Republic of Kenya

Economic Evaluation of Adaptation Measures to Climate under Uncertainty

Executive Summary

July, 2016

Japan International Cooperation Agency

NIPPON KOEI Co., Ltd.

— Table of Contents —

CURRENCY

Monthly Exchange Rate in March 2009

US$ 1.00 = KSh 77.13 = J.Yen 97.95

ABBREVIATIONS AND ACRONYMS

ARC2	Africa Rainfall Estimate Climatology Version 2
BCR	Benefit-Cost Ratio
CenTrends	The Centennial Trends Greater Horn of Africa Precipitation
CIF	Cost, Insurance and Freight
CP	Cropping Pattern
CMIP5	Coupled Model Intercomparison Project Phase 5
DSSAT	Decision Support System for Agrotechnology Transfer
EIRR	Economic Internal Rate of Return
FAO	Food and Agriculture organization of the United Nations
FAO-PM	FAO Pennman-Monteith equation
GCM	General Circulation Model
GDP	Gross Domestic Products
HW	Headworks
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	IPCC Fifth Assessment Report
ISIMIP	The inter-Sectoral Impact Model Intercomparison Project
JICA	Japan International Cooperation Agency
LR	Long Rain season
MCM	Million Cubic Meter
MIAD	Mwea Irrigation Agriculture Development Centure
MIS	Mwea Irrigation Settlement
MISWUA	MIS Water Users Association
MOA	Ministry of Agiculture
MOA ERA	MOA Economic Review of Agriculture
NCEP	National Centers for Environmental Prediction
NIB	National Irrigation Board
NPV	Net Present Value
NWMP2030	Kenya National Water Master Plan 2030
NRDS	National Rice Development Strategy (2008-2018)
OECD	Organisation for Economic Co-operation and Development
O&M	Operation and Maintenance

RDM	Robust Decision Making
RCP	Representative Concentration Pathways
RMSE	Root Mean Square Error
SAPROF	Special Assistance for Project Formulation
SHER Model	Similar Hydrologic Element Response Model
SR	Short Rain season
WRMA	Water Resource Management Authority
WUA	Water Users Association
WATCH	Forcing Data methodology applied to ERA-Interim data
WPP 2015	World Population Prospects 2015

Meteorological Variables

pr	Precipitation
tas	Near-Surface Air Temperature
tasmax	Daily Maximum Near-Surface Air Temperature
tasmin	Daily Minimum Near-Surface Air Temperature
sfcWind	Ner-Surface Wind Speed
huss	Near-Surface Specific Humidity
hurs	Near-Surface Relative Humidity
rsds	Surface Downwelling Shortwave Radiation
rlds	Surface Downwelling Longwave Radiation
ps	Surface Air Pressure
ET	Evapotranspiration

Climate Scenarios

BL	Baseline
DH	Dry-High Scnario
DL	Dry-Low Scenario
MM	Medium-Medium Scenario
WH	Wet-High Scenario
WL	Wet-Low Scenario

1. Overview of the Project

1. 1. Project Name

Economic Evaluation of Adaptation Measures to Climate under Uncertainty

1. 2. Background

According to the Working Group II Report of the Fifth Assessment Report (AR5) which was published in 2014 by Intergovernmental Panel on Climate Change (IPCC), evidence of climate-change impacts is strongest and more comprehensive for natural system. With the growing recognition that some negative effects of climate change will be inevitable no matter how deeply we reduce greenhouse gas emissions, governments across the world are beginning to show interest in the issue of climate change adaptation. JICA also runs various projects directly and indirectly related to climate change adaptation. To conduct such projects, we need a methodology to evaluate JICA projects in terms of the effectiveness on climate change adaptation. A particularly difficult issue in developing such a methodology, however, is how to consider the uncertainty of climate change, i.e., the fact that we do not know exactly what will happen in the future under climate change.

This research project "Economic Evaluation of Adaptation Measures to Climate Change under Uncertainty" aims to gain methodology insights through conducting a case study of evaluation focusing on a particular JICA project, namely the Mwea Irrigation Development Project, for which climate change adaptation is not a main objective but which could have come, most likely positive, impacts for the communities in adapting to future climate change. The study is essentially a simulation study, computing various scenarios under different realizations of climatic and socioeconomic conditions in 2030 based on a method of uncertainty analysis called the RDM (Robust Decision Making) approach.

1. 3. Objectives

The objectives of the study are;

- to utilize RDM for evaluation of the various options which were proposed for Mwea irrigation scheme in SAPROF,
- to develop the methodology how to evaluate the robust measurement for the future under deep uncertainty,
- to study what is the appropriate information provision to formulate the agreement among the stakeholders to promote the measurement,
- to extract the points of the further application for the other projects.

1. 4. Conditions

- The basic data required for the study are obtained from available on the SAPROF report and public data on internet. The newly field survey by the contractor was not implemented.

- The interview or discussions with the stakeholders in the study field are effectual to development of the frame work of the adaptation measure options. In this study, the survey study or interview research was not implemented by the contractor.

1.5. Applicant for contract

Japan International Cooperation Agency

Nibancho Center Building 5-25, Niban-cho, Chiyoda-ku, Tokyo 102-8012, Japan

1.6. Contractor

NIPPON KOEI Co., Ltd.

1-14-6 Kudanshita, Chiyoda-ku, Tokyo 102-8539, Japan

1.7. Date of Signing Contract

July 1st, 2015

1.8. Time of Contract

From July 1st, 2015

To July 29th, 2016

1.9. Scope of the Study

Table 1-1 Items for the Study

Items	Unit	Quantity
1. Preparation	Set	1
2. Data collection	Set	1
3. Formulation of framework of adaptation options	Set	1
4. Development of simulation models	Set	1
5. Scenario simulation and Evaluation	Set	1
6. Discussion and Conclusions	Set	1
7. Reporting	Set	1
8. Meeting for discussion	Times	4

2. Preparation

2.1. Understandings of the Study

Robust decision making (RDM) was developed by RAND Corporation, an American nonprofit global policy thinktank. RDM is an analytic framework that helps identify potential robust strategies, characterize the vulnerabilities of such strategies, and evaluate trade-offs among them. RDM is being used to help decisionmakers in areas such as water resources planning, energy, and coastal resilience – areas often plagued with "deep uncertainty" in which stakeholders do not know or agree on the relationship among actions, consequences, and probabilities.

JICA has been promoting the mainstreaming of consideration of climate change impact on the projects that will be implemented going forward. RDM will be key methodology for planning in various sectors.

We understood the extraction of the key points in RDM study process and clarifying future issues to improve the methodology are important points for the outcomes of the study.

2.2. Workflow of the Study

The workflow of the study is illustrated in Figure 2-1.

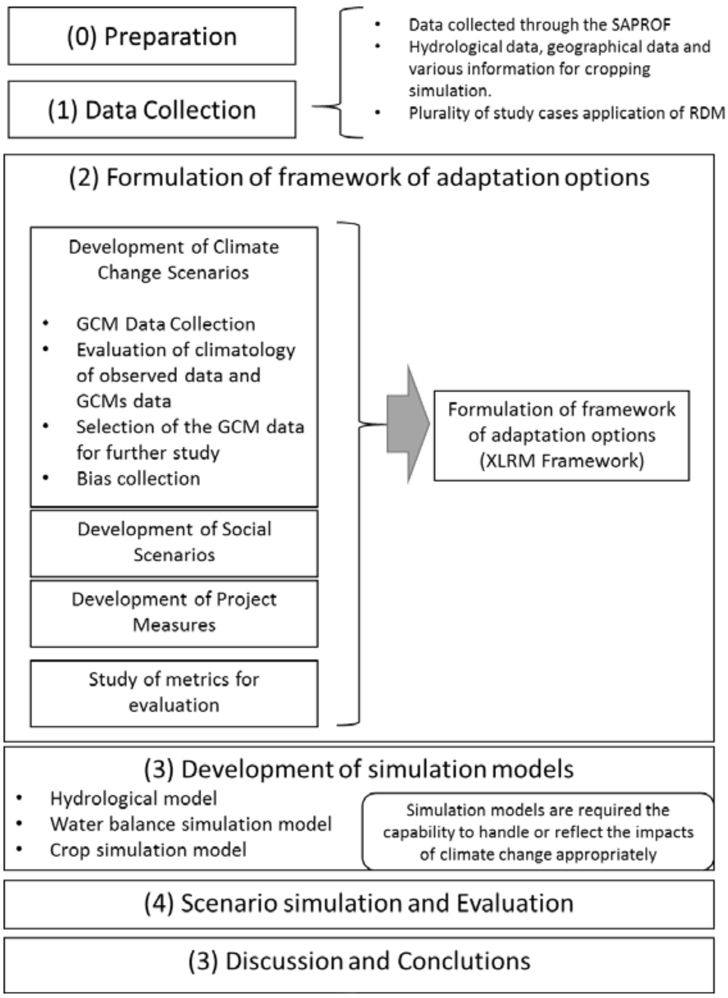

Figure 2-1 Workflow of the Study

3. Data Collection

Hydrological records, topographical data and various information regarding with agricultural crops were collected mainly from the SAPROF study report.

Mwea irrigation scheme (MIS) was formulated by SAPROF project which was carried out from November 2008 to September 2009. In SAPROF, the detailed design of the irrigation scheme studied in 1996 was reviewed with newly obtained data set those were collected during the implementation of SAPROF.

The data from SAPROF was collected about 7 or 8 years ago. Therefore, conditions of the irrigation area have been changed from the condition when the study was under implementation. It will be costed to collect the latest information and data from the site. The objectives of this study is to develop the methodology to evaluate the countermeasures under deep future uncertainty. We focused to implement the study of development of the methodology and decided to utilize the available data from SAPROF.

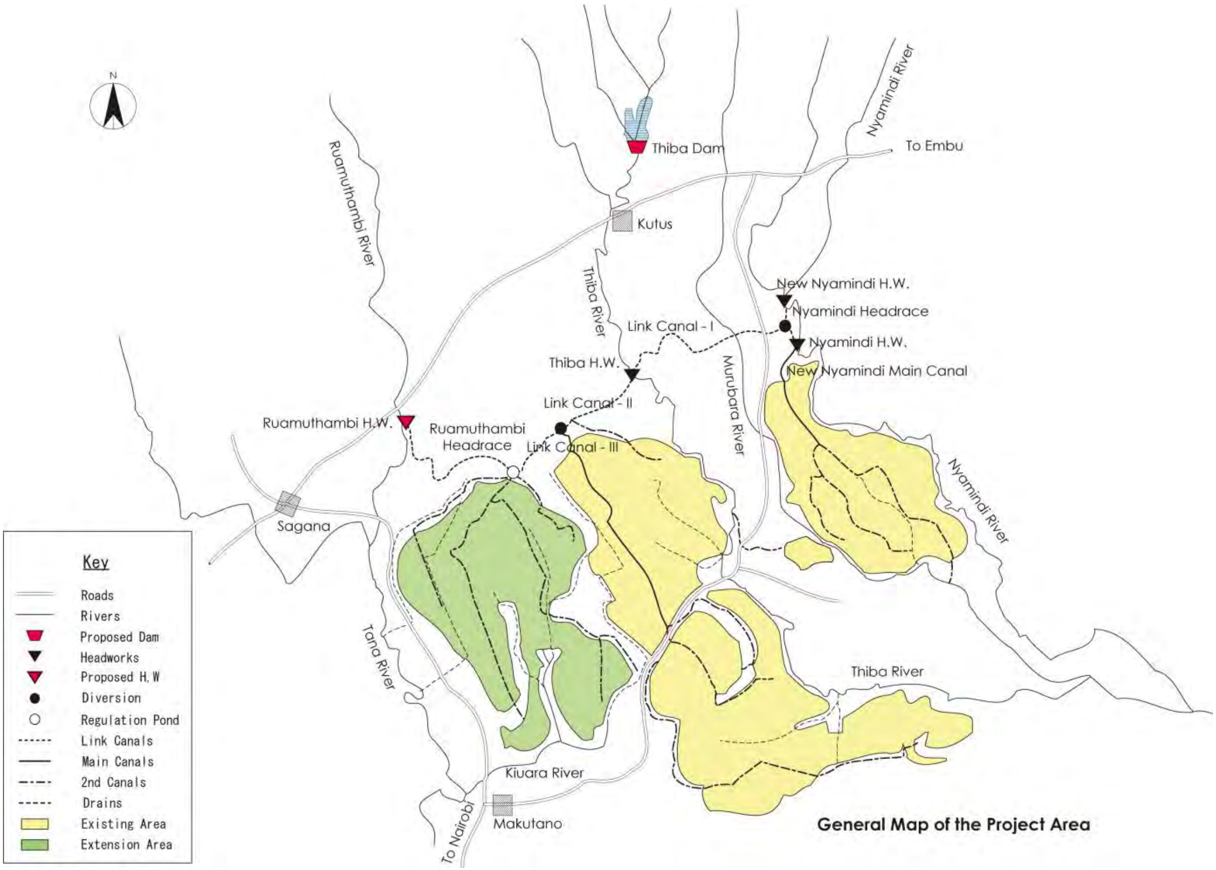

Figure 3-1 General Map of Mwea Irrigation Project Area

4. Formulation of framework of adaptation options

4.1. Development of climate change scenarios

The GCM Data set of four (4) representative concentration pathways (RCP) in CMIP5 are collected for selection of the subjective future climate scenarios for this study. Ideally, all of combinations of GCMs and RCPs are subjected to the study. The reason of the cost and period for handling all combinations data, we selected 5 scenarios for the study.

4.1.1. Targets of data collection of GCM

Table 4-1 Targets of Data Collection of GCM Data Sets

Temporal resolution	Monthly Data	Daily Data	3 hourly Data
Targets	All combinations of GCM and RCP which were available on data distribution center of CMIP5. Historical simulation cases were also collected. The available combinations are about 130 scenarios.	Selected 5 scenarios (GCM and RCP) and historical simulation data of those GCM. In total, 10 scenarios were subjected for detailed study.	Same as left
Periods for simulation	Present (from 1976 to 2005, 30 years) Future (from 2006 to 2100, 30 years) Notes: Even though 30 years are sufficiently for detailed study, we collected long term data set and examined a trend analysis to know the models behavior.	Present (from 1976 to 2005, 30 years) Future (from 2016 to 2045, 30 years) Notes: Kenya national political plan, Kenya Vision, is targeting 2030.	Same as left
Areal range	Whole data of global area.	Whole data of global area.	Same as left
Weather variable	Total precipitation (pr), Air temperature at ground surface (tas: daily mean, tasmax: daily maximum, tasmin: daily minimum), Relative humidity (huss), Downword long wave radiation (rlds), Downword short wave radiation (rsds)		Total precipitation (pr)

4.1.2. RCP Scenarios

There are four (4) RCP scenarios were developed by a cooperative process across various disciplines involved in climate research.

There are four pathways: RCP8.5, RCP6, RCP4.5 and RCP2.6 - the last is also referred to as RCP3-PD.

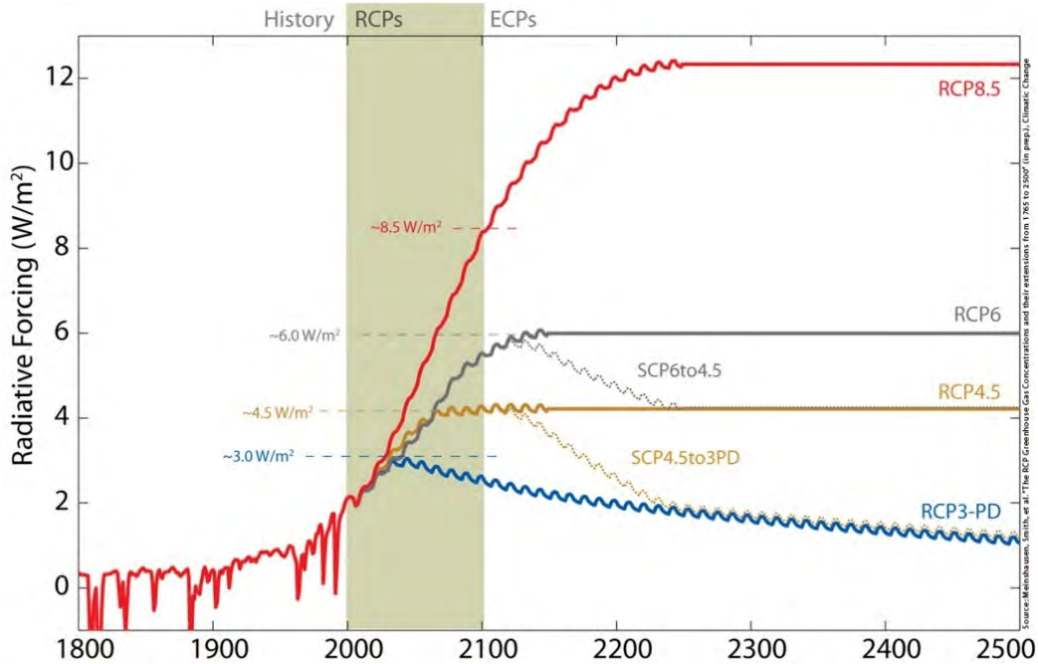

Figure 4-1 Global Anthropogenic Radiative Focing for the high RCP8.5, the medium-high RCP6, the medium-low RCP4.5 and the low RCP (source: http://www.pik-potsdam.de/~mmalte/rcps/)

4.1.3. Available GCM Data

We selected the GCM for data collection with the following criteria;

1) Historical (present climate condition) data set are also available as well as future data set of at least one RCP scenario.

2) Daily data set of total precipitation (pr), air temperature at ground surface (tas), relative humidity (huss) and downward shortwave radiation data are available.

The number of GCMs which satisfies above conditions were 31 models at July of 2015. The data availabilities of GCM in CMIP5 are summarized in Table 4-2. The data were obtained from CEDA Repository (https://esgf-index1.ceda.ac.uk/search/cmip5-ceda/) which is one of the representative data distribution server of CMIP5 data sets.

Table 4-2 Monthly data availability of CMIP5 data sets on CEDA

Country	Centre(s)	Centre Acronym(s)	Model No.	Model	monthly data availability (historical + rcp)				
					tas	pr	rsds	rlds	huss
China	Beijing Climate Center	BCC	1	BCC-CSM1.1	✔	✔	✔	✔	✔
			2	BCC-CSM1.1(m)	✔	✔	✔	✔	✔
China	Beijing Normal University	BNU	3	BNU-ESM	✔	✔	✔	✔	✔
Canada	Canadian Centre for Climate Modelling and	CCCma	4	CanAM4					
			5	CanCM4					
			6	CanESM2	✔	✔	✔	✔	✔
Italy	Centro Euro-Mediterraneo sui Cambiamenti	CMCC	7	CMCC-CESM	✔	✔	✔	✔	
			8	CMCC-CM	✔	✔	✔	✔	
			9	CMCC-CMS	✔	✔	✔	✔	
France	Centre National de Recherches Mété́	CNRM-CERFACS	10	CNRM-CM5	✔	✔	✔	✔	✔
			11	CNRM-CM5-2					
Australia	Commonwealth Scientific and Industrial	CSIRO-BOM	12	ACCESS1.0	✔	✔	✔	✔	✔
			13	ACCESS1.3	✔	✔	✔	✔	✔
Australia	Commonwealth Scientific and Industrial	CSIRO-QCCCE	14	CSIRO-Mk3.6.0	✔	✔	✔	✔	✔
China	The First Institute of Oceanography, SOA	FIO	15	FIO-ESM	✔	✔		✔	✔
Netherlands/Ireland	EC-EARTH consortium published at Irish	ICHEC	16	EC-EARTH	✔	✔			
Russia	Russian Academy of Sciences, Institute of	INM	17	INMCM4.0	✔	✔	✔	✔	✔
Brazil	National Institute For Space Research	INPE	18	HadGEM2-ES (INPE)					
France	Institut Pierre Simon Laplace	IPSL	19	IPSL-CM5A-LR	✔	✔	✔	✔	✔
			20	IPSL-CM5A-MR	✔	✔	✔	✔	✔
			21	IPSL-CM5B-LR	✔	✔	✔	✔	✔
China	Institute of Atmospheric Physics, Chinese	LASG-CESS	22	FGOALS-g2	✔	✔	✔	✔	✔
China	Institute of Atmospheric Physics, Chinese	LASG-IAP	23	FGOALS-gl					
			24	FGOALS-s2					
Japan	Atmosphere and Ocean Research Institute	MIROC	25	MIROC-ESM	✔	✔	✔	✔	✔
			26	MIROC-ESM-CHEM	✔	✔	✔	✔	✔
			27	MIROC4h					
			28	MIROC5	✔	✔	✔	✔	✔
UK	Met Office Hadley Centre	MOHC	29	HadCM3					
			30	HadGEM2-A					
			31	HadGEM2-CC					
			32	HadGEM2-ES					
Germany	Max Planck Institute for Meteorology	MPI-M	33	MPI-ESM-LR	✔	✔	✔	✔	
			34	MPI-ESM-MR	✔	✔	✔	✔	
			35	MPI-ESM-P					
Japan	Meteorological Research Institute	MRI	36	MRI-AGCM3.2H					
			37	MRI-AGCM3.2S					
			38	MRI-CGCM3	✔	✔	✔	✔	✔
			39	MRI-ESM1					
USA	NASA/GISS (Goddard Institute for Space	NASA-GISS	40	GISS-E2-H	✔	✔	✔	✔	✔
			41	GISS-E2-H-CC	✔	✔	✔	✔	✔
			42	GISS-E2-R	✔	✔	✔	✔	✔
			43	GISS-E2-R-CC	✔	✔	✔	✔	✔
USA	National Center for Atmospheric Research	NCAR, NSF-DOE-NCAR	44	CCSM4 (Journal)	✔	✔	✔	✔	✔
			45	CESM1(BGC) (Journal)	✔	✔	✔	✔	✔
			46	CESM1(CAM5) (Journal)	✔	✔	✔	✔	✔
			47	CESM1(CAM5.1,FV2) (Journal)					
			48	CESM1(FASTCHEM)					
			49	CESM1(WACCM) (Journal)					
Norway	Bjerknes Centre for Climate Research,	NCC, NMI	50	NorESM1-M	✔	✔	✔	✔	✔
			51	NorESM1-ME	✔	✔	✔	✔	✔
South Korea	National Institute of Meteorological Research,	NIMR, KMA	52	HadGEM2-AO	✔	✔	✔	✔	✔
USA	Geophysical Fluid Dynamics Laboratory	NOAA-GFDL	53	GFDL-CM2.1					
			54	GFDL-CM3	✔	✔	✔	✔	✔
			55	GFDL-ESM2G	✔	✔	✔	✔	✔
			56	GFDL-ESM2M	✔	✔	✔	✔	✔
			57	GFDL-HIRAM-C180					
			58	GFDL-HIRAM-C360					
				Number of Models	37	37	35	36	31

4.1.4. Evaluation of climate sensitivity of GCMs and selection of subjective scenarios

The monthly climatological precipitation and air temperature were calculated for all collected GCM data. The target area for calculation was selected to cover whole Kenya. The changing ratio from present to future data of GCM are evaluated for whole grids in the target area. The changing behavior is called climate sensitivity.

The metrics “sensitivity” can be considered as a future scenario. Rainfall will increase or decrease, temperature will rise or descent, then evapotranspiration will increase or decrease. Those climate conditions will influence on the benefit of the irrigation project very much. For the objective of this study, it will be ideal to examine all available scenarios to cover whole range of uncertainty. Because of the time and cost for this study, we selected five (5) scenarios to cover the entire changing range of precipitation and temperature changing.

