6.5 Water Balance

6.5.1 Water Balance Simulation Model

MIKE-SHE is applied for the water balance analysis of natural groundwater recharge and surface runoff. The results are utilized for water allocation simulation (MIKE-Basin). MIKE-SHE is the distributed physics model for surface water with the tank models applied for intermediate runoff and groundwater analysis. MIKE-Basin is the software to establish the water allocation/utilization model by inputting water resources data, river structure, water demand, etc.

Input data to calibrate the water balance simulation model by MIKE-SHE is shown in **Table 6.5.1**.

Table 6.5.1 Input Data of the Simulation Model

Item		Explanation
Observed Data	Rainfall (Daily)	The rainfall is applied in calibration period. It is given by WRA and calculated by Thiessen method. The different Thiessen polygon by day is used depending on available station.
	Evaporation (Daily)	The evaporation is applied in calibration period. It is given by WRA and calculated by Thiessen method. The different Thiessen polygon by day is used depending on available station.
Geographical Information	Land Use Map	The land use map made in 1990 is applied. Land use is classified into 6 classes: Forest land, Grassland, Cropland, Wetland, settlements, and Other land.
	Soil, Geological Map	The soil, geological map made in 1987 is applied. It is classified into 3 categories, basement rock, alluvial sediment, and weathered basement
	DEM	SRTM made in 2000 is applied. SRTM is stored DEM in mesh size of 90m.
	Basin Boundary	Basin Boundary is delineated from SRTM based on WRU.
	Groundwater Basin Boundary	Groundwater basin boundary is delineated based on basin boundary.
	River Network	Major rivers are considered to carry the water from upstream to downstream.
	Cross Section	Cross section is made based on DEM. It is assumed to be simple shape.
Others	Position of Observatories	Hydrological Station
	Mesh size	1 km mesh size
	Map Coordination	Arc 1960 UTM Zone 36S

Source: Project Team

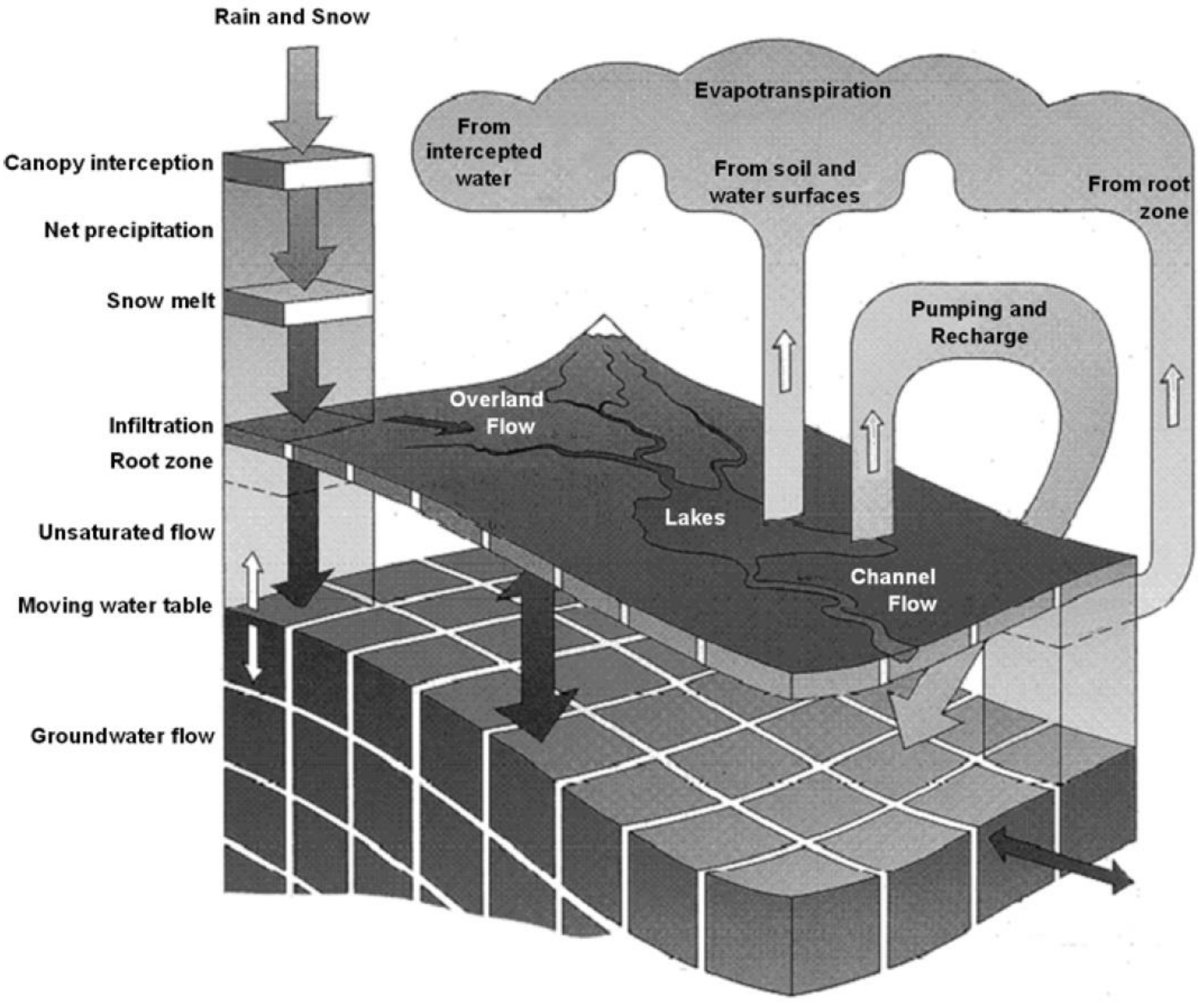
(1) Outline of the Simulation Model

The water balance simulation model is constructed to evaluate water balance in Malawi. There are watersheds flowing into and out from Lake Malawi. These are modeled. The model of Lake Malawi is constructed separately because it is needed to consider inflow from countries other than Malawi.

The rainfall runoff model (MIKE-SHE) is applied to calculate water balance in Malawi using rainfall, evaporation, discharge, land use and geological condition. MIKE-SHE is a distributed physics model developed by DHI. Runoff and Recharge are calculated from rainfall and evaporation. For groundwater, tank model is applied. The framework of the model is shown in **Figure 6.5.1**.

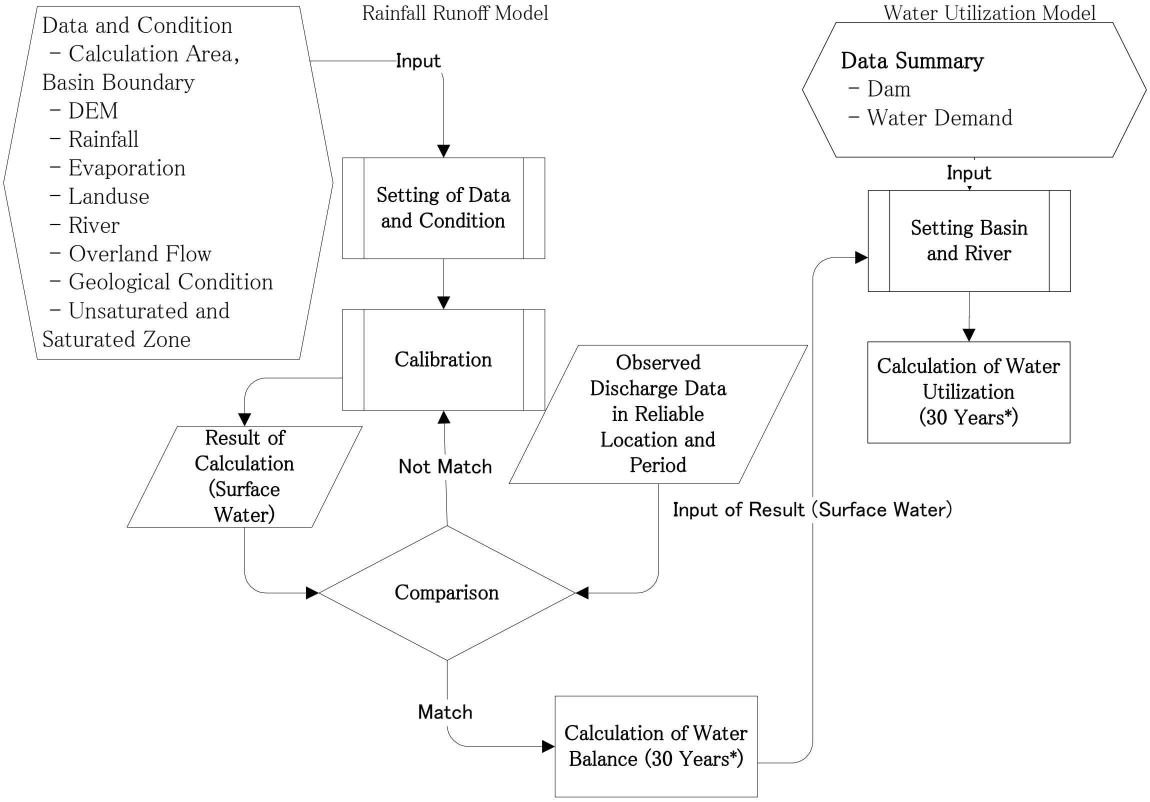
Furthermore, the water utilization model (MIKE BASIN) is constructed for calculating allocation of water. The water balance is represented by inputting the result of rainfall runoff model and water demand.

The flowchart of construction of the model is shown in **Figure 6.5.2**. The outline of the input data for the model is shown in **Table 6.5.2** and **Table 6.5.3**.



Source: DHI

Figure 6.5.1 Outline of MIKE-SHE



Source: Project Team

Figure 6.5.2 Flow Diagram of Model Construction and Simulation

Table 6.5.2 Input Data of the Hydrological Model

Item	Contents	Type	Described in
Calculated Area	Whole Land Excluded Lakes and River Basin of International Border	GIS Data	(2)
Basin Boundary	Made from DEM		(2)
DEM	SRTM (2000)		(3)
Precipitation	Daily Basin Average	Observed Data	(4)
Evaporation	Daily Basin Average		(5)
Land Use Map	1990 Map	GIS Data	(5)
River, Surface runoff	River Network, Cross Section Based on DEM		(6)
Geological Condition, Unsaturated and Saturated Zone	1987 Map, Interflow and Baseflow		(8)

Source: Project Team

Table 6.5.3 Input Data of the Water Utilization Model

Item	Contents	Type	Described in
Reservoir	Location, Capacity, Flow Rule	Observed Data	6.5.4
Water Demand	Demand of Irrigation, Livestock, Water Supply, Environmental Flow		
Basin Boundary	Same as Hydrological Model	GIS Data	
River Network	Same as Hydrological Model		
Runoff	Result of Hydrological Model	Calculated Data	

Source: Project Team

(2) Calculation Area and Basin Boundary

The calculation area is the whole of Malawi except lakes such as Lake Malawi. The model of Lake Malawi is constructed separately. The inflow and outflow of Lake Malombe is assumed as the outflow from Lake Malawi. The water resources from other countries is not targeted because the flow to international rivers from other countries is unclear. The excluded basin is 4% of the whole area.

The basin boundary is made by DEM considering the boundary of WRU. The mesh size is 1km considering calculation time and case in Japan.

The calculation area and basin boundary is shown in **Figure 6.5.4**.

(3) DEM

DEM of SRTM which is developed global elevation data is applied. The mesh size of SRTM is 90 m, therefore, the value of the calculation mesh is average value in the mesh. Topography is shown in **Figure 6.5.4**.

(4) Rainfall

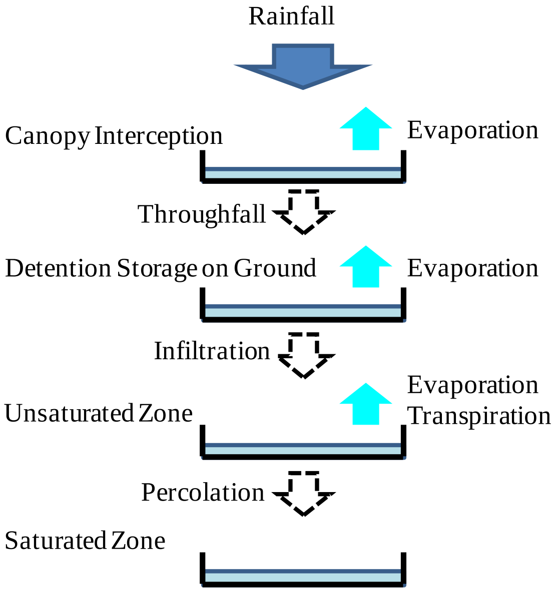
The Rainfall data is input to the model as basin average by WRU. The basin average rainfall is calculated by Thiessen method.

(5) Evapotranspiration and Land Use

The evapotranspiration data is input to the model as basin average by WRU. The basin average evapotranspiration is calculated by Thiessen method.

The pan evaporation is observed evaporation from water surface in the pan. Pan coefficient is multiplied for calculating the evapotranspiration in the land area where there is no water surface. Pan coefficient is 0.65 from the reference. The evapotranspiration from marsh such as Elephant marsh is assumed as observed value (pan evaporation).

The process of evaporation shown in **Figure 6.5.3** is considered to represent actual evapotranspiration from the land where there is limitation of water. The water is lost from first process in order until the maximum evapotranspiration. The water is not lost when there is deficit of water. The amount of evapotranspiration from each process is actual evapotranspiration.



Source: Project Team

Figure 6.5.3 Process of Evapotranspiration

The first process is the canopy interception. The water of rainfall is lost from canopy as initial loss. The canopy interception storage capacity (Imax) is applied to represent the amount of water captured by this phenomenon. Imax is calculated by the following formula.

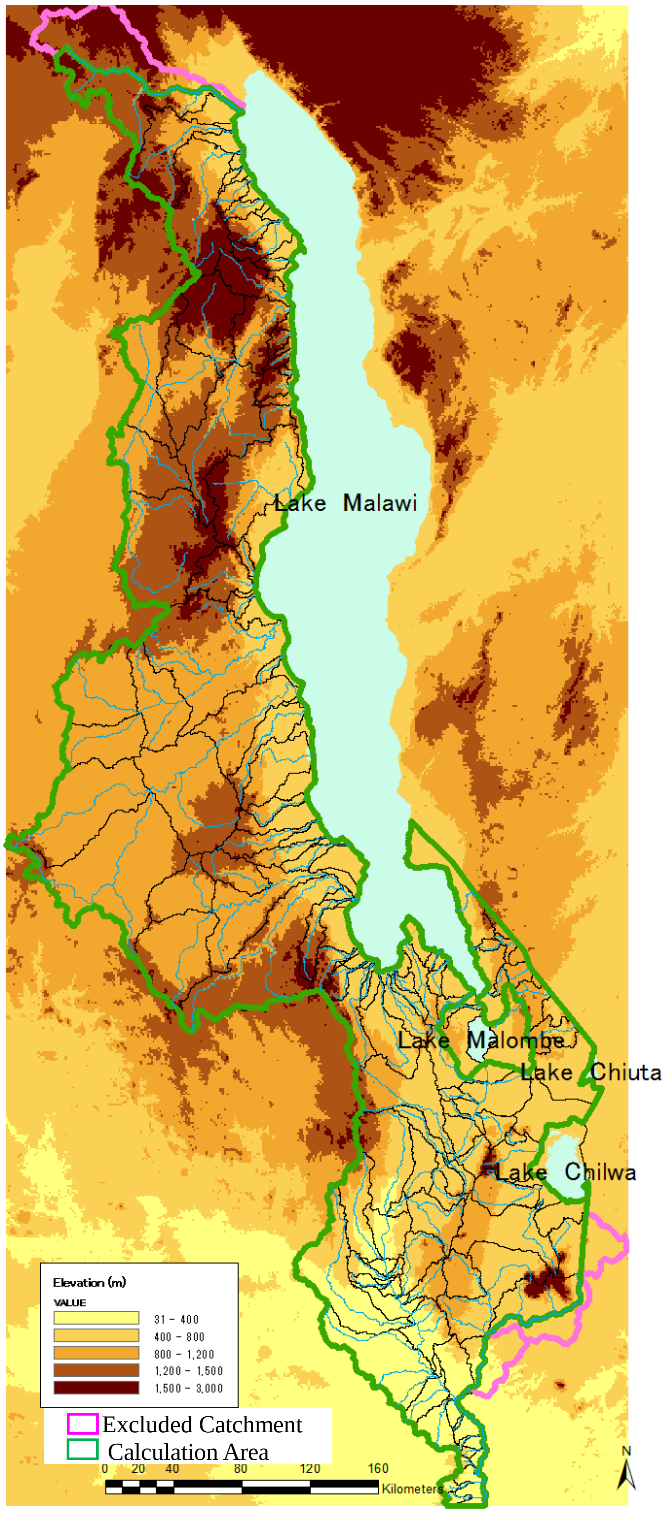
Imax = Interception Coefficient * Leaf Area Index

The interception coefficient is 0.5 mm from the reference. Leaf area index (LAI) is the area of leaf to unit ground area.

After canopy interception, evapotranspiration from detention storage on ground and unsaturated and saturated zone occur. The evapotranspiration from unsaturated zone depends on root depth set by land use.

LAI and root depth is determined by land use shown in **Table 6.5.4**. Land use map made in 1990 is applied as shown in **Figure 6.5.6**.

The value of LAI is determined by the reference and other study. LAI by land use is studied in the reference using global dataset. The maximum and minimum LAI in forest, croplands and grasslands is 6.48, 1.2, 5.0, 1.9, 2.9 and 0.52 respectively. However, the value should be determined by applied area. The value of LAI is determined to reference these data.



Source: Project Team

Figure 6.5.4 Calculated Boundary of Area and Topology

The root depth of grassland and cropland is determined to reference the information of FAO. The vegetation in Malawi is various such as coffee, tea, maize and tobacco. The root depth of grassland and cropland is 1 m considering these root depth of FAO is 0.25 – 1.7 m shown in **Table 6.5.5**.

The root depth of forestland is determined 5 m as the root depth of the Brachystegia from the reference which is occupied by 92% of trees on forestland in Malawi. (**Table 6.5.6**, **Figure 6.5.5**)

(6) River

The water in the basin flows to the mesh of lower elevation and finally flows to the river. After that, it is transported to the downstream basin through the river.

The cross section of the river assumed the shape of the inverted triangle at upstream and downstream of the river. The elevation of the cross section is from DEM.

Table 6.5.4 LAI and Root Depth by Land Use

	LAI	Root Depth (mm)
Forest land	5	5000
Grassland	1	1000
Cropland	4	1000
Wetland	0	0
Settlements	0	0
Other land	0	0

*Assuming temporal distribution is constant

Source: Project Team

Table 6.5.5 Root Depth of Grass and Crop

Crop	Maximum Root Depth (1) (m)
Rye Grass hay	0.6-1.0
Sudan Grass hay (annual)	1.0-1.5
Turf grass	0.5-1.0
Coffee	0.9-1.5
Tea	0.9-1.5
Sugar Beet	0.7-1.2
Sugar Cane	1.2-2.0
Rice	0.5-1.0
Maize	1.0-1.7(field corn) 0.8-1.2(sweet corn) *0.3-1.0
Tobacco	*0.25-0.8

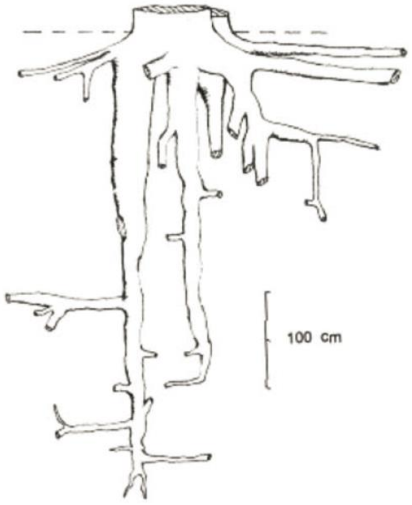
(1)The larger values for Zr are for soils having no significant layering or other characteristics that can restrict rooting depth. The smaller values for Zr may be used for irrigation scheduling and the larger values for modeling soil water stress or for rainfed conditions.

