.e., total and change in NPV). The overall time-frame considered for the simulations is 50 years with a 30 year assumed lifetime for the individual projects incorporating discounted costs and gains. This is especially important for the constructions of HPPs where initial costs are usually very high and long term benefits are gained over time.

The scenarios include estimated total, or change in NPV of hydropower, agriculture, other sectors, other projects, and flood protection. The economic model is restricted as it does not assess how economic gains and increased productivity will have a multiplying effect on the economies and societies of the riparian countries. In addition, other water using activities are difficult to accurately estimate in economic terms despite being fundamental for rural livelihoods, wildlife, ecosystem services to mention a few. Hence, any analysis of the implied trade-off between NPV estimates for different sectors in each scenario must be done with caution and calls for more detailed assessment.

In addition, the economic model estimated the employment impact of the scenarios. One of the important benefits from developing irrigation for agricultural productivity would be the substantial creation of jobs (in addition to benefits such as diversification of the economy, food security and so forth.). Hydropower investments, on the contrary, create more employment initially and less over time. Yet the ability to supply increased and more reliable energy is directly crucial for driving economic growth and job creation. As the model cannot fully estimate the employment impact, the numbers are more indicative of potential and analysis of the employment figures calls for the same caution as with NPV.

In terms of NPV, increased hydropower production would produce significant economic benefits.

Table 3.3. Supplementary regulation requirements: Scenario 0, Scenario 3 to Scenario 8

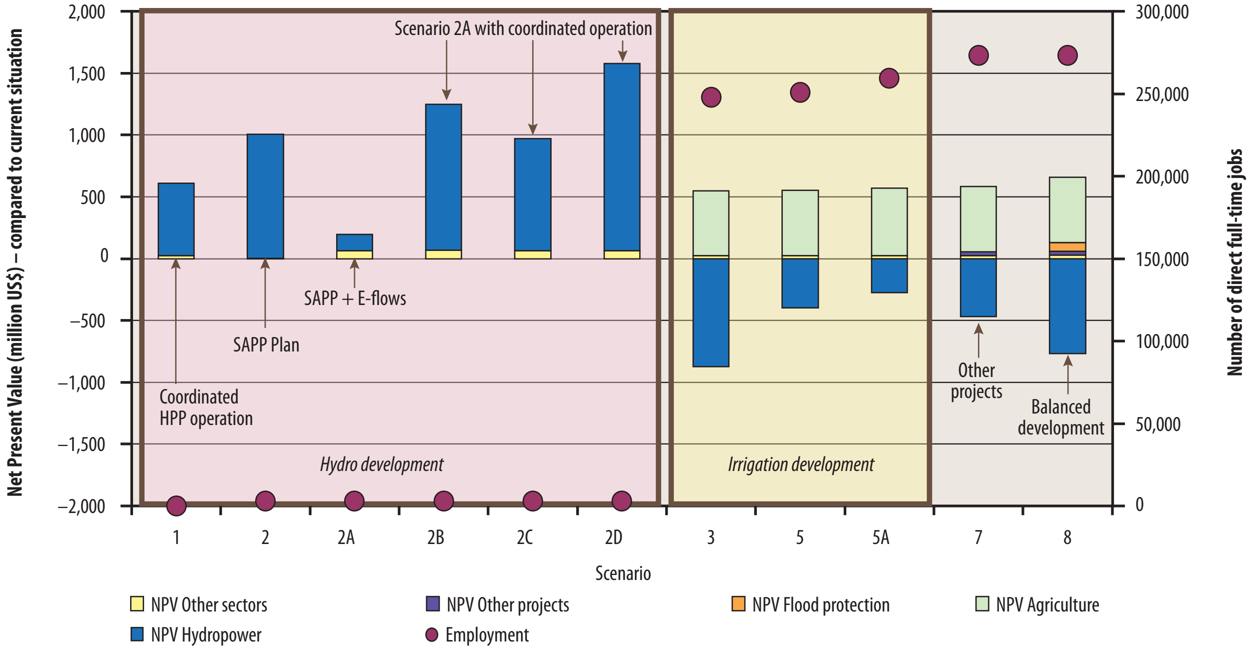
Scenario	Supplementary regulation compared with base case (million m^3)
Scenario 0	0
Scenario 3	254
Scenario 4	3,078
Scenario 5	254
Scenario 5A	219
Scenario 6	3,328
Scenario 6A	3,248
Scenario 7	254
Scenario 8	254

Investment in upgrades, extensions and new infrastructure for hydropower could thus be financially viable. Interestingly, the scenarios clearly show that economic benefits can already be achieved through cooperation and conjunctive operation of the existing HPPs (whilst also taking environmental concerns and other water-using sectors into consideration).

Figure 3.4. gives an overview of the economic assessment. The potential employment impact is presented in the right hand y-axis, whereas the left hand y-axis presents total net present value (US$ m). In this simplified illustration, the NPV estimates at first indicate trade-off between investing in irrigation and in hydropower. In reality, however, any trade-off will depend on additional conditions. Moreover, economic gains from energy generation and agricultural expansion are extremely sensitive to unit pricing. Scenario 5A and Scenario 6A explore the impact of coordination of irrigation (moving irrigated area from upstream to downstream) and the NPV gains indicate that any negative trade-off could be offset.

Table 3.4. lists the total NPV of each scenario and water using sector or activity, as well as employment effect. Total NVP estimates illustrate the significant gains that could be achieved in hydropower and agriculture, but also how there appears to be a trade-off in investments. Due to reasons outlined above as well as the importance of high IRR, these should be analyzed with caution.