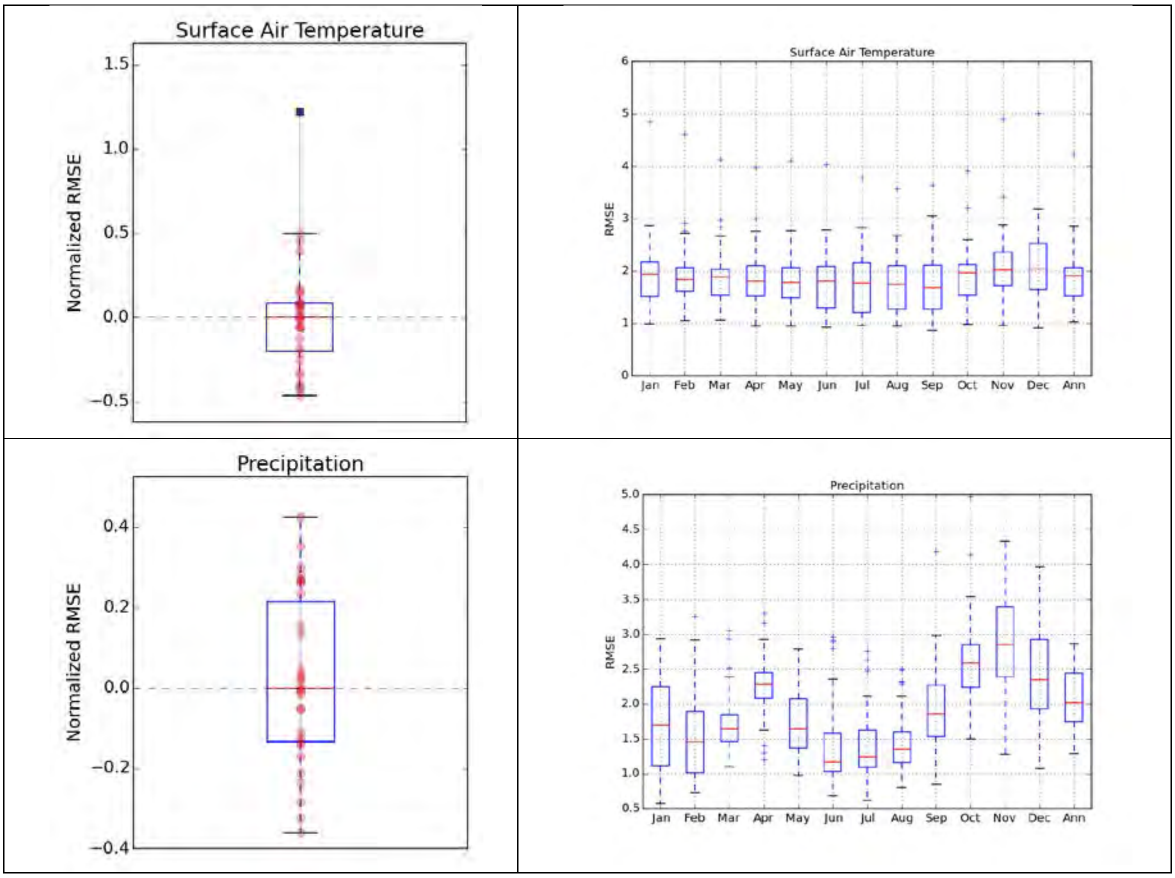

Figure 4-2 Evaluation of the performance of GCMs representative capability of present climate. The box plots of the left side are quantified using Gleckler’s metrics (Gleckler et. Al. 2008). The right hand shows monthly evaluation.

Table 4-3 Selected five scenario of climate change

No.	Climate Scenario Code	Future climate condition	GCM Model (RCP Scenario)	Change of Precipitation	Change of air temperature
1	DH	Severe for water resource and agriculture	GFDL-ESM2G（rcp85）	Degrease 0.896 times	Increase (high) 1.32 degC
2	DL		FGOALS-g2 (rcp26)	Decrease 0.985 times	Increase（low) 0.622 degC
3	MM	Moderate change among the GCMs	GFDL-ESM2M（rcp85）	No change 1.025 times	Increase (middle) 0.909 degC
4	WH		MIROC-ESM-CHEM（rcp85）	Increase 1.382 times	Increase (high) 1.487 degC
5	WL	Very low change	CSIRO-Mk3-6-0（rcp60）	Increase 1.17times	Increase（low) 0.805 degC

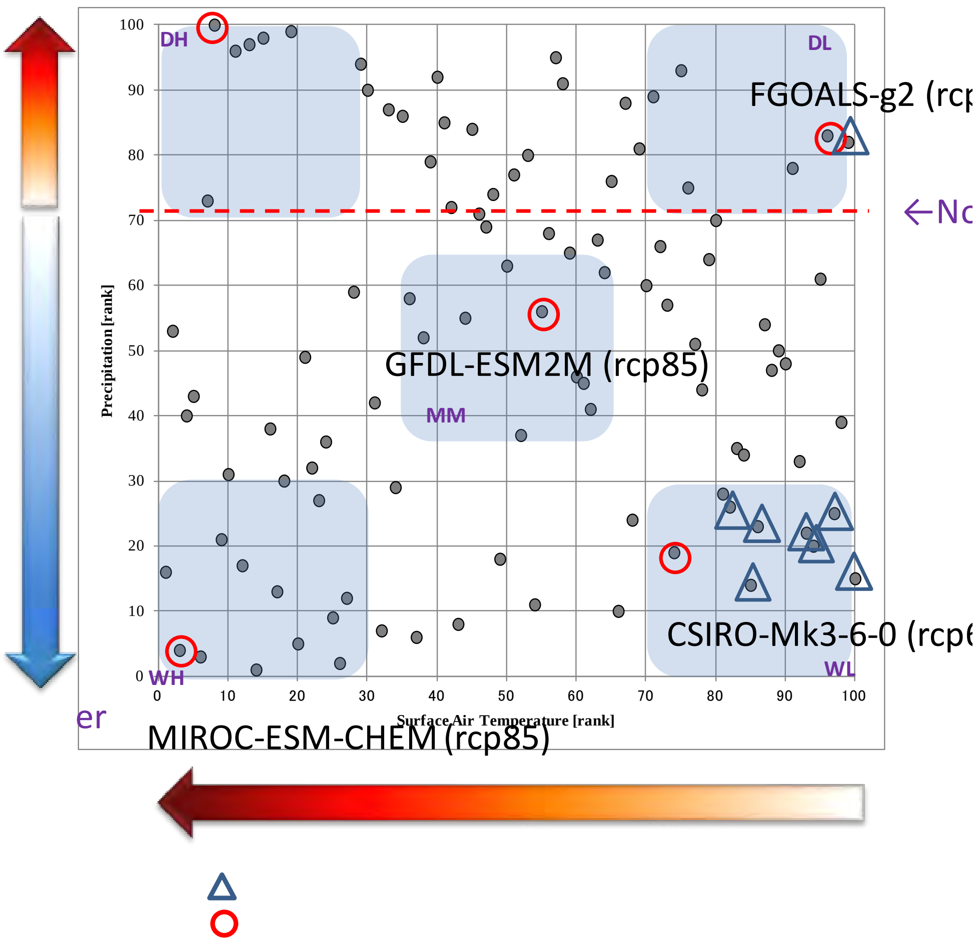

Figure 4-1 Evaluation of sensitivity of climate change and selection of the subject scenario for the detailed study

4.1.5. Bias correction

Statistical bias correction was carried out for the selected five GCMs. Statistical bias correction is commonly applied within climate impact modelling to correct climate model data for systematic deviations of the simulated historical data from observations. ISI-MIP methodology was chosen for this study. ISI-MIP is designed to synthesize impact projections in the agriculture, water, biome, health, and infrastructure sectors at different levels of global warming.

$$R_{Corrected} = F_{OBS}^{-1}\{F_{GCM}[R_{GCM}]\}$$

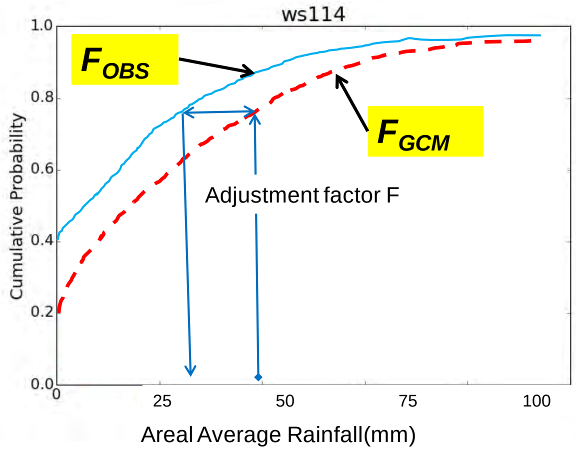

Figure 4-2 Schematic image of bias correction of precipitation

The observation data was developed by combining WFDEI and station observation data. The observation data was gridded into 0.1degree size. The grid size of raw GCM data is over 1 degree. The bias corrected data was compiled into 0.1degree grid data. We have to mind this process is not downscaling. The river flow data simulated by runoff model using the 0.1degree bias corrected GCM data shows very different statistical character from that of observed river flow data. The finer grid data is dominated by the large size of raw GCM data. The depth-area-duration relationship of real rainfall was not represented in the bias corrected GCM data.

In order to cope with this problem, we developed additional process for making future climate scenario data, future projection. The temporal and spatial pattern of future projection data was based on observation grid data. The intensity of the projection data was transferred along the relationship between raw and bias corrected GCM data which was estimated through ISI-MIP bias correction. The schematic image of future projection process was illustrated in Figure 4-3.

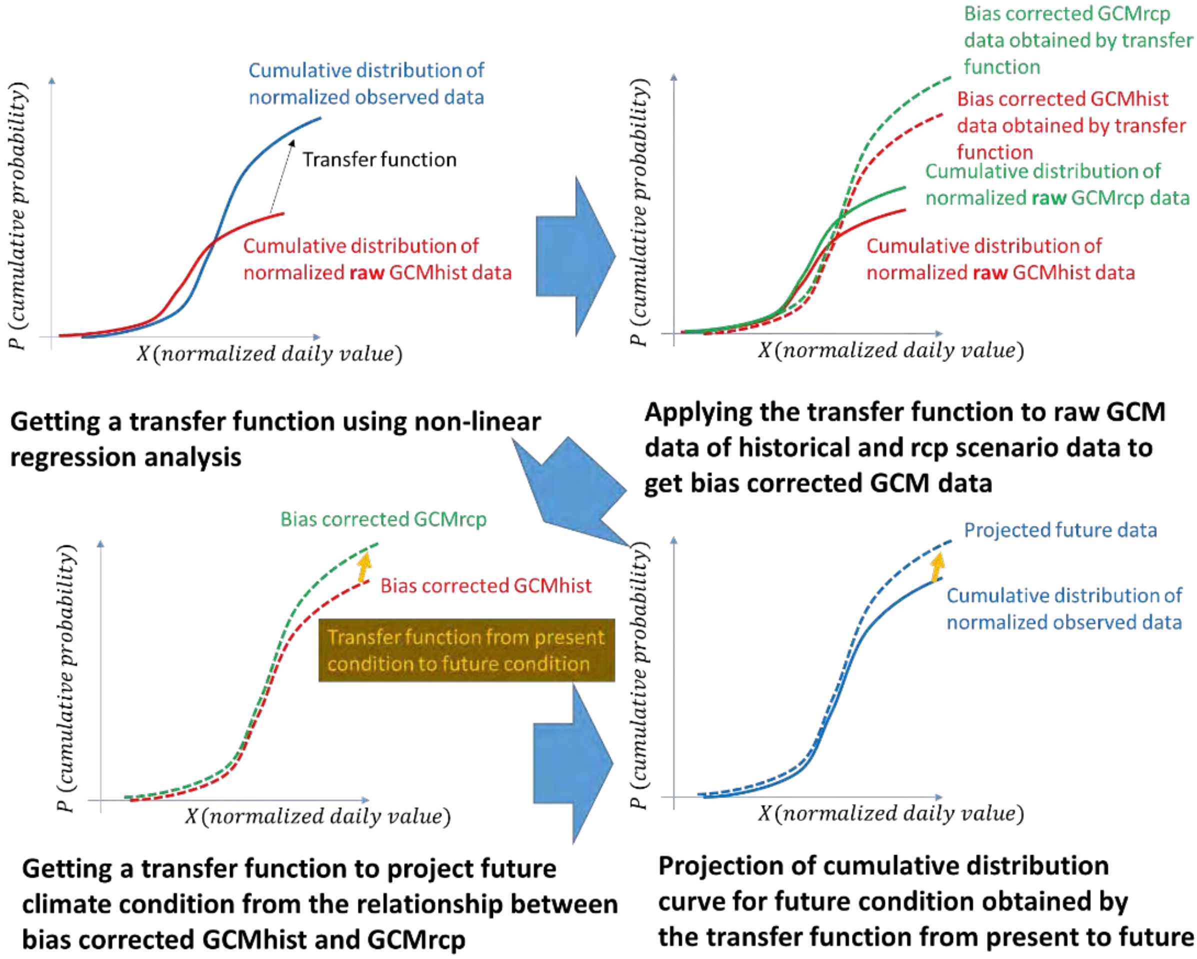

Figure 4-3 Future projection process

Climatology of the precipitation, surface temperature and potential evapotranspiration, which was evaluated using FAO No.56 Penman-Montieth method, were computed. The areal mean values were calculated for upper and lower area of MWEA related catchment area. The catchment area is located on the South-East side of Mt. Kenya, which is a highest mountain in the country. The precipitation in the upper area is higher than lower zone and the air temperature in the upper area is cooler than lower zone. Climatology of the value of rainfall minus potential evapotranspiration height was shown in Figure 4-4.

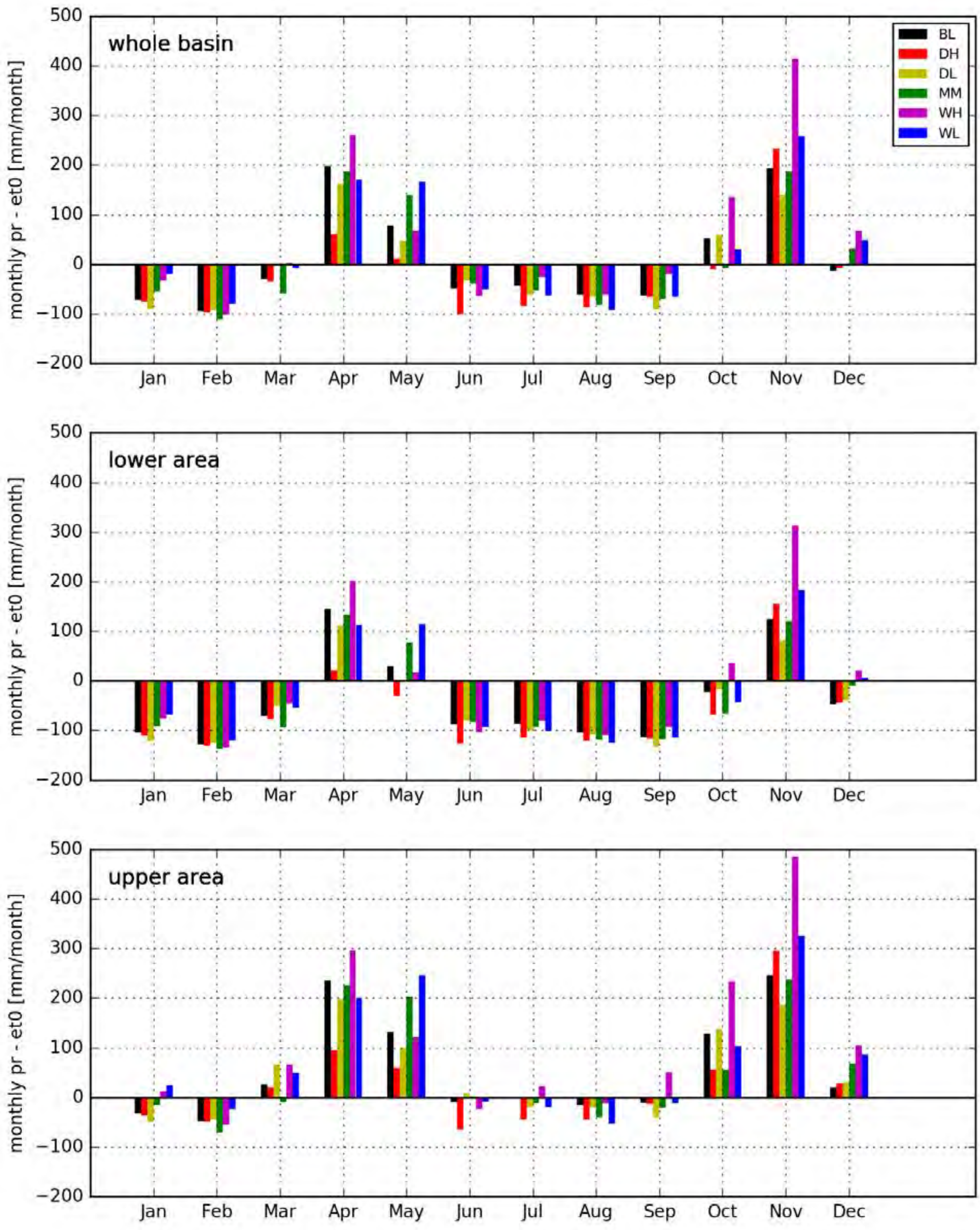

Figure 4-4 Climatology of Pr – ET0 of obsereved data (BL) and selected future climate scenarios

4.2. Development of social scenarios

Social scenarios for future condition were developed. The scenarios were developed with referring Kenya's national development program "Kenya Vision 2030". The subjective items for the social scenarios were;

- National population
- Rice consumption per capita
- Competitiveness of domestic rice crop against imported rice

4.2.1. Data collection for development of social scenarios

The collected data list was tabulated in Table 4-4. All of the data listed in the table were available on the internet.

Table 4-4 List of the data collection for social scenario development

Data source	Organization, published date	Items to collect
Kenya Vision 2030	October 2007	Future projection of national status, population projection, rice consumption, and etc.
National Rice Development Strategy (2008-2018) (NRDS)	Ministry of Agriculture	Projection of future population, and rice consumption
2009 Kenya population and housing Census, Analytical Report on Population Projections, Volume XIV	Kenya National Bureau of Statistics, Ministry of State for Planning, National Development and Vision 2030, March 2012	Detailed information of population projection
MOA ERA 2010 Economic Review of Agriculture 2010	Ministry of Agriculture (MOA), June 2010	Rice consumption, production and unit price.
OECD FAO Agricultural outlook 2015	OECD, FAO	Future projection of rice consumption
Commodity Forecast, July 2016, World Bank	World Bank, July 2016	Future projection of international price of rice
WPP 2015 World Population Prospects	United Nations, 2015	Future population prospects
FAO2012 Monitoring Africal Food and Agricultural Policies	FAO, 2012	Rice production, import amount and consumption of actual record

4.2.2. Future projection of social condition

4.2.2.1 Basic Economic Condition for Study

The basic conditions of the economic evaluation were listed as followings;

- Reference year of price: 2008

- Exchange rate: JICA official rate as of March. 2009.
- Project life of the irrigation facilities: 50 years.
- Future market price of agricultural crops: Mean price value during project life time. Future price was referred to commodity forecast of World Bank at 2016.

4.2.2.2 National Population

Three (3) future national population options were set for this study referring to the WPP 2015 conducted by UN. There are high, low and moderate rate cases of future population projection at 2030.

Table 4-5 Population options in future

Scenario	Population [unit: thousand]
Present (BL)	46,050
High	67,891
Moderate	65,412
Low	62,933

4.2.2.3 Unit rice consumption

Rice is one of the mail staple flood in Kenya following to maize. The consumption rate of rice has been growing in high rate for these years. According to NRDS, present rice consumption was estimated as 8kg/year/capita and the growing rate was 12%/year. This growing rate was much higher than the other food.

It is not realistic to suppose such a high rate will be kept toward the future. The annual unit consumption in 2030 can be prospected as 100kg/year/capita simply applying 12%. The consumption rate in neighboring country Tanzania, where rice is main staple food, was referred as the higher consumption situation.

Table 4-6 Rice consumption options in future of 2030

Scenario	Unit rice consumption [kg/capita/year]	Remarks
Present (BL)	8.0	Achieved value at 2008. NRDS.
High	20.0	Supposed to be same as present consumption rate of Tanzania.
Moderate	9.76	Consumption rate of 2030 with 1%/year of growing rate. Projected by OECD-FAO Agricultural Outlook 2015.
Low	8.0	Not changed from present rate.

4.2.2.4 Domestic rice production

The domestic rice production in Kenya has been investigated by National Irrigation Board (NIB) and Ministry of Agriculture (MoA). NIB accounts unmilled rice production in irrigated crop area and MOA accounts gross domestic production of milled rice. It is necessary to note that the data regarding with rice should be distinguished between milled and unmilled rice, those unit price and weight are different. The weight of milled rice was estimated by multiplying factor of 0.65 to unmilled rice weight, that was applied in SAPROF study.

The domestic rice production was shown in Table 4-7.

Table 4-7 Domestic rice production in Kenya (milled and unmilled)

tonnes

year	2005	2006	2007	2008	2009	2010	Average
Milled Rice Production in Kenya[1]	57,942	64,840	47,256	21,881	42,202	44,468	46,432

1: MOA-ERA and CountryStat Database

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crop year	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	Average
Paddy (Unmilled Rice) Production in MWEA[1]	58,520	57,422	51,458	38,560	32,406	52,000	48,394
Paddy (Unmilled Rice) Production on all schemes[1]	62,677	62,986	53,113	40,065	37,198	72,500	54,757
Milled Rice Production in MWEA[2]	38,038	37,324	33,448	25,064	21,064	33,800	31,456
Milled Rice Production on all schemes[2]	40,740	40,941	34,523	26,042	24,179	47,125	35,592

1: KNBS/NIB Statistical Abstract 2010 and Economic Survey 2011

2: Author's own calculations

4.2.2.5 Market Price of Rice

Economic evaluation in this study was conducted in two viewpoints, namely national view and farmers view. The international market price was applied for the economic benefit evaluation for national view, while the local market price was used for the economic evaluation in terms of farmer’s livelihood.

(1) International Market Price

International market price alters were developed with referring to commodity prices forecast published by World Bank in 2016. The lead time of the forecast was to 2025 in that. The real price of rice as of 2009 in international market was obtained by applying manufactures unit value (MUV) index to real price of 2010. The present price and forecast of real price towards 2025 was shown in Table 4-8 and Figure 4-5.

The real price of rice in international market as of 2015 was US$352.1 in constant 2009 US$, while the forecast real price in 2025 was US$317.4. The rice price was prospected to degrade gradually. The real price as of 2025 supported in SAPROF study was US$ 444.8 in constant 2009 US$. The assumed future price was higher than present real price. World commodity price forecast as of November 2008 was referred in

SAPROF study. The rice price was dropped significantly from 2008 to 2015, then the price forecast has changed recently.

Real rice price options were developed for high scenario, moderate scenario and low scenario for this study. The high scenario was referred to price projected in SAPROF which was highest projection among the forecasts mentioned above. The moderate option was set from present real price and lowest forecast was referred to the price of 2025 which was prospected in the newest world commodity price forecast. The real price of 2015 was referred as the baseline scenario in the study.

Table 4-8 Forecast of international market price of milled rice

Historical data / Forecast

	Commodities Price Forecast, July 2016			SAPROF
	nominal price	constant 2010 US dollars	constant 2009 US dollars	constant 2009 US dollars
年	$/ton	$/ton	$/ton	$/ton
2013	505.9	477.0	460.1	
2014	422.8	399.0	384.9	
2015	386.0	365.0	352.1	
2016	400.0	372.0	358.8	
2017	401.1	367.0	354.0	
2018	402.2	362.0	349.2	
2019	403.3	357.0	344.4	
2020	404.4	352.0	339.5	444.8
2021	405.5	348.0	335.7	
2022	406.6	343.0	330.9	
2023	407.8	338.0	326.0	
2024	408.9	334.0	322.2	
2025	410.0	329.0	317.4	

Note:

1) Based on the Commodity Forecast, July 26, 2016, World Bank: Developtment Prospects Group (website)
Rice (Thailand), 5% broken, white rice (WR), milled,
indicative price based on weekly surveys of export transactions, government standard, f.o.b. Bangkok.

2) The projected prices in 2010 constant US$ were adjusted by the factor of 96.462 (MUV)
to allow for price escalation between 2009 and 2010.