Source:
FAO: http://www.fao.org/nr/water/cropinfo.html
* http://www.fao.org/docrep/x0490e/x0490e0e.htm

Table 6.5.6 Classification of Forest

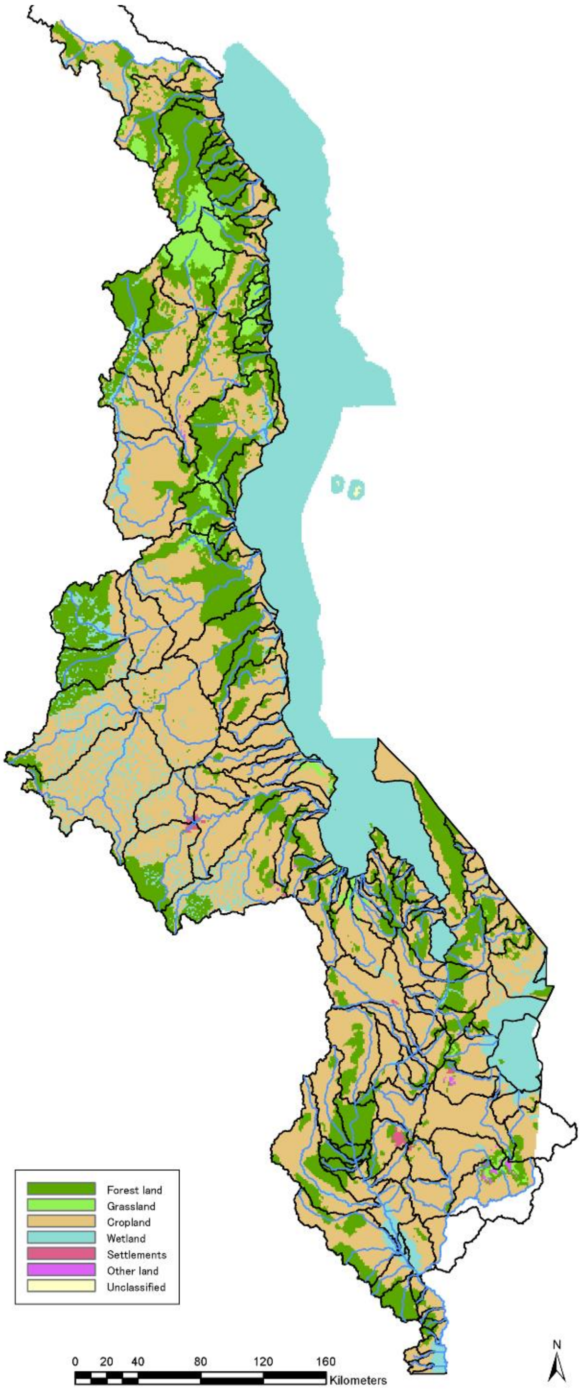
Classification	Classification	Area	
		(ha)	(%)
Forest (less than 20% open land)	Evergreen	82,615.80	3%
	Brachystegia in hill area	1,685,853.00	92%
	Brachystegia in flat area	733,108.10	
	Eucalyptus	24,042.70	1%
	Gmelina	721.9	0%
	Pine	107,289.70	4%
	Rubber	2,665.00	0%
	Tung	1,710.10	0%
	Logged	4,817.40	0%

Source: Project Team



Source: Homepage of Science and Engineering at The University of Edinburgh

Figure 6.5.5 Root of Brachystegia



Source: Project Team

Figure 6.5.6 Land Use

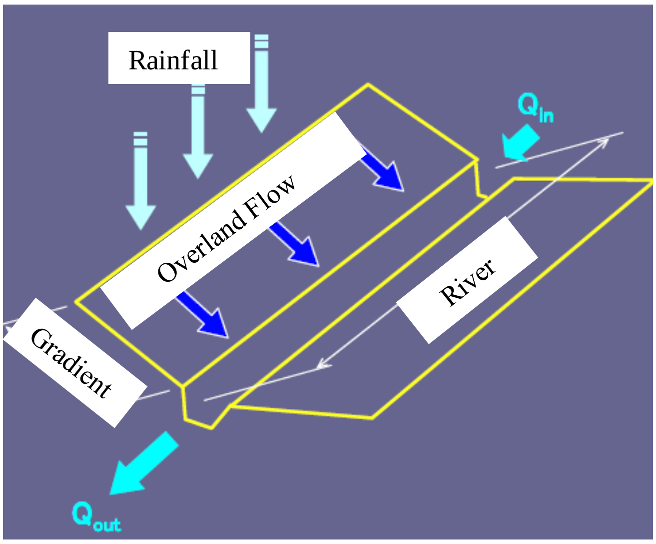
(7) Overland Flow

It is assumed that the process of the overland flow is based on the Manning's law shown in **Figure 6.5.7**. The parameters of the overland flow are shown in **Table 6.5.7**. To grasp the effect of the parameters, sensitivity analysis of the parameters is conducted. The result of analysis indicated that the parameter did not affect the simulation result (simulated hydrographs) so much. Weathered basement surface is low permeability, the overland flow of simulation is higher than observed data. Therefore, detention storage value is changed to meet observed data. Other parameters are standard value.

Table 6.5.7 Overland Flow Parameters

Parameter	Value
Slope	0.01
Slope Length (m)	100
Manning Number ($m^{1/3}/s$)	10
Detention Storage (mm)	5000
Initial Depth (m)	0

Source: Project Team



Considering the slope flow of unit width, unit flow is q.

q is represented by the following formula substituting Manning formula.

$q=1/n\times A\times (A/p)^{2/3}\times I^{1/2}$

(p: unit width, n: roughness coefficient, I: slope gradient, A: area)

Source: Added in Ministry of Land, Infrastructure, Transport and Tourism, Japan

Figure 6.5.7 Description of Manning Law

(8) Geological Condition

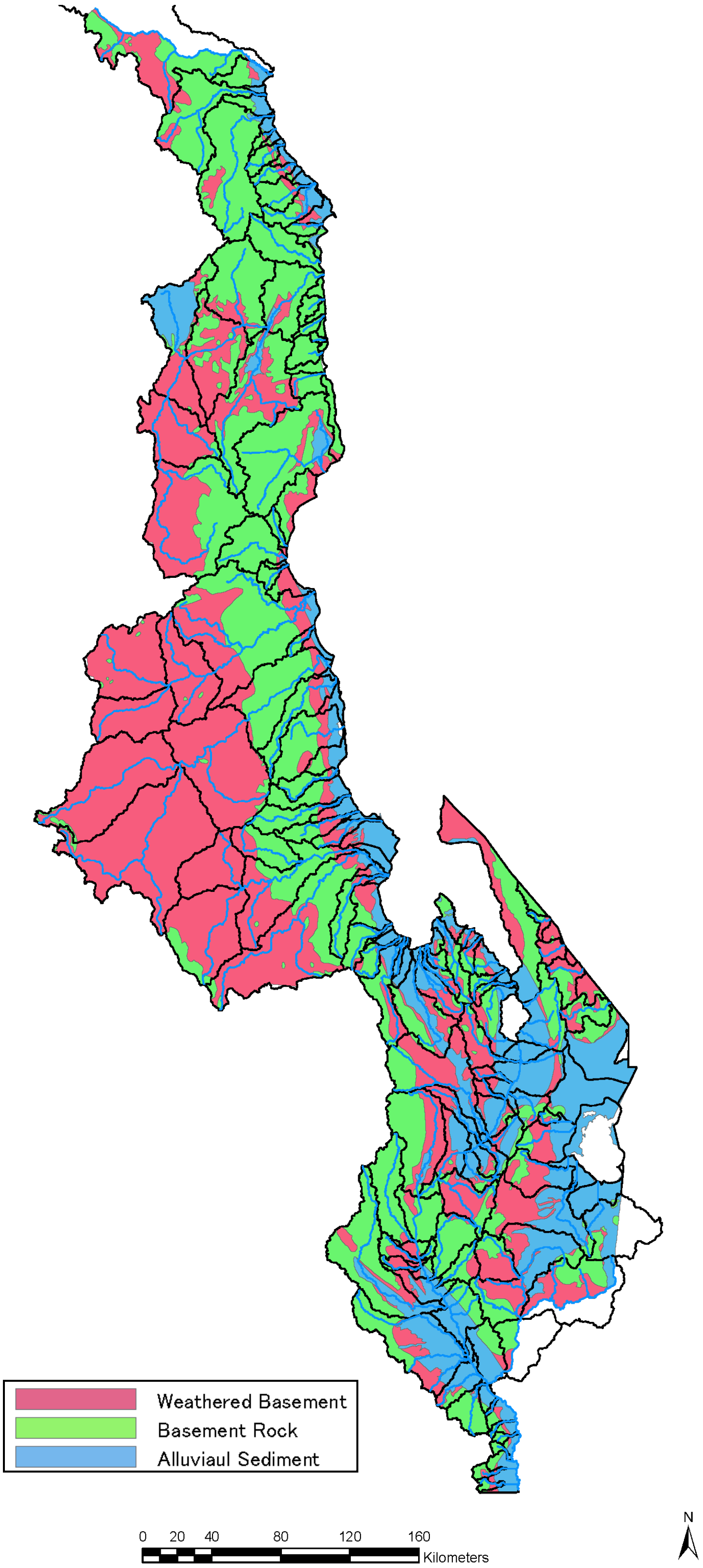
The soil and stratal architecture is categorized typical basement rock, alluvial sediment and weathered basement. The distribution of the geological condition is shown in **Figure 6.5.8**. Basement rock traverses longitudinally. Weathered basement is distributed in an inland area mainly. Alluvial sediment is distributed in south area. The geological map was made in 1987.

The soil of aquifer is assumed to be alluvium. The depth of the aquifer of the basement rock, alluvial sediment and weathered basement is 2, 50, and 15 m respectively considering the geological characteristics and referring to the M/P of 1986 (**Table 6.5.8).** The permeability of the aquifer is assumed to be that of sand and gravelly sand. It is assumed that the basement is rock which is impermeable. Considering typical model of weathered basement aquifer shown in **Subsection 3.3.2**, soil layer of weathered basement is assumed to be composed of two types of soil, upper is clay and lower is alluvium.

Table 6.5.8 Classification of Unsaturated Zone

Basement Rock		Alluvial Sediment		Weathered Basement	
Depth(m)	Soil	Depth(m)	Soil	Depth(m)	Soil
1-2	Alluvium(High Permeability)	1-50	Alluvium(High Permeability)	1-5	Clay(Low Permeability)
				5-15	Alluvium(High Permeability)

Hydraulic Conductivity: Alluvium 0.01, Clay 0.00005
Source: Project Team



Source: Project Team

Figure 6.5.8 Geological Map

(9) Unsaturated and Saturated Zone

The velocity of water infiltrating the ground is low. As a result, interflow and base flow occur. Interflow is the comparatively rapid flow to river and lake with time lag from unsaturated zone. Base flow is the flow after long detention from saturated zone. These are modeled respectively.

The parameters to represent the detention time and storage volume are determined as shown in **Table 6.5.9** and **Table 6.5.10**. Time constant is the calibration parameter. It is determined by comparison of the calculated and observed flow. UZ feedback fraction which is the rate of flow back to unsaturated zone from saturated zone is also a calibration parameter.

Actual geological condition is not homogeneous. There are porous areas and holes of animals and plants by places although homogeneous in the model. To represent the inhomogeneous flow in the model, it is assumed that 25% (maximum) of recharge flows to saturated zone directly.

Table 6.5.9 Default Parameters for Interflow

Parameter		Value
Specific Yield		0.3
Initial Depth (m)		5
Bottom Depth (m)		5
Interflow	Time Constant (d)	14*
	Threshold Depth (m)	5
Percolation	Time Constant (d)	14

Source: Project Team
*Calibration Parameter
*Bottom and Threshold Depth do not have significant affect.

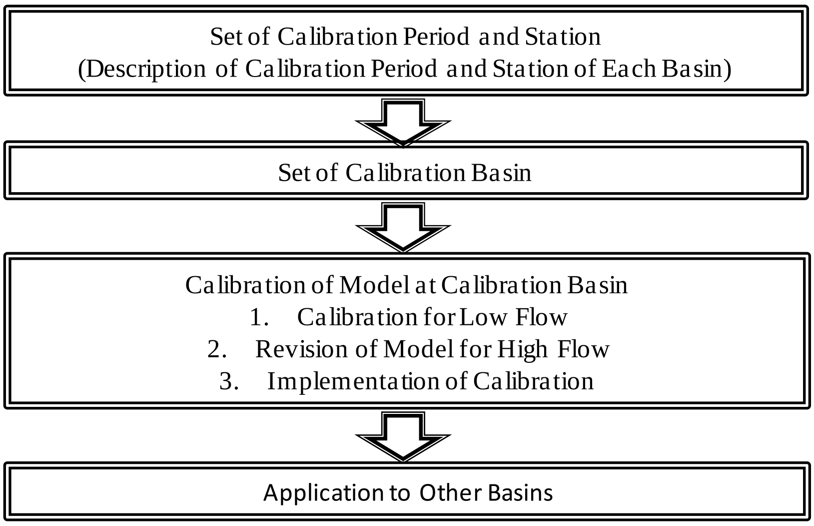
Table 6.5.10 Default Parameters for Base Flow

Parameter	Value
Specific Yield	0.3
Time Constant for Base Flow (d)	365*
Dead Storage Fraction	0*
UZ Feedback Fraction	0.1*
Initial Depth (m)	20
Threshold Depth for Base Flow (m)	20
Threshold Depth for Pumping (m)	20
Depth to the Bottom of the Reservoir (m)	20

Source: Project Team
*Calibration Parameter
*Bottom and Threshold Depth don’t have significant affect.

(10) Calibration Method

The flowchart of the calibration is shown in **Figure 6.5.9**. First, calibration period and place by basin are determined. Second, calibrated basin is determined. Third, calibration of low flow is implemented. It is difficult to adjust to both low flow and high flow generally. Therefore, low flow is firstly calibrated which is important for the study of the water utilization for long term. After that, the model is revised for adjustment of high flow. Considering the identified parameter in calibration basins, applicability of the model to other basins is confirmed.



Source: Project Team

Figure 6.5.9 Flow of Calibration

(11) Calibration Period and Station

The 6-year period from 1980 to 1986 is targeted as the calibration period. It is determined considering the year (1986) which is the year of formulation of the National Water Resources Master Plan leading to the development of water resources and reliable duration of the evaporation data (after 1980). In this duration, calibration period is determined at each calibration station considering reliable discharge data for calibration. Existing periods of rainfall, evaporation and discharge data are shown in **Table 6.5.11**.

Table 6.5.11 Period of Each Existing Data

Hydro Year		1980/1981	1981/1982	1982/1983	1983/1984	1984/1985	1985/1986
Rainfall Data		100%	100%	100%	100%	100%	100%
Evaporation Data		100%	100%	100%	100%	100%	100%
Flow Data	1P2	100%	99%	100%	88%	91%	96%
	2B22	0%	81%	100%	100%	92%	67%
	3E3	90%	26%	100%	88%	99%	98%
	4C2	77%	61%	80%	59%	81%	98%
	5D1	0%	0%	0%	0%	0%	88%
	6D10	0%	0%	0%	0%	0%	83%
	7G14	100%	100%	100%	98%	95%	94%
	7H3	100%	100%	100%	100%	100%	100%
	8A5	99%	96%	98%	100%	99%	100%
	9A2	100%	100%	100%	100%	100%	92%
	11A7	100%	100%	92%	100%	100%	100%
	14B2	100%	83%	100%	100%	100%	100%
	14C8	100%	100%	100%	100%	96%	100%
	15A8	0%	73%	36%	79%	82%	100%
	16F2	100%	100%	98%	100%	92%	100%
	17C6	100%	100%	100%	100%	100%	100%

Hatching: More than 80%
Source: Project Team

The calibration station is determined considering period and reliability of existing discharge data at downstream. The reliability is evaluated by flow shape, discharge data of flow observation and comparison of upstream and downstream as follows:

- Shape of hydrograph
- Balance of upstream and downstream
- Comparison of flow observation
- Location of station
- Others

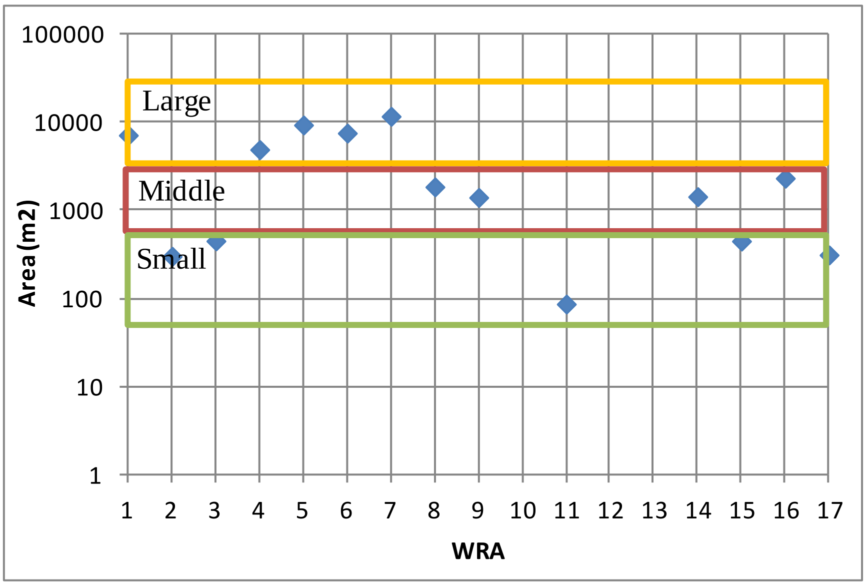
For the study of water balance, the low flow is important. Therefore, the evaluation of reliability is focused on the dry season.

The calibration station and period of each station is shown in **Table 6.5.12**.

(12) Calibration Basin

Calibration basin is determined considering water utilization and basin size.

The calibration station is classified into three by basin size shown in **Figure 6.5.10**. There is one station in each basin. The calibration basin is determined by each basin size by evaluating water demand. The basin in which the demand is low close to natural flow regime serves as the calibration basin, such as WRA 7, 8, and 15. There is the Lunyangwa Dam in WRA 7, but it is located upstream of tributary and its effect is not large. The geological condition of calibration basin is basement rock (WRA 7, 15) and weathered basement (WRA 8) which occupy most.



Source: Project Team

Figure 6.5.10 Area of Representative Station of WRA

Table 6.5.12 Calibration Station and Period

WRA	Evaluation Station	Shape of Hydrograph	Balance of Upstream and Downstream	Comparison of Flow Measurement	Location of Station	Other	Period
1	1P2						1980-1986
	1L12		*	*			
	1G1	*	*		*		
2	2B22			*(Partial)			1983-1985
	2B21	*		*	*		
	2B6			*	*		
	2B33	*			*		
	2B8	*			*		
3	3E3						1980-1986
4	4C2						1980-1986
	4B1		*				
	4B9	*					
5	5D1						1980-1986
	5C1				*		
	5D2	*			*		
6	6D10				(*)		1980-1986
	6C1	*			*		
7	7G14						1980-1986
	7G18					*	
	7E2	*			*		
	7H3						1980-1986
	7H1				*		
	7H2				*		
8	8A5	*(Partial)					1981-1986
	8A8				*	*	
9	9A2						1980-1986
	9A7	*	*				
	9A4				*		
11	11A7	*(Partial)					1982-1985
	11A6	*					
14	14B2						1980-1986
	14A2				*(Tributary)		
	14C8						1980-1986
	14C2						
15	15A8						1980-1986
	15A4	*					
	15B14					*	
16	16F2						1980-1986
	16E6					*	
17	17C6	*(Partial)					1980-1984
	17C10	*					

*:Not Good Point
Hatching: Calibration Station
Source: Project Team

Table 6.5.13 Water Demand by WRA

Large

WRA	Representative Station	Area of Station (km2)	Annual Demand /Area (m3/km2)	Water Supply and Hydropower Dam (Constructed or Operation Year)	Geological Condition
1	1P2	7200	5,773	Mpira(NA), Mudi (1953), Nkula(1966), Tedzani(1973), Kapichira (2000)	Basement Rock
4	4C2	4940	2,459	Kamuzu1(1966)	Weathered Basement
5	5D1	9410	2,883		Weathered Basement
6	6D10	7610	10,811	Chitete(NA)	Weathered Basement
7	7G14	11800	506	Lunyangwa(NA)	Weathered Basement

Middle

WRA	Representative Station	Area of Station (km2)	Annual Demand /Area (m3/km2)	Water Supply and Hydropower Dam (Constructed or Operation Year)	Geological Condition
8	8A5	1860	1,789		Basement Rock
9	9A2	1410	4,355		Basement Rock
14	14B2	1440	59,218		Weathered Basement
16	16F2	2334	14,253		Basement Rock

Small

WRA	Representative Station	Area of Station (km2)	Annual Demand /Area (m3/km2)	Water Supply and Hydropower Dam (Constructed or Operation Year)	Geological Condition
2	2B22	302	4,744	Mulunguzi(NA)	Alluviaul Sediment
3	3E3	452	7,161		Basement Rock
11	11A6	86.5	6,032		Weathered Basement
15	15A8	450	2,356		Basement Rock
17	17C6	313	9,305	Wovwe (1995)	Basement Rock

Source: Project Team

(13) Calibration of Model at Calibration Basin

1) Calibration for Low Flow

Calibration is implemented for low flow which is important for the evaluation of water resources. Time constants for interflow and base flow are calibration parameters. These are identified as shown in **Table 6.5.14** to match observed and calculated value, considering recharge to the ground which does not affect the flow to the river such as direct flow to the lake and other basin, and which takes time to reach groundwater for storage on the impermeable layer such as perched water and dambo. Though actual groundwater flow is complicated and various, it is uniform in the model. To represent these phenomena, dead storage fraction (fraction of recharge which does not flow to the river) and UZ feedback fraction (fraction of flow from saturated zone which flows to unsaturated zone) are considered. Twenty to thirty percent (20-30%) of the recharge does not affect the river flow. Ten to thirty percent (10-30%) of flow from saturated zone flows to unsaturated zone.