Figure 3.4. Summary of economic analysis: Net present value and employment results by development scenario *(compare to current situation)*



3.5 CONCLUSION

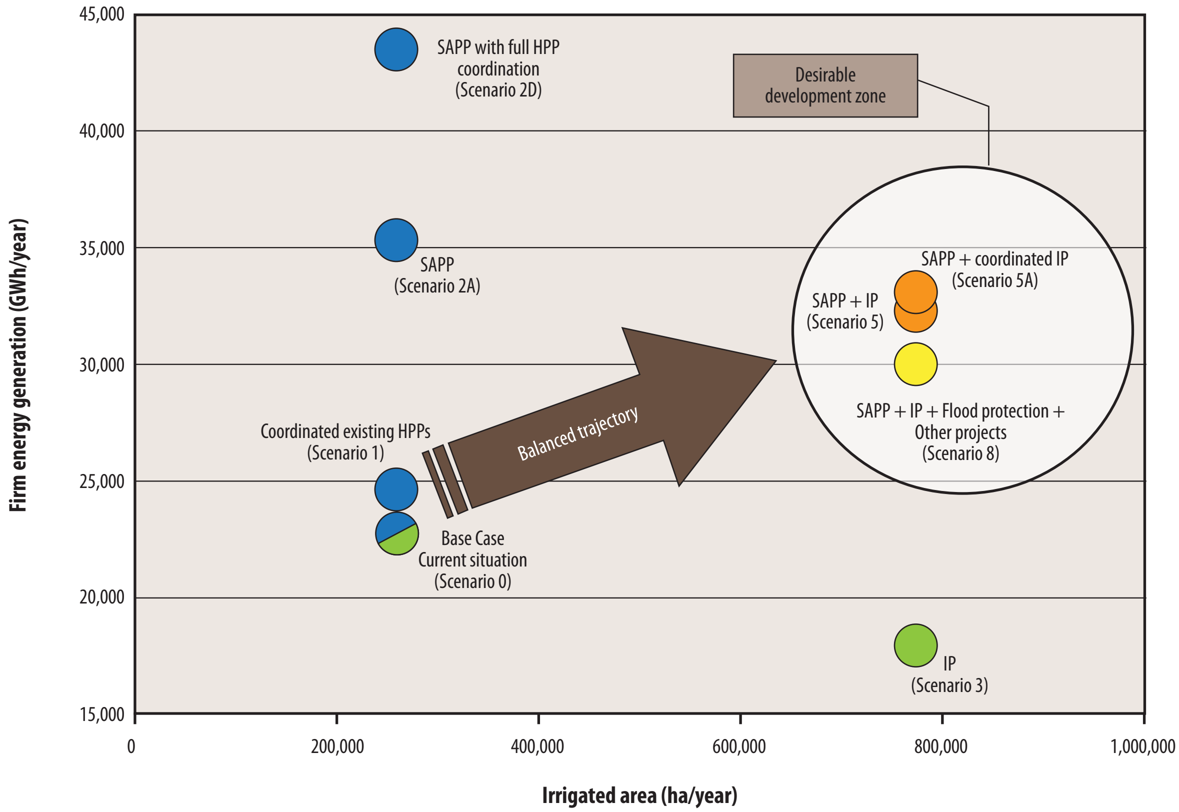
Figure 3.5. was developed from the modeling results and in accordance with the analytical framework described earlier. It indicates a step-by-step approach to determining the threshold values for the potential joint development of the hydropower and agricultural sectors.

Table 3.4. Net present value (US$ m) and employment potential (jobs per year): Scenarios 1–8

Scenario	Hydropower	Agriculture	Other sectors	Other projects	Flood protection	Total NPV	Employment (number of jobs)
1	585.33	0.00	23.24	0.00	0.00	608.57	0
2	1,003.50	0.00	3.16	0.00	0.00	1,006.66	3,065
2A	128.55	0.00	65.10	0.00	0.00	193.65	3,065
2B	1,180.11	0.00	66.36	0.00	0.00	1,246.47	3,065
2C	906.60	0.00	64.18	0.00	0.00	970.78	3,065
2D	1,515.82	0.00	63.31	0.00	0.00	1,579.14	3,065
3	−872.49	526.78	22.90	0.00	0.00	−322.82	247,902
4	−3,798.85	2,397.04	−13.01	0.00	0.00	−1,414.81	1,131,677
5	−398.28	526.78	23.90	0.00	0.00	152.41	250,967
5A	−275.22	545.30	24.44	0.00	0.00	294.52	259,364
6	−3,807.92	2,386.34	−9.75	0.00	0.00	−1,431.34	1,134,742
6A	−3,630.17	2,407.37	55.44	0.00	0.00	−1,167.36	1,131,677
7	−467.41	526.78	24.47	32.59	0.00	116.44	273,269
8	−769.46	526.78	26.73	32.59	72.67	−110.68	273,269

Note: The substantial social and environmental benefits associated with Scenario 8 have only been partially quantified. Therefore the NPV value for Scenario 8 is highly underestimated.

Figure 3.5. Potential for energy generation and irrigation by development scenario



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 per year and average energy production of approximately 60,000 GWh per year, thereby meeting all or most of the estimated 48,000 GWh per 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 anaylsis 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 per year and some 774,000 hectares of irrigated land. Those goals could be achieved while providing some level of flood protection and artificial flooding in the Lower Zambezi.

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