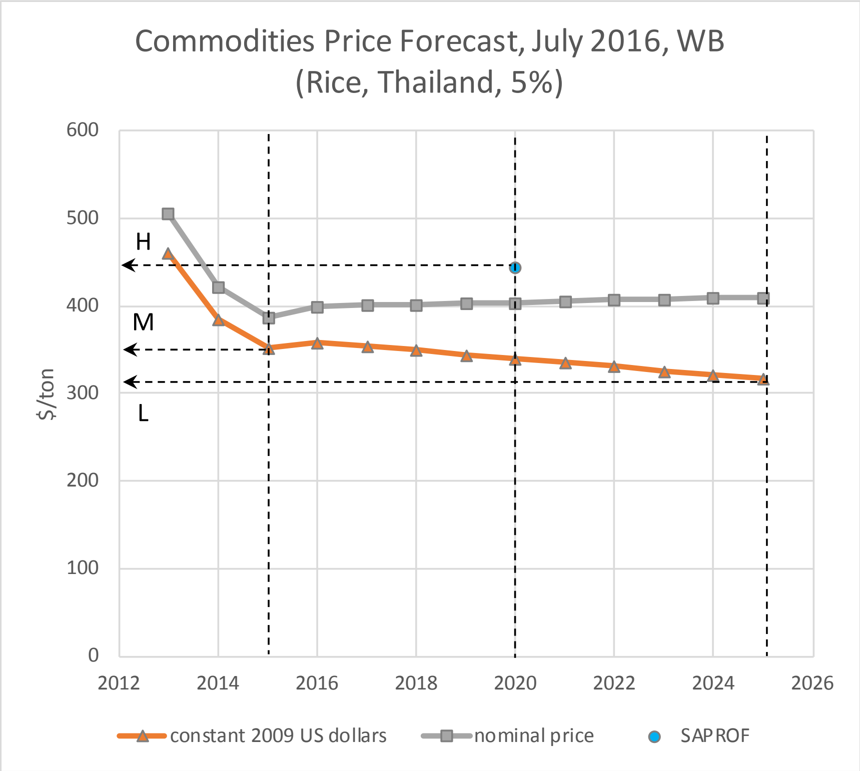


Figure 4-5 Rice price forecast

(2) Farm gate price

The farm gate price can be obtained by subtracting market costs from market price. The farm gate price is of unmilled rice. Three (3) options were developed from the market price options mentioned above. The weight ratio of milled rice to unmilled rice was supposed to be 65%.

Table 4-9 Farm gate price options

Scenario	Farm Gate Price [KSh/t]
Present (Baseline)	23,758
High	28,483
Moderate	23,758
Low	21,988

4. 3. Development of Project Measures

4.3.1. Development Area for the Project

The total coverage area of the MIS scheme was 6,660 ha in 1996 when the D/D was prepared. Currently, the irrigation area has expanded officially to 7,952 ha or more as a result of the expansion of the out-growers area from 1996 to 2008. NIB recognizes that water security in and around the MIS scheme is of utmost importance, and directed all its efforts to supply water to every corner of the MIS scheme as far as water is available. To enhance water security, NIB approved the official involvement of the out-growers as water users of the MIS scheme. Although water supply is not guaranteed, NIB committed to supply irrigation water to them. The out-grower areas in and around the MIS scheme are represented by Curukia, Nderwa North, and Kiyamanyeki, including Mwea Prison and Marura, where rice and upland crops are planted. The Curukia area (890 ha) extends to the eastern part of the original Mutithi area (3,130 ha). The total out-grower area widely changed from a range between 1,300 ha and 2,000 ha, depending on water availability in relevant years.

The major out-growers are already given official status to obtain irrigation water supplied by NIB. This means that water use of the out-grower areas is fully under the control of NIB. The current water abstraction from Link Canal-I in the Nderwa North area and Link Canal-II in the Marura area can be regulated to supply more water to the downstream area of the scheme. In addition, registered out-growers are obliged to pay a fixed water charge to NIB. The involvement of out-growers into the scheme management will yield significant benefits for the scheme as a whole, although future water management will become more crucial. Therefore, the principle used in the study is to accommodate the out-grower areas as long as the water balance study ensures water supply. Priority must be given to upstream areas namely, Nderwa North, Marura, and Mutithi. If excess water is available, Kiyamanyeki and Mwea Prison may be covered.

4.3.2. Alternative cropping patters proposed in SAPROF

The proposed Thiba Dam will enable all the farmers to receive sufficient irrigation water for SR rice. The crops for LR will be selected by farmers. Double cropping of rice is technically feasible in the MIS scheme, and upland crops for LR are also possible according to MIAD. In this sense, the following cropping patterns are proposed.

Table 4-10 Proposed Cropping Patterns

Proposed Cropping Patterns	Cropping Season		
	Short Rain (SR)	Ratoon	Long Rain (LR)
CP-1:SR Rice - LR Rice	Pishori (Basmati)	Nil	Pishori (Basmati)
CP-2:SR Rice - NERICA in LR	Pishori (Basmati)	Nil	NERICA
CP-3:SR Rice - Ratoon - Upland Crops	Pishori (Basmati)	To be raised	NERICA, Soybeans and Vegetables
CP-4:Upland Crops - Upland Crops	Soybeans and Vegetables	Nil	Maize

CP-1 and CP-2 are to introduce double cropping of rice. Under both cropping patterns, LR rice will be expanded as far as irrigation water is available. In order to expand the planted area of LR more than CP-1, a part of Pishori will be replaced by NERICA, of which the water requirement is lower than Pishori rice under CP-2.

CP-3 aims at crop diversification from rice to upland crops of high value in LR, which contributes not only to farm family income but also to water saving in LR. Under CP-3, Pishori rice will be planted in all the paddy fields in SR and harvested in November to December. After harvesting SR rice, ratoon will be carefully raised and harvested after two months. Although the grain yield of ratoon is limited to only 1.4 t/ha, the farmers can save on crop production cost, especially on tractor hiring services and procurement of chemical fertilizers. After ratoon rice, vegetables and maize will be planted in LR. Upland NERICA is also one of candidate crops for LR.

CP-4 is to be introduced to irrigated upland fields, where lowland rice can not be planted. The upland fields are scattered in the MIS area and not suitable for rice cultivation due to their higher elevations and coarse-textured soils of higher permeability.

Table 4-11 Alternative Plans of Mwea Irrigation Development Project

Project Component	Alternative Plans			
	Plan 1	Plan 2	Plan 3	Plan 4
Thiba Dam	●	●	●	●
Link Canal-I (Rehabilitation)	●	●	●	●
Link Canal-II (Rehabilitation)	●	●	●	●
Nderwa North + Marura Areas (Improvement)		●	●	●
Link Canal-III (New construction)			●	●
Curukia Area (Improvement)			●	●
Mutithi East Area (Extension)			●	●
Ruamthambi Headworks and Head race (New)				●
Mutithi West Area (Extension)				●

Prepared by SAPROF team

4.3.3. Project options for study

Taking into account the above mentioned basic considerations, the following three sets of project options were selected as alternative options for the RDM study.

Table 4-12 Project options for RDM study

Case No.	Cropping patterns	Irrigation Plan	remarks
1	CP3	Plan3	Most recommended plan in SAPROF study.
2	CP1	Plan3	Case for comparison of best plan (case no.1). The cropping pattern is different from case 1
3	CP3	Plan2	Case for comparison with best plan. The irrigation option is different from case 1

4.4. Development of metrics for evaluation

The metrics which measures the effectiveness and benefit of the proposed project options under deep uncertainty were selected. The metrics in the RDM analysis not only to measure the benefit but also to be utilized for finding pros and cons of the proposed project options. In the RDM analysis, several number of metrics are applied to review the behavior of the projects from various viewpoints.

4.4.1. Metrics for evaluation

4.4.1.1 Metrics for economic superiority

The most important metrics to measure the superiority of the project options is metrics for economic superiority and profitability. The cost and benefit analysis for each project options under every combination of climate and social scenarios were examined. The metrics for the economic superiority were selected as followings;

- Economic internal rate of return (EIRR)
- Net present value (NPV)
- Benefit-cost ratio (BCR)

The analysis conditions were provided as followings. These are same conditions as the economic study in SAPROF.

- Social discount rate for calculation of NPV is 10%. Additionally, several rates were applied for sensitive analysis of the discount rate.
- The life time of the project was supposed to fifty (50) years which was established referring to the setting of SAPROF study.
- The benefit and cost were transferred to real price at reference year of 2009 to remove fluctuation

of prices. The deflator was referred to commodity forecast by World Bank.

- The project benefit was supposed to be incurred at the timing of completion of the facilities construction. The crop yield was supposed to be double for three (3) years of after completion of dam construction and the ratoon crop yield was supposed to increase gradually for three (3) years after that.
- The benefit was accounted as the difference of farm income between with and without project.

4.4.1.2 Metrics for farm gate economic superiority

The consensus building among the farmers and project developer is indispensable in the process of the decision making for project selection. The metrics for measuring the benefit for the farmers also developed for the RDM analysis.

- The metrics of crop productivity: unit crop yield, total irrigation area, net annual crop area
- The metrics of economic income of farmers: farmer's income

4.4.1.3 Metrics for water resources

The new water resources were developed by the construction of Thiba dam and Link Canal III to increase the stability of irrigation water distribution and enlarge the irrigable area. The metrics to measure the efficiency and stability of the water resources were selected as followings;

- The amount of irrigation water supply
- The annual sufficiency of irrigation water. The sufficiency was calculated as the ratio of supplied water to demand water.
- The sufficiency of irrigation water for the critical period of crop. The critical period is 35 days of between 50 days and 15 days before harvest.

4.4.1.4 Metrics for food security

Rice self-sufficiency rate of Kenya is only about 10% and the deficit is covered by import rice. The amount of the import rice is about 200 to 300 tonnes per year and that costs about 100 million US$, in the case of the unit cost of import rice is supposed to be 350 US$ per tonnes. According to the data of FAO 2010, 74% of the import rice to Kenya was from Pakistan. The other major countries from which Kenya imported were Vietnam (9%), Thailand (4%), Egypt (4%) and India (4%), according to the statistical data from 2006 to 2010.

It is expected to reduce risk of the food security that the domestic rice production improved by the MWEA irrigation project. In the Kenya vision 2030, the importance of the increasing rice production was mentioned for the national food security. Ministry of Agriculture (MoA) developed National Rice Development Strategy (NRDS) in which the twofold increase of domestic rice production and self-sufficient of rice was set as a strategic goal. The enlargement of the irrigated rice field was main approach to accomplish the goal.

The metrics for the efficiency of the project in regard with the food security was listed as followings;

- Enlarged irrigation area and net crop area which was accomplished by the project.
- Achievement of the project to the increasing of domestic rice production.
- Achievement of the project to the improvement of self-sufficiency of rice.
- Saving amount of foreign currency which was obtained by increasing domestic rice production and reducing import rice.

The evaluation of rice self-sufficiency and saving foreign currency was based on the following conditions;

- The rice production by the other area of MWEA was same as present situation, that was evaluated as 14,975 tonnes which was mean of six (6) years from 2004/05 to 2010.
- The amount of the increase of rice production by the project was subtracted from the import rice.

Table 4-13 Milled rice production, trade and apparent consumption in Kenya, 2005-2010

Table 2: Milled Rice Production, Trade and Apparent Consumption in Kenya, 2005-2010

	2005	2006	2007	2008	2009	2010
Production	57,942	64,840	47,256	21,881	42,202	45,313
Imports	228,206	232,305	261,712	299,070	308,158	284,368
Exports	n.a.	801	597	1,481	2,310	1,640
Apparent consumption	279,800	296,344	308,371	319,470	348,050	328,041
Import dependency ratio	80%	78%	85%	93%	87%	86%

Source: Imports: MOA ERA 2010 for production 2005-10 and consumption in 2005; SA Table 46 for 2005 exports (likely HS 100620,100630, 100640), GTA for imports and exports 2006 - 10 (HS 1006).

4.4.1.5 Metrics for environmental impact and multifunctional rule of project

The other function and benefit of the project can be considered such as regularization function of river flow, groundwater recharge effect of dam, preservation function of view or mitigation function of flood. According to the EIA report, there are not big negative impact on the environment and social condition, although it must be noted the impact of the fertilizer and agrochemical on water quality. It is reported in the resettlement action plan report (RAP) that the resettlement households were accounted 542 at Thiba dam construction site and 85 at new construction site of irrigation channel.

These are import factor for evaluation of the project effect, though it is difficult to evaluate quantitatively. The negative impact can be considered as not so significant that the evaluation for the environmental and social impact of the project was not regarded in this study.

4.4.1.6 Summarize of developed metrics for RDM analysis

The developed metrics for RDM analysis was tabulated in Table 4-14.

Table 4-14 Metrics for the RDM study on Mwea irrigation project under uncertainty of climate change

Class	Metrics
Water Resource	Annual possible irrigation water resource
	Coefficient of annual variance of irritation water
	Day of reduction on water intake
	Average water storage rage of Thiba dam
Crop yield	Mean annual crop yield
	Annual variability of crop yield
Quality of rice	Event probability of Rice Blast
Economic	Mean annual gross income
	Annual variability of annual gross income

4.4.2. Approach of evaluation of project benefit

The approach of evaluation of project benefit under the multi scenario of climate change and social options were organized in this section.

4.4.2.1 Evaluation of project effect

The main benefits which are induced by the project are itemized as followings;

- Increase effect on crop yield: The enlargement of irrigation field by development of new water resources and facilities of distribution bring boost of the crop yield.
- Quality improvement of crop: The improvement of irrigation water sufficient can expected to induce the improvement of crop quality.

The latter one is difficult to evaluate because that can't be evaluated by the crop simulation model DSSAT. The project effect on crop quality was not analyzed in this study.

4.4.2.2 Factor of crop yield increase

The factors of crop yield increase were itemized as followings;

- Increase of unit crop yield by improvement of irrigation amount and sufficiency with construction of new dam and renovation of headrace.
- Extension of the net planting area by increase of irrigation water.

The unit crop yield under the climate scenario and water supply by the irrigation project options were estimated by crop evaluation model DSSAT. The net planting area was referred to the proposed planting plan corresponding with the irrigation project options by SAPROF.

The factors of unit crop yield were tabulated in Table 4-15.

Table 4-15 Factors of unit crop yield

Cases	Climate scenario	Factors of unit crop yield
With project (Project Case1, 2, 3)	Present climate (BL)	Present crop yield + increase of crop yield by irrigation enhancement + increase of planting area － reduction of planting area of Thiba dam construction area
	Future climate (DL, DH, MM, WH, WL)	Present crop yield + change of crop yield by climate change + change of sufficiency of irrigation water + improvement of irrigation facilities + increase of planting area - reduction of planting area of Thiba dam construction area
Wighout project (Case0)	Present climate (BL)	Present crop yield
	Future climate (DL, DH, MM, WH, WL)	Present crop yield + change of crop yield by climate change + change of sufficiency of irrigation water

4.4.2.3 Basic idea of comparison among scenario combinations

In order to evaluate quantitatively the project effect under climate change, comparison analysis of crop yield for scenarios was performed. The comparison conditions were developed to distinguish the effect of project and climate change.

(1) Evaluation of climate change impact

The base case of the comparison was the combination of project cases with BL case of climate scenario, which was present climate condition. The comparison between BL and future climate scenario on a project case can bring the impact of the climate change in future.

(2) Evaluation of irrigation project effect

The basic idea to identify the irrigation project effect was comparison between the project case0 and the cases of with project under the same climate scenario. This condition for the comparison was same as for the cost-benefit analysis.

(3) Evaluation of multiple effect

The multiple effect of climate change and irrigation project cases was evaluated by the comparison between the combination cases and the case of present irrigation system and present climate scenario.

4.5. Formulation of framework of adaptation options (XLRM Framework)

We organized the key components of the decision-centric analysis using an "XLRM" framework (Lempert et al. 2003; Groves et al., 2014b). This framework was the focus of the first worKShop and helped to build a common understanding of the water management challenges among the technical team and stakeholders throughout the project. It also usefully guided data gathering and model development.

Uncertainty Factors (X)	Response Packages / Policy Levers (L)
Climate System ● Projected future climate scenarios ● Impact of climate change on unit crop yield ● Impact of climate change on water resources Social System ● Future rice consumption (consumption rate and population) ● Future market price ● Future economic discount rate	Present irrigation system and cropping management Proposed three project cases in SRPROF
Models (R)	**Performance Metrics (M)**
● Physical based runoff model (SHER Model) ● Irrigation system water balance model ● Crop simulation model (DSSAT)	● Crop yield ● Irrigable water ● Annual income of unit area ● Economic evaluation indexes (EIRR, NRV, CBR) ● Rice self-supporting ration

5. Development of simulation models

5.1. Simulation models for RDM analysis

Runoff model, irrigation water balance model and crop simulation model were developed to evaluate the project effect under the multiple combination cases for RDM analysis. It is necessary to have a sufficient explanation capability for the simulation models of the relationship between the climate scenario, project cases and the project effectiveness. The simulation models which were based on physical mechanism were selected and the model parameters were set and calibrated to represent the behavior of the river flow, irrigation water supply and deficit and crop production. ?? shows the selected simulation models.

Table 5-1 Simulation models for evaluation project effect under multiple scenarios

Simulation model	Applied model	Remarks
Runoff model	SHER model Developed by Nippon Koei and University of Tokyo	The model is a kind of distributed physical based model. Climate change impact was compiled to weather data of rainfall and potential evapotranspiration. The weather data were applied to the model as boundary conditions. SHER model was based on physical equations so that can evaluate the impact of the climate scenario on the hydrological conditions adequately.
Irrigation water balance model	Standard water demand and supply analysis model was developed.	Based on the river flow data derived from runoff model, the water demand and possible irrigation water supply was calculated. The sufficiency of water supply was applied to the crop simulation model.
Crop simulation model	DSSAT Developed by DSSAT Foundation	The weather data, such as daily precipitation, temperature, shortwave radiation were applied for the model. The detailed crop condition, such as soil type, scheme of planting and fertilizer application schedule are also input to the model. DSSAT is one of the most famous crop simulation model.

5. 2. Development of hydrological model

The objective of rainfall-runoff analysis is to estimate the naturalized river flow. The estimated runoff will be used for assessment of renewable water resources as well as water balance study. The naturalised flow is defined as the river runoff that is not affected by any water uses in a catchment area. A series of naturalised flow is required for the assessment of the water demand and supply balance in the future. The daily runoff of rivers was calculated.

In addition to above, the vulnerability of future water resources by climate change was evaluated using the projected future climate and the prepared rainfall-runoff model.

5.2.1. SHER Model

Similar Hydrologic Element Response (SHER) model which was developed by Dr. Mushiake of Tokyo University and Prof. Herath of United Nations University et al was applied for rainfall-runoff model. The model can simulate basin-scale hydrological cycle including river flow, infiltration, groundwater recharging and interflow.

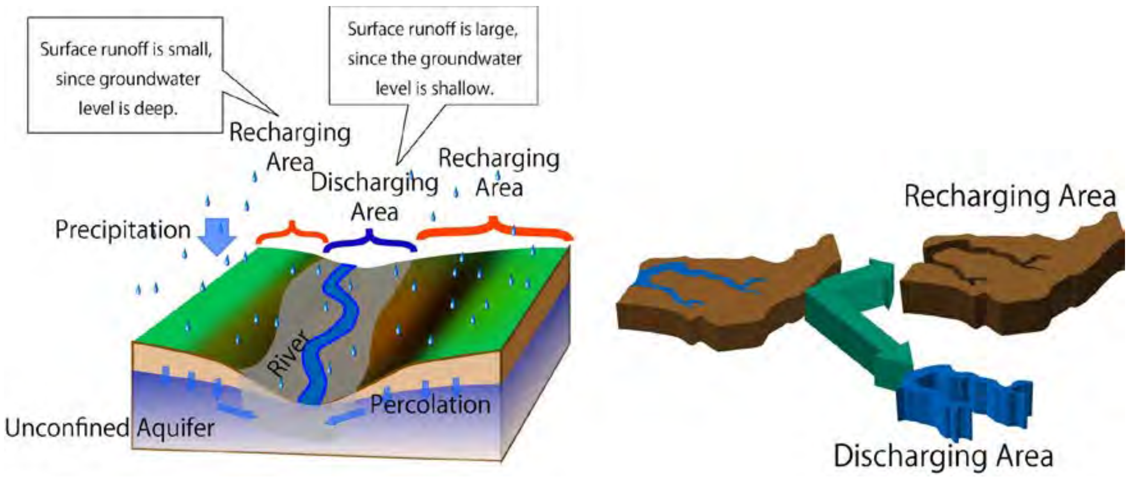


Figure 5-1 Conceptual image of SHER Model

5.2.1.1 Development of model data for MWEA catchment

The topographic data, sub-surface soil type, aquifer type and landuse data were the compiled for the input dataset for the MWEA catchment. The river network and the block delineation for the MWEA model was illustrated in Figure 5-2.

The soil parameter was the main parameter for the model calibration to represent the observed river flow with the observed weather data for 30 years from 1981 to 2010. The result of the model calibration was shown in Figure 5-3.

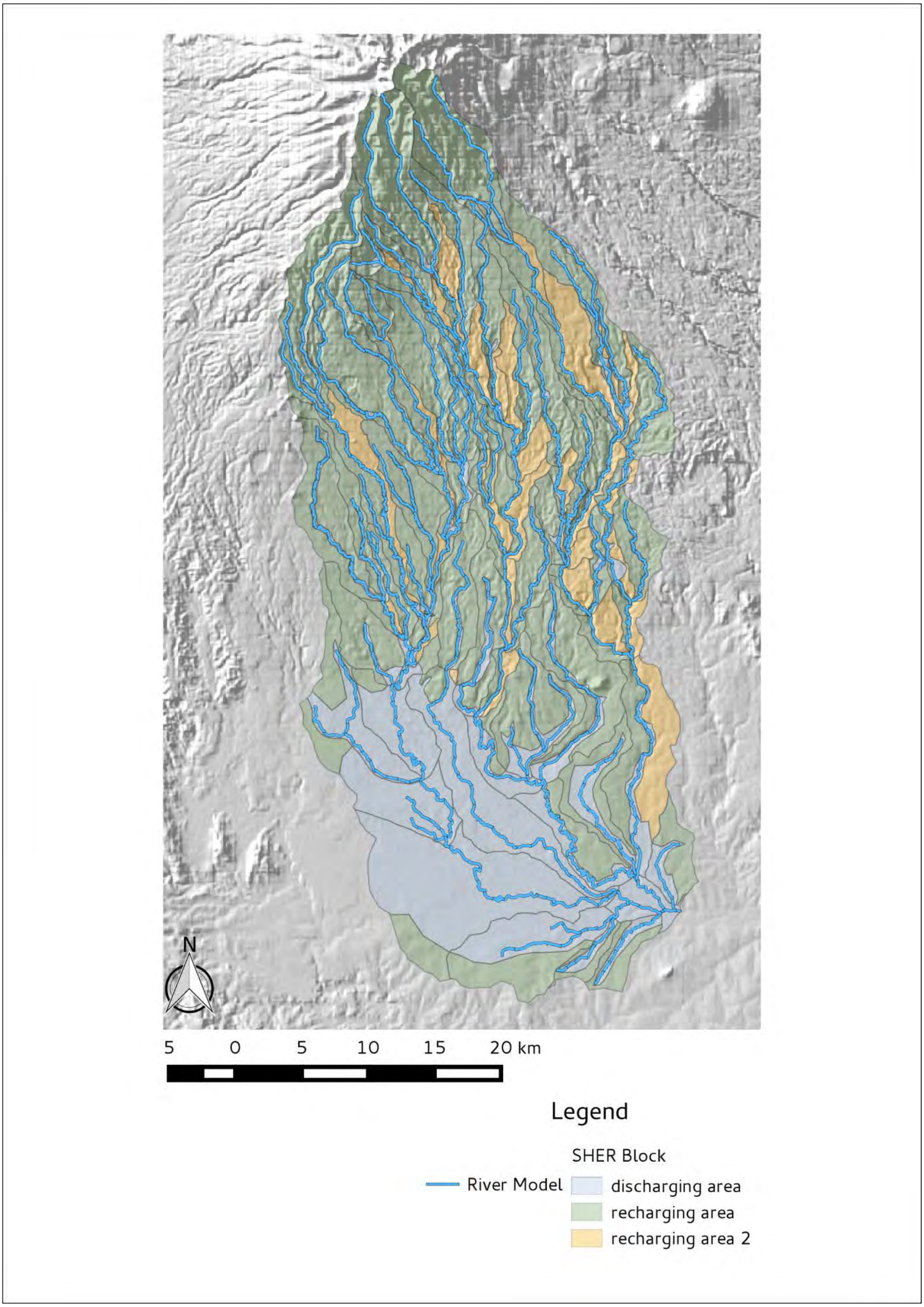


Figure 5-2 Block delineation for SHER model

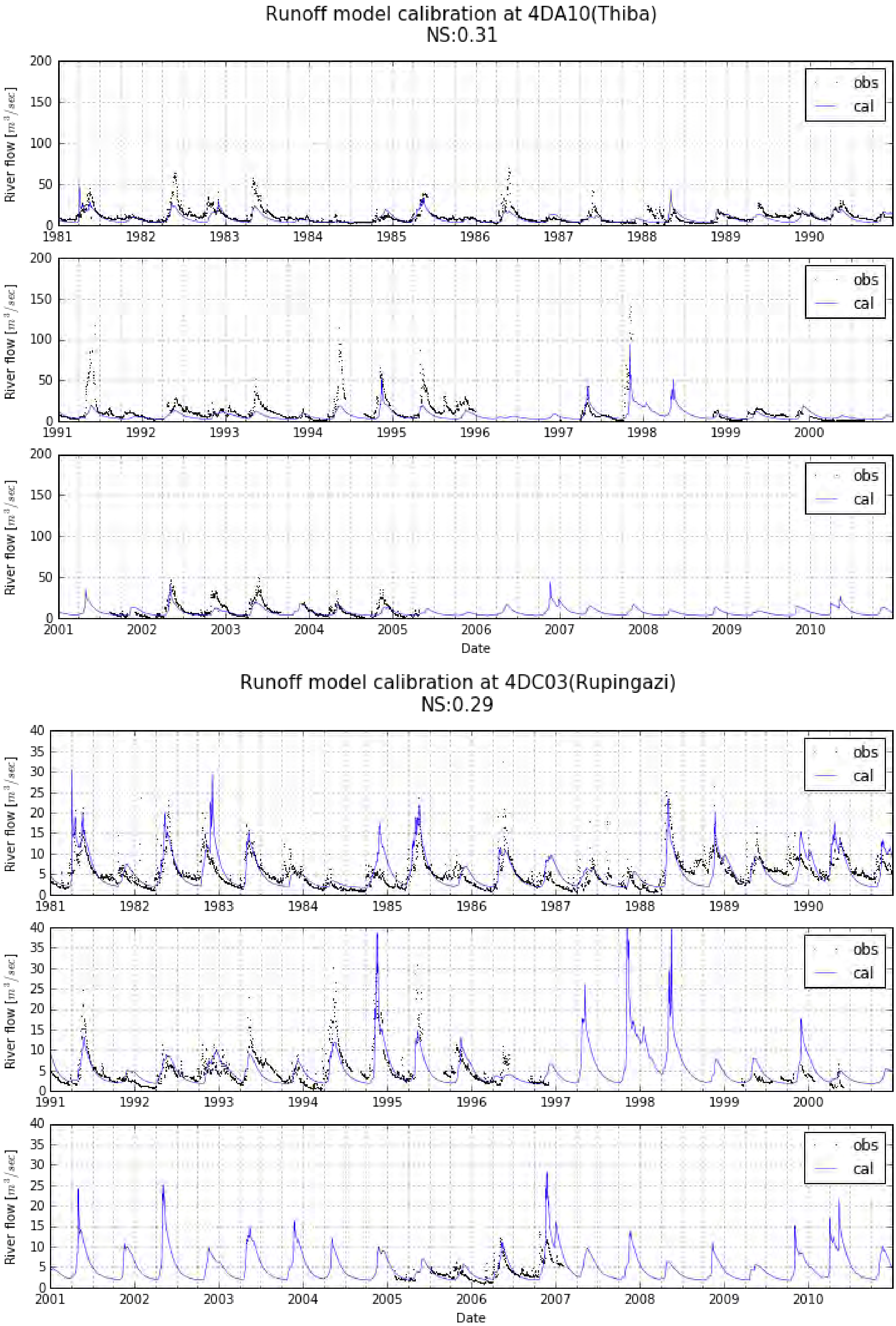


Figure 5-3 Hydrograph of calibrated runoff simulation

5.2.1.2 Runoff analysis under future climate scenario

Runoff analysis under the future projected climate scenario was carried out. River flow data of five (5) of future scenario and one (1) present climate scenario were obtained and those were applied for the irrigation water balance analysis mentioned in next section.