Table 6.5.14 Time Constant for Interflow and Base Flow of Representative Basin

WRA	Time Constant for Interflow (day)	Time Constant for Baseflow (day)
7	20	250
8	8	365
15	4	365

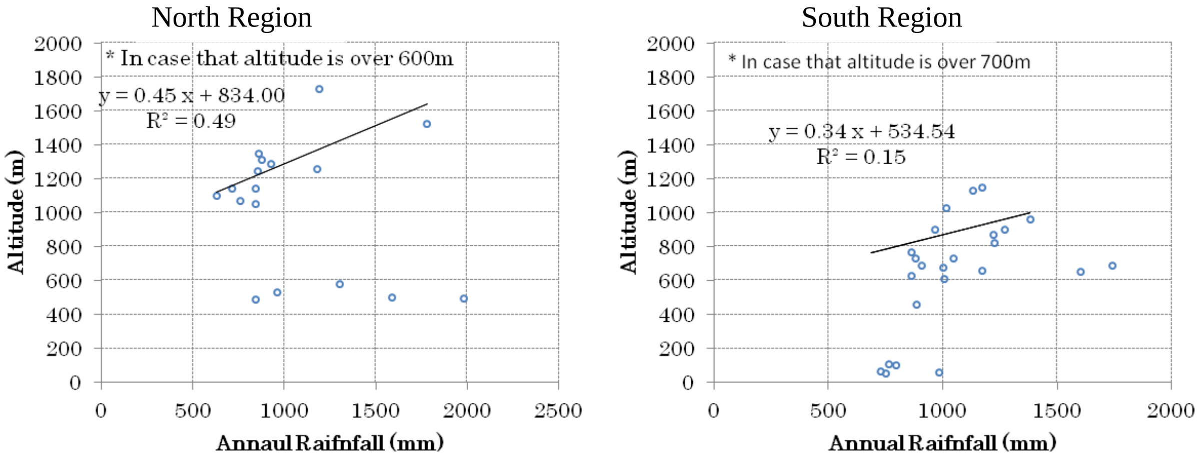
Source: Project Team

2) Revision of Model for High Flow

It is difficult to adjust to both low flow and high flow because these are different phenomena, although the model is revised to adjust to high flow.

To adjust to high flow, extrapolation of rating curve to calculate high flow and effect of local rainfall is considered. These are evaluated as follows:

1. The flow which is over maximum flow observation is excluded for calibration because of extrapolation of rating curve.
2. There is the relation between annual rainfall and altitude shown in **Figure 6.5.11**
3. Rainfall of the model is increased depending on the altitude in the mountain affected by the local rainfall. In the model, rainfall in WRA 8 and 14C are applied.



Source: Project Team

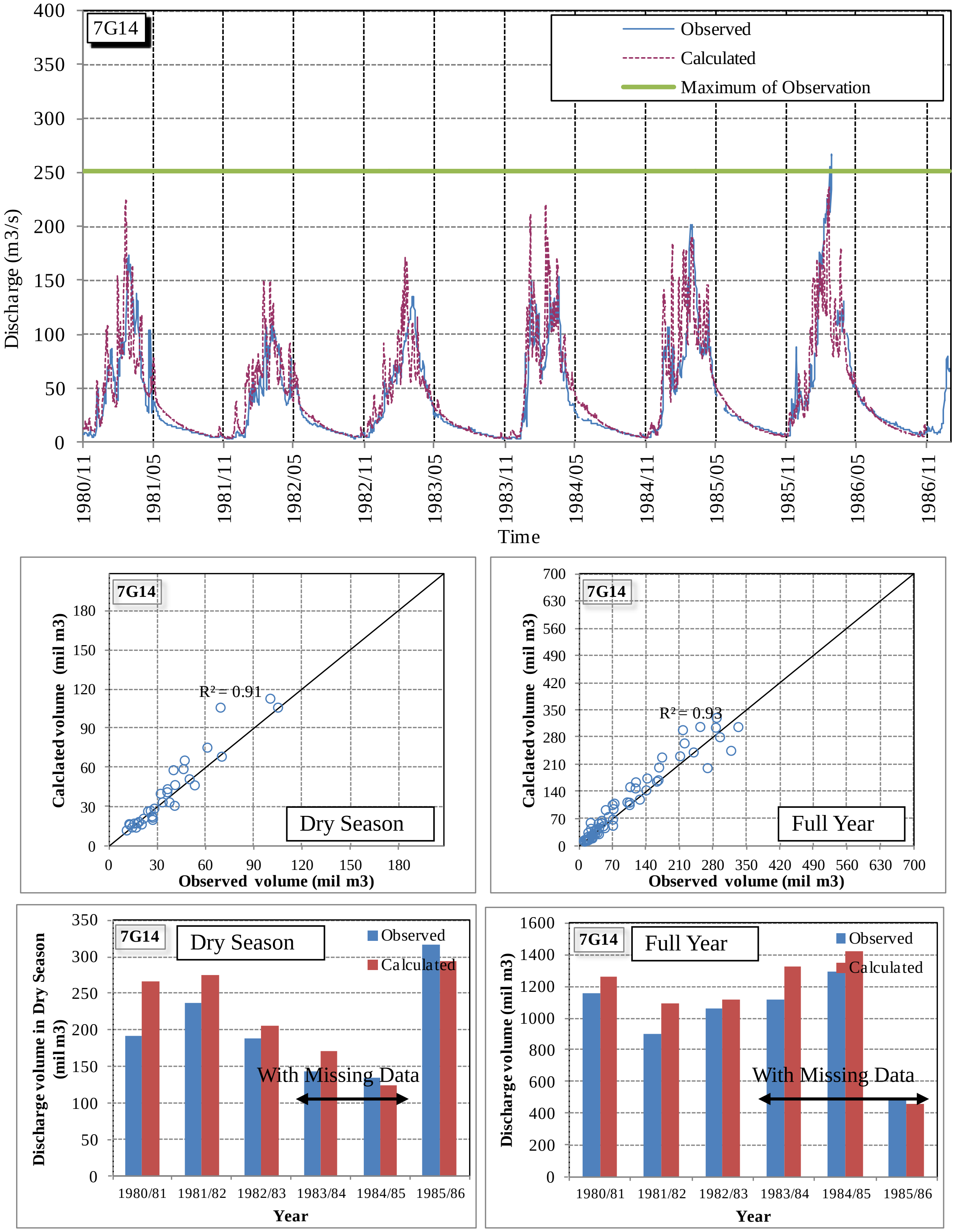
Figure 6.5.11 Relation between Rainfall and Altitude

3) Implementation of Calibration

The calibration is implemented by comparison of observed and calculated monthly flow volume in annual and dry season. As reference, annual flow volume is compared.

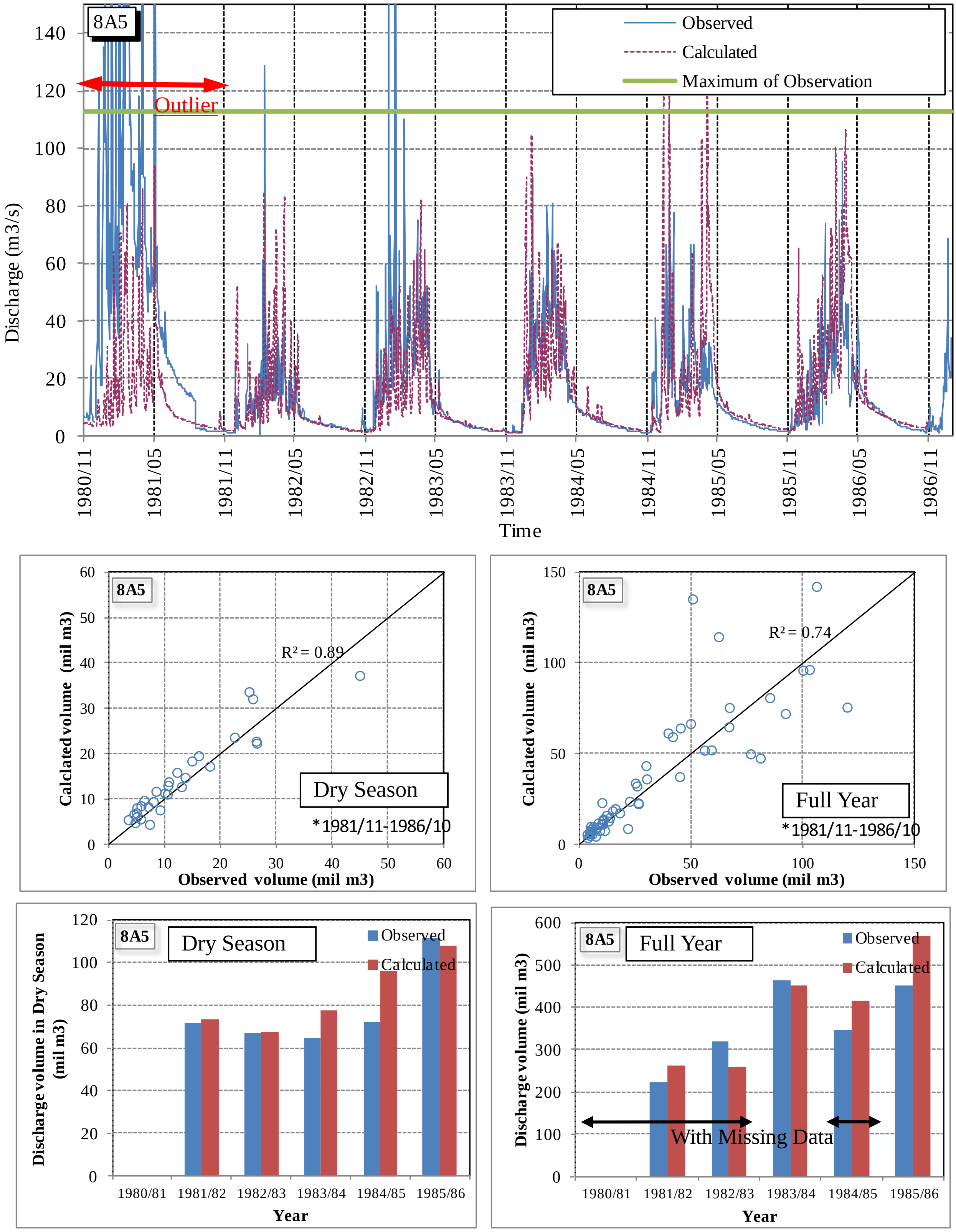
As a result, the validity of the model is shown from the following viewpoint:

- The shape of hydrograph is represented.
- The monthly flow volume is represented. The correlation is high because of the correlation coefficient is over 0.9.



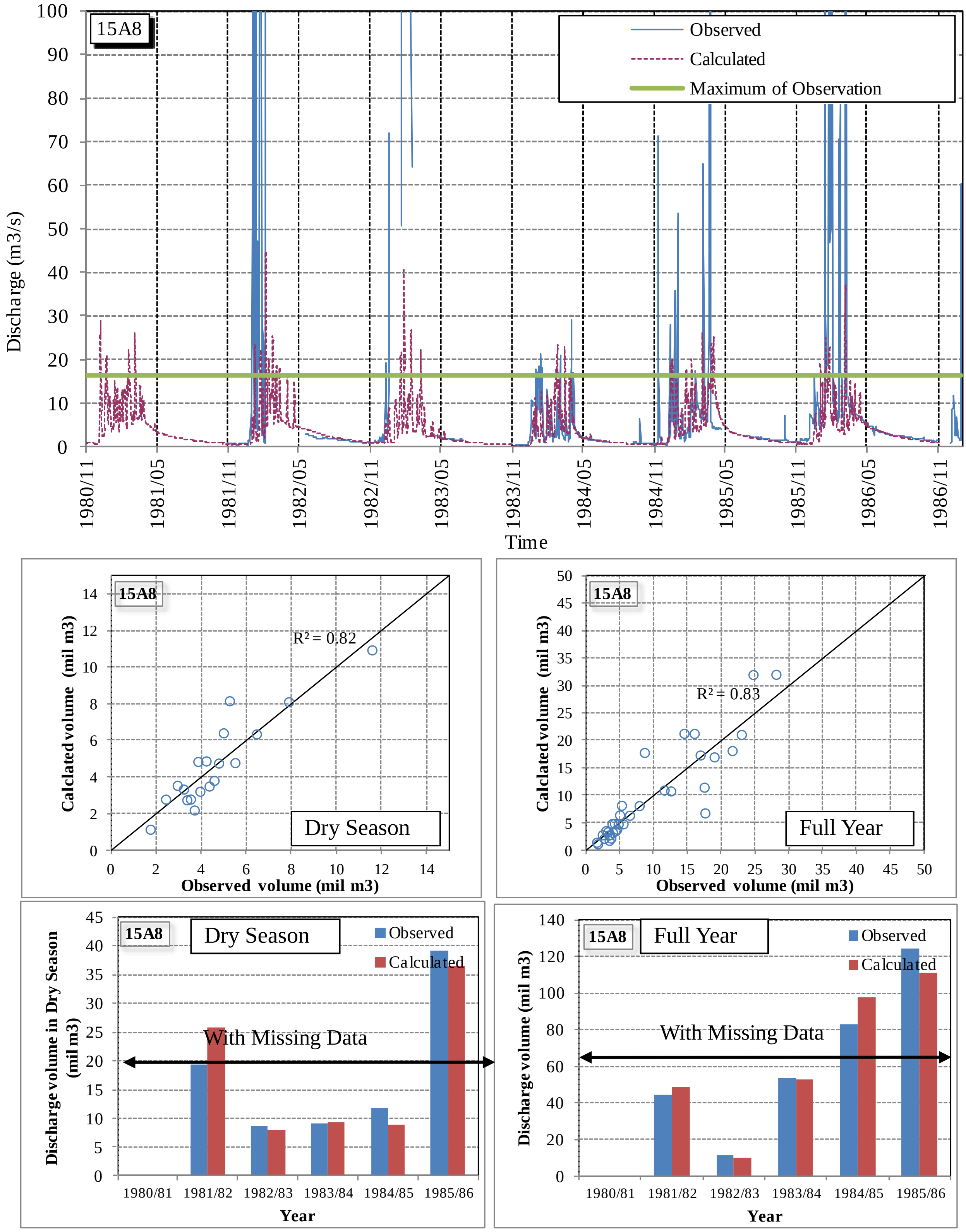
Source: Project Team

Figure 6.5.12 Calibration at 7G14



Source: Project Team

Figure 6.5.13 Calibration at 8A5



Source: Project Team

Figure 6.5.14 Calibration at 15A8

(14) Application to Other Basins

The parameters are applied to the other basins based on identified parameters. Upon application, the adjusted parameters are applied considering basin characteristic as follows:

- Time constant for interflow is affected by basin shape because interflow is the comparatively rapid flow from unsaturated zone. Therefore, considering shape characteristics (basin area / river length), the parameters are applied to the other basins. When the value of shape characteristics is high, the shape of basin is round and the time of flow into the river is long. When the value of shape characteristics is low, the shape of basin is elongated and the time of flow into the river is not long. Therefore, there is linear relation between shape characteristics and time constant for interflow.
- The geological condition affects the time constant for base flow because base flow is from saturated zone and takes time for it to flow into a river. Therefore, the time constant for base flow is the same in the same geological condition. In addition, the time constant for base flow in basement rock is longer than that of other geological conditions.

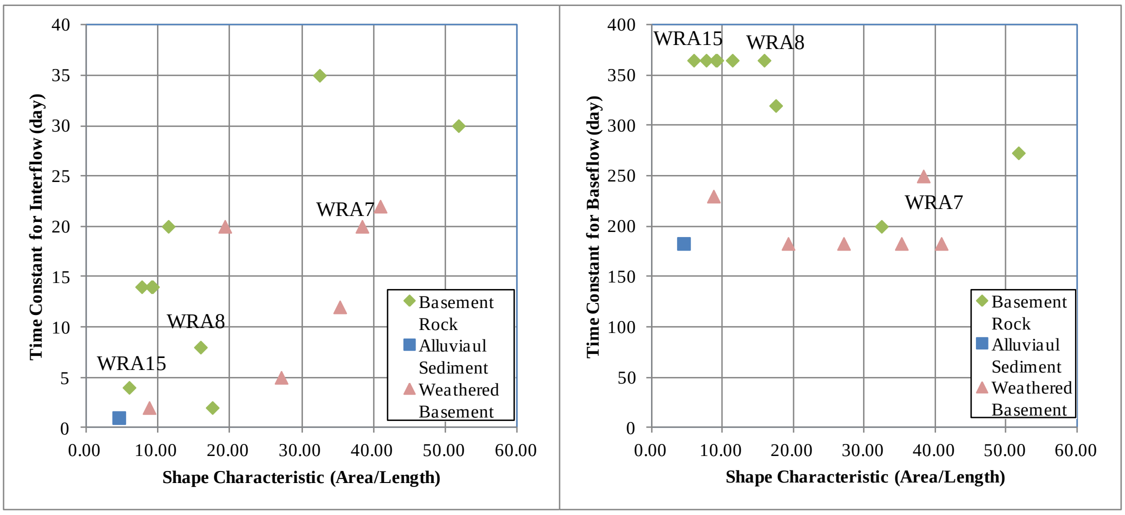
The applied parameters are shown in **Table 6.5.15** and **Figure 6.5.15.** The results are shown in Table 6.5.16 as the correlation coefficient between observed and calculated monthly flow volume (when calculating the correlation of coefficient, the observed data was selected depending upon the accuracy).

The correlation coefficient is very high ranging from 0.71 to 0.99; therefore, it can be said that the parameters can be applied for the other basins and the applicability of the model is proven to utilize simulation results for the master plan study.

Table 6.5.15 Time Constant for Interflow and Base Flow

WRA	Time Constant for Interflow (day)	Time Constant for Baseflow (day)	Shape Characteristic (Area/Length)	Dominant Geological Condition
1	30	273	51.7	Basement Rock
2	1	183	4.5	Alluviaul Sediment
3	14	365	9.0	Basement Rock
4	20	183	19.2	Weathered Basement
5	12	183	35.2	Weathered Basement
6	22	183	40.8	Weathered Basement
7	20	250	38.3	Weathered Basement
7(H)	20	365	11.3	Basement Rock
8	8	365	15.8	Basement Rock
9(9A)	2	320	17.5	Basement Rock
11	2	230	8.7	Weathered Basement
14A,B,D	5	183	27.0	Weathered Basement
14C	14	365	9.2	Basement Rock
15	4	365	5.9	Basement Rock
16	35	200	32.4	Basement Rock
17	14	365	7.7	Basement Rock

Source: Project Team



Source: Project Team

Figure 6.5.15 Relation between Area, Time Constant for Interflow and Base Flow

Table 6.5.16 Application Result

WRA	Evaluation Station	Applicability (Correlation Coefficient of Volume)		Note
		In Whole Year	In Dry Season	
1	1P2	0.90	0.89	
2	2B22	0.96	0.71	1983/5-1985/10
3	3E3	0.94	0.91	
4	4C2	0.96	0.79	
5	5D1	0.99	0.87	
6	6D10	0.93	0.98	
7	7G14	0.97	0.95	
	7H3	0.76	0.80	
8	8A5	0.86	0.94	1981/11-1986/10
9	9A2	0.99	0.91	
11	11A7	0.83	0.85	1981/11-1986/4
14	14B2	0.80	0.80	
	14C8	0.84	0.81	
15	15A8	0.91	0.91	
16	16F2	0.90	0.92	
17	17C6	0.75	0.78	1980/11-1985/4

Source: Project Team

(15) Improvement of the Model in the Future

It is needed to improve the model in the future as follows:

- Appropriate management of the rainfall and evaporation station and data to grasp the distribution of the rainfall and evaporation
- Acquisition of reliability of the observed water level, rating curve and discharge especially in flood.