The evaluation points of the river flow were selected at the irrigation water intake points.

- New Nyamindi Headwork
- Proposed Thiba Dam Site
- Thiba Headwork

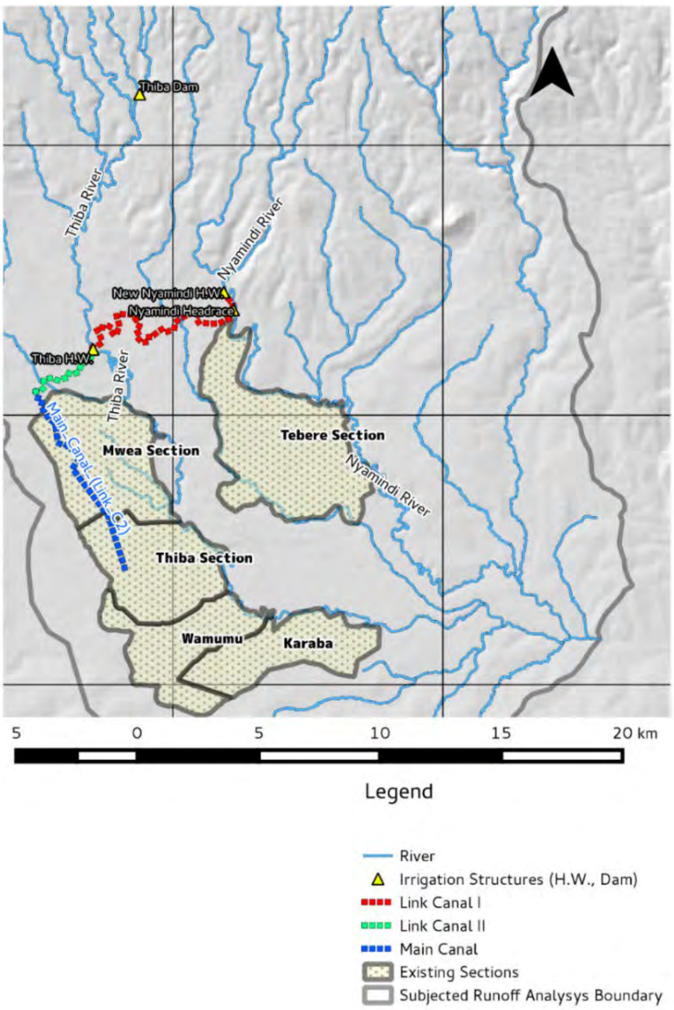


Figure 5-4 Intake points of MWEA

Annual discharge volume at the intake points of MWEA which were obtained by the developed runoff model was summarized in Table 5-2 and Figure 5-5.

Table 5-2 Estimated annual discharge volume at intake points of MWEA

unit [MCM/year]

case	Thiba Headwork	New Nyamindi Headwork	total
BL	227.6	195.2	422.7
DH	152.6	132.4	284.9
DL	193.9	169.8	363.7
MM	234.0	191.9	425.9
WH	427.0	353.4	780.3
WL	315.2	261.4	576.6

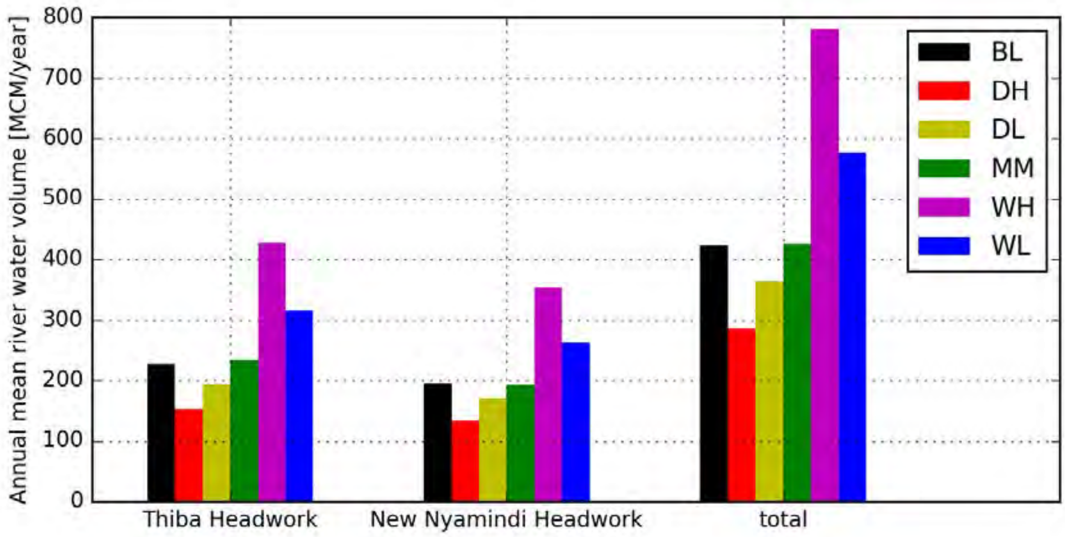


Figure 5-5 Evaluated annual discharge volume at intake points of MWEA

5. 3. Water balance simulation model

5.3.1. Present irrigation system

Table 5-3 shows a summary of existing irrigation area. The data was obtained from SAPROF study report.

The out-growers area is defined as follows; the area is located at outside of five sections of the original MIS scheme, but recently developed with paddy or upland crops, and needs irrigation water after the Link Canal-I was constructed in 1992. Farmers, in the Nderwa North area, illegally tapped irrigation water from Link Canal-I by unauthorized means such as pump, siphon, or sometime breaking bank without respecting to the water distribution system in the original MIS scheme. The MIS office recently legalized and incorporated those farmers to the MIS scheme by providing simple off-takes in the Link Canal-I so that farmers can contained to MIS scheme.

Table 5-3 Existing irrigation area in and around the MIS

System/ - Section	Year 1995[*1] (ha)	D/D 1996[*2] (ha)	Plan 2008/09[*3] (ha)
Original MIS Scheme			
1. Nyamindi system			
- Tebere	1,290	1,300	1,380
2. Thiba system			
- Mwea		1,220	1,271
- Thiba	4,603 (Mwea, Thiba, Wamumu, Karaba)	1,150	1,141
- Wamumu		1,120	1,154
- Karaba		1,070	991
- MIAD	90	-	90
- Upland crop fields in MIS scheme	800	800	600
Sub-total of Original MIS	**6,783**	**6,660**	**6,627**
Out-growers Area[*4]			
- Curukia[*5]	-	-	891
- Mutithi	-	2,580	-
- Upland crop fields in Mutithi area	-	550	-
- Nderwa North	-	230	434
- Marura	-	-	-
- Kiamanyeki and Mwea Prison	-	-	-
- Karaba	-	-	-
Sub-total of Out-growers	-	**3,360**	**1,325**
Total	**6,783**	**10,020**	**7,952**

Note: In MIS Scheme, the irrigation area is categorized System, Section, and Unit in accordance with level and size; the names of Units are not listed in the above table.
*1 Proposed by Water Management Manual 1995 (JICA)
*2 Mutithi and Nderwa North areas (3,360 ha) was proposed for irrigation development by D/D in 1996
*3 Made by MIS Scheme office for the year 2008/09
*4 Out-growers did not exist before 1998
*5 Curukia area is a part of Mutithi area but called by a different name by MIS Scheme office at present.
Prepared by SAPROF Team

Figure 5-6 shows existing irrigation and drainage system in the MIS Scheme.

The Nyamindi headworks (H.W.) is an irrigation water source of the Nyamindi system (the Tebere section). The water taken at the Nyaminidi H.W. flows in the Nyamindi headrace, and divided into two directions i.e. Nyamindi Main Canal and Link Canal-I. Nayminid Main Canal conveys irrigation water to the Nyaminid system. Link Canal-I was constructed so as to convey water from the Nyamindi river to the Thiba river. Thiba H.W. takes water of the Thiba river together with water supplied by Link Canal-I. The water taken at Thiba H.W. flows in Link Canal-II. Link Canal-II functions to convey water to Thiba Main Canal.

The existing irrigation system has two distinct irrigation systems; one is the

Nyamindi system and the other is the Thiba system. The Thiba system is comprised of four sections i.e. Mwea, Thiba, Wamumu and Karaba sections. On the contrary, the Nyamindi system covers the Tebere section only. The name of section derives from local name of the area concerned.

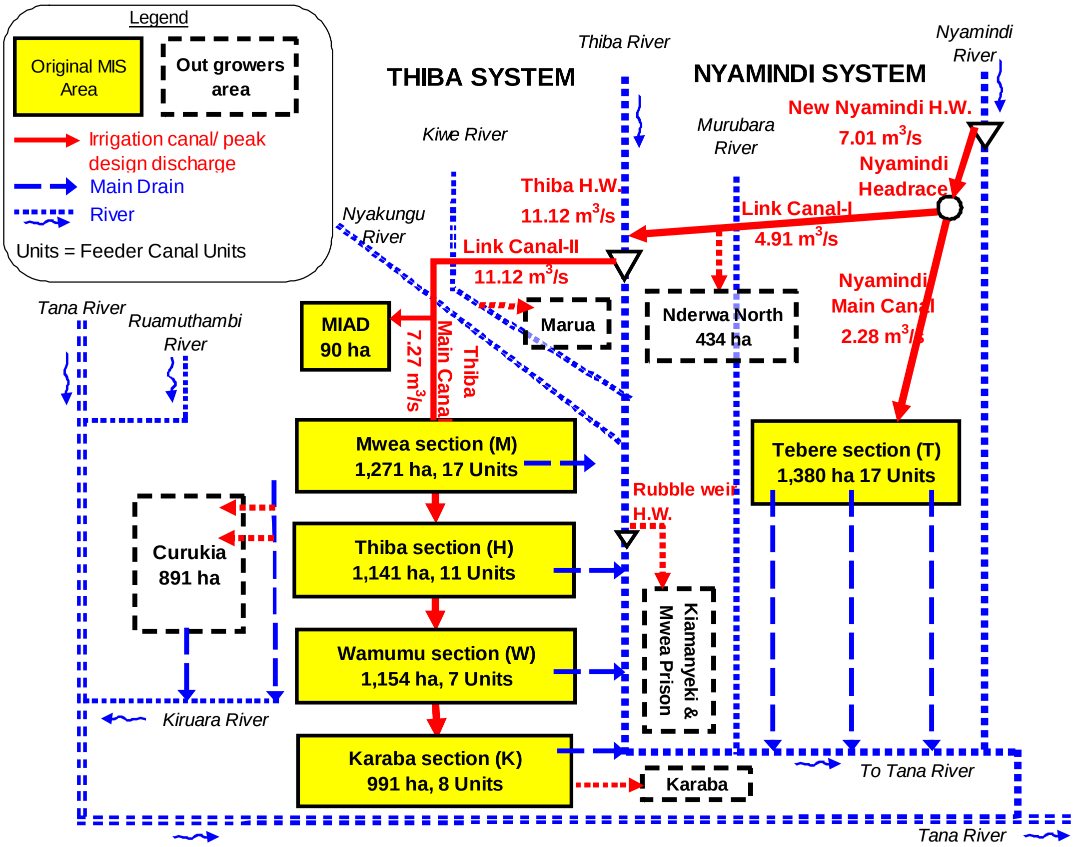


Figure 5-6 Existing major irrigation and drainage system in MIS

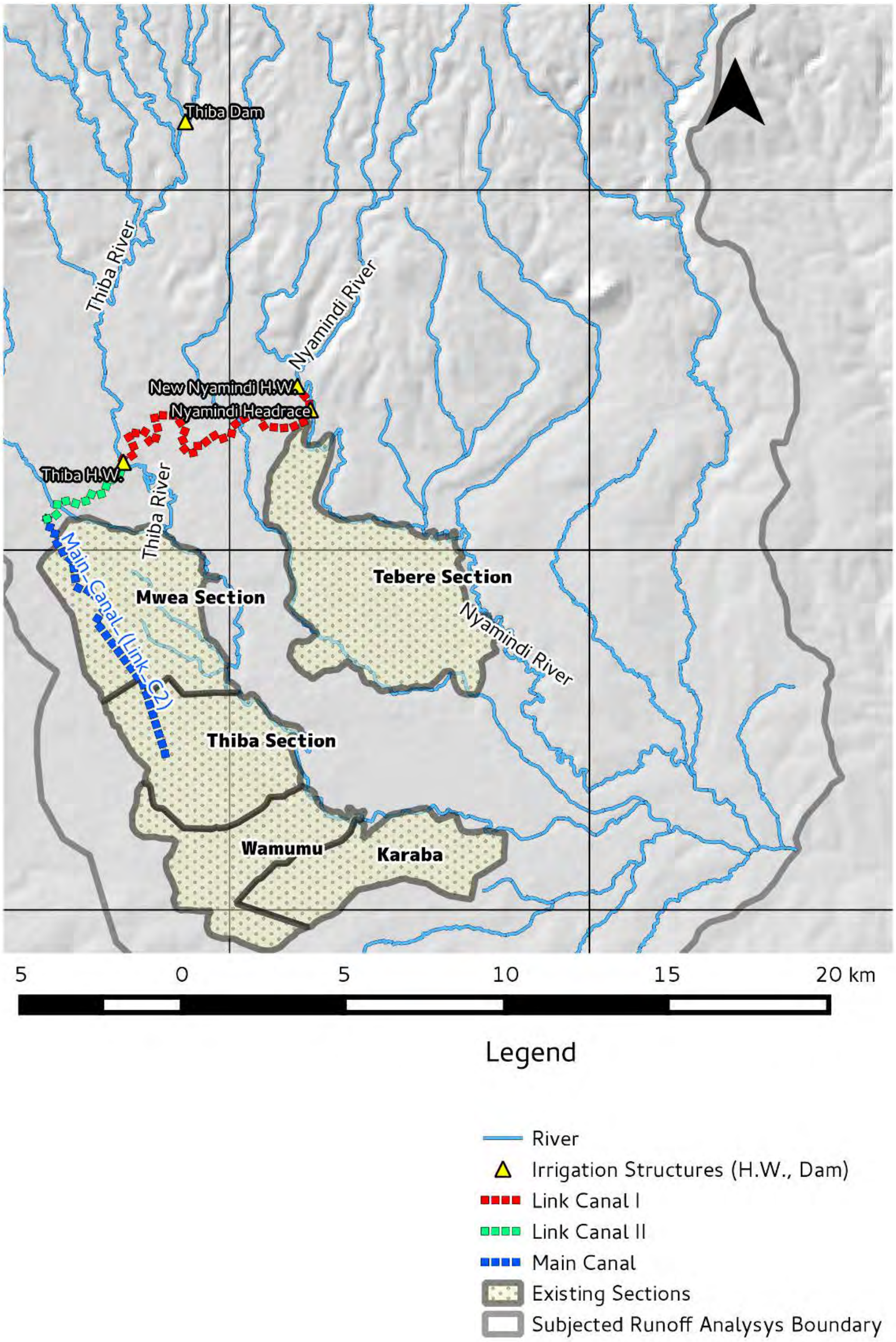


Figure 5-7 Irrigation Area, Link Canal and water intake facilities in MWEA Irrigation System

5.3.1.1 Water management and operation

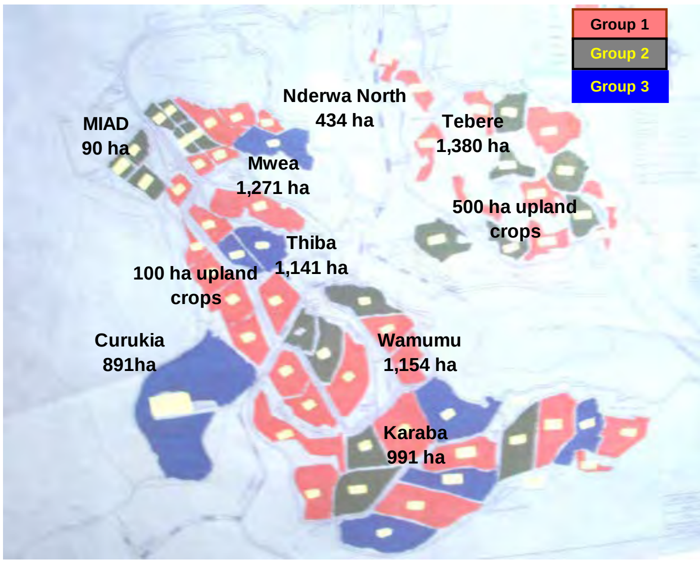
The irrigation water supply in the MIS scheme is staggered in order to meet availability of water resources. The irrigation water is supplied according to the irrigation schedule, in which 60 Units in the MIS scheme are divided into three (3) groups, as presented below.

Group 1; starts between 1st April to mid May, and harvests in early December
Group 2; starts between mid May to end June, and harvests in middle December
Group 3; starts between 1st October to 31 October, and harvest in middle March

Table 5-4 Paddy cultivation and irrigation schedule in 2008/2009

Section	Group 1		Group 2		Group 3		Total	
	Area (ha)	Unit	Area (ha)	Unit	Area (ha)	Unit	Area (ha)	Unit
Tebere	799	11	581	6	0	n.a.	1,380	17
Mwea	650	9	293	5	329	3	1,271	17
Thiba	875	8	266	3	0	n.a.	1,141	11
Wamumu	481	3	462	3	210	1	1,154	7
Karaba	656	5	145	1	190	2	991	8
Curukia	0	n.a.	0	n.a.	891	6	891	6
Nderwa north	0	n.a.	270	2	164	2	434	4
Total	3,460	36	2,016	20	1,784	14	7,261	70

Source: MIS Scheme Office



Source: MIS Scheme Office

Figure 5-8 Spatial distribution of rice cultivation/ irrigation in 2008/2009

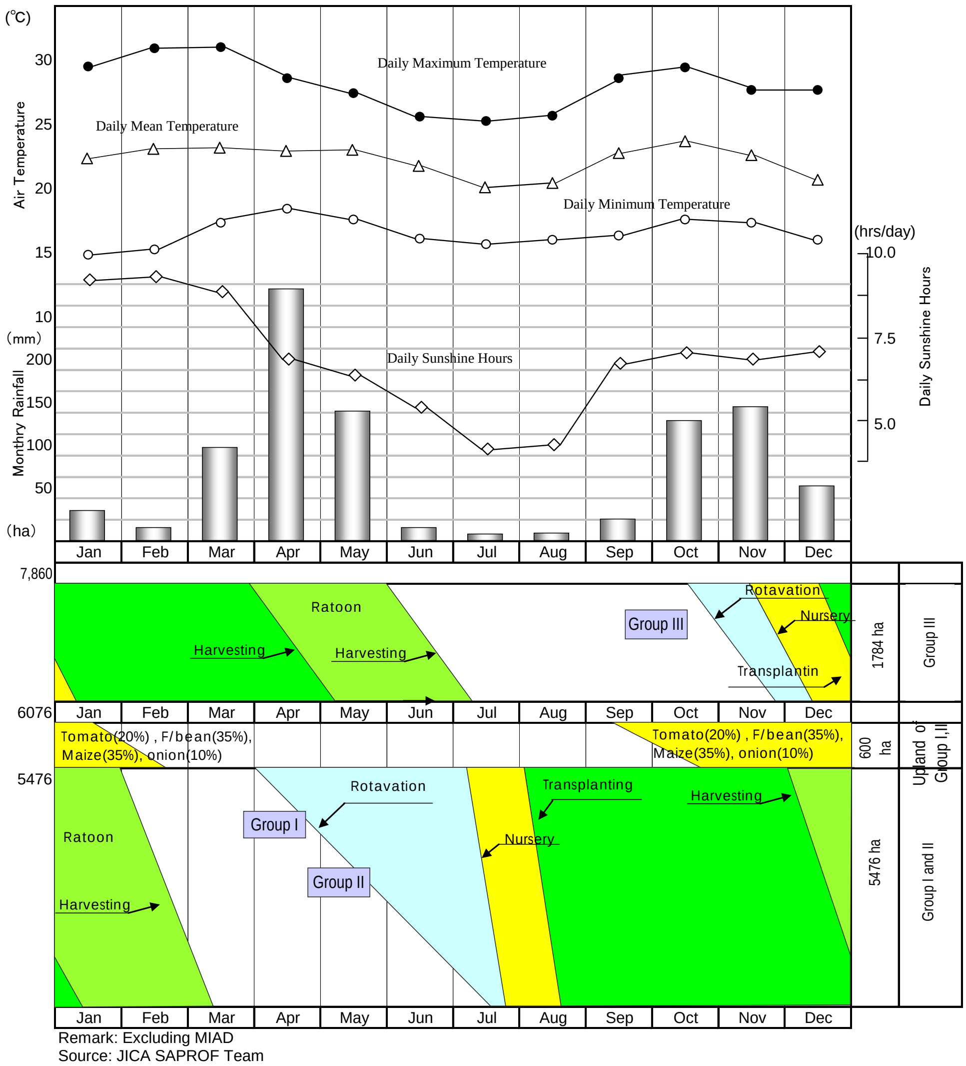


Figure 5-9 Present cropping pattern of the MIS scheme in 2008/2009

5.3.2. Alternative irrigation system proposed in SAPROF

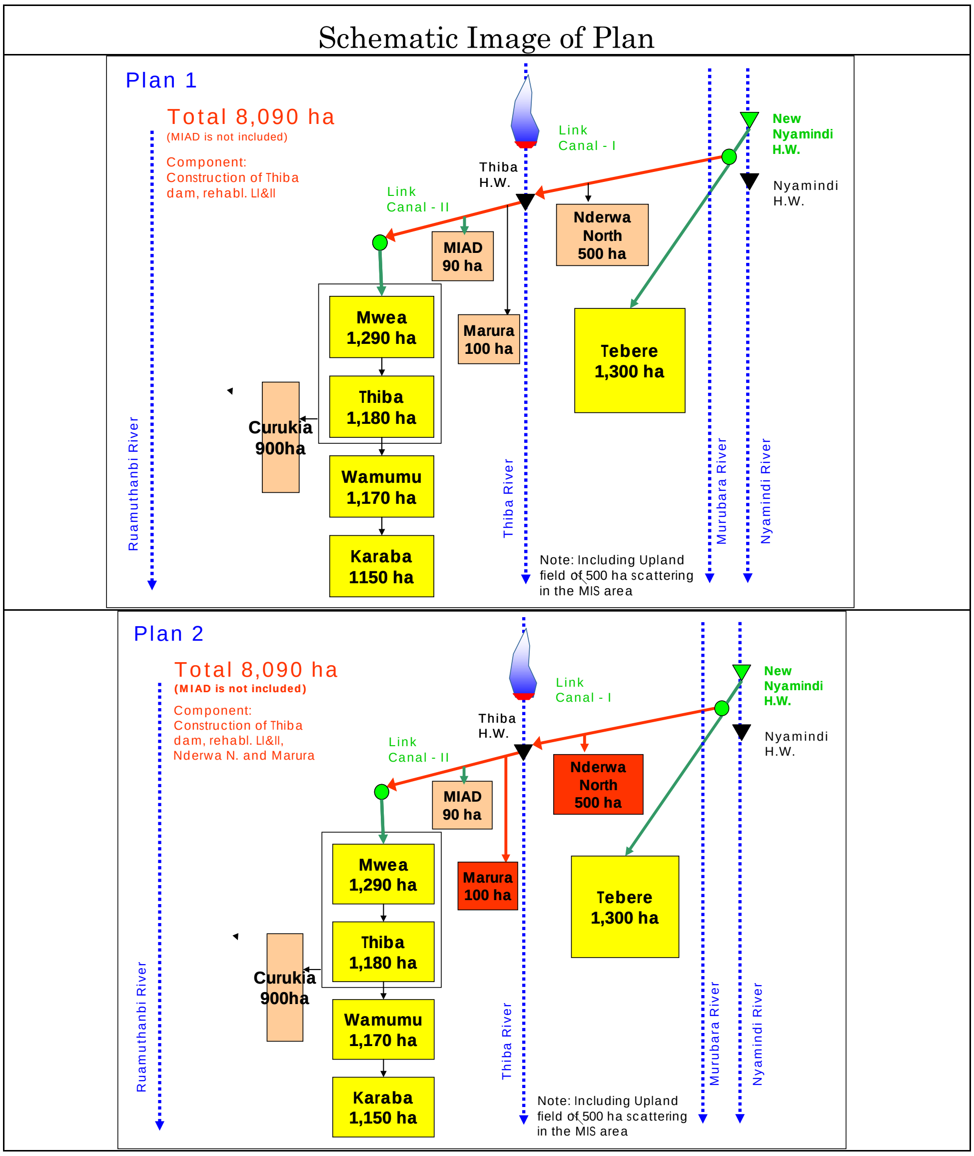
The problem on present irrigation system was that the possible water supply was less than the water demand for the cropping area. The official cropping area of MIS was 6,660ha at the time of D/D studied in 1996. The official area had been spread to 7,952ha at the time of SAPROF study in 2008. The out-growers those intake the irrigation water unofficially had been enlarged.

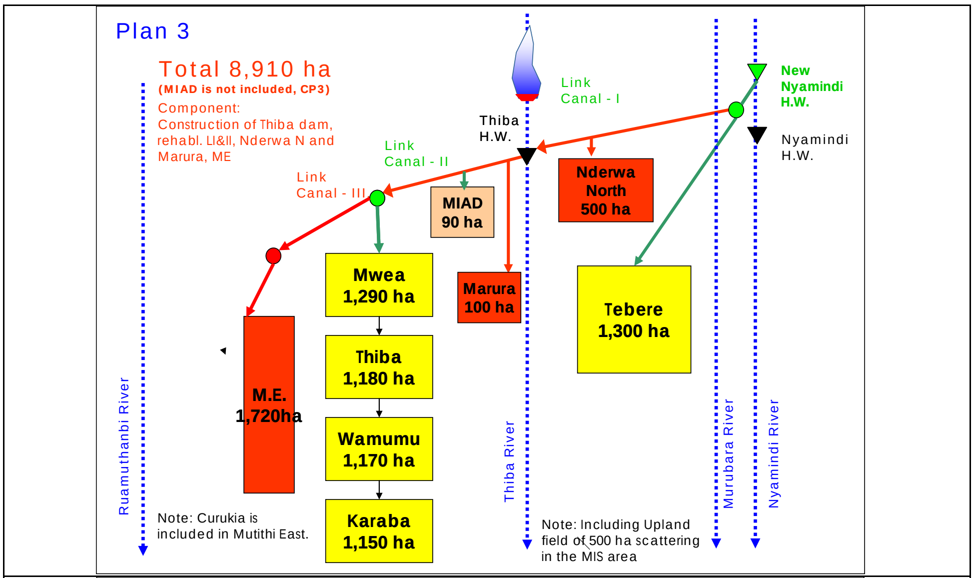
To cope with the chronic deficit of irrigation water against the expanding water demand, four alternative plans were developed in SAPROF study. The main measure in the alternatives were new construction of Thiba dam to develop new water resources and rehabilitation of the Link Canal I and II to maintain the efficiency of the water supply. The alternatives proposed in SAPROF were shown in Table 5-5 and Figure 5-10.

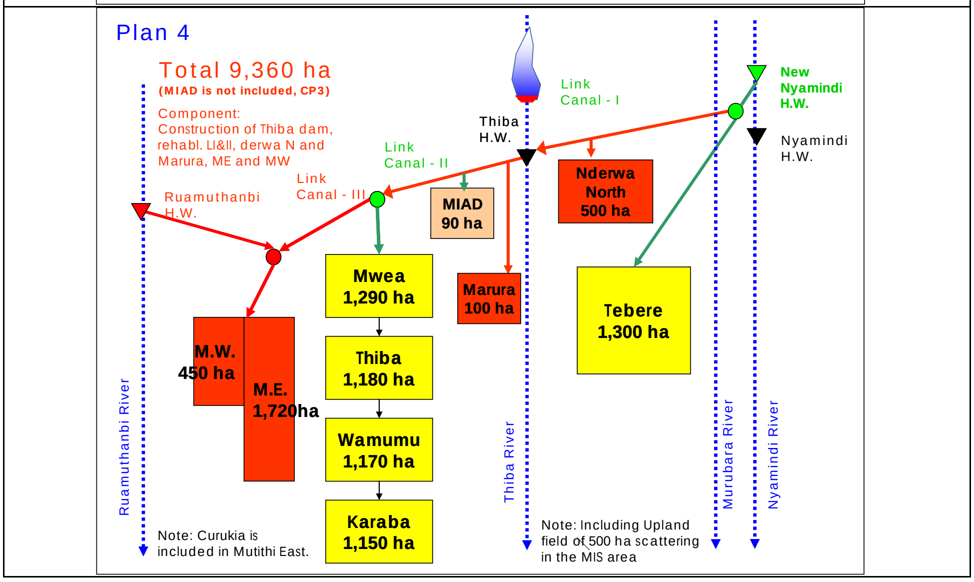
Table 5-5 Alternative plans of MWEA irrigation system proposed in SAPROF

Project Component	Alternative Plans			
	Plan 1	Plan 2	Plan 3	Plan 4
Thiba Dam	●	●	●	●
Link Canal-I (Rehabilitation)	●	●	●	●
Link Canal-II (Rehabilitation)	●	●	●	●
Nderwa North + Marura Areas (Improvement)		●	●	●
Link Canal-III (New construction)			●	●
Curukia Area (Improvement)			●	●
Mutithi East Area (Extension)			●	●
Ruamthambi Headworks and Head race (New)				●
Mutithi West Area (Extension)				●

Figure 5-10 Schematic image of alternative irrigation plan proposed in SAPROF




Plan 3
Total 8,910 ha
(MIAD is not included, CP3)
Component:
Construction of Thiba dam,
rehabl. LI&II, Nderwa N and
Marura, ME
Link
Canal - I
Thiba
H.W.
New
Nyamindi
H.W.
Nyamindi
H.W.
Link
Canal - II
Link
Canal - III
Nderwa
North
500 ha
MIAD
90 ha
Mwea
1,290 ha
Marura
100 ha
Tebere
1,300 ha
Thiba
1,180 ha
M.E.
1,720ha
Wamumu
1,170 ha
Karaba
1,150 ha
Ruamuthanbi River
Thiba River
Murubara River
Nyamindi River
Note: Curukia is
included in Mutithi East.
Note: Including Upland
field of 500 ha scattering
in the MIS area


Plan 4
Total 9,360 ha
(MIAD is not included, CP3)
Component:
Construction of Thiba dam,
rehabl. LI&II, derwa N and
Marura, ME and MW
Link
Canal - I
Thiba
H.W.
New
Nyamindi
H.W.
Nyamindi
H.W.
Link
Canal - II
Link
Canal - III
Ruamuthanbi
H.W.
Nderwa
North
500 ha
MIAD
90 ha
Mwea
1,290 ha
Marura
100 ha
Tebere
1,300 ha
M.W.
450 ha
Thiba
1,180 ha
M.E.
1,720ha
Wamumu
1,170 ha
Karaba
1,150 ha
Ruamuthanbi River
Thiba River
Murubara River
Nyamindi River
Note: Curukia is
included in Mutithi East.
Note: Including Upland
field of 500 ha scattering
in the MIS area

5.3.3. Cropping Patterns

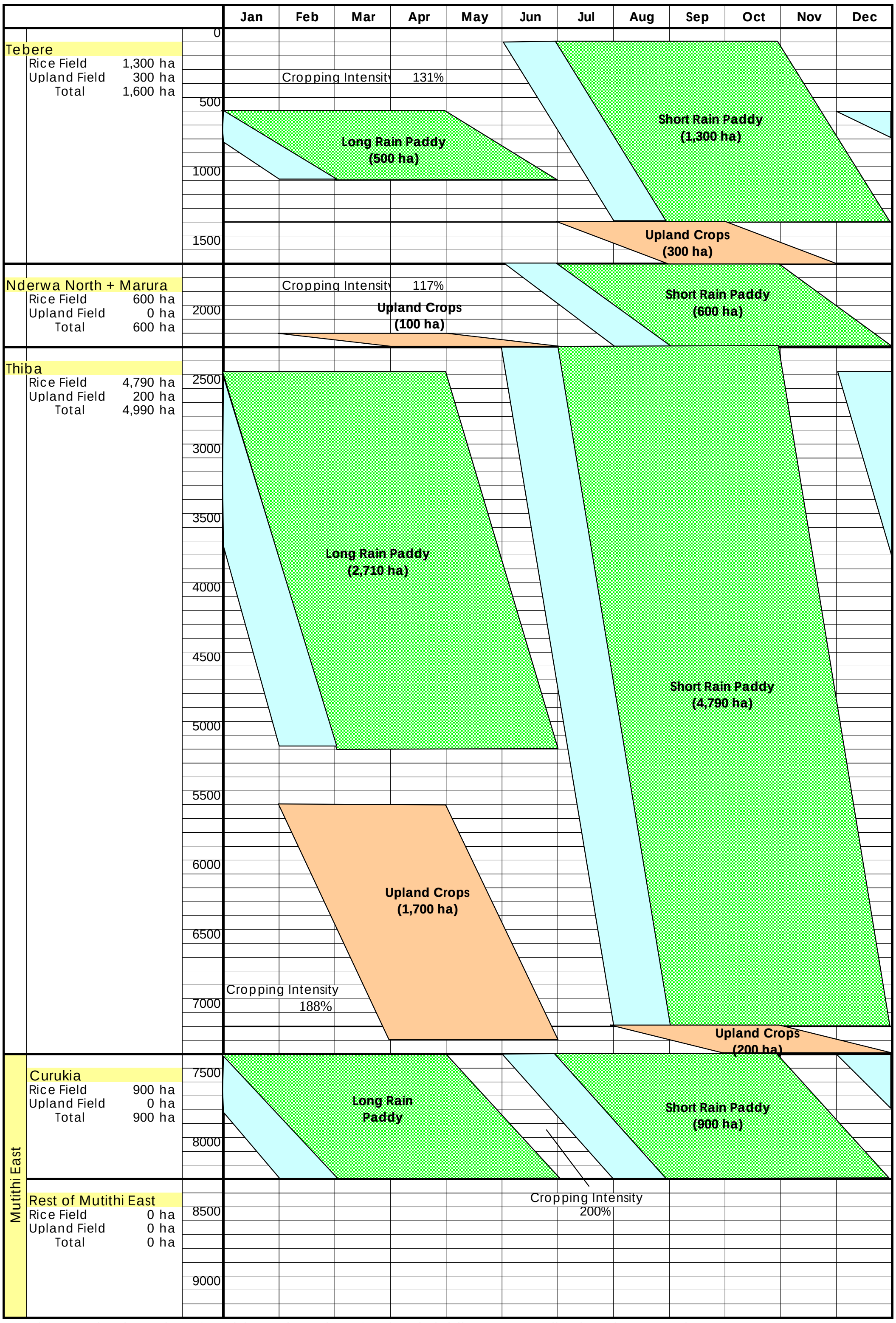
The proposed Thiba Dam will enable all the farmers to receive sufficient irrigation water for SR rice. The crops for LR will be selected by farmers. Double cropping of rice is technically feasible in the MIS scheme, and upland crops for LR are also possible according to MIAD. In this sense, the following cropping patterns are proposed.

Table 5-6 Proposed cropping patterns in SAPROF

Proposed Cropping Patterns	Cropping Season		
	Short Rain (SR)	Ratoon	Long Rain (LR)
CP-1:SR Rice - LR Rice	Pishori (Basmati)	Nil	Pishori (Basmati)
CP-2:SR Rice - NERICA in LR	Pishori (Basmati)	Nil	NERICA
CP-3:SR Rice - Ratoon - Upland Crops	Pishori (Basmati)	To be raised	NERICA, Soybeans and Vegetables
CP-4:Upland Crops - Upland Crops	Soybeans and Vegetables	Nil	Maize

CP-1 and CP-3 were selected as preferable plans among the four alternatives and those were subjected to the further detailed analysis, water balance study and benefit-cost analysis. In this study CP-1 and CP-3 were selected for the further study.

The cropping pattern charts of CP-1 and CP-3 were shown in Figure 5-11 and Figure 5-12.

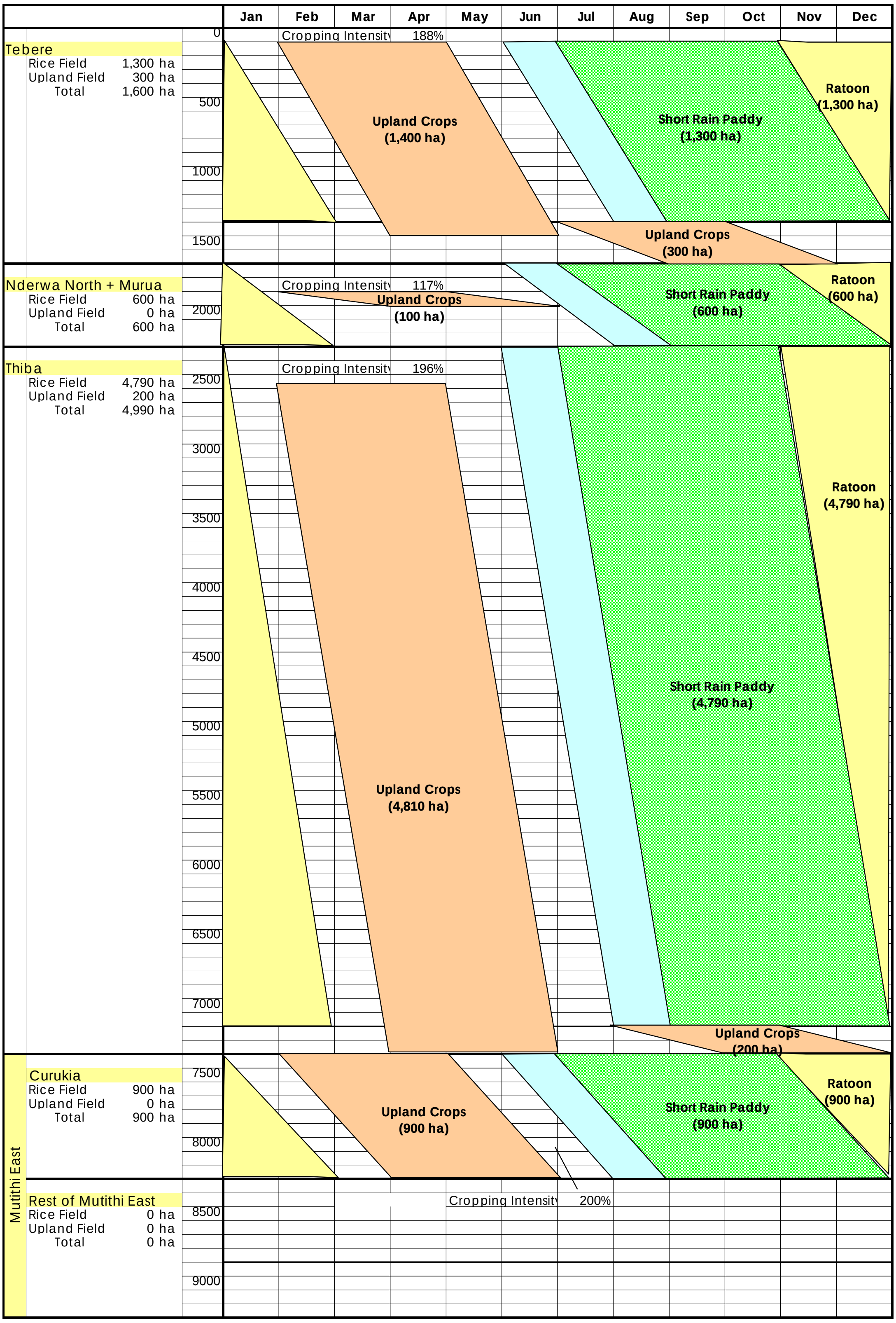


Total : 8,090 ha (7,590ha of Paddy and 500 ha of Upland Field) Overall Criopping Intensity: 173%

MIAD 90 ha is not included in the areas during both SR and LR.

Planted Area by Section under Plan 2 (Proposed Cropping Pattern 1)

Figure 5-11 Cropping patterns of proposed plan CP-1



Total : 8,090 ha (7,590 ha of Paddy and 500 ha of Upland Field) Overall Criopping Intensity: 189%

MIAD 90 ha is not included in the areas during both SR and LR.

Planted Area by Section under Plan 2 (Proposed Cropping Pattern 3)

Figure 5-12 Cropping pattern of proposed plan CP-3

5.3.4. Water balance analysis

5.3.4.1 Alternative irrigation projects

The combination of irrigation plans and cropping patters for RDM study was summarized in Table 5-7. Water balance analysis for the four cases were carried out. In SAPROF study, the water balance study was aimed to figure out the possible irrigation area with the developed irrigation water condition with 80% confidence level. In this study, we based on the proposed cropping area by SAPROF and weather and river flow data for the subjected climate scenarios were applied for the water balance analysis.

Table 5-7 Alternative of irrigation projects

Plan	Cropping patterns	Irrigation plan
Case 0 Present condition	Group1~3 Alternative irrigations	Existing Nyamindi, Thiba system
Case 1	CP-3 : SR – Ratoon – LR	Plan3 : Thiba dam＋Link Canal III＋ Extend of irrigation area
Case 2	CP-1: SR– LR Nerica	Plan3 : Same as above
Case 3	CP-3:	Plan2 : Thiba dam

The cropping area for the subjected irrigation projects case 0, 1, 2 and 3 were shown in Table 5-8 to Table 5-11.

Table 5-8 Cropping area of Case0 (present irrigation system and cropping pattern)

System/Section	Existing Area [ha]	Area breakdown of cropping pattern [ha]			
		Short rain		Long rain	
		Group1 [ha]	Group2 [ha]	Group3 [ha]	total [ha]
1. Nyamindi System	**1,380**	**799**	**581**	**-**	**1,380**
Tebere	1,380	799	581	-	1,380
2. Thiba System	**5,247**	**2,662**	**1,166**	**729**	**4,557**
Mwea	1,271	650	293	329	1,272
Thiba	1,141	875	266	-	1,141
Wamumu	1,154	481	462	210	1,153
Karaba	991	656	145	190	991
MIAD	90	-	-	-	*1
Upland crop fields in MIS scheme	600	-	-	-	*2
Sub-Total of Original MIS	**6,627**	**3,461**	**1,747**	**729**	**5,937**
					-
Out-growers Area					-
Curukia	891	-	-	891	891
Nderwa North	434	-	270	164	434
Sub-Total of Out-growers Area	**1,325**	**-**	**270**	**1,055**	**1,325**
					-
Total Irrigation Area	**7,952**	**3,461**	**2,017**	**1,784**	**7,262**

*1 MIAD was not included in Group1, 2 & 3 area, since MIAD is R&D cropping activity. For the water balance study, the demand water for MIAD shall be included. The breakdown of irrigation schedule groups was supposed to be equal area to 3 groups.

*2 There is no detailed information for breakdown area of upland crop to irrigation schdule group. According to the Figure 4.2.2 of SAPROF final report, upland crop field area is 300ha in Tebere section and 200ha in Mwea section. The cropping season of upland crop is allocated for short rain in Table 4.2.4 in SAPROF final report.
In water balance study, we suppose 300ha upland area in Tebere section and 300ha in Thiba system, and whole upland crop are cropped in short rain season.

Table 5-9 Cropping area of Case1 (irrigation plan 3 and CP-1)

System/Section	Net Area [ha]	Area breakdown of cropping pattern [ha]			
		Short rain paddy + Ratoon	Short rain upland	Long rain Paddy	Long rain upland
1. Nyamindi System	**1,800**	**1,800**	**300**	**-**	**1,400**
Tebere	1,300	1,300	300	-	1,400
Nderwa North	500	500	-	-	-
2. Thiba System	**4,980**	**4,980**	**200**	**-**	**5,000**
MWEA	1,290	1,290	* No information about breakdown area		
Thiba	1,180	1,180			
Wamumu	1,170	1,170			
Karaba	1,150	1,150			
Marura	100	100			
MIAD	90	90			
3. Extension Area	**1,320**	**1,320**	**400**	**-**	**1,700**
Mutithi East	420	420	400	-	800
Curukia	900	900	-	-	900
Total Irrigation Area	**8,100**	**8,100**	**900**	**-**	**8,100**

Table 5-10 Cropping area of Case2 (irrigation plan 3 and CP-1)

System/Section		Net Area [ha]	Area breakdown of cropping pattern [ha]			
			Short rain paddy + Ratoon	Short rain upland	Long rain Paddy	Long rain upland
1. Nyamindi System		**1,800**	**1,800**	**300**	**500**	**100**
	Tebere	1,300	1,300	300	500	-
	Nderwa North	500	500	-	-	100
2. Thiba System		**4,980**	**4,980**	**200**	**2,300**	**1,700**
	MWEA	1,290	1,290	* No information about breakdown area		
	Thiba	1,180	1,180			
	Wamumu	1,170	1,170			
	Karaba	1,150	1,150			
	Marura	100	100			
	MIAD	90	90			
3. Extension Area		**1,320**	**1,320**	**-**	**800**	**300**
	Mutithi East	420	420		200	-
	Curukia	900	900		600	300
Total Irrigation Area		**8,100**	**8,100**	**500**	**3,600**	**2,100**

Table 5-11 Cropping area of Case3 (irrigation plan 2 and CP-3)

System/Section		Net Area [ha]	Area breakdown of cropping pattern [ha]			
			Short rain paddy + Ratoon	Short rain upland	Long rain Paddy	Long rain upland
1. Nyamindi System		**1,800**	**1,800**	**300**	**-**	**1,400**
	Tebere	1,300	1,300	300	-	1,400
	Nderwa North	500	500	-	-	-
2. Thiba System		**4,980**	**4,980**	**200**	**-**	**5,000**
	MWEA	1,290	1,290	* No information about breakdown area		
	Thiba	1,180	1,180			
	Wamumu	1,170	1,170			
	Karaba	1,150	1,150			
	Marura	100	100			
	MIAD	90	90			
3. Extension Area		**900**	**900**	**-**	**-**	**900**
	Curukia	900	900	-	-	900
Total Irrigation Area		**7,680**	**7,680**	**500**	**-**	**7,300**

5.3.4.2 Procedure

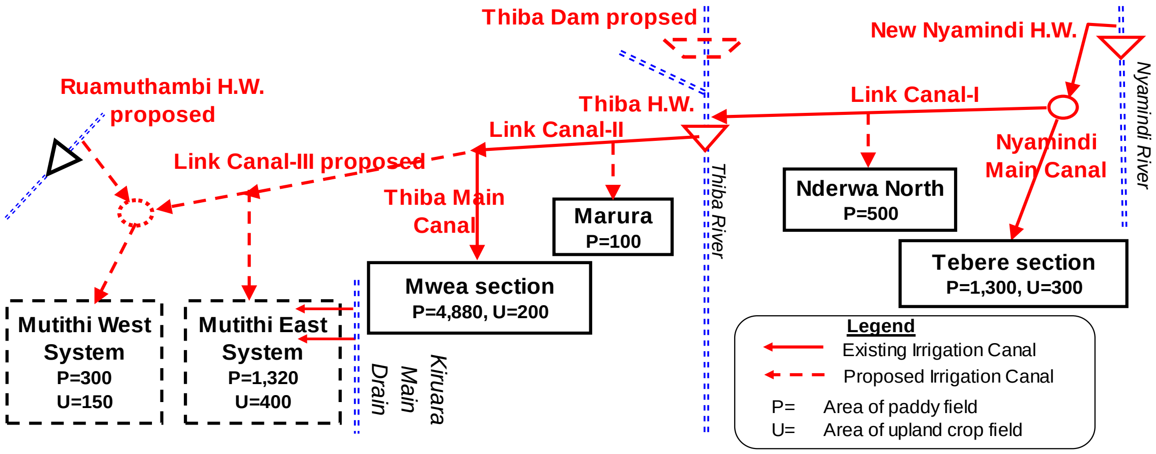


Figure 5-13 Configuration of water resources structures

Taking into consideration the configuration of water resource structures and irrigation systems, the water balance analysis was carried out with Table 5-12.