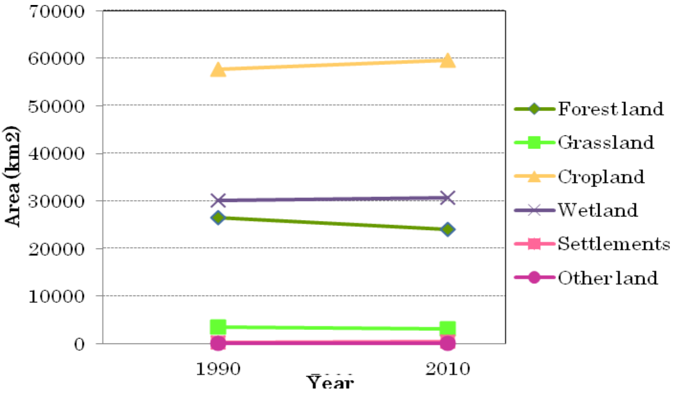
(16) Estimation of Water Resources

To estimate the present condition of water resources in Malawi, the calculation is conducted under the same hydrological condition existing for 30 years from November 1980 to October 2010 including the calibration period. The calculation condition is changed from calibration condition as follows:

- Land use is changed from 1990 to 2010.
- Inflow to the Shire River is changed from observation data to the result of model of Lake Malawi.
- There is no pan evaporation data after 2003 and there is missing data after 2001. Therefore, daily pan evaporation after 2001 is the daily divided monthly average value from 1981 to 2000.

1) Change of Land Use

Land use in 1990 is applied for calibration but for the calculation of water resources from the present condition, land use is changed to the latest land use in 2010 Land uses in 1990 and 2010 are shown in **Figure 6.5.16** and **Figure 6.5.18**. Fores land decreased. While cropland increased Forest land changed to cropland by burn field. Settlement increased slightly and grassland decreased slightly. The roo depth and LAI is highest, therefore evapotranspiration becomes lower.

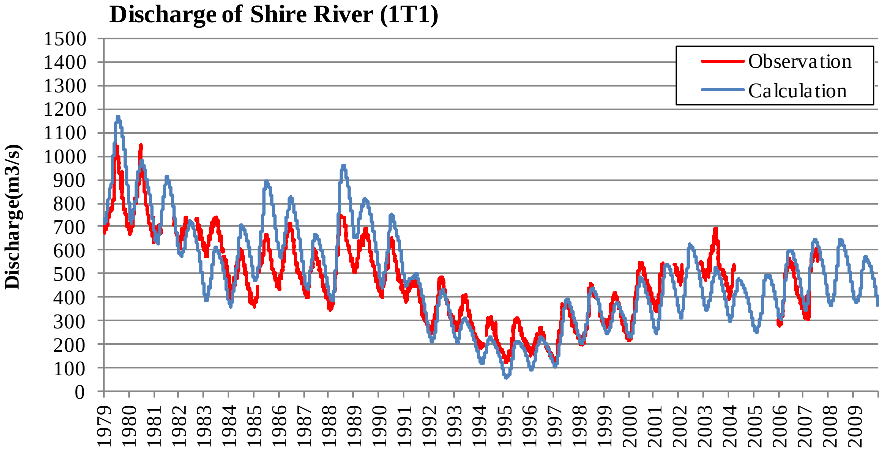


Source: Project Team

Figure 6.5.16 Changes of Land Use between 1990 and 2010

2) River Outflow from Lake Malawi

The inflow of the Shire River is the outflow from Lake Malawi. The inflow of the Shire River is calculated by the water balance model of Lake Malawi, which is applied because water utilization from Lake Malawi and the effect of climate change is considered using the model. The comparison between the flow calculated in the water balance model of Lake Malawi and the observed flow is shown in **Figure 6.5.17**. The calculated flow represents observed flow.



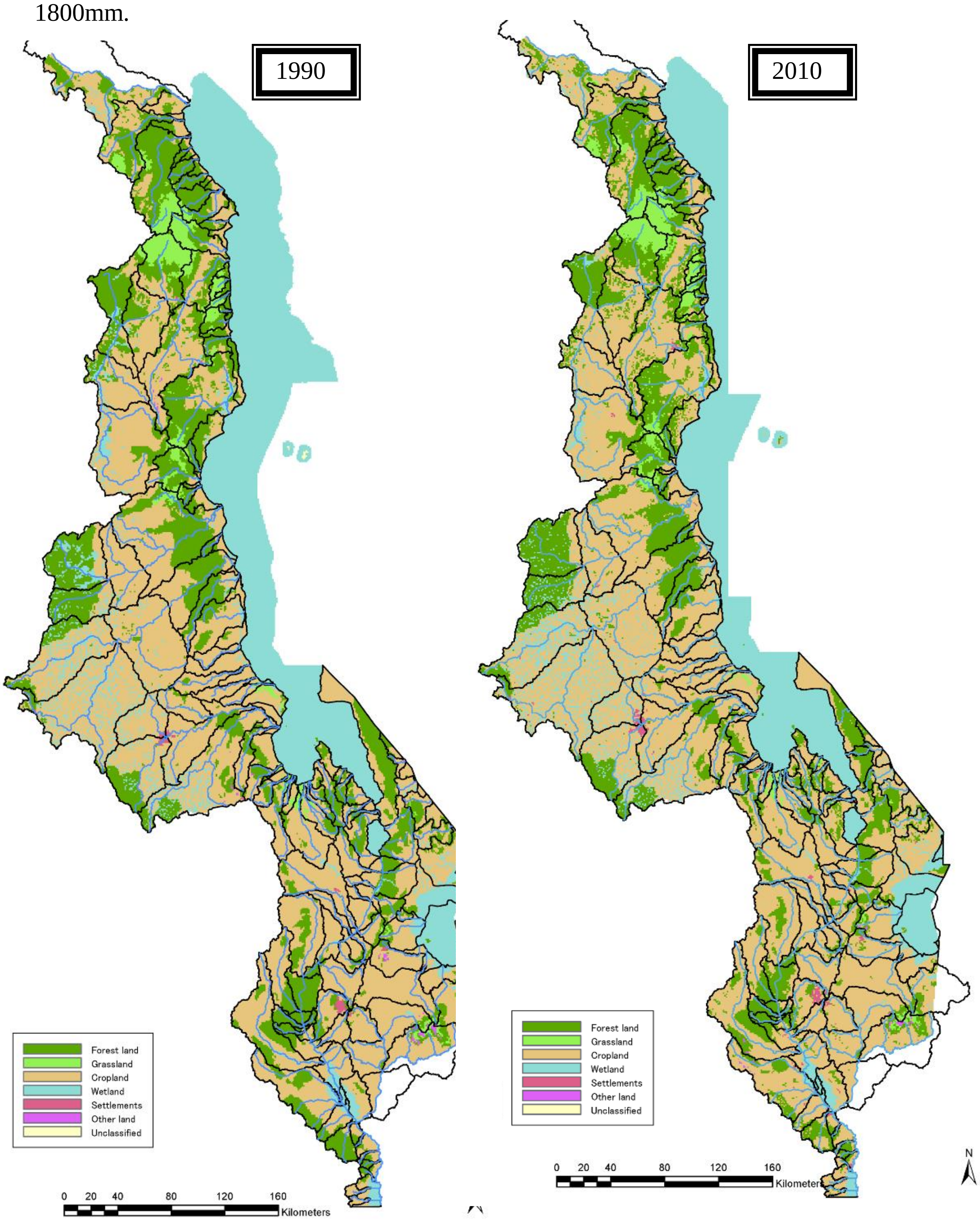
Source: Project Team

Figure 6.5.17 Observed and Calculated River Outflow

3) Pan Evaporation Data

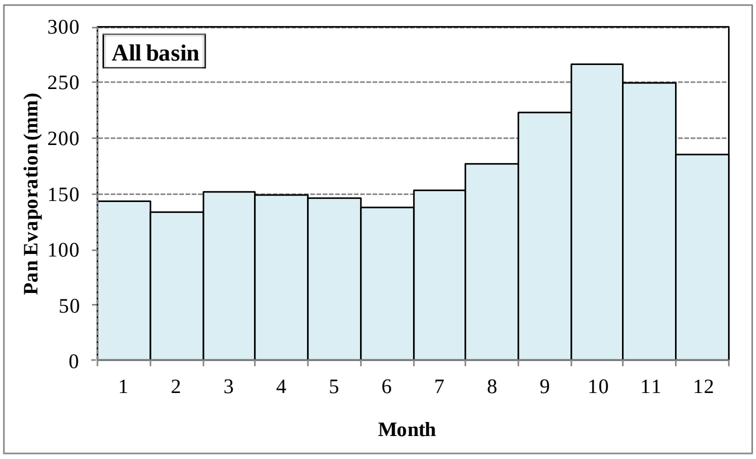
There is no pan evaporation data after 2003 and there is missing data after 2001. Therefore, daily pan evaporation after 2001 is the daily divided monthly average value from 1971 to 2000, as shown in

Figure 6.5.19. Pan evaporation becomes high from September which is the end of the dry season to November which is the beginning of the wet season. The average annual pan evaporation is about 1800mm.



Source: Project Team

Figure 6.5.18 Land Use Maps in 1990 and 2010



Source: Project Team

Figure 6.5.19 Monthly Pan Evaporation

6.5.2 Water Balance Model of Lake Malawi

Lake Malawi is bordered by three countries, Malawi, Tanzania and Mozambique, whose rivers flow into the Lake Malawi. On the other hand, outflow from Lake Malawi is only through the Shire River which is at the southern tip.

To estimate the impact on water level and outflow of Lake Malawi due to water intake, water balance model of Lake Malawi is constructed.

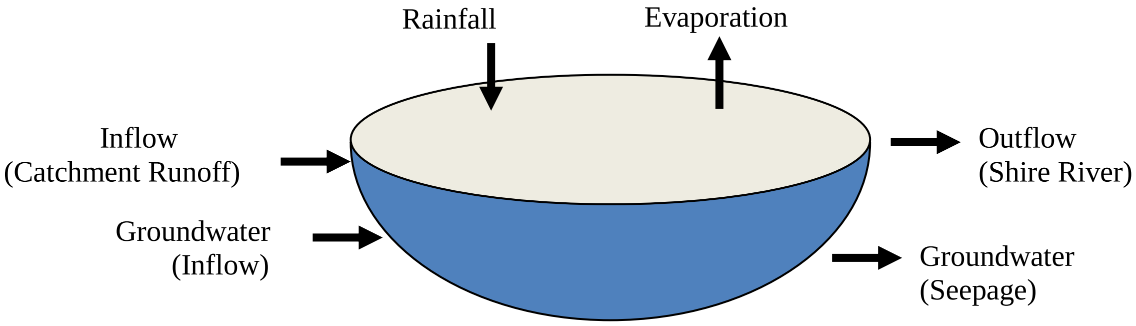
(1) Outline of Water Balance Model of Lake Malawi

The model is constructed based on the water balance shown in **Figure 6.5.20**. For the inflow of Lake Malawi, inflow from river basins, rainfall on Lake Malawi and inflow of groundwater are considered. For the outflow, the outflow of the Shire River, evaporation from Lake Malawi and the outflow of groundwater (infiltration, seepage) are considered. The model is calibrated by comparison between the observed and calculated water levels of Lake Malawi.

<Composition of Water Balance Model of Lake Malawi>

-Inflow: River Inflow, Rainfall, Groundwater

-Outflow: River Outflow (Shire River), Evaporation, Groundwater (Infiltration, Seepage)



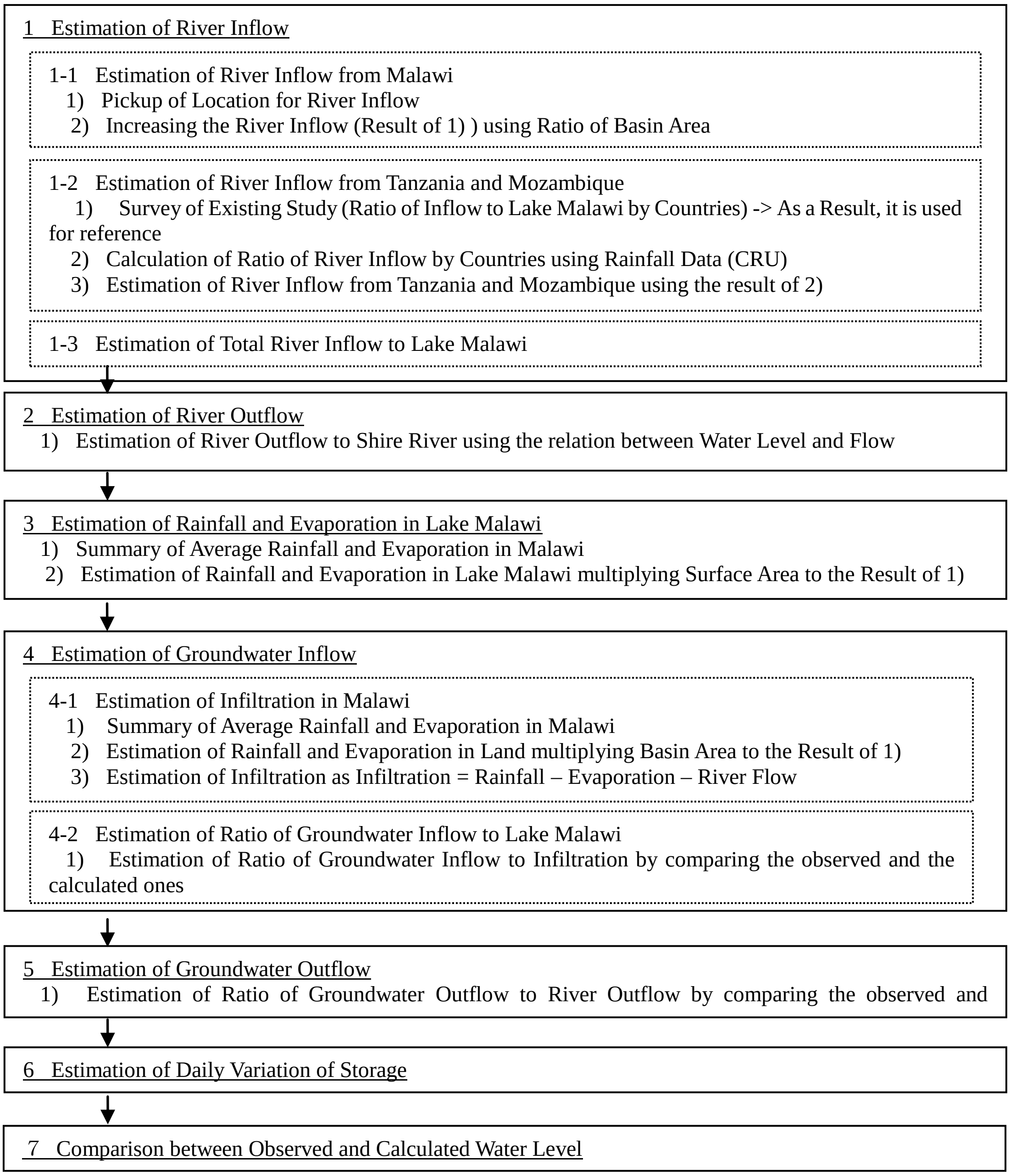
Source: Project Team

Figure 6.5.20 Outline of Water Balance Model of Lake Malawi

Table 6.5.17 Data of the Model

Data	Outline
River Inflow	-The river inflow is the result of rainfall runoff model which is increased by basin area ratio -The inflow from Tanzania and Mozambique is estimated by satellite rainfall
Rainfall on Lake Malawi	-Average rainfall in Malawi estimated by Thiessen method
Inflow of Groundwater	-Calibration parameter (It is difficult to grasp the characteristics.)
River Outflow	-The river outflow is estimated by the relation between water level of Lake Malawi and outflow studied by reference.
Evaporation from Lake Malawi	-Average evaporation in Malawi estimated by Thiessen method
Outflow of Groundwater (Infiltration, Seepage)	-Calibration parameter (It is difficult to grasp the characteristics.)

Source: Project Team



1 Estimation of River Inflow

1-1 Estimation of River Inflow from Malawi
1) Pickup of Location for River Inflow
2) Increasing the River Inflow (Result of 1)) using Ratio of Basin Area

1-2 Estimation of River Inflow from Tanzania and Mozambique
1) Survey of Existing Study (Ratio of Inflow to Lake Malawi by Countries) -> As a Result, it is used for reference
2) Calculation of Ratio of River Inflow by Countries using Rainfall Data (CRU)
3) Estimation of River Inflow from Tanzania and Mozambique using the result of 2)

1-3 Estimation of Total River Inflow to Lake Malawi

2 Estimation of River Outflow
1) Estimation of River Outflow to Shire River using the relation between Water Level and Flow

3 Estimation of Rainfall and Evaporation in Lake Malawi
1) Summary of Average Rainfall and Evaporation in Malawi
2) Estimation of Rainfall and Evaporation in Lake Malawi multiplying Surface Area to the Result of 1)

4 Estimation of Groundwater Inflow

4-1 Estimation of Infiltration in Malawi
1) Summary of Average Rainfall and Evaporation in Malawi
2) Estimation of Rainfall and Evaporation in Land multiplying Basin Area to the Result of 1)
3) Estimation of Infiltration as Infiltration = Rainfall – Evaporation – River Flow

4-2 Estimation of Ratio of Groundwater Inflow to Lake Malawi
1) Estimation of Ratio of Groundwater Inflow to Infiltration by comparing the observed and the calculated ones

5 Estimation of Groundwater Outflow
1) Estimation of Ratio of Groundwater Outflow to River Outflow by comparing the observed and

6 Estimation of Daily Variation of Storage

7 Comparison between Observed and Calculated Water Level

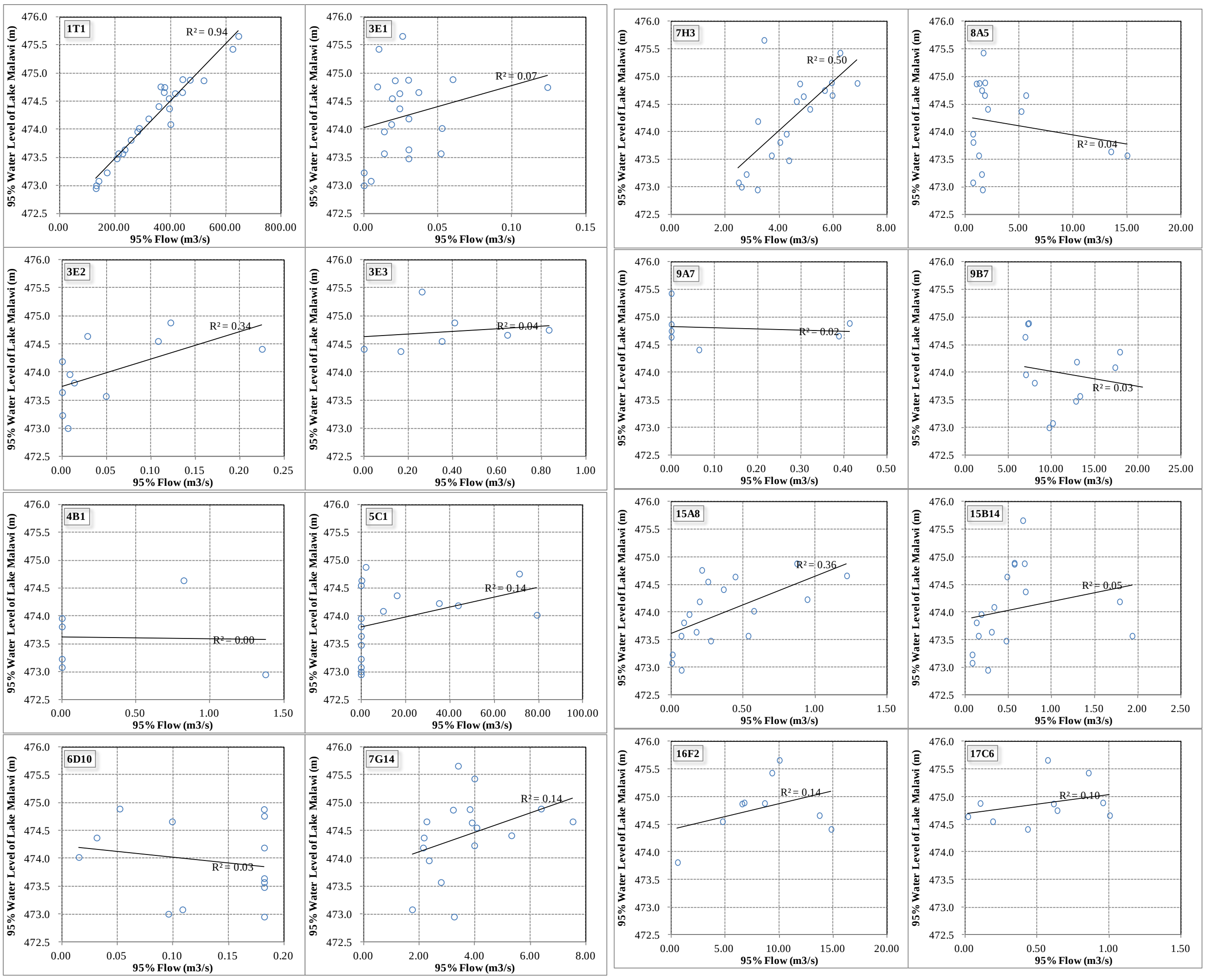
Source: Project Team

Figure 6.5.21 Flow of Construction of the Model

(2) Hydrological Characteristic of Lake Malawi

To grasp water use availability of Lake Malawi, the water level condition of Lake Malawi is investigated, confirming the relationship between the drought water level of Lake Malawi and the drought river flow shown in **Figure 6.5.22**.