Table 5-12 Steps of water balance analysis

Step	Water resources	Irrigation area
Step1	Deduct water demand and river maintenance flow in the downstream from available discharge in each site of intake facilities.	
Step2	New Nyamindi headwords	Nyamindi system (Tebere section)
Step3	Link Canal-I (surplus from step2)	Nderwa North area
Step4	Link Canal-I (surplus from step3) + Thiba river (discharge from catchment area other than Thiba dam)	Marura area + Mwea system including Curukia area
Step5	Thiba dam (supplemental supply to Step4)	Step4 + Mutithi East system
Step6	Ditto	Step5 + Mutithi West system

5.3.4.3 Sufficiency of irrigation supply

The sufficiency of irrigation water supply against the water demand for the planed cropping area and cropping pattern was calculated for the multiple combination of the climate and irrigation project scenarios those were twenty-four (24) patterns comprised by four (4) irrigation projects and six (6) climate scenarios. The heat map of the sufficiency of the irrigation water were shown in Figure 5-14.

The sufficiency rate was calculated the ratio of annual possible distributed water volume to demand water for each cropping sections, and those were summed up with weighted mean of cropping area. The value of sufficiency rate can be compare each cases even those consists of different cropping area and demand water volume.

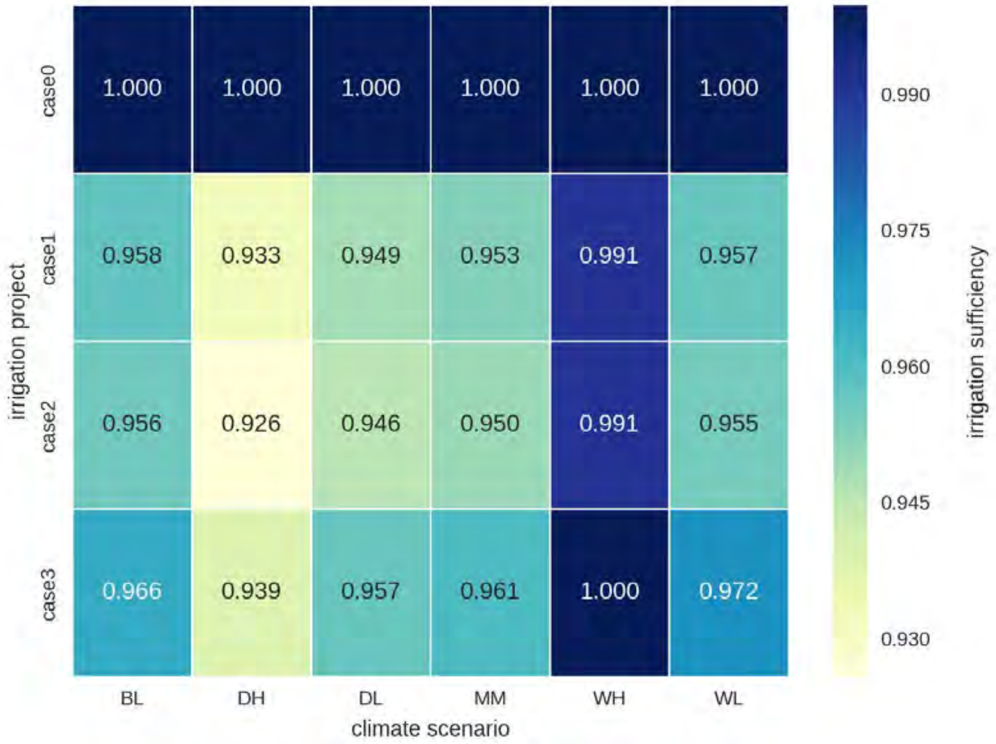


Figure 5-14 Annual sufficiency rate of irrigation water for each multiple combination cases

The air temperature of every future climate scenario was forecasted to rise from present. The rainfall will vary to increase or decrease for each climate scenario. The sufficiency rate will be affected by climate scenario significantly.

Case1 to 3 was the proposed irrigation project which plots extension of possible cropping area for the developed irrigable water. The expansion of cropping area planned in Case1 to 3 were expects the possible water supply by the plan until reaches the very limit of 80% confidence. Very slight difference on the hydrological data, i.e. the difference of data utilized in SAPROF and this study, can be caused the small deficit of the water supply as shown in Case1 to 3 in Figure 5-14.

5. 4. Crop simulation model

5.4.1. DSSAT

DSSAT and its crop simulation models have been used for many applications ranging from on-farm and precision management to regional assessments of the impact of climate variability and climate change. It has been in use for more than 20 years by researchers, educators, consultants, extension agents, growers, and policy and decision makers in over 100 countries worldwide.

The crop models require daily weather data, soil surface and profile information, and detailed crop management as input. Crop genetic information is defined in a crop species file that is provided by DSSAT and cultivar or variety information that should be provided by the user. Simulations are initiated either at planting or prior to planting through the simulation of a bare fallow period.

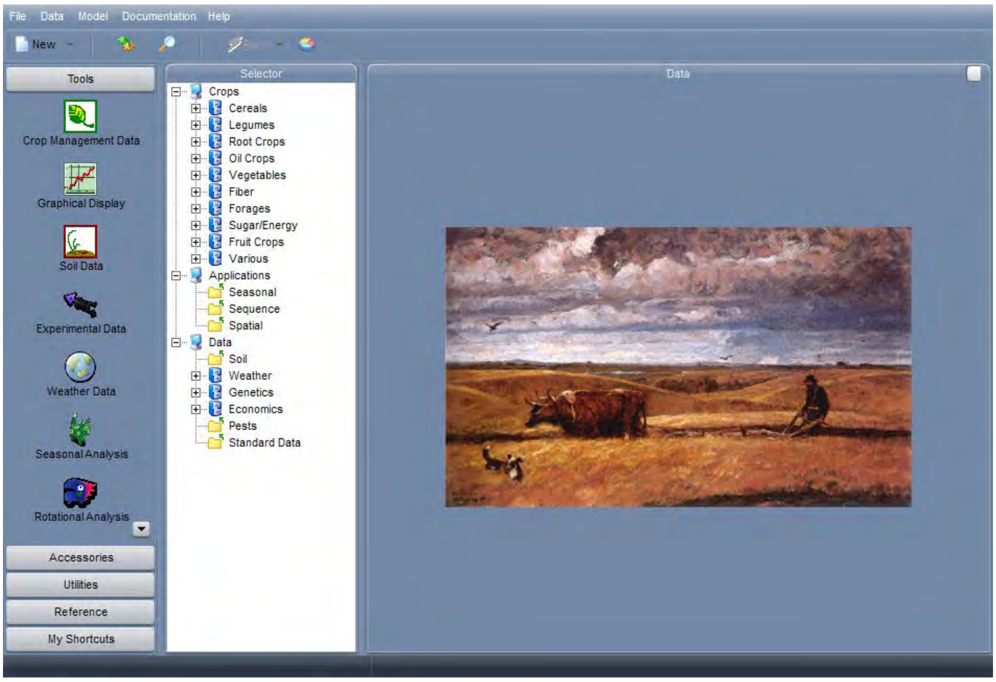


Figure 5-15 Graphic front end of DSSAT

5.4.2. Evaluation of rice production

5.4.2.1 Model calibration

DSSAT requires various type of the data for the simulation, such as weather data of rainfall, temperature and solar radiation, soil type, fertilization schedule, planting geometry and so-on. Those required data set were obtained from SAPROF mainly. To evaluate the effect of climate and irrigation water on the rice productivity, the calibration work was conducted to represent the recorded rice production.

The irrigation water which were calculated by the water balance analysis mentioned in previous section couldn't be applied directly to DSSAT model. The irrigation timing which is triggered by the soil water contents was main parameter to calibrate. Twenty (20) percent of water content for trigger of irrigation was identified to represent the unit crop yield record.

Table 5-13 Calibration result of rice crop evaluation model

Year	Reference			Simulation	
	Total (KNBS)	SR, Main crop Yield	LR, Main crop Yield	SR, Main crop Yield	LR, Main crop Yield
	kg/ha	kg/ha	kg/ha	kg/ha	kg/ha
Ratio to total (Main + Ratoon) unit yield		0.7	0.84		
Ratio to annual unit yield (SR+LR)		1.12	0.63		
2006/07	6180	4845	3270	4201	2839
2007/08	4940	3873	2614	4873	2138
2008/09	4360	3418	2307	3646	1976
2009/10	4940	3873	2614	2470	3661
2010/11	5080	3983	2688	4154	
平均値	5100	3998	2699	3869	2654

5.4.2.2 Anticipated crop production under improved irrigation

The anticipated yield under the improved irrigation situation was referred to information of MIAD (Mwea Irrigation Agricultural Development Centre) in SAPROF. We also referred the data. To explain the effect of the improved irrigation system on crop production, the model parameter of threshold water contents of soil for starting irrigation was calibrated as 60%.

The anticipated rice crop under the improved irrigation system was shown in Table 5-14.

Table 5-14 Anticipated rice yield under improved irrigation system

Crop	Present yield [t/ha]	Anticipated yield under improved irrigation system [tom/ha]
SR Paddy (Basmati)	3.9	5.5
Ratoon (Basmati)	1.4	2.5
LR Paddy (Basmati)	2.7	5.5
LR Nerica	3.0	4.2

5.4.2.3 Estimation of Nerica and Ratoon crop yield

The plant variety parameters for Basmati was referred to the study [1] by W.O.Nyang'au of Jomo Kenyatta University. This parameter for plant genotype is very sensitive to the crop yield. The genotype parameter for Nerica and ratoon was not provided. It was difficult to develop the crop evaluation model for the crops.

The present and anticipated crop yield was provided in SAPROF. The ratio of them to the crop of Basmati which was evaluated through DSSAT was applied for evaluation of their crop yield in this study. The applied ratio of crop production was shown in Table 5-15.

Table 5-15 Unit crop yield ratio of Nerica and Ratoon to Basmati

Irrigation project	Crops	Rate for evaluation of production
Without project	SR Basmati Ratoon	SR Basmati Ratoon (1.7) / SR Basmati (3.9) = 0.44
	LR Basmati Ratoon	LR Basmati Ratoon (0.5) / LR Basmati (2.7) = 0.19
	LR Nerica	LR Nerica (3.0) / SR Basmati (3.9) = 0.77
With project	SR Basmati Ratoon	SR Basmati Ratoon (2.5) / SR Basmati (5.5) = 0.45
	LR Nerica	LR Nerica (4.2) / SR Basmati Main (5.5) = 0.76

5.4.2.4 Evaluation of rice crop yield under scenario combinations

The calibrated model was applied with twenty-four (24) multiple scenario combinations which consists of six (6) climate scenarios and four (4) project cases. The simulation period was 30 years.

The evaluated unit crop yield of Basmati with and without project under six (6) climate scenarios were shown in Figure 5-16 and Figure 5-17.

The climate change effects to reduce the crop production from present condition. This was conceived that the highest daily air temperature rising in every future climate scenario impedes the growth of crops.

The crop productivities were evaluated to be increased by the irrigation project. The sufficient water supply can reduce the negative impact of temperature rising in future climate.

The mean unit rice crop for thirty (30) years were summarized in Figure 5-18.

[1] W.O.Nyang'au et al, Estimating Rice Yield under Changing Weather Conditions in Kenya Using CERES Rice Model, International Journal of Agronomy volume 2014, Article ID 849496.

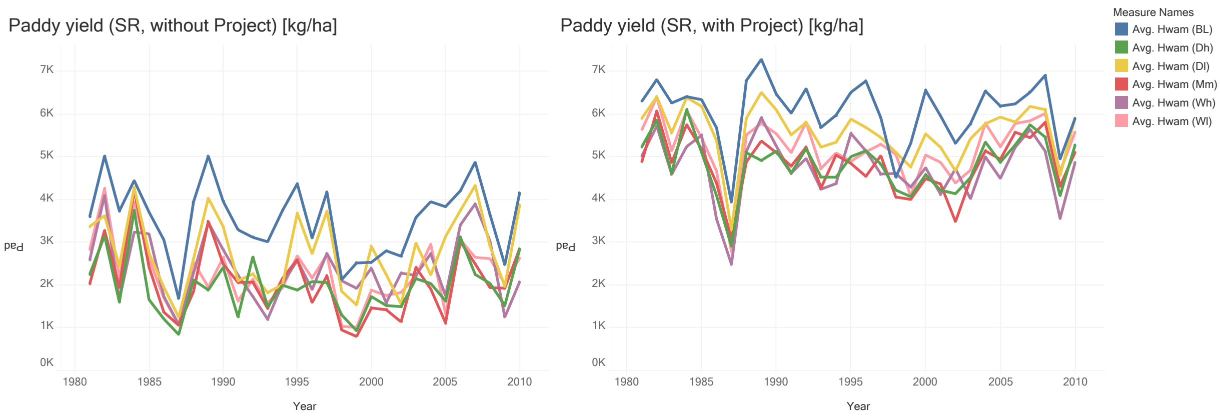


Figure 5-16 Unmilled rice production of short rain crop with and without project under 6 climate scenarios

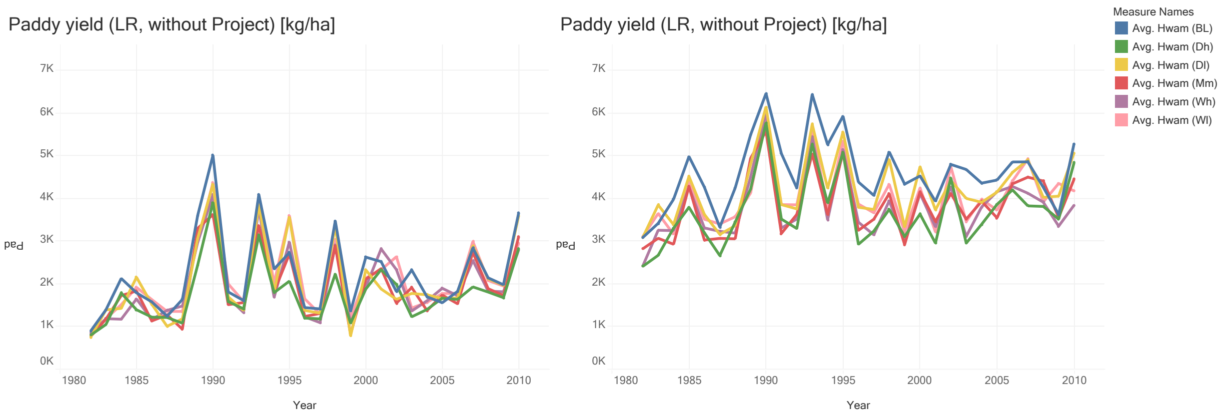


Figure 5-17 Unmilled rice production of long rain crop with and without project under 6 climate scenario

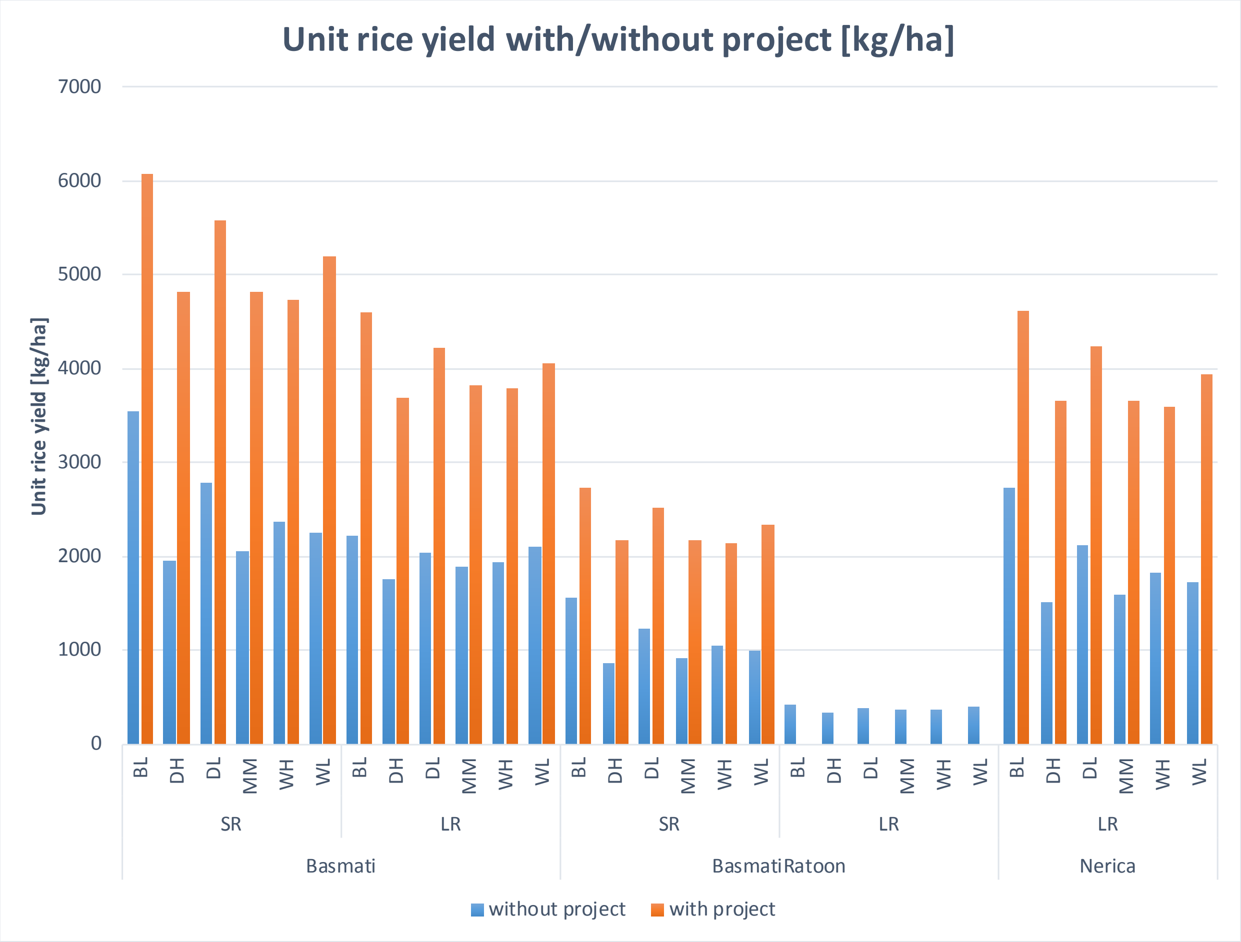


Figure 5-18 Mean unit rice yield with and without project

5.4.3. Evaluation of upland crop production

Upland crop was key of the proposed plan to assure the benefit of the project. In long rain period the unit crop yield of rice was very smaller than that of short rain crop. The unit market price of upland crop is higher than the rice price. And the demand water per crop production is lower than that of rice. Those were the reason to propose the upland crop in long rain season in SAPROF.

DSSAT has a capable to simulate some types of upland crops but not for all crop types mentioned in SAPROF. The crop and the methodology of evaluation was summarized in Table 5-16.

Table 5-16 Evaluation approach for upland crop production

Crop	Evaluation methodology
Maize	Evaluated by DSSAT Maize model.
Green Gram	Not available on DSSAT. The production yield was estimated by the average of change ratio of the other crops under the condition of climate scenario and irrigation plans, which could be evaluated by DSSAT, i.e., maize, french beans, soybeans and tomato.
French bean	Evaluated by DSSAT french bean model
Soy bean	Ditto
Tomato	Ditto
Onion	Not available on DSSAT. Same approach as green gram was applied.

The evaluated upland crop production under multiple combination of climate scenario and irrigation project cases were tabulated in Table 5-17.

Table 5-17 Upland crop production under combination of climate scenario and irrigation projects

unit: ton/year

project	clim	Maize	Soy bean	French Bean	Tomato	Green Gram	Onion
Case 0	BL	795	187	152	268	80	152
	DH	900	184	148	269	82	156
	DL	830	183	149	273	80	153
	MM	858	169	135	256	76	145
	WH	757	208	131	206	74	140
	WL	871	193	145	250	80	152
Case 1	BL	2,700	4,500	11,700	9,000	1,800	2,700
	DH	2,848	4,371	11,396	9,210	1,809	2,713
	DL	2,779	4,403	11,567	9,221	1,808	2,712
	MM	2,787	4,178	10,651	8,840	1,732	2,598
	WH	2,331	4,464	10,513	7,213	1,606	2,410
	WL	2,755	4,442	11,344	8,681	1,774	2,661
Case 2	BL	1,090	1,248	3,077	2,443	502	769
	DH	1,177	1,209	2,985	2,487	503	771
	DL	1,127	1,220	3,039	2,500	504	771
	MM	1,144	1,157	2,801	2,396	483	739
	WH	976	1,248	2,759	1,951	448	688
	WL	1,143	1,237	2,985	2,354	495	759
Case 3	BL	2,363	3,938	10,239	7,877	1,575	2,363
	DH	2,494	3,829	9,982	8,068	1,584	2,376
	DL	2,434	3,856	10,130	8,077	1,583	2,375
	MM	2,440	3,657	9,322	7,738	1,516	2,274
	WH	2,031	3,888	9,156	6,283	1,399	2,099
	WL	2,410	3,886	9,922	7,594	1,552	2,328

6. Results

6.1. Economic evaluation

The economic evaluation had the objective of evaluating the economic efficiency that can be reached with the proposed project. In order to examine the alternatives of the development plans, the following metrics were calculated for each scenario: Economic Internal Rate of Return (EIRR), Net Present Value (NPV), and Benefit Cost Ratio (BCR). The "with-" and "without-project" situations are used for evaluating the incremental benefits generated by the project. Detailed calculation methods and the corresponding results are presented in the main report. The result is summarized in this chapter.

6.1.1. Basic assumptions

The following assumptions were considered in the evaluation:

- The time extent of the project is set to 50 years according to the period of return set in the design.
- The Project cost is calculated in local currency, i.e., Kenyan shilling (KSh),with an exchange rate equal to that of March 2009.
- Agriculture production at the current dam site was deducted from the benefits of the with-project situation.

6.1.2. Results

Figure 6-1 shows the calculated BCR with a NPV at a discount rate of 10%. In case1 and case3, more than half of the scenarios show positive NPVs and BCRs greater than one. Some scenarios show a negative NPV because an increase in the price of rice was caused by the effects of climate change. Considering the discount rate of 10%, and because the initial investment of case3 is lower than that of case1, the NPV of case3 is larger than that of case1. Case2 is not feasible in terms of the national economy because its cropping pattern, which includes ratoon rice and vegetables, is not profitable.

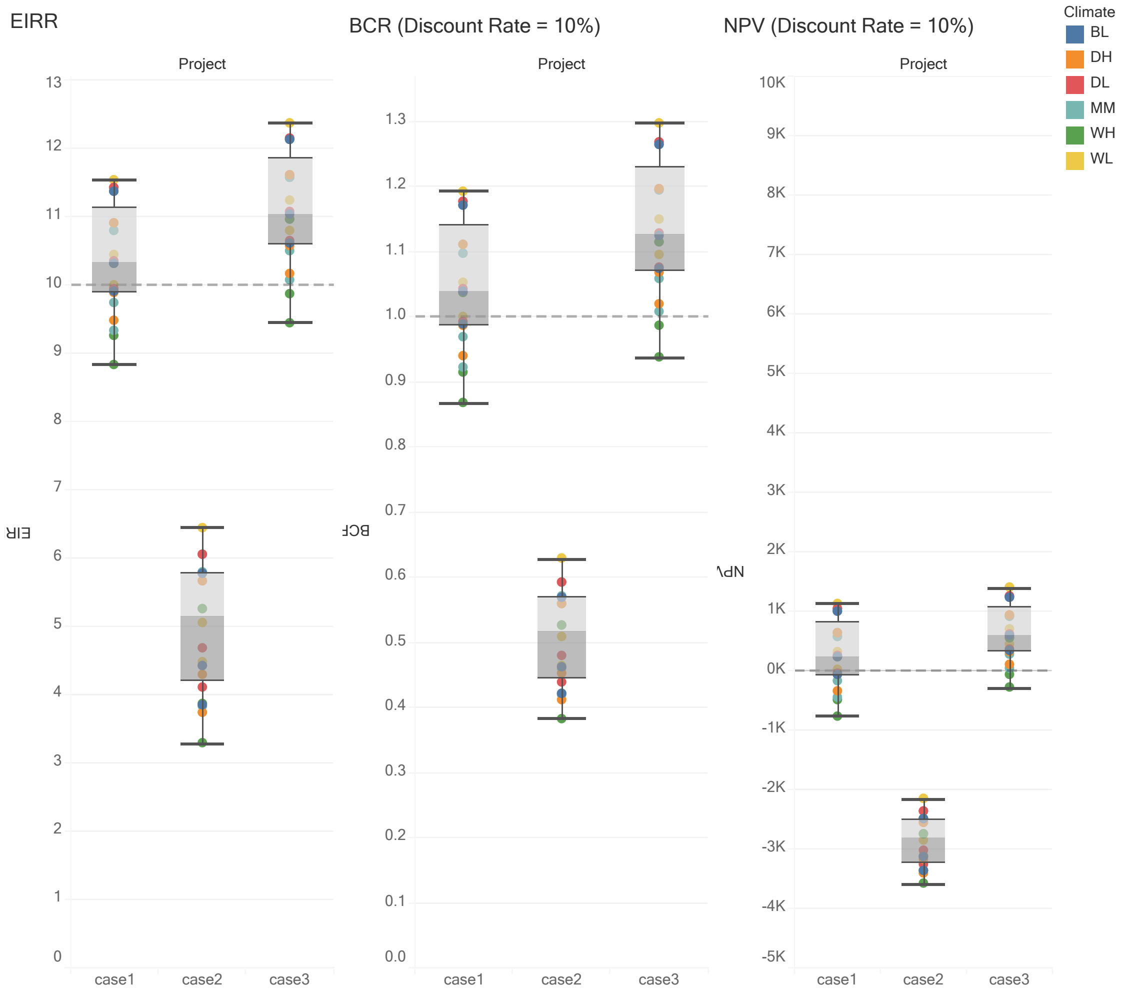


Figure 6-1 Economic evaluation of the proposed projects (EIRR, BCR, and NPV)

6.1.3. Sensitivity analysis of the NPV

NPV calculation is quiet sensitive to changes in the discount rate. Small changes in the discount rates yield large changes in the NPV. Therefore, a sensitivity analysis was considered necessary for evaluating the discount rate. Considering the alternative rates of 2, 5, 10, and 12 percent, Figure 6-2 shows the results of this analysis as box plots. It can be observed that for the case3, which has an initial investment smaller than that of case1, has a larger NPV than case1 at a discount rate of 10%. On the other hand, case1 yields a larger NPV than case3 when the discount rate is 5%. This outcome reveals that larger discount rates make the initial investment less valuable.

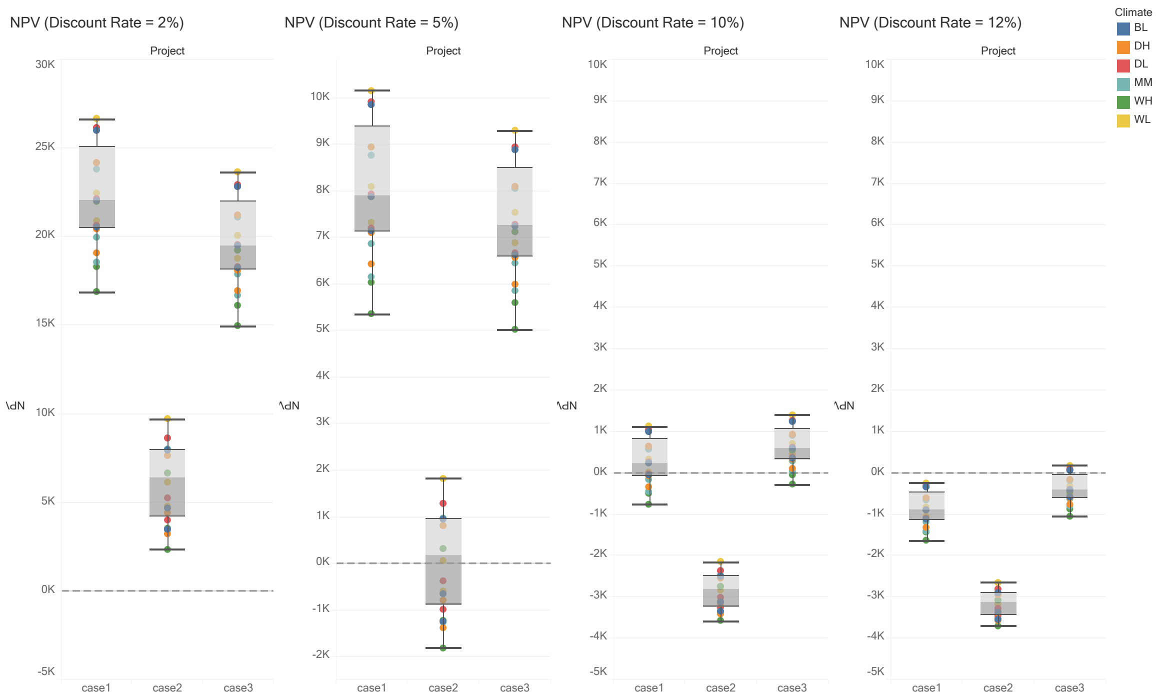


Figure 6-2 Sensitivity analysis of NPV

6. 2. Evaluation of several different types of metrics

We evaluated the proposed project using several different metrics. The results for rice yield, income of farmers, self-sufficiency ratio of rice, and water supply are shown below.

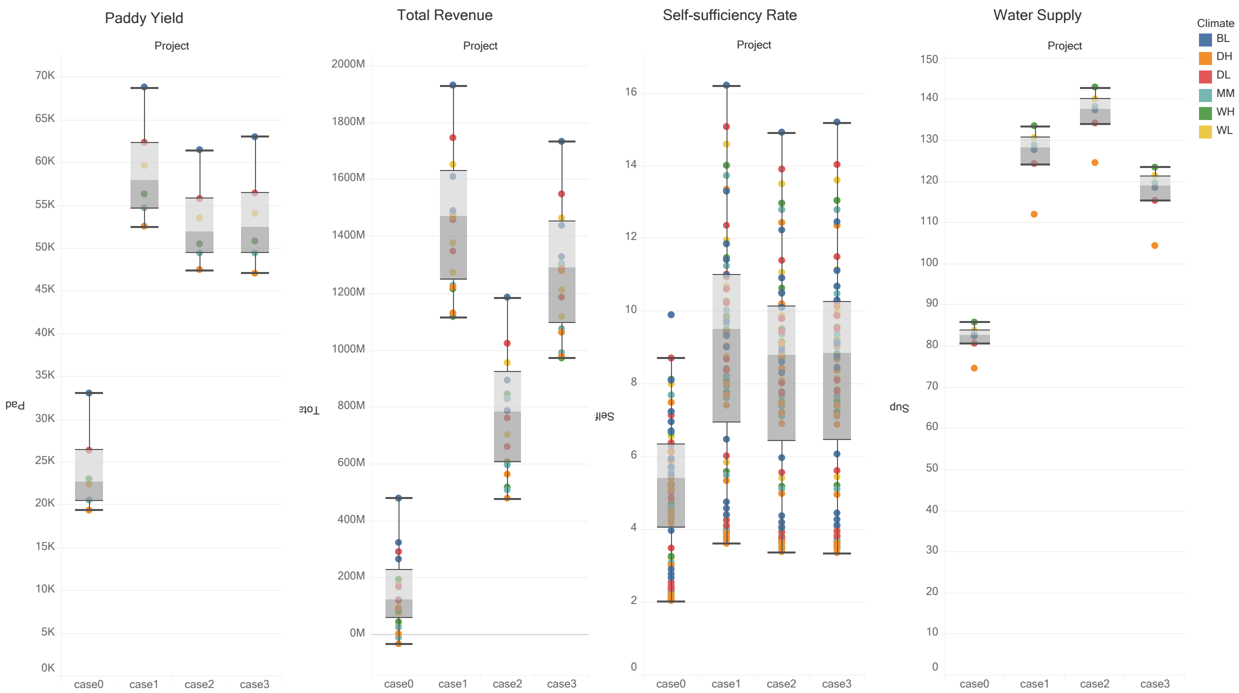


Figure 6-1 Evaluation of several metrics (unit rice yield, total revenue, self-sufficiency rate of rice, and water supply)

6.2.1. Climate change impact

We evaluated climate change impacts by comparing a present climate scenario and different future climate scenarios. Through multi-scenario ensemble analysis, we quantitatively evaluated the expected change and its uncertainty.

The evaluated climate change impact on paddy yields is shown in Figure 6-2. The result shows that paddy yield will decrease in all climate scenarios and proposed projects. The change ratio of paddy yields for the with-project conditions (case1, case2, and case3) are smaller than that of the without-project condition (case0). There is no apparent difference in the paddy yields for the with- and without-project conditions because the percentage of decrease is reduced by the project. Conversely, even an increase of yield can be observed that is being caused by the project. Therefore, it can be inferred that the project can reduce the adverse impact on paddy yields caused by climate change.

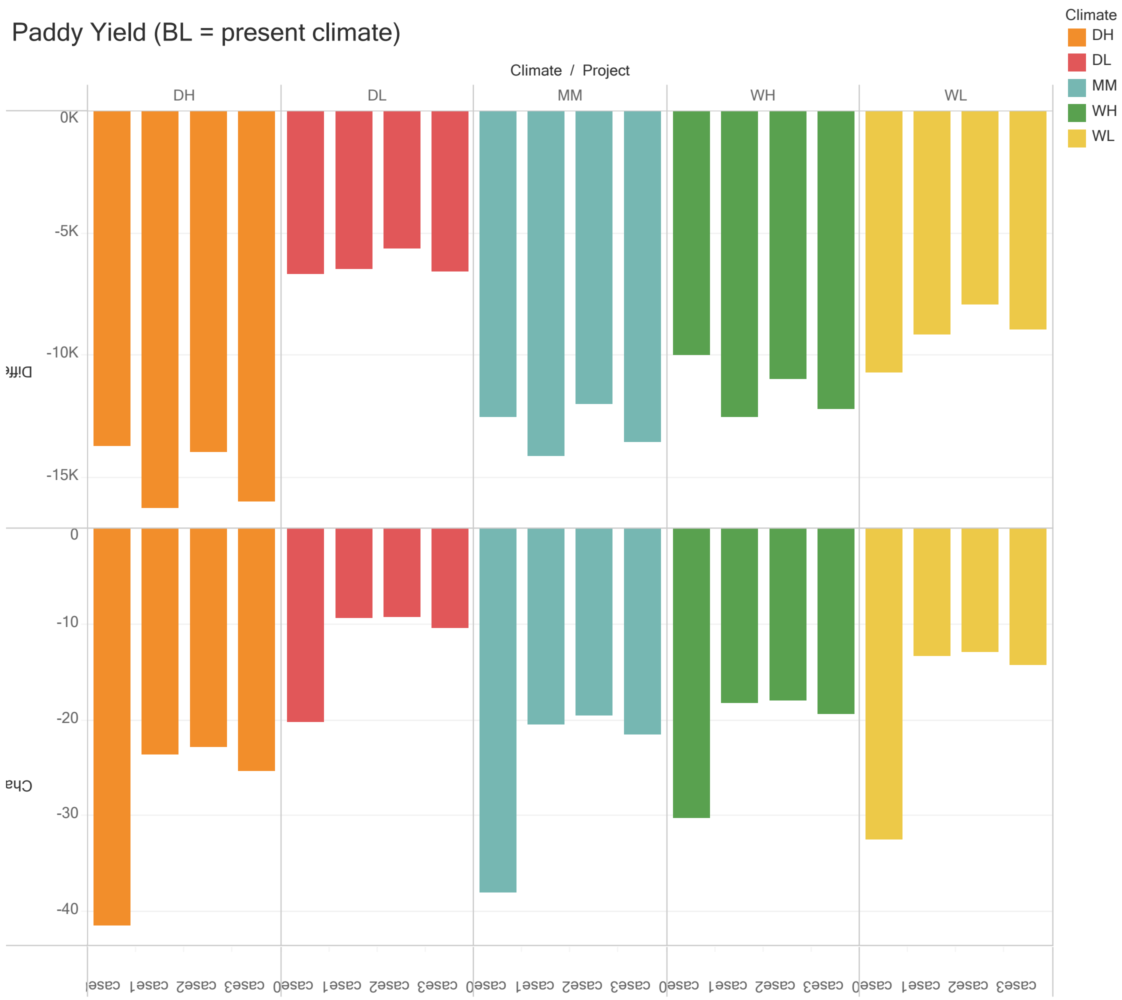


Figure 6-2 Difference and Change Ratio of Paddy Yield (comparison between present and future climate scenarios)

The impacts of climate change evaluated with the aforementioned metrics (paddy yield, total revenue, self-sufficiency rate of rice, and water supply) are detailed in Figure 6-3. The following inferences can be made from the results:

- The impacts caused by climate change on paddy yield, total revenue, and self-sufficiency rate of rice are adverse (negative vales).
- The results of the without-project condition show that the total annual revenue, which is approximately 480 million KSh, will reach negative values in the worst case scenario. For this reason, there is a serious concern about continuing farming in MIS.
- The uncertainty of future self-sufficiency rate of rice is considerably large because the future population, and the consequent future rice consumption, is uncertain.
- Generally, the project seems to be able to reduce the negative impact of climate change. Thus, it can be said that the project can reduce the vulnerability to climate change.
- The climate change impact on water supply shows both positive and negative results, reflecting changes which depend on river discharge.

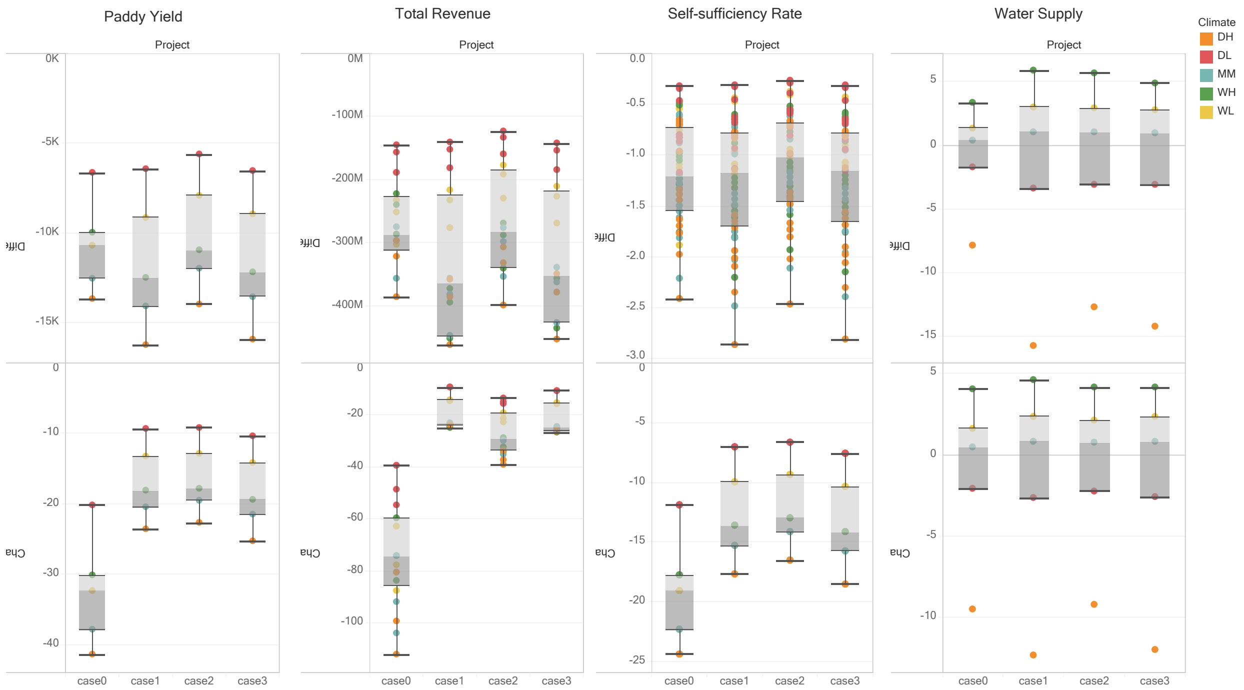


Figure 6-3 Difference and change ratio of several metrics (comparison between future and present climate scenarios)

6.2.2. Quantification of project benefits

A "with-" and "without-project" situation is used for evaluating incremental benefits generated by the project. The results are shown in Figure 6-4. All the proposed projects show an apparent benefit considering the positive values obtained for all metrics. The most beneficial project case seems to be the case1 in terms of paddy yield, total revenue, and self-sufficiency rate of rice. The total revenue of case2 is about half of that of case1 because the cropping pattern of case2 with SR and LR paddy does not include profitable crops: ratoon rice and vegetables. The change in water supply is equivalent to the change in demand of water supply. Case2 with SR and LR paddy needs much water than case1 and case2 with SR paddy, ratoon rice, and LR upland crops. Case3 needs less water than case1 because its irrigation area is smaller.

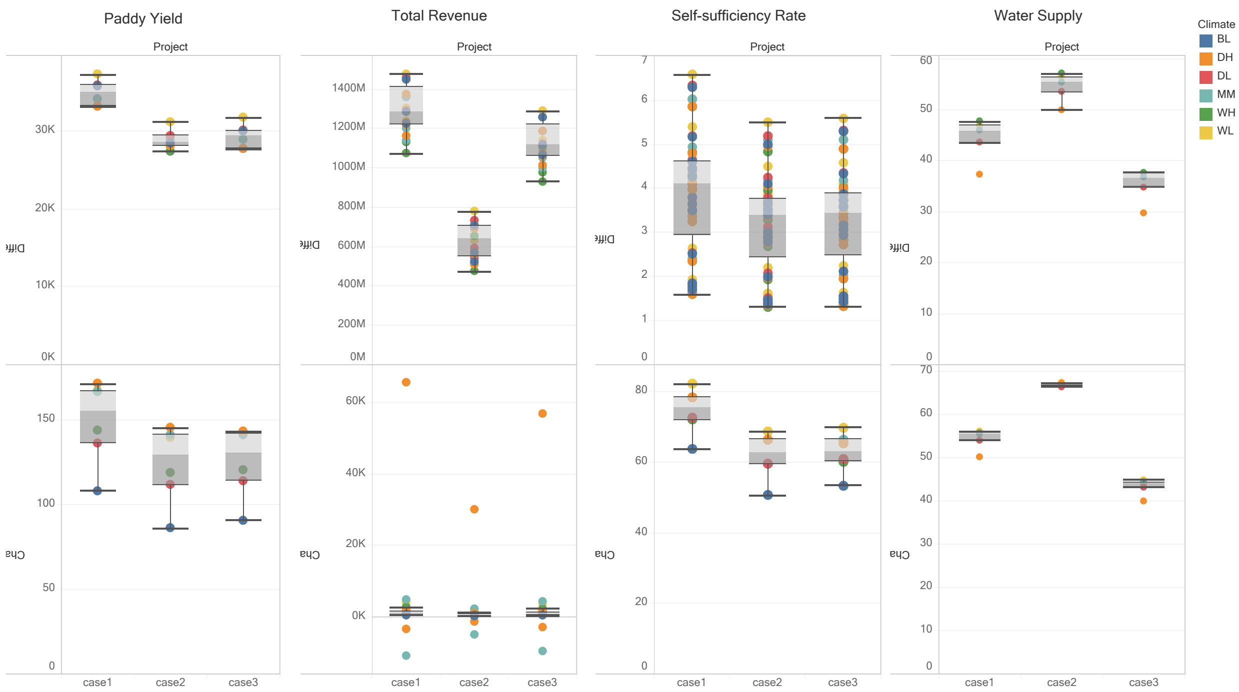


Figure 6-4 Difference and change ratio of several metrics (comparison between "with-" and "without-project" scenarios)

6.2.3. Quantification of change from baseline

In order to quantitatively evaluate the impact of the project, we compared each future scenario with a condition corresponding to the "without-project" present climate. With this kind of analysis, the impact of climate change and the impact of the project can be observed simultaneously.

The results, shown in Figure 6-5, confirm that even considering the adverse impacts of climate change, the project will generate significant increase in paddy yield, total revenue and water supply.

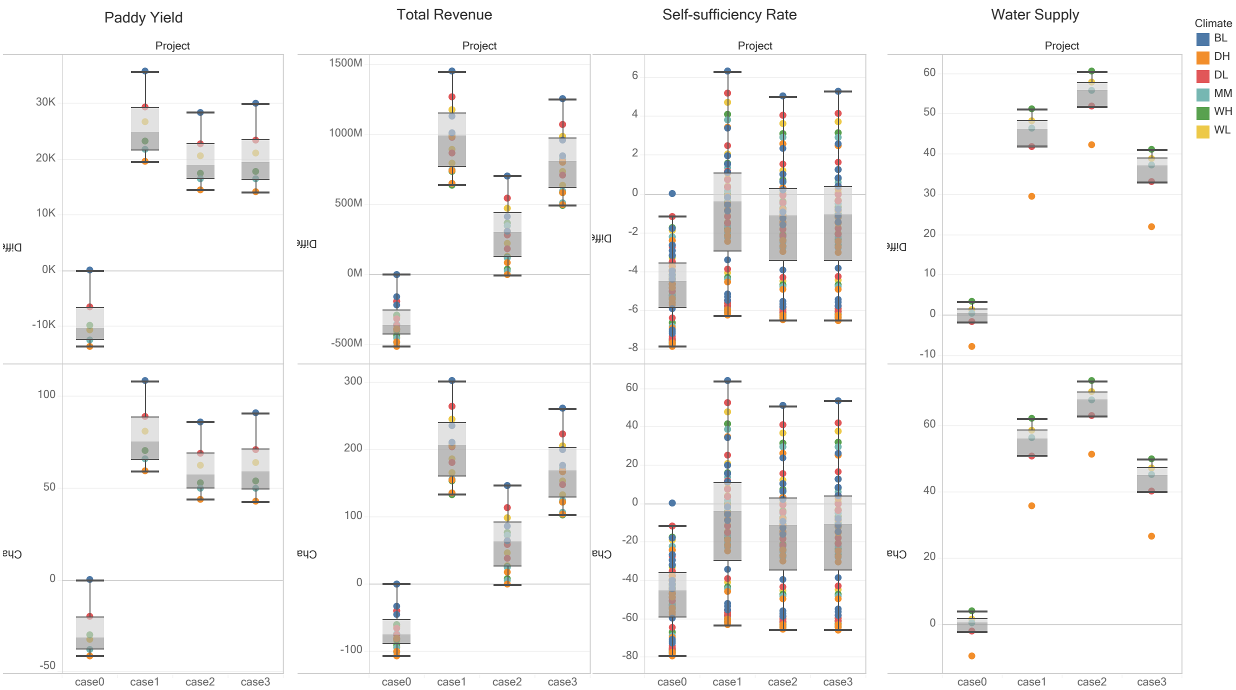


Figure 6-5 Difference and change ratio of several metrics (comparison between present and future conditions)

6.2.4. Demand (rice consumption) vs. supply (rice production)

The proposed project is expected to approximately double the current paddy production, of which the MIS has a share of more than 60%. Consequently, the increase of domestic paddy production that can be reached with the project is notable. For the past several years, the self-sufficiency rate in Kenya has been around 10-20%, which is quite low. Thus, the project is expected to offer a positive contribution towards increasing the paddy self-sufficiency rate.