As the result, when river basins around Lake Malawi are drought condition, the water level of Lake Malawi also becomes unavailable condition to extract the water at low cost. That is to say, when drought occurs in basins around Lake Malawi, Lake Malawi is also situated in lower water level status.



Source: Project Team

Figure 6.5.22 Comparison of 95% Flow and 95% Water Level of Lake Malawi

(3) River Inflow to Lake Malawi

1) Estimation Method

Observed water level and discharge data of Lake Malawi are available, but there are gaps or missing data and the reliability is low. Therefore, the result of the rainfall runoff model is applied.

The river inflow from Tanzania and Mozambique is estimated using the ratio by countries studied as reference.

<Flow of Estimation of River Inflow>

1. Inflow from Malawi is estimated by using the flow of rainfall and runoff mode.
2. Inflow from Malawi is increased by basin area to calculate the total inflow from Malawi.
3. Estimation of the ratio by country
4. Inflow from Tanzania and Mozambique is estimated by using the ratio
5. Total inflow to Lake Malawi is estimated by the inflow from the other countries.

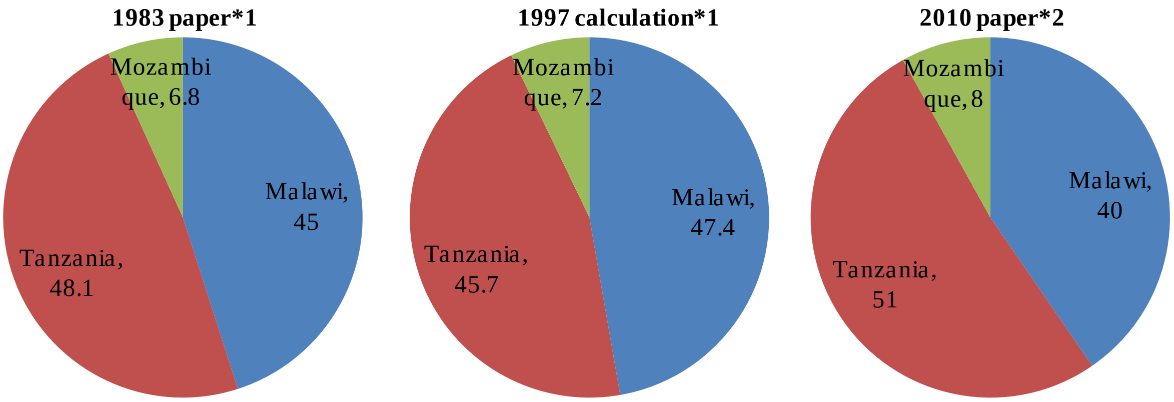
2) River Inflow from Malawi

Inflow from Malawi is estimated by using the flow of rainfall and runoff model and increased by basin area to calculate the total inflow from Malawi. The river inflow from Malawi is shown in **Figure 6.5.24** to **Figure 6.5.27**.

3) River Inflow from Tanzania and Mozambique

(i) Existing Study

The ratio of river inflow to Lake Malawi by the other countries is studied from some references. Inflows studied in 1983, 1997 and 2010 are as shown in **Figure 6.5.23**. Inflow from Tanzania is higher than that from Malawi in 2010. On the other hand, inflow from Tanzania and Malawi is almost the same in other years. Inflow from Mozambique is smaller than that from the other countries. These have been calculated annually, therefore, these are not the monthly or daily ratio. The rate is not always the same. When drought occurs in Malawi, drought may not occur in the other countries. Therefore, it is not advisable to apply them to the daily water balance calculation.

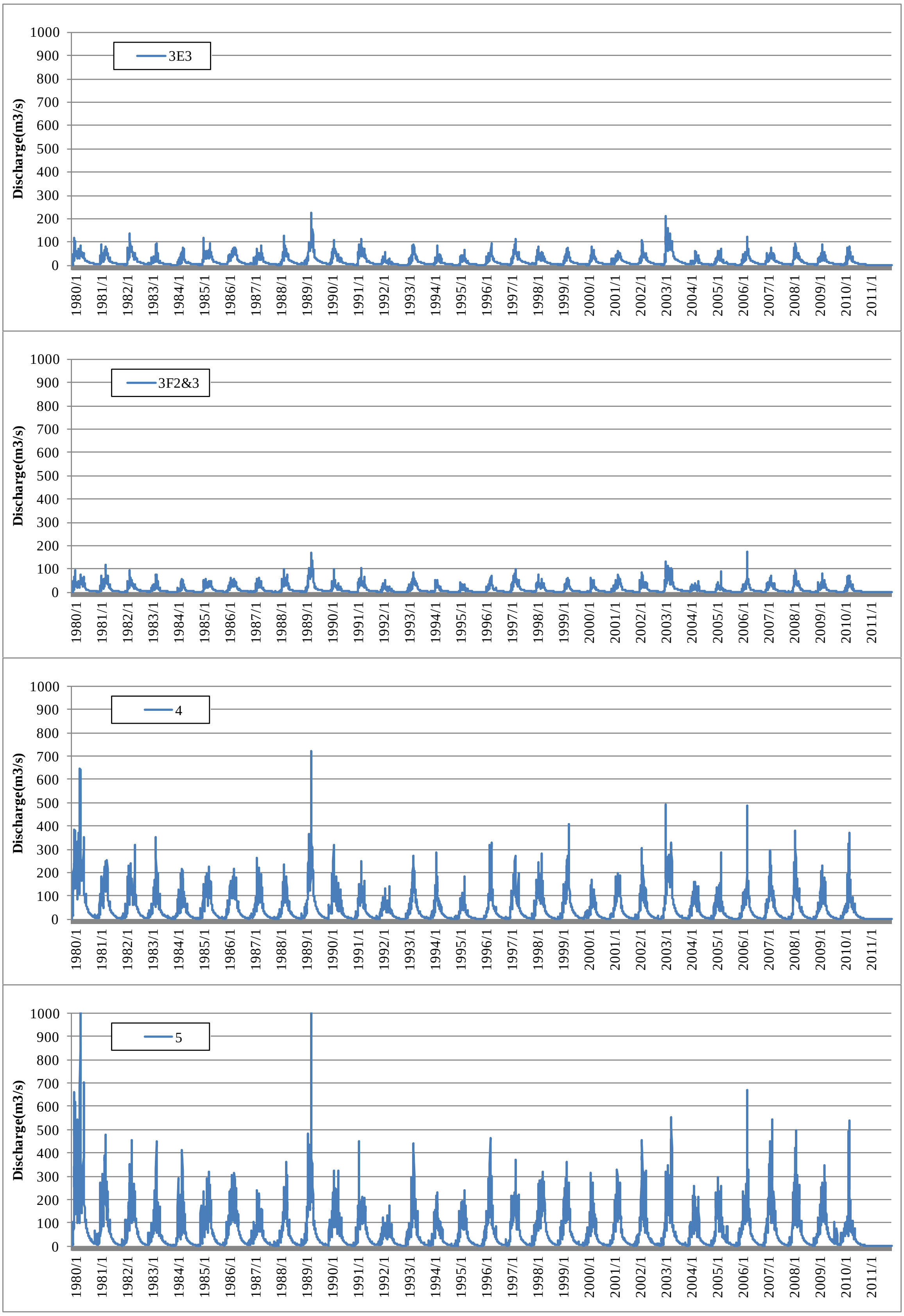


*1 Source: WATER QUALITY REPORTEdited ByHarvey A. Bootsma & Robert E. Hecky

*2 Source: Water Balance Model of Lake Malawi and its Sensitivity to Climate Change

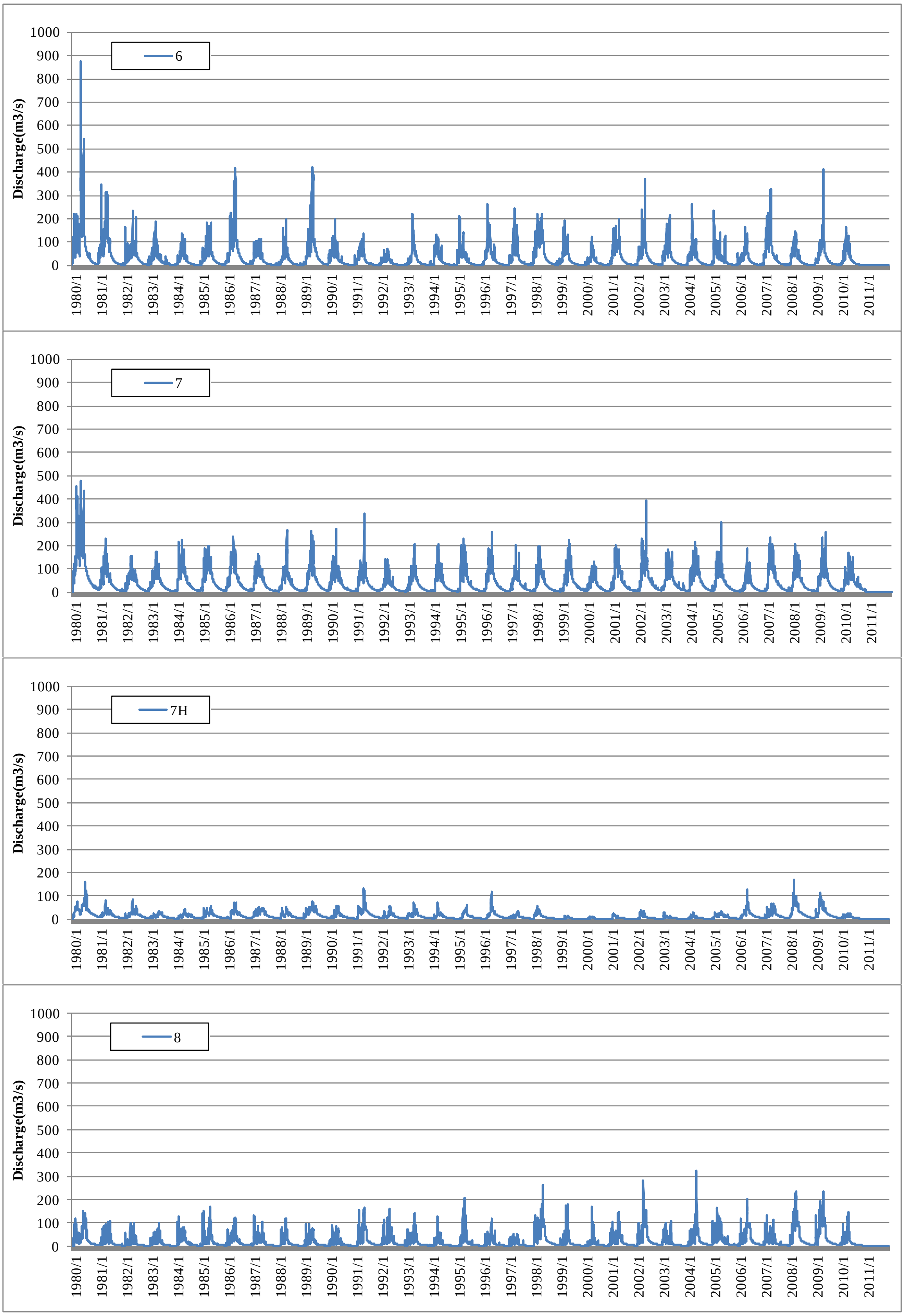
Source: Project Team

Figure 6.5.23 Ratio of River Inflow by Country



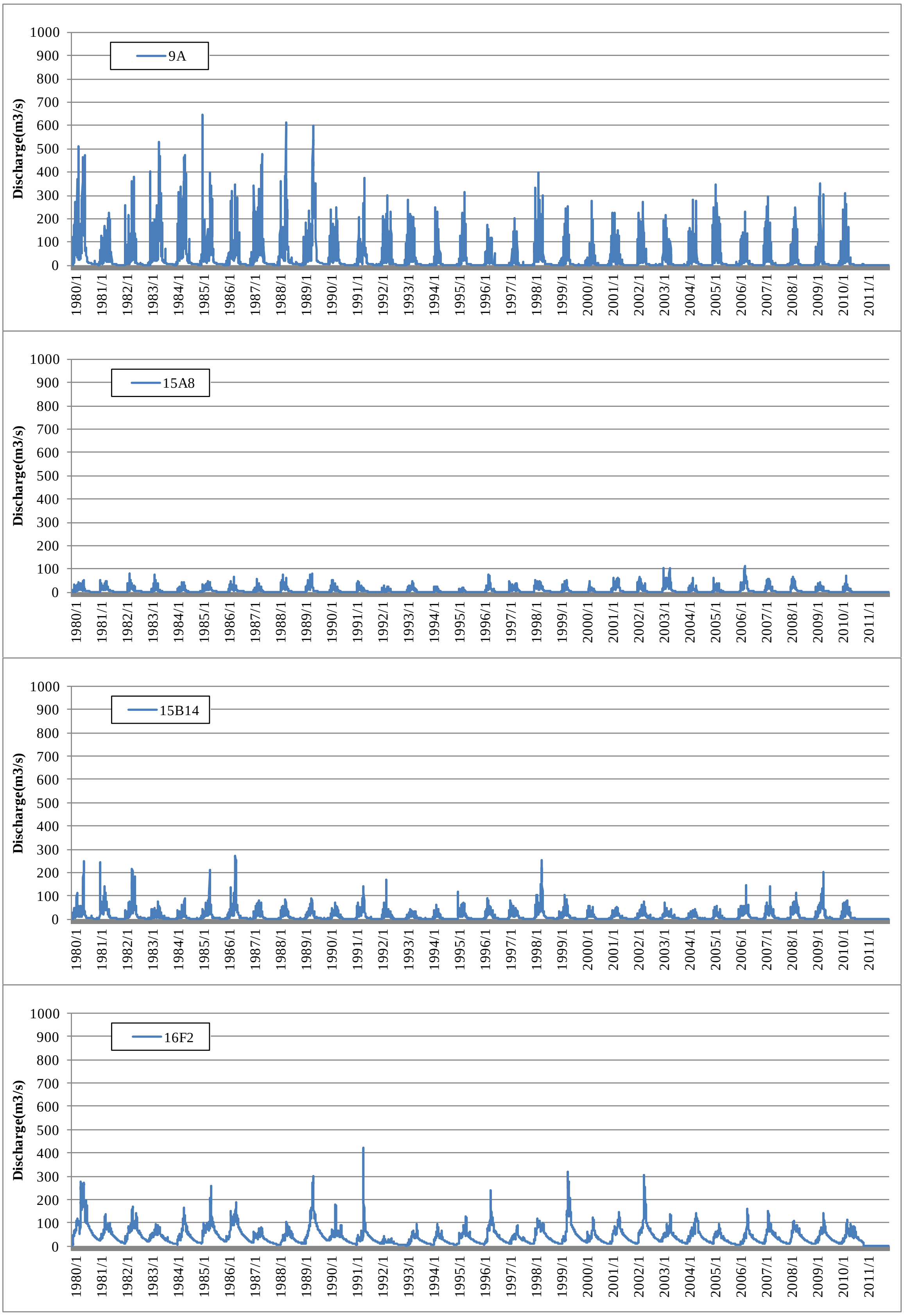
Source: Project Team

Figure 6.5.24 River Inflow from Malawi (1/4)



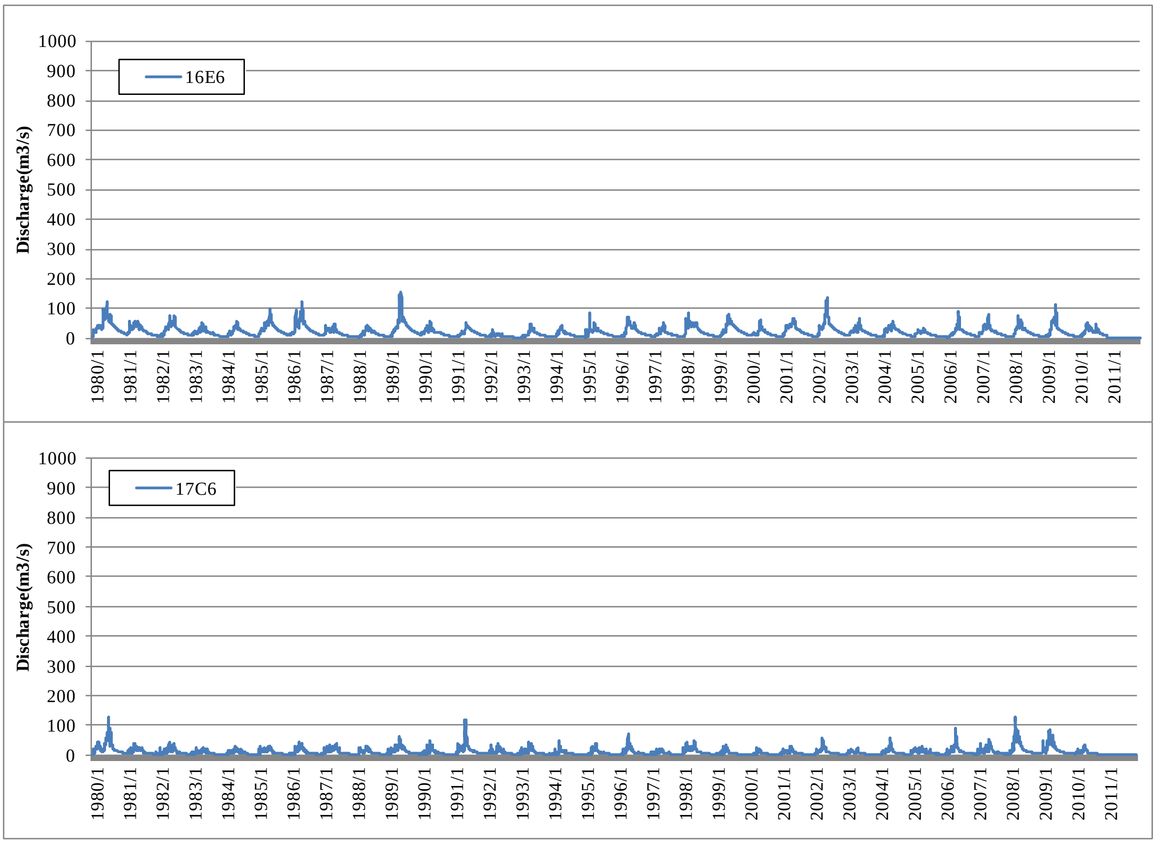
Source: Project Team

Figure 6.5.25 River Inflow from Malawi (2/4)



Source: Project Team

Figure 6.5.26 River Inflow from Malawi (3/4)



Source: Project Team

Figure 6.5.27 River Inflow from Malawi (4/4)

Table 6.5.18 Ratio of Inflow

			1983 paper	1997 calculation	2010 paper
WRA	WRA, WRU or River	Basin	Ratio of Lake Malawi Inflow (%)	Ratio of Lake Malawi Inflow (%)	Ratio of Lake Malawi Inflow (%)
3	WRA3	Southern Lakeshore & Mtakataka Lakeshore	3.2	3.6	2
4	WRA4	Linthipe	4.5	11.9	5
5	WRA5	Bua	3.7	3.9	5
6	WRA6	Dwangwa	2.4	1.6	2
7	South Rukuru	South Rukuru	4.2	1.4	6
	North Rumphi	North Rumphi	1.6	1	2
8	WRA8	North Rukuru	1.7	1.5	2
9	Lufira	Lufira	1.2	0.7	2
	Songwe	Songwe	6.1	7.3	8
15	WRU15	Nkotakota Lakeshore	5.2	9	0
16	WRU16F&G	Luweya & Usisya Lakeshore	5.4	1.8	6
	WRU16E	Dwambadzi Lakeshore	3.9	2.2	
17	WRA17	Karonga Lakeshore	1.9	1.5	0
Malawi Total (including Songwe basin in Tanzania, except WRA10)			45	47.4	40
Tanzania (except Songwe basin)			48.1	45.7	51
Mozambique (including WRA10)			6.8	7.2	8
Total			99.9	100.3	99
			*1	*1	*2

*Assumption of allocation of WRA10

*1 Source: WATER QUALITY REPORTEdited ByHarvey A. Bootsma & Robert E. Hecky

*2 Source: Water Balance Model of Lake Malawi and its Sensitivity to Climate Change

Source: Project Team

(ii) Estimation of Ratio of River Inflow by Country using CRU Data (Mesh Rainfall Data)

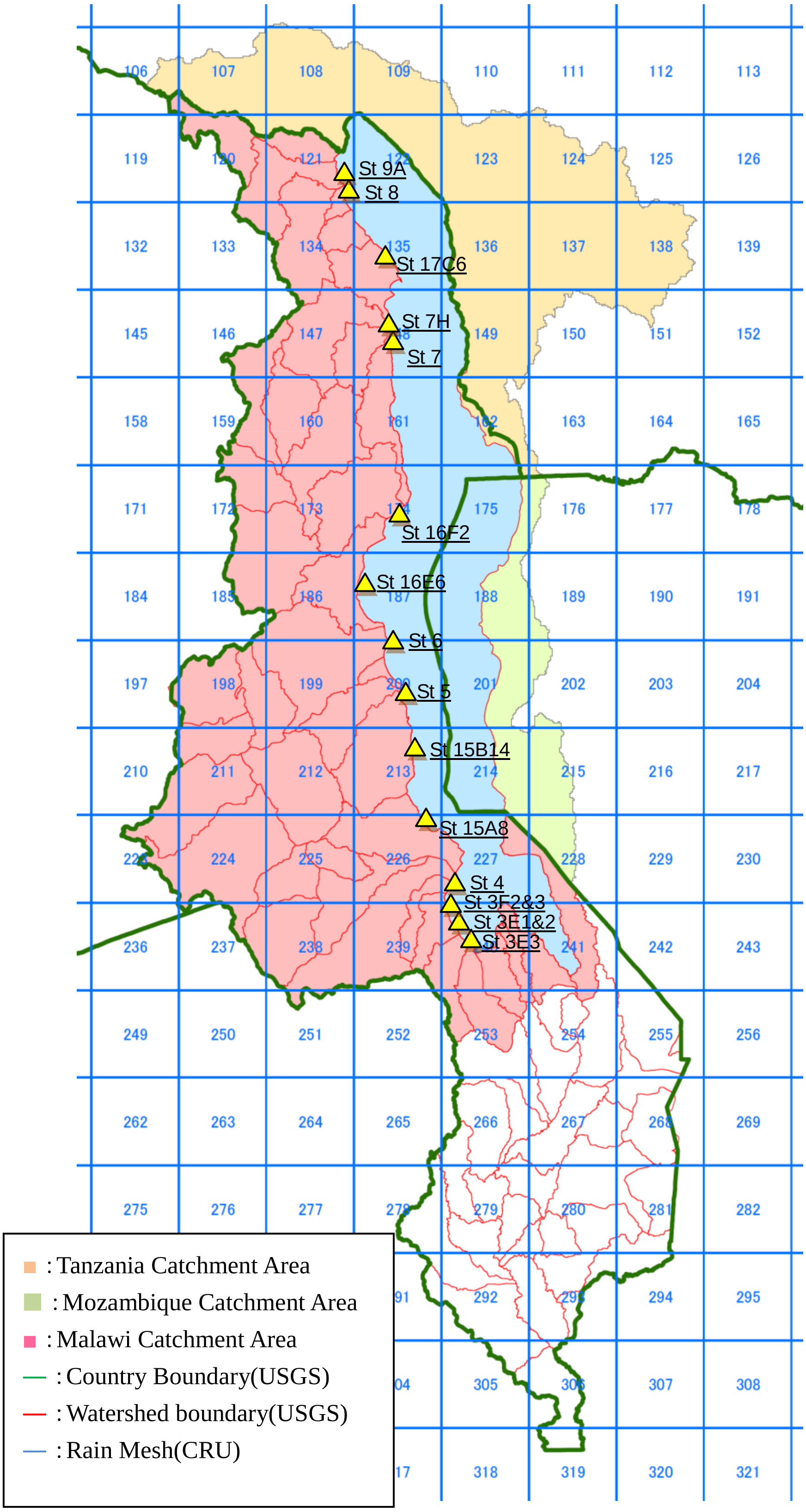
-Outline of CRU Data

The ratio of river inflow by country of existing study is not suitable for daily calculation as mentioned before. Therefore, ratio of river inflow by country is estimated by using the Climatic Research Unit (CRU) TS (time series)Version 3.10.01 rainfall data. CRU data is global data set from University of East Anglia. The outline of the data is shown in **Table 6.5.19**. Mesh of CRU data and watershed of Lake Malawi is shown in **Figure 6.5.28**.

Table 6.5.19 Outline of CRU TS Data

	CRU 3.10.01
Data	Precipitation, etc.
Period	1901-2009
Cover Area	360-lat x 720-long grid on land area
Grid Size	0.5x0.5 degree (720 columns, 360 rows)
Monthly/Daily	Monthly
Data Access	https://hc.box.com/shared/f9mgrl1qfx
Data Format	• ASCII data • NetCDF data

Source: Project Team

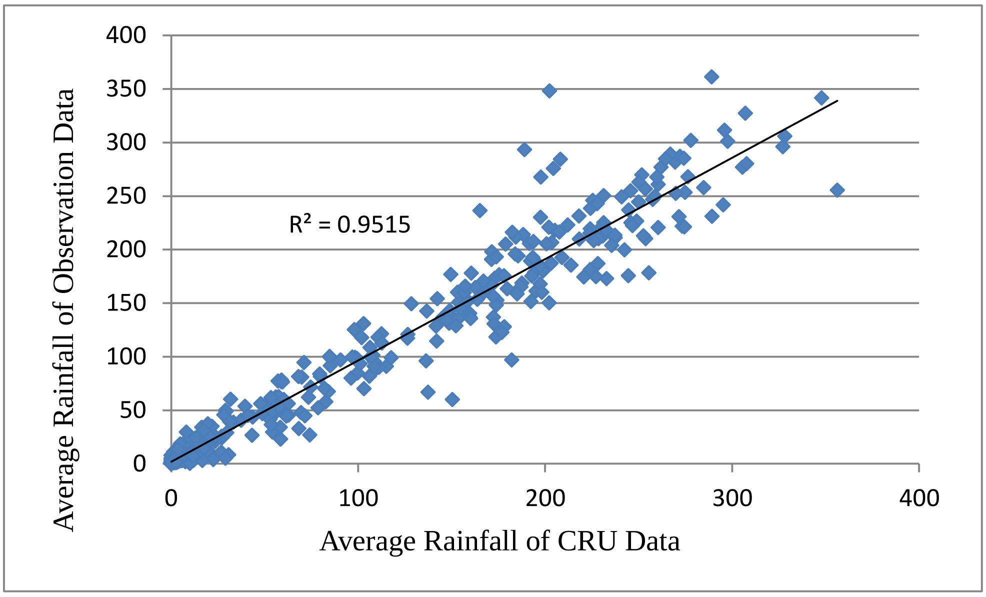


Source: Project Team

Figure 6.5.28 CRU Mesh and Watershed of Lake Malawi

-Verification of CRU Rainfall Data

To verify the CRU rainfall data, average rainfall of CRU data and observed rainfall data are compared. The result is shown below. The correlation between them is high. Therefore, CRU rainfall data is valid.

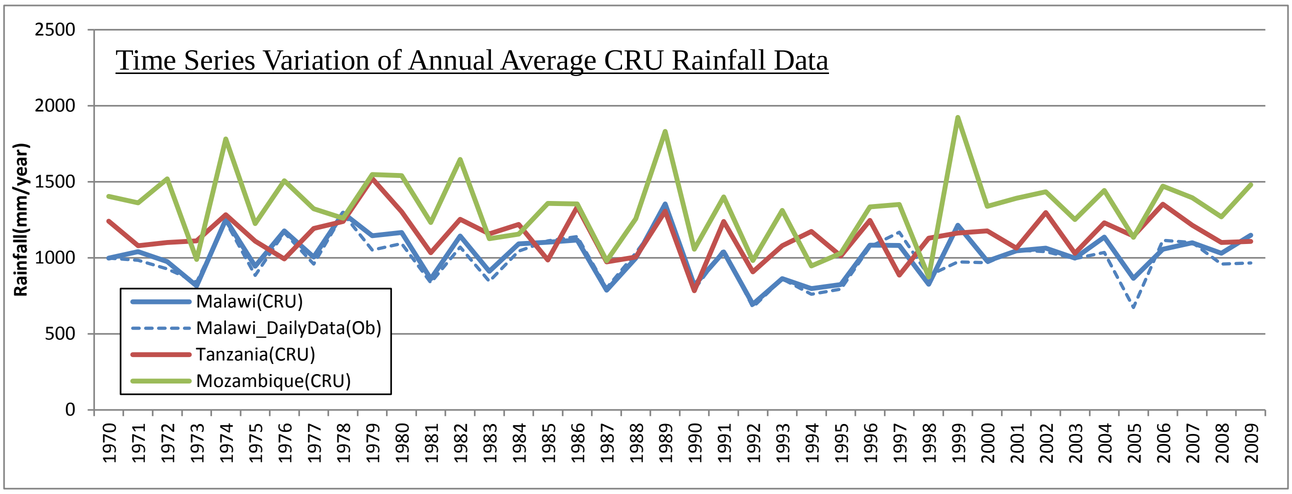


Source: Project Team

Figure 6.5.29 Comparison of Observed and CRU Data (1970.1-2009.12)

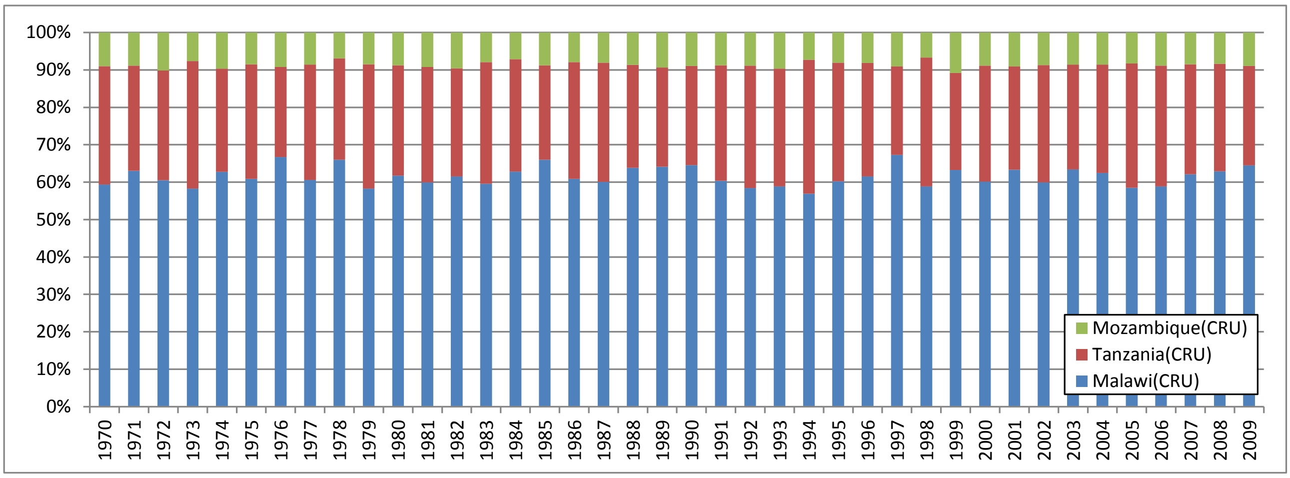
-Time Series Variation of Annual CRU Rainfall Data

Time series variation of annual average CRU rainfall data and ratio of annual rainfall by country is shown in **Figure 6.5.30** and **Figure 6.5.31**. Time series of annual average CRU rainfall data fluctuates. On the other hand, ratio of annual rainfall by country is almost the same. The ratio of Malawi, Tanzania and Mozambique is 60%, 30% and 10% respectively. The variation of rainfall of the countries shows the same trend, but the year with the smallest rainfall is different among the countries.



Source: Project Team

Figure 6.5.30 Annual Rainfall of CRU



Source: Project Team

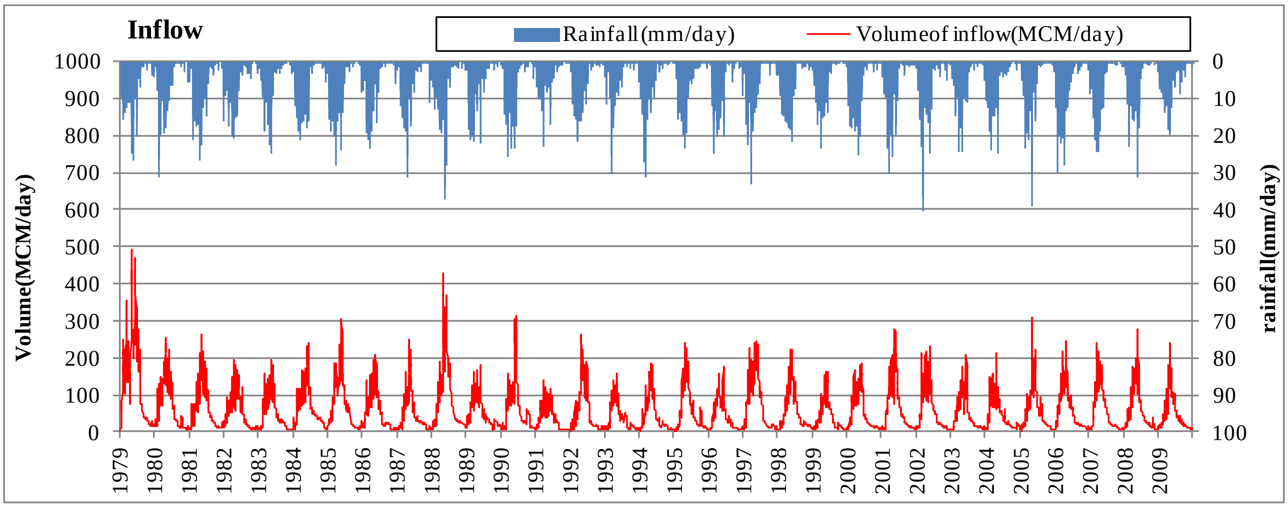
Figure 6.5.31 Ratio of Annual Rainfall by Country

-Time Series Variation of Monthly CRU Rainfall Data

The ratio of monthly rainfall by country is shown in **Figure 6.5.33** to grasp the difference between wet season and dry season. Since the ratio by country is different by month, the river inflow from Tanzania and Mozambique is estimated using the ratio of monthly CRU rainfall data to represent monthly variations.

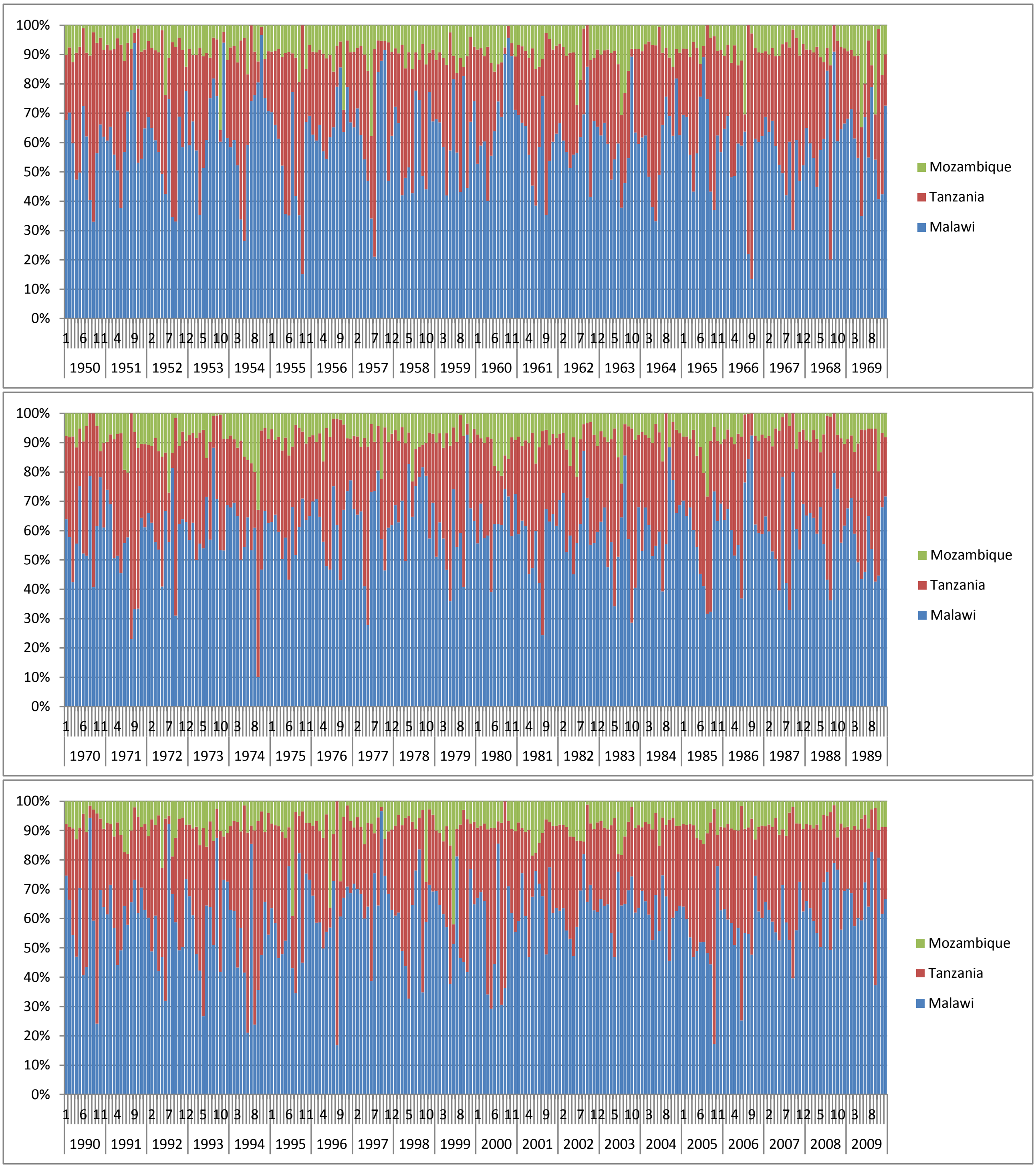
(iii) Estimation of River Inflow to Lake Malawi

The total river inflow to Lake Malawi is estimated by increasing the river inflow of Malawi which is calculated by the rainfall runoff model using the ratio of monthly CRU rainfall data by country. This is shown in **Figure 6.5.32**. The river inflow in wet season fluctuates annually. The river inflow in dry season is a few percent of that in wet season.