The self-sufficiency rate is the ratio of supply (rice production) and demand (rice consumption). Figure 6-6 shows the distribution of all scenarios. Each mark represents a future scenario. Circles indicate scenarios in which the self-sufficiency rate is above the present rate, while crosses indicate future scenarios in which the self-sufficiency rate is below the present rate. The lines separating different colors in the background represent the actual values of self-sufficiency rate. Even though the project is expected to double the current paddy production, the increase of demand is significant, which precludes more than half of the scenarios to increase the self-sufficiency rate. Case1 is able to improve the self-sufficiency rate in more future scenarios than the other proposed projects. Thus, case1 is the best project case in terms of self-sufficiency rate.

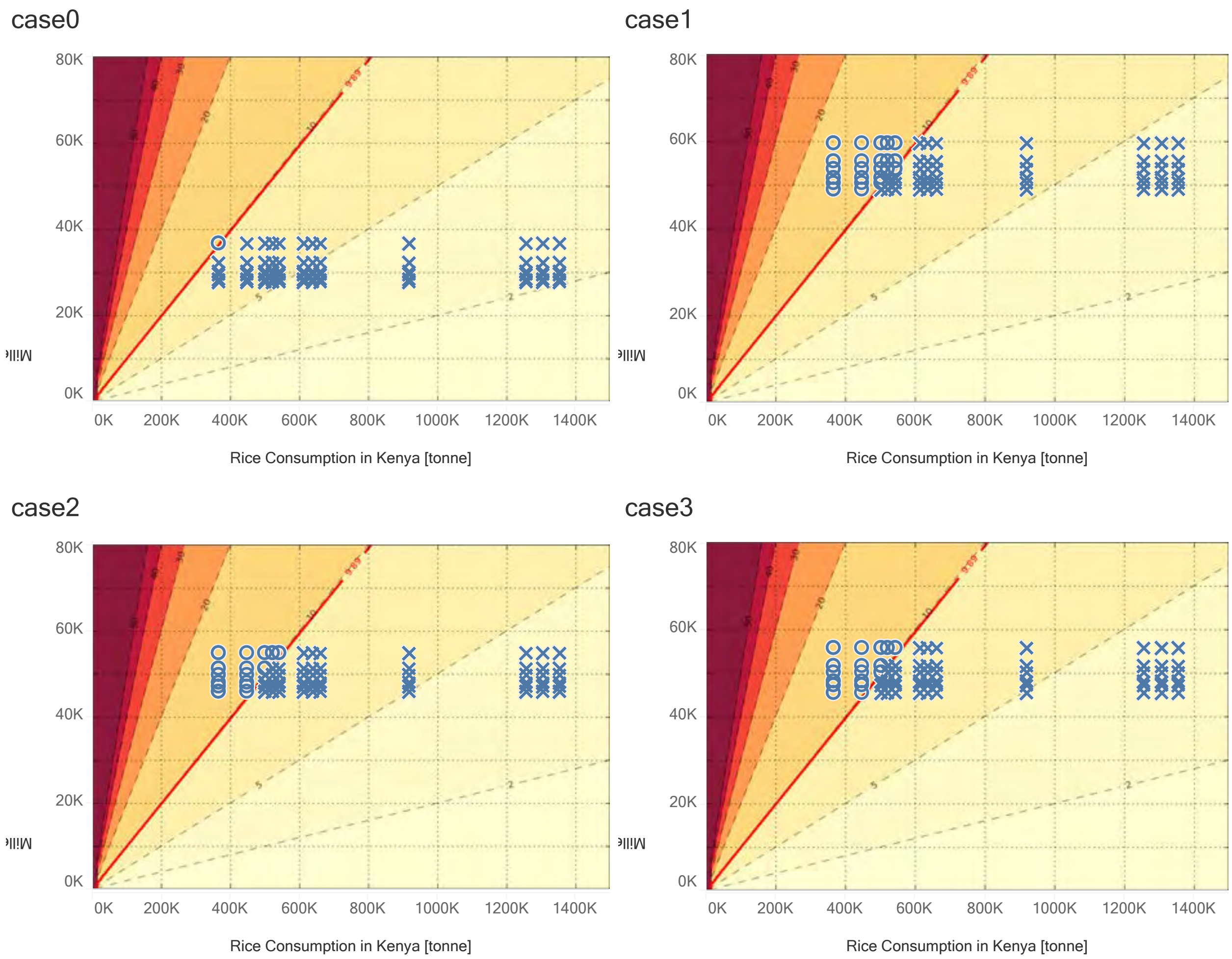


Figure 6-6 Demand (rice consumption in Kenya) vs. supply (rice production in Kenya)

6.2.5. Self-sufficiency rate vs. economic revenue

Figure 6-9 shows the distribution of all scenarios in a scatter plot, where the horizontal axis represents the "total economic revenue" and the vertical axis represents the "self-sufficiency rate". Each mark represents a future scenario. We set the project performance thresholds of self-sufficiency rate at 9.89 (current value) and the total economic revenue at 959 million KSh (twice the current value). The region of desirable performance above the specified thresholds has white background; the region below the thresholds (failure) has gray background. Similar to the previous figure, circles indicate future scenarios with a desirable outcome, while crosses indicate future scenarios with undesirable results.

The number of undesirable outcomes is the smallest for the case1, which is the project with the most robust plan in terms of improving self-sufficiency rate and economic revenue.

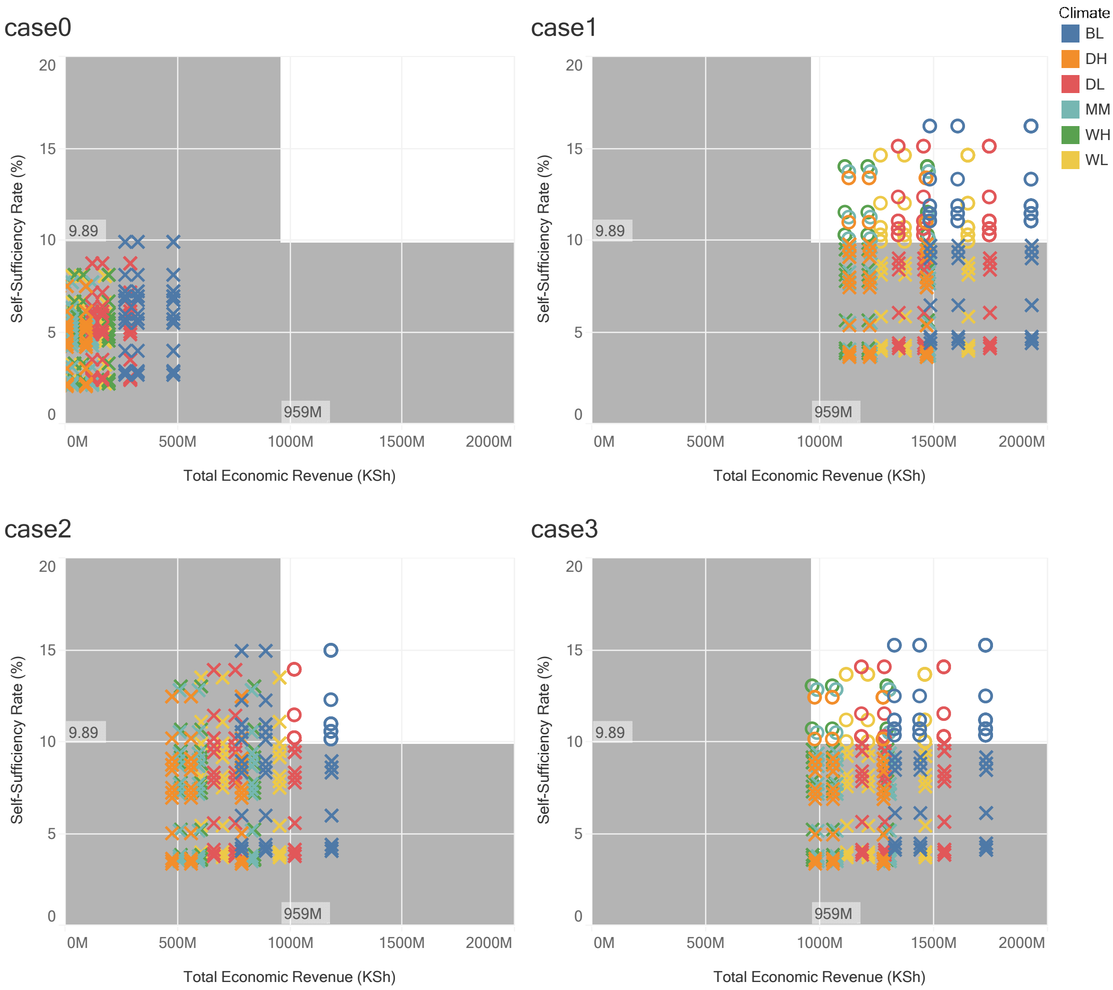


Figure 6-7 Self-sufficiency rate vs. economic revenue

6.2.6. Saving foreign currency

Figure 6-8 shows amount of imported milled rice and its difference between with- and without-project conditions. According to the obtained results, and without considering climate change and social changes, 35,745 tonnes of imported milled rice can be substituted by the production that can be generated by the project. Therefore, around US$ 8.18 million can be saved. These results show how Kenya may benefit from the project.

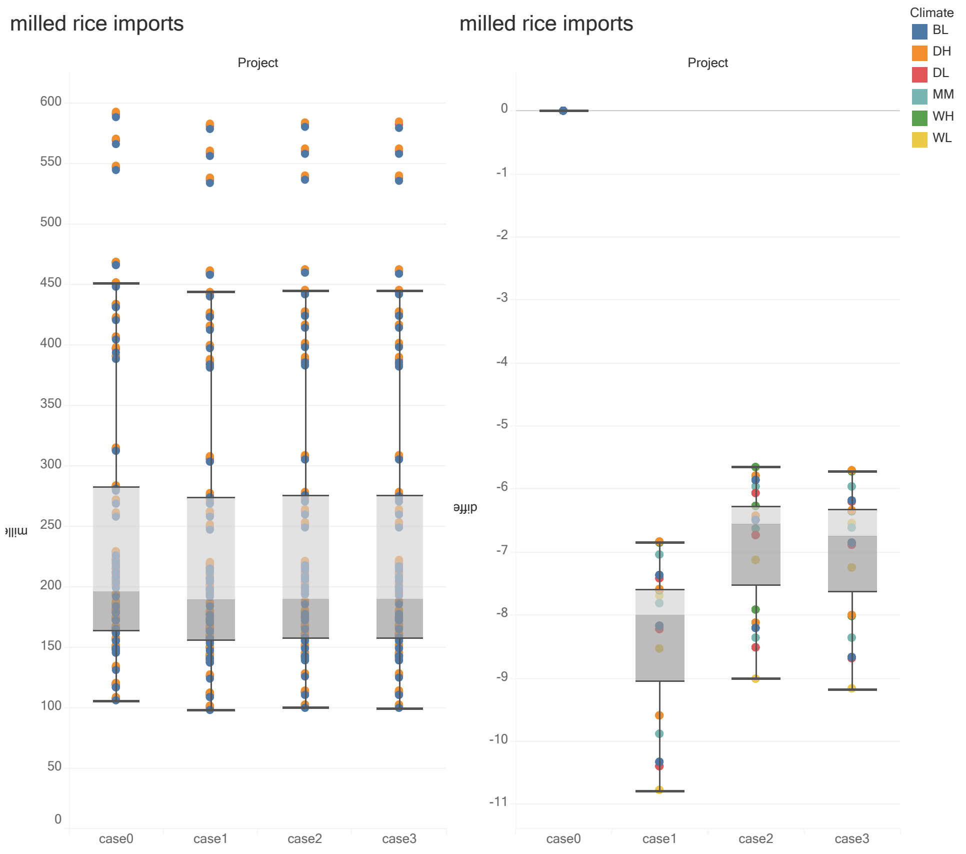


Figure 6-8 Amount of imported milled rice (left) and its difference between with- and without-project conditions (right)

6.2.7. Annual farm income

Besides the economic evaluation from the national viewpoint, annual farm income is also evaluated from the farmer's point of view. Figure 6-9 shows the result of this evaluation. Change of net irrigable area and annual irrigable area are also shown.

The most effective proposed project is case1, in which the farm income increases more than 3 times and the annual irrigation area increases almost twice. Remarkable effects on farmer's income will be achieved by the project. On the other hand, without the project the farm income decreases to negative values in the worst climate scenario (DH climate scenario). The negative impact of climate change on farm income is significant. Thus, the improvement of irrigation systems to ensure stable irrigation water is crucial for the farmers in the MIS.

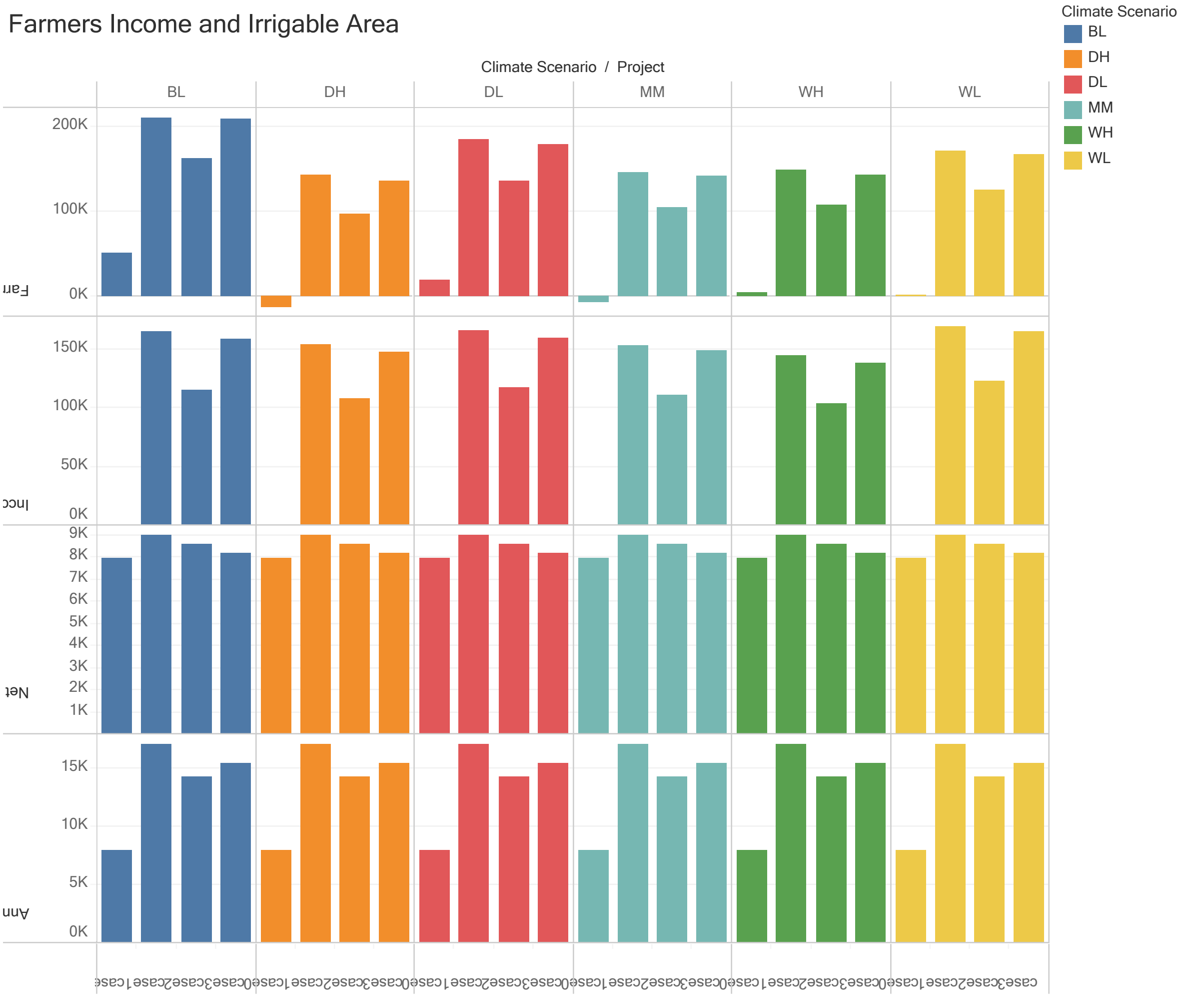


Figure 6-9 Annual farm income, net irrigable area, and annual irrigable area.

7. Conclusion and future agenda

We evaluated the project resilience against the climate change impact with deep uncertainty. The number of cases examined in this study were so many that the process of this work was very complicated. The study of RDM can be explained as a sensitive analysis of the project effectiveness under the multi options. The sensitive analysis is not new technology, though we can find new scopes and new ideas from the RDM study about how to develop the adaptation plan to the deep uncertainty conditions. In this chapter, the findings obtained from this study was summarized and the future works which should be explored next.

7. 1. Conclusion

The unit yield of rice will be reduced in future climate condition, because of the highest air temperature rise. According to the sensitive analysis of the rice crop simulation model DSSAT, the sufficient irrigation water supply to the rice field can be ease the reduction of the unit crop yield in the worming future.

The newly development of irrigation water by construction of Thiba dam can strengthen the possible amount of water supply for the MWEA irrigation area and that will enable the expansion of crop area. Dam is expected to enhance the resilience against the climate change impact on the water resources system. This is true. Meanwhile, the irrigation plan anticipates the possible maximum irrigation area with the increased water resource by dam. Consequently, the water sufficiency rate will not be changed with or without project.

Irrigation project of case 1 and 3 scheduled upland crop in long rain season. The expected income of the upland crops was better than the rice crop of long rain season in present condition, because the unit crop yield of rice in long rain season is worse than that of short rain season. The benefit of case 1 and 3 was expected best among the studied project cases, even though there were conceivable risk of unit crop reduction caused by climate change.

The total expected income of case 1 was higher than that of case 3 slightly. The initial project cost of case 3 was lower than case 1 because the new construction of Link Canal III was not planned in case 3. According to the sensitive analysis with value of discount rate, case1 will be beneficially in the case of lower discount rate because the annual income of case 1 is better. In the case of higher discount rate, case 3 will be superior because the initial cost was lower than case 1.

The development of new irrigation system and refreshment work of the existing system is indispensable to ensure the supply of sufficient water for the crops in the dry climate of MWEA. The proposed irrigation project of case 1 which results the best annual income among the alternative cases can be concluded as best robust plan in the view of economic benefit, food security and saving foreign currency. The discount rate will not be expected to be increased in future.

The enhancement of national rice production is important policy and strategy for the country. Meanwhile, for the farmers, there are about 6,000 people in MIS area, the improvement of income of their crop area was most concerned topic. The proposed plan by SAPROF was basically scheduling the combination of rice in short rain season and upland crops in long rain season. The proposed plan will engage stable and income and secure the stable productivity even under the impact of climate change. The stability and sustainability of the individual agricultural business and life will support the security of regional rice production and improvement of capacity of adaptation to the climate change.

7. 2. Advantage of RDM for adaptation planning

In this study, the new planning scheme, Robust Decision Making, was practiced to evaluate the effectiveness and robustness of MWEA irrigation project under deep uncertainty. In order to account the kinds of uncertainties which will influence on the project in future, several alternative options were set up in three factors, namely future climate scenario, social scenario and irrigation project alternatives. Each options are possible and difficult to estimate the probability of realization. Through the RDM analysis, every alternative options were examined. The robustness of the project alternatives can be understood from the large number of cases by combination of factors. What measure will be most robust, what is advantage and disadvantage of the project and how the climate change impact or social change will influence on the project were enabled to be discussed by the large number of the evaluated indexes which measures the effectiveness or benefit of the projects. RDM analysis can bring us helpful and useful materials for decision making. That is most important advantage of the study approach of RDM.

The project alternatives were subjective in the RDM analysis. The other factors of uncertainty scenarios, such as climate and social conditions, were environmental conditions of the projects. The RDM analysis scheme is aimed to evaluate the effectiveness and robustness of the projects. This is measure oriented analysis. Therefore, the discussion is focused on the project evaluation.

Even though technology of the projection of future climate condition progressing day by day, there must be large uncertainty in the future projection. Important point for the decision maker is not how accurate projection but find out what plan will be robust. In this context, the RDM analysis approach is very effective.

It is necessary to understand that the result of the RDM analysis is not final conclusion. The analysis study will continue cyclic. The decision should be made through the exchange of idea and thoughts with stakeholders. It is necessary to discuss what kind or which level of risk will be tolerable among the various standpoints. The proof of effectiveness of RDM analysis on consensus development are needed to be studied.

7. 3. Future works

(1) More options of climate change scenarios

- Only five (5) scenarios of future climate were developed in view of calculation cost. The scenarios were selected those can cover whole range of possible future with small number of scenarios.
- The hydrological projections were along the characteristics of the selected climate scenario. The river flow will be increase with the climate scenario of increasing rainfall. In other hand, the crop yield projection was complicated process and not simple to understand the relationship with climate condition.
- New technics and modification ideas on bias-correction were developed in this study. It is easier to handle more number of climate scenarios. It will contribute to more confidential study.

(2) Study on adaptive pathway

- Adaptive pathway is one of the RDM technic analyzing robustness and flexibility of implementation process with changing uncertainty factors of climate and social conditions.
- The developed project alternatives in this study were consists of several measures, for instance, case 1 was consists of development of Thiba dam and Link Canal III and renovation of existing weir and canal.
- It will be brought us new findings by the study of adaptive pathway of implementation process of each proposed structures in MWEA irrigation project.

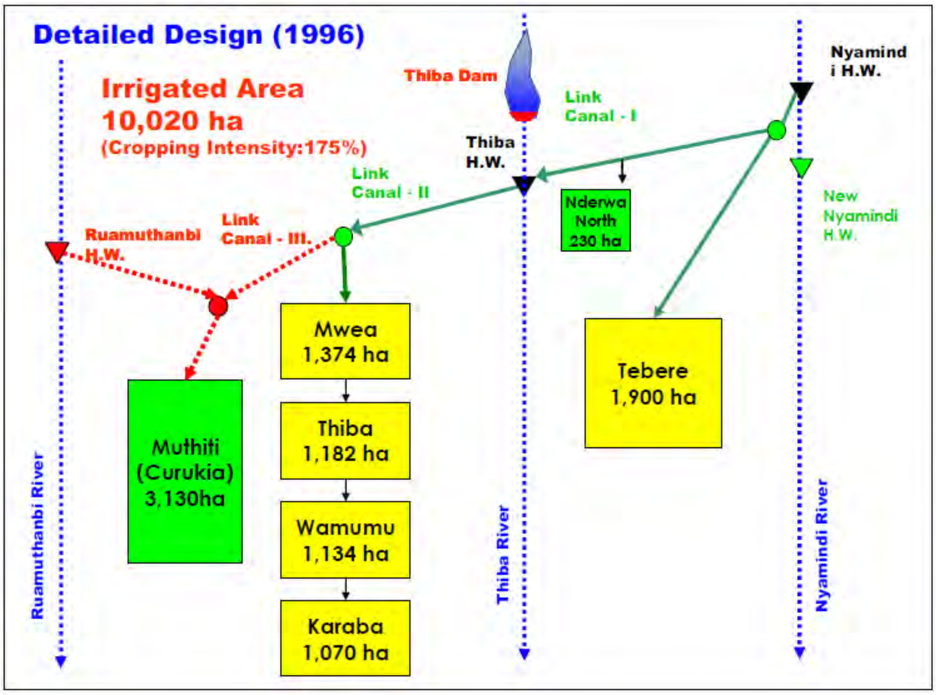


Figure 7-1 Example of MWEA irrigation scheme option（from report of SAPROF）

(3) Additional uncertainty options frame

- One of the important idea for additional uncertainty option is implementation schedule. It is known fact that there are many projects delay from the planned implementation schedule. The delay of implementation causes additional costs and reduce the benefits of the projects.
- Non-structural measure will be important options to increase robustness of the projects. It is difficult to study the effectiveness of the non-structural measure in the traditional planning scheme.

(4) Update of MWEA information

World Bank implemented the rehabilitation project on MWEA irrigation scheme in 2013. The rehabilitation of the primary headraces was conducted. The conditions of irrigation management were changed from the information researched in SAPROF study. The update of the current information of MWEA scheme will be achieve more convincing discussion.