Source: Project Team

Figure 6.5.32 Inflow Volume of Lake Malawi



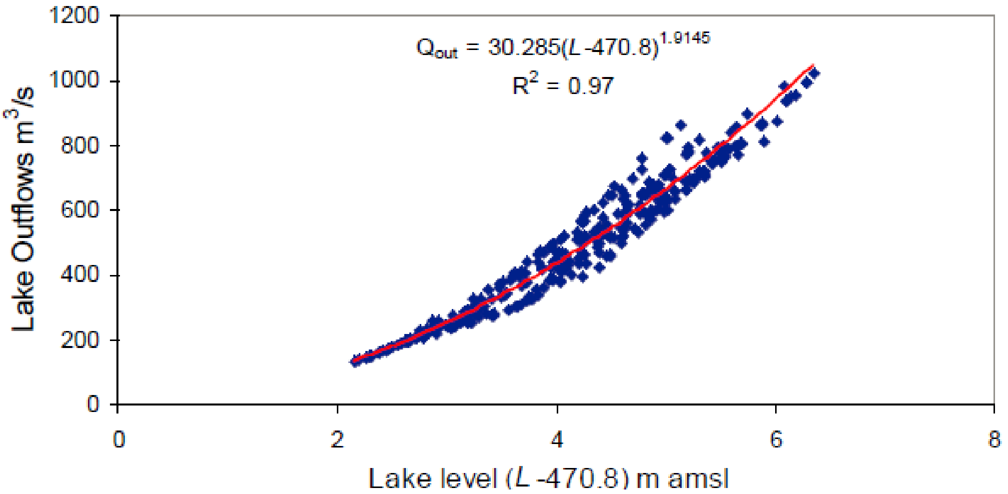
Source: Project Team

Figure 6.5.33 Ratio of Each Country to Rainfall of Lake Malawi Basin

(4) River Outflow from Lake Malawi

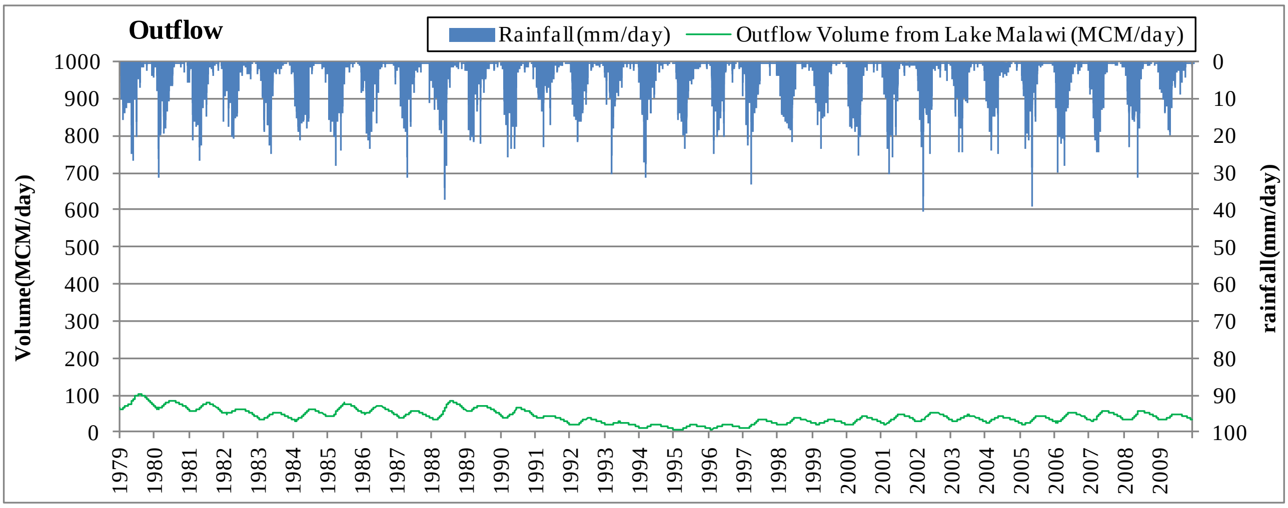
The outflow from Lake Malawi flows down to the Shire River. The flow from the outlet of Lake Malawi can be estimated by relational expression of existing study between water level of the lake and the discharge of 1T1 station located downstream of the lake. The relationship is shown in **Figure 6.5.34**.

The estimated outflow from the lake is summarized in **Figure 6.5.35**. As compared with the inflow, the variation of the outflow is smaller.



Source: Water Balance Model of Lake Malawi and its Sensitivity to Climate Change, Patsani G Kumambala and Alan Ervine, The Open Hydrology Journal, 2010, 4, 152-162

Figure 6.5.34 Correlation between Water Level and Outflow from Research Paper



Source: Project Team

Figure 6.5.35 Outflow Volume of Lake Malawi

(5) Groundwater Inflow to Lake Malawi

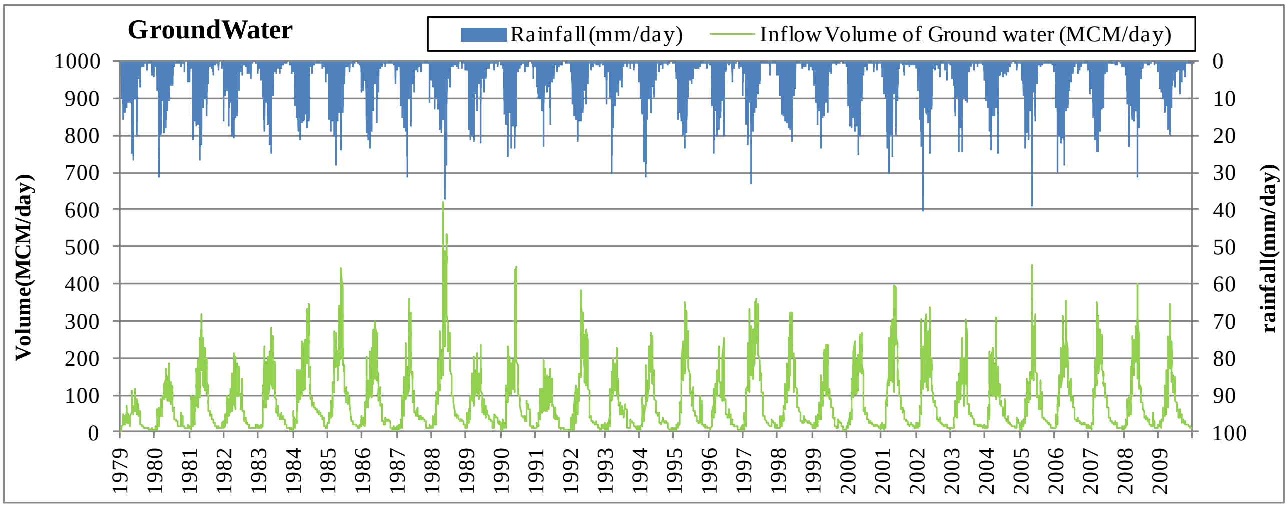
Groundwater level around Lake Malawi increases a few meters after wet season from the observed groundwater level in well (**Chapter 3**). Therefore, it is useful to estimate groundwater inflow using ratio of rainfall.

It is assumed that infiltration to groundwater is the remainder obtained by subtracting evaporation and river flow from rainfall and some percentage of infiltration flows into Lake Malawi as groundwater inflow. As a result of trial calculation, groundwater inflow to Lake Malawi is assumed as infiltration.

<Estimation Method of Groundwater Inflow>

Infiltration = Rainfall – Evaporation – River Flow

Groundwater Inflow = Infiltration * 1.00



Source: Project Team

Figure 6.5.36 Inflow Volume of Groundwater

(6) Groundwater Outflow from Lake Malawi (Infiltration, Seepage)

From the contour line of groundwater level, groundwater inflow around Lake Malawi is from the west area like the gradient of surface and outflow from the southern tip of Lake Malawi in the direction of the Shire River (**Figure 6.2.13**). Infiltration and seepage from Lake Malawi is considered, but it is difficult to quantify them. Therefore, the calibration parameter of groundwater outflow from Lake Malawi is assumed and estimated under the following assumptions.

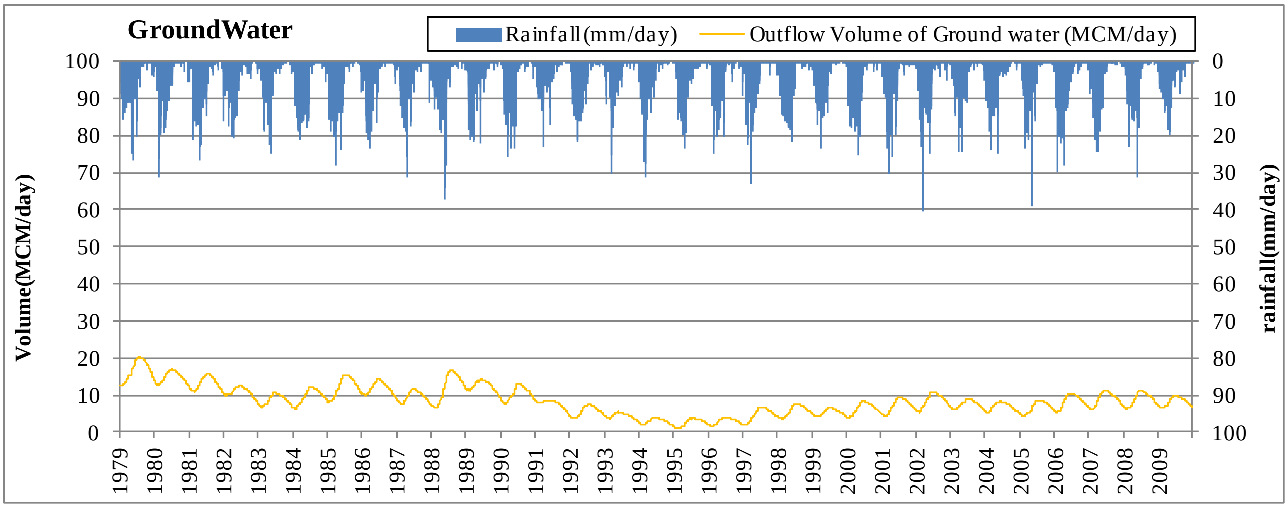
-The osmotic pressure is assumed higher as the volume (water level) is larger.

-That is, it is assumed that groundwater outflow fluctuates like the river outflow because there is a relation between the water level of Lake Malawi and river outflow.

As a result of trial calculation, groundwater outflow from Lake Malawi is estimated by multiplying 0.20 to river outflow.

<Estimation Method of Groundwater Outflow>

Groundwater Outflow = River Outflow * 0.20



Source: Project Team

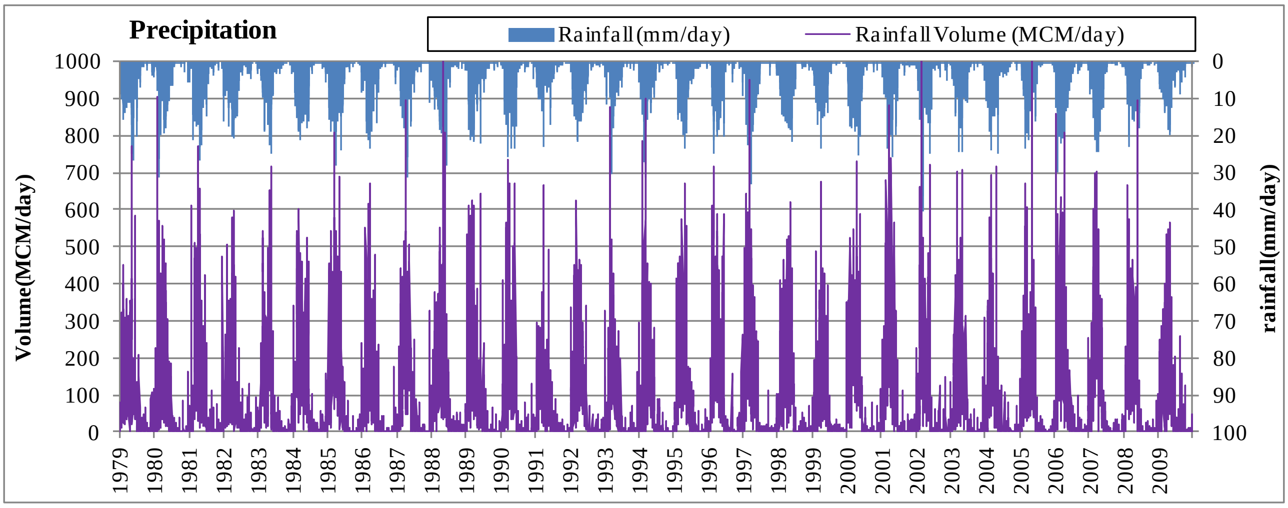
Figure 6.5.37 Outflow Volume of Groundwater

(7) Rainfall and Evaporation from Lake Malawi

Rainfall and evaporation from Lake Malawi is assumed as average rainfall and evaporation of land area in Malawi. There is no evaporation data after 2003 and there is missing data after 2001. Therefore, daily evaporation after 2001 is the daily divided monthly average value from 1991 to 2000. These are shown in **Figure 6.5.38** and **Figure 6.5.39**.

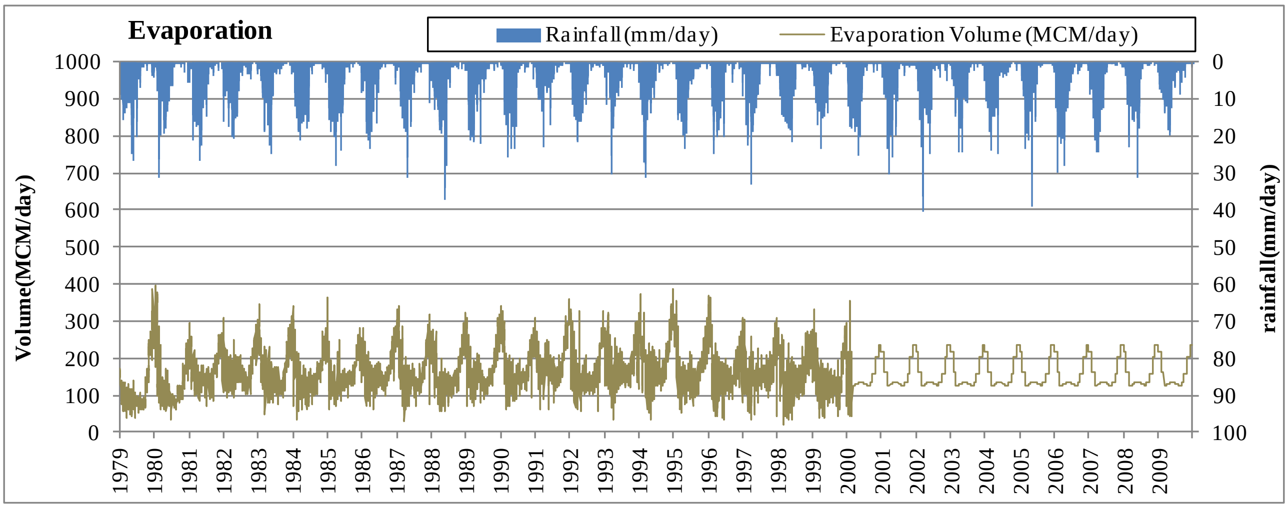
To calculate the volume of rainfall and evaporation, the surface area of Lake Malawi is needed. It is different by water level, but the variation range is about 4 m as shown in **Figure 6.1.27**. On the other hand, accuracy of bathymetry of existing study (**Figure 6.5.40**) is 100 m which is rougher than that of variation range of water level of Lake Malawi. Therefore, surface area is assumed constant which is 28,760 km^{2*}.

* Source: National Water Resources Master Plan (1986)



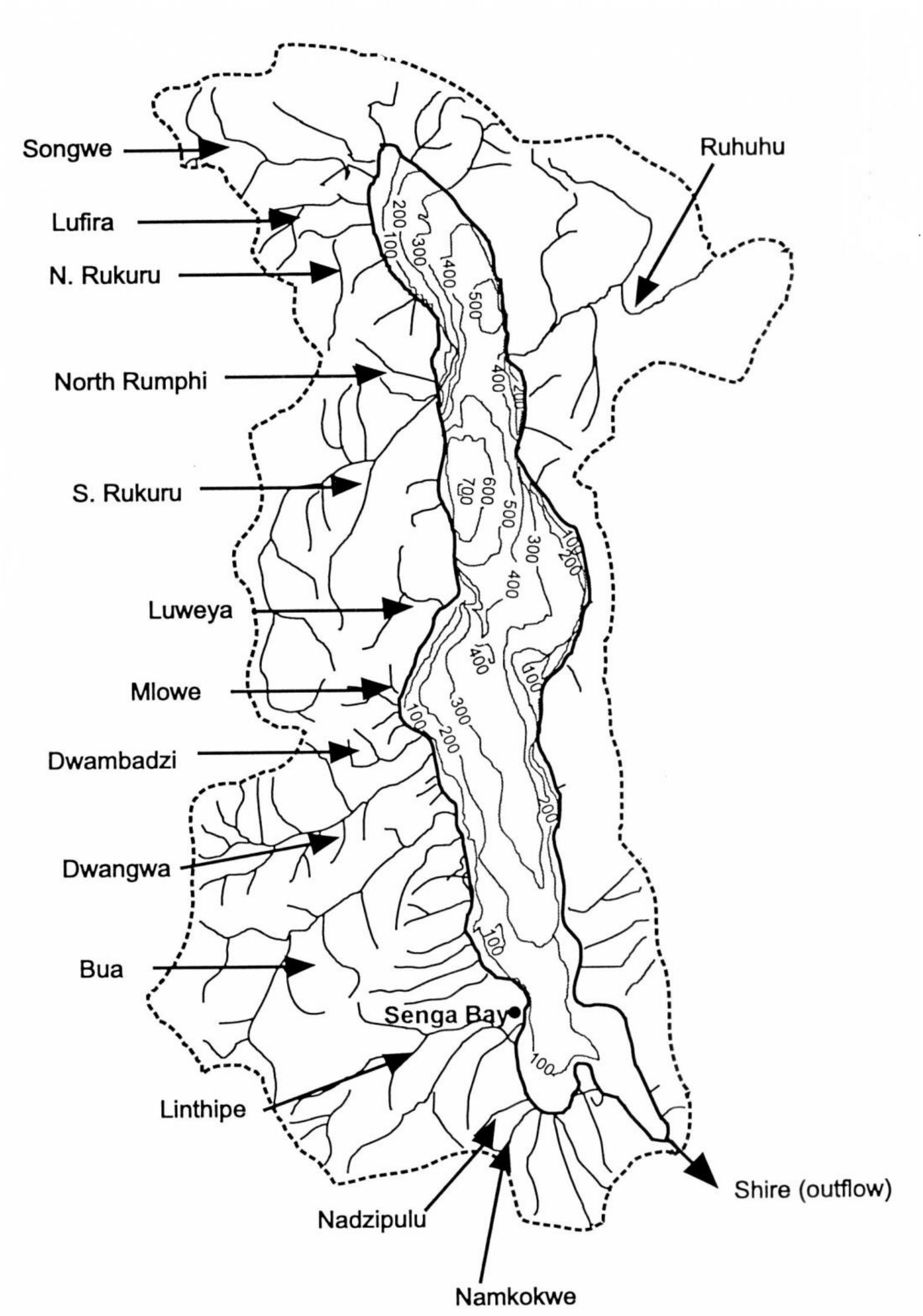
Source: Project Team

Figure 6.5.38 Inflow Volume of Rainfall



Source: Project Team

Figure 6.5.39 Outflow Volume of Evaporation

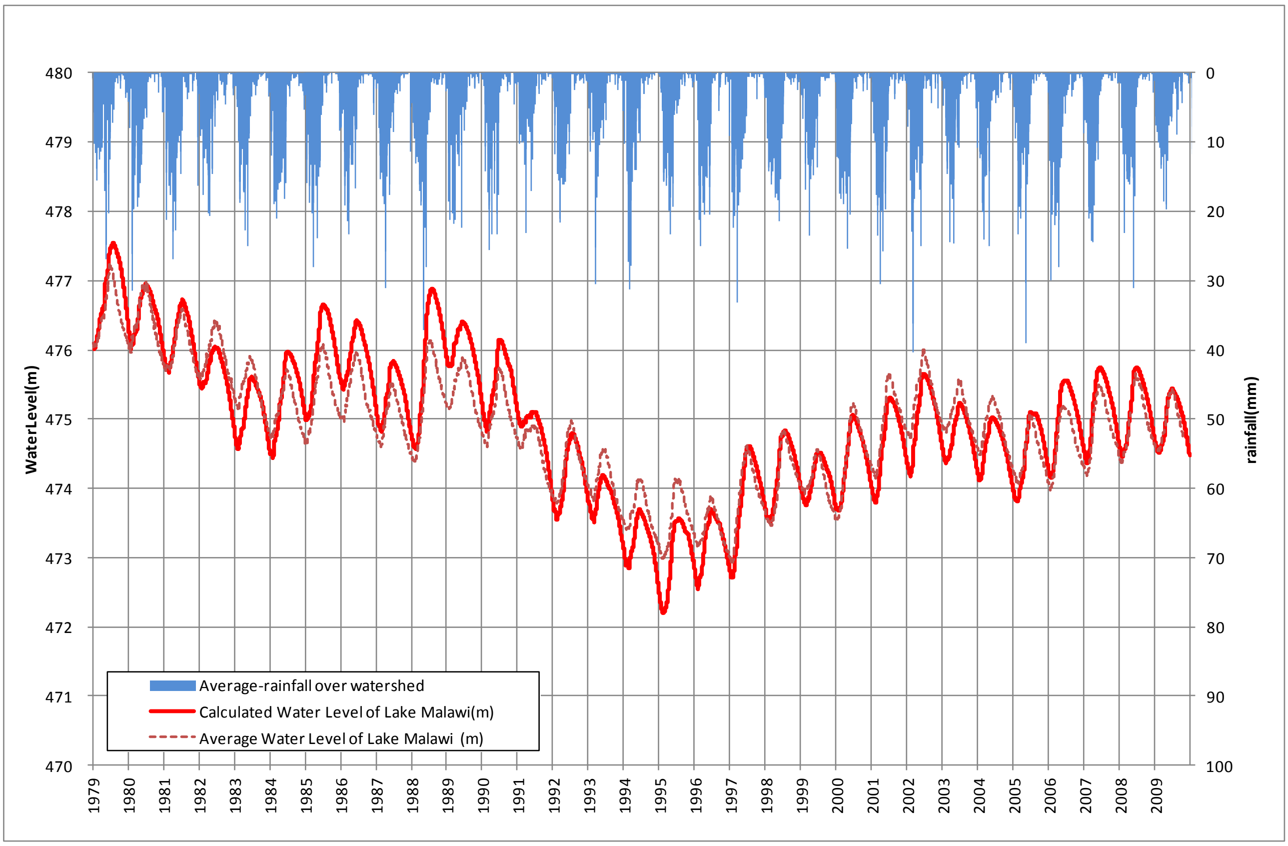


Source: WATER QUALITY REPORT Edited By Harvey A. Bootsma & Robert E. Hecky

Figure 6.5.40 Bathymetry of Lake Malawi

(8) Calibration of the Model

Calibration period is for 30 years from November 1981 to October 2010. The result is shown in **Figure 6.5.41**. The variation of wet season and dry season and the annual variation are well represented by the model.



Source: Project Team

Figure 6.5.41 Calibration of Water Level of Lake Malawi

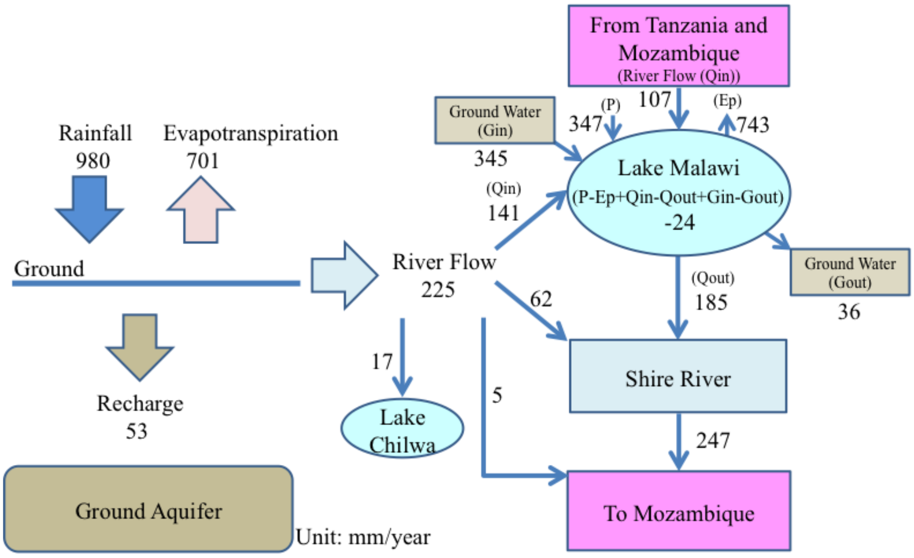
6.5.3 Estimation of Water Resources in Malawi

The water balance in Malawi is calculated by the average of 30 years from November 1980 to October 2010 applying the rainfall runoff model and the water balance model of Lake Malawi. As shown in **Figure 6.5.42**, rainfall is 980 mm, evapotranspiration is 701 mm, river flow is 225 mm and recharge is 53 mm. River flow volume and recharge volume is 21.2 bil. m^3/year and 4.9 bil. m^3/year respectively.

The water balance by WRA is shown in **Table 6.5.20**. River flow is from 129 mm/year to 582 mm/year, and recharge is from 22 mm/year to 183 mm/year. Ratios of recharge to rainfall is from 3% to 17%.

The annual water balance of Lake Malawi is shown in **Figure 6.5.43** and **Figure 6.5.44**. The ratio of evaporation is highest at 39.0%. The rainfall and groundwater inflow are highest among inflow which value is 18.1%.

The water balance of Lake Malawi is that total outflow is higher than total inflow. It is because the water level of Lake Malawi tends to decrease in the calculation period.



Source: Project Team

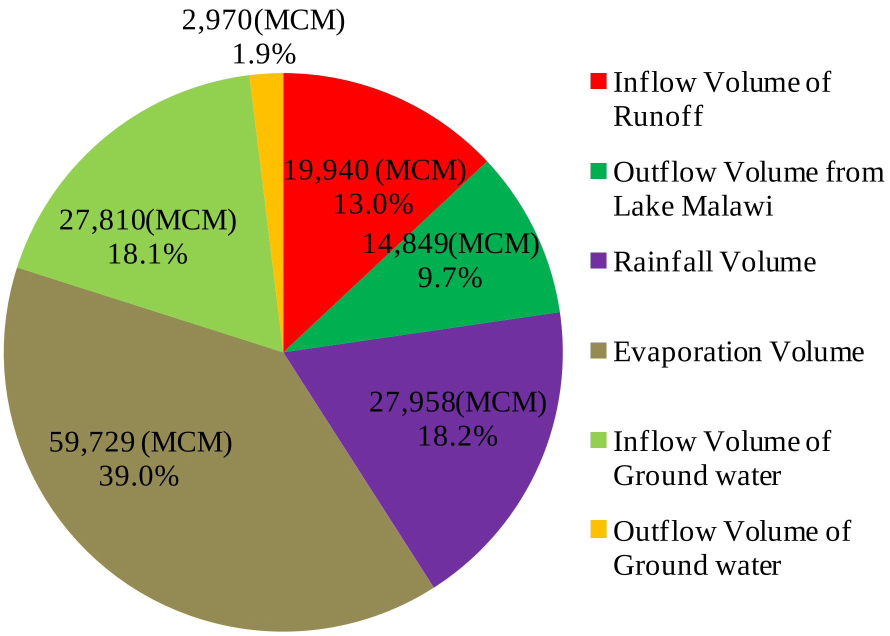
Figure 6.5.42 Water Balance in Malawi

Table 6.5.20 Water Balance by WRA

Unit: mm

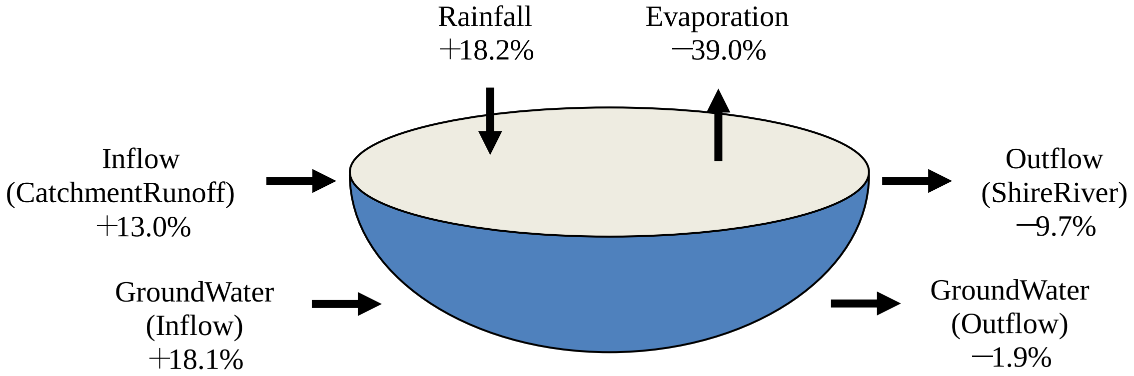
WRA	P	Ep	Q	Re	Re/P
Total	980	701	225	53	5%
1	888	656	201	30	3%
2	1086	558	345	183	17%
3	910	640	222	47	5%
4	929	737	154	38	4%
5	944	729	180	35	4%
6	931	767	129	35	4%
7	807	648	138	22	3%
8	1285	932	306	47	4%
9	1065	797	233	35	3%
10	874	709	139	26	3%
11	941	634	212	95	10%
14	1436	768	582	85	6%
15	1139	734	301	104	9%
16	1222	691	439	92	8%
17	1153	802	261	90	8%

Source: Project Team



Source: Project Team

Figure 6.5.43 Pie Chart of Water Balance of Lake Malawi



Source: Project Team

Figure 6.5.44 Water Balance of Lake Malawi

6.5.4 Water Utilization Model

To estimate water balance in Malawi, water resources amount and water demand are compared so that water deficit is estimated. The water balance is studied by each water resource mentioned below.

For the calculation of surface water balance, the water utilization model (MIKE BASIN) was established. In the water utilization model, the deficit is calculated comparing water demand with river flow discharge. The river flow discharge is calculated by the verified rainfall runoff model. Therefore, calibration of the water utilization model is not needed. The dam for water supply (Mulunguzi, Mudi, Mpira, Lunyangwa, Kamuzu, Chitete) and the large dams for hydropower (Tedzani, Kapichira, Nkula) are mounted on the model.

For groundwater balance, volume of recharge and water demand of groundwater is compared to study sustainability in water use. The result of the Darcian flow method is applied as recharge. The result of rainfall runoff model is applied as reference.

To confirm water balance of Lake Malawi, water balance model of Lake Malawi is independently established.

(1) Environmental Flow

The environmental flow is the ensured flow for river environment in order to reduce the impact of human activity such as intake for irrigation and hydropower.

There are some methods to estimate environmental flow but there is no prescribed guideline for environmental flow in Malawi. In the water board in Malawi, the following methods are applied to estimate environmental flow in the study on water resources development such as the planning of dam.

1. Lilongwe Water board

Applied higher value estimated by the following method:

-The minimum monthly flow of the 1-in-10 dry year (Aquatic Base Flow Method)

-The flow rate estimated by flow measurement at the end of dry season 2009

2. Blantyre Water Board

-The minimum monthly flow of the 1-in-10 dry year in the plain (Aquatic Base Flow Method)

-The average minimum dry flow less evaporation losses for over a 10-year period for rivers in mountains.

3. Northern Region Water Board

-Minimum flow equal to 10% of the average annual flow (Tennant Method)

As the result of discussion with MoAIWD, the flow duration curve analysis method is applied for estimation of environmental flow which is 90 percentile flow (Q90). For the calculation of environmental flow, the flow calculated by the rainfall runoff model is applied because there is missing observed flow data and the quality of observed flow is not good.

The environmental flow is indicated in **Table 6.5.21**. In case several major rivers flow down in WRUs such as 15A, 15B and so on, the environmental flow of the WRUs is estimated by summing environmental flow of each river in WRU.

In the feasibility studies and preliminary design for Lilongwe's new water source, the minimum flow in the rivers is studied by low flow measurement and the specific mean flow is determined as 0.1 $l/s/km^2$. Likewise, in the consultancy services for feasibility studies and preliminary design for Blantyre's new raw water source and other purposes, the minimum flow in the rivers is studied by low flow measurement and a specific mean flow is determined as 6.43 $l/s/km^2$ at the sites located in mountains, 1 $l/s/km^2$ in the rivers south of Blantyre and 0.2 $l/s/km^2$ in the rivers north of Blantyre. From the environmental flow from Q90, specific flow of WRU4D which is located at Lilongwe is 0.28, and that of WRU1E which is located at Blantyre is 0.2. Comparing with these, the environmental specific flow in the Project is appropriated.

(2) Target Drought

Water balance has been examined in 10-year drought level. Two-year drought is studied as a reference. The target drought assumes that of the total runoff volume in dry season considering the hydrological characteristics. In WRAs it is defined as the target drought at the lowest basin. In a WRAs consisting of not only one basin such as the basin around Lake Malawi, the target drought of total runoff volume in dry season is assumed as shown in **Table 6.5.22**

(3) Water Demand

The Environmental flow, water supply demand (for river and dam command area), irrigation demand and demand for livestock are summarized. At the moment, the tentative priority level is set to calculate water deficit as described below; however, the priority will be made sure at the M/P formulation phase.

The first priority of water intake is the security of environmental flow. The environmental flow is the needed flow to reduce the impact on natural environments caused by artificial intake. After securing environmental flow, the artificial intake is conducted. The second is water supply demand which is vital water for human beings. The third is irrigation demand which is the largest demand in Malawi. The fourth is demand for livestock.

There is return flow only for paddy. Of the used water in paddy, 10% returns to the river.

Water demand is as shown in **Table 6.5.23** to **Table 6.5.26** and in **Figure 6.5.45** and **Figure 6.5.46**. The 75% of demand excluding environmental flow is irrigation demand. Water supply in a large city such as Lilongwe (4D), Blantyre, Muzuzu (7D) and Zomba (2B) is large compared with water supply in other WRU. Intake for water supply of Blantyre is located at the Shire River and it is inter-basin diversion to Blantyre. Therefore, demand of Blantyre is summarized separately.

Table 6.5.21 Environmental Flow

WRA	WRU	Environmental Flow (m3/s)	WRA	WRU	Environmental Flow (m3/s)	WRA	WRU	Environmental Flow (m3/s)
1 (Shire River)	1A	350.07	5	5C	3.82	1 (Tributaries)	1A	1.84
	1B	360.40		5D	2.81		1B	1.79
	1C	364.03		5E	1.26		1C	1.28
	1E	372.47		5F	0.76		1E	2.03
	1F	407.69	6	6A	0.21		1F	1.72
	1G	411.60		6B	0.18		1G	2.98
	1H	381.45		6C	0.58		1H	2.63
	1K	377.67		6D	1.93		1K	2.05
	1L	374.42	7	7A	1.42		1L	1.43
	1M	369.36		7B	2.01		1M	0.85
	1N	367.41		7C	2.65		1N	0.39
	1O	366.47		7D	1.74		1O	1.19
	1P	362.11		7E	2.97		1P	0.94
	1R	357.34		7F	3.51		1R	1.82
	1S	353.28		7G	5.86		1S	1.41
	1T	347.91		7H	3.15		1T	0.53
2	2A	0.07	8	8A	2.73			
	2B	0.47	9	9A	0.64			
	2C	0.12		9B	0.65			
	2D	0.04	10	10A	0.11			
3	3A	0.82	11	11A	0.41			
	3B	0.59	14	14A	0.16			
	3C	1.35		14B	1.21			
	3D	1.14		14C	7.01			
	3E	1.38		14D	8.75			
	3F	0.63	15	15A	2.20			
4	4A	0.14		15B	2.86			
	4B	2.48		15C	0.31			
	4C	1.37	16	16E	8.65			
	4D	0.52		16F	8.87			
	4E	0.25		16G	4.71			
	4F	0.12	17	17A	0.07			
				17B	1.15			
				17C	2.39			

Source: Project Team

Table 6.5.22 Ten-Year Drought by WRA

WRA	1/2 Year	WRA	1/2 Year	WRA	1/10 Year	WRA	1/10 Year
1	2009/2010	8	1984/1985	1	1995/1996	8	2002/2003
2	2000/2001	9	2003/2004	2	1994/1995	9	2007/2008
3	1989/1990	10	1999/2000	3	1993/1994	10	1991/1992
4	1982/1983	11	2008/2009	4	1993/1994	11	1994/1995
5	1987/1988	14	1992/1993	5	1991/1992	14	1994/1995
6	1992/1993	15	2006/2007	6	1994/1995	15	1999/2000
7	2000/2001	16	1997/1998	7	1999/2000	16	2004/2005
		17	2001/2002			17	1996/1997

Source: Project Team

(4) Surface Water Balance in Present Condition

The water balance in present condition is studied by WRU comparing between total water demand and total surface water resources in each WRU.

With regard to WRA1, there is the Shire River, but the Shire River flows in a low land area. When the water in the Shire River is utilized, it may be needed to pump up the water which is costly due to necessity of additional water-related facility. Therefore, water demand is compared not with water resources of the Shire River but with that of own basin in this section.

The present water balance will be examined in 10-year drought level. Two-year drought is studied as a reference.

The flow of study is given below:

1. Calculation of natural flow (rainfall runoff model)
2. Calculation of flow considering water utilization (water utilization model)
3. Calculation of water level in Lake Malawi and flow to the Shire River using item 2. (water balance model of Lake Malawi)
4. Calculation of deficit comparing with water utilization (water utilization model)

The results summarized by WRA are shown in **Figure 6.5.45** and **Figure 6.5.48**. The inflow, demand and deficit are summarized by month while calculation is conducted daily. Therefore, even if the monthly inflow is higher than monthly demand, deficit occurs.

The deficit occurs in dry season and beginning of wet season. Even if the water demand is small compared with the water resources in wet season, the water resources gap between wet season and dry season is large. Therefore, deficit occurs in the dry season.

The comparison between 10- and 2-year droughts is shown in **Table 6.5.27**. Almost all deficits of WRAs in 2-year drought are lower than those in 10-year drought. The deficit of WRA1 in 2-year drought is higher than that in 10-year drought because target drought is determined by downstream of WRA. Therefore, there may not be exactly 10- or 2-year drought in WRU.

The sufficiency for water demand is estimated dividing amount of supplied water by water demand as shown in **Figure 6.5.49** by WRU. The sufficiency in central and south west regions such as WRA2, 10, 11, 14 and some WRU in WRA4, 5, 7 is not high as compared with other regions. There is a gap between sufficiency in wet season and dry season as shown in **Figure 6.5.50** and **Figure 6.5.51**.

Table 6.5.23 Monthly Water Balance (Nov-Jan) by WRA (10-Year Drought)

(1,000m^3/month)

WRA	11			12			1		
	Inflow	Demand	Deficit	Inflow	Demand	Deficit	Inflow	Demand	Deficit
1	38,507	110,799	74,204	236,728	92,141	16,963	546,168	83,015	0
2	10,808	3,625	1,596	29,105	3,674	642	257,743	3,169	18
3	21,548	16,683	38	18,775	17,088	668	104,271	16,992	1
4	29,067	12,838	1,775	68,279	12,583	258	356,261	11,454	0
5	43,195	12,774	464	137,614	11,967	0	174,376	12,007	0
6	7,863	25,861	22,074	66,856	12,041	5	193,942	7,854	0
7	21,920	24,926	9,362	32,144	25,486	10,914	96,944	25,466	6,118
8	13,359	7,451	0	45,076	7,565	0	121,135	7,394	0
9	4,618	5,234	2,891	52,020	4,874	594	120,121	3,692	0
10	1,792	620	78	9,827	468	26	19,322	531	0
11	1,425	1,928	1,390	28,428	1,934	60	112,494	1,679	0
14	30,480	24,824	10,880	68,708	24,301	1,075	346,924	24,200	0
15	12,695	19,279	7,106	18,877	16,025	1,533	137,413	14,765	0
16	67,366	59,376	176	108,753	60,360	197	216,838	59,716	0
17	10,012	10,709	902	19,803	11,030	417	27,176	9,793	0
Blantyre	189,084	3,220	0	186,828	3,327	0	307,842	3,327	0

Source: Project Team

Table 6.5.24 Monthly Water Balance (Feb-Apr) by WRA (10-Year Drought)

(1,000m^3/month)

WRA	2			3			4		
	Inflow	Demand	Deficit	Inflow	Demand	Deficit	Inflow	Demand	Deficit
1	855,132	71,102	0	1,043,034	87,431	0	660,978	111,482	0
2	258,445	2,905	0	73,783	3,169	0	35,467	3,070	326
3	218,997	15,359	0	101,554	16,705	0	62,063	16,073	0
4	235,306	10,296	0	135,734	12,379	0	69,943	10,780	0
5	159,873	10,640	0	224,501	13,252	0	136,361	11,514	0
6	151,690	6,389	0	131,928	12,948	0	64,412	20,102	0
7	193,748	23,044	405	250,927	25,466	0	157,433	24,659	282
8	70,591	6,680	0	54,558	7,394	0	87,004	7,155	0
9	127,758	3,340	0	170,618	3,689	0	17,017	3,570	0
10	4,751	490	0	28,994	499	0	5,050	571	0
11	90,411	1,516	0	35,235	1,561	0	8,128	1,512	0
14	252,449	21,882	0	98,425	24,200	0	79,646	23,423	0
15	212,730	13,601	0	222,881	14,750	0	93,448	14,279	0
16	206,187	54,018	0	311,079	59,714	0	182,803	57,794	0
17	28,472	8,877	0	39,591	9,793	0	59,912	9,477	0
Blantyre	436,647	3,113	0	704,506	3,327	0	683,904	3,220	0

Source: Project Team

Table 6.5.25 Monthly (May-Jul) Water Balance by WRA (10-Year Drought)

(1,000m^3/month)

WRA	5			6			7		
	Inflow	Demand	Deficit	Inflow	Demand	Deficit	Inflow	Demand	Deficit
1	434,896	125,649	15,309	308,894	114,992	17,058	238,816	91,040	210
2	16,196	3,784	551	6,792	3,760	704	4,546	6,556	3,836
3	41,443	18,025	0	30,346	19,640	7	23,773	22,553	1,352
4	36,249	13,851	0	20,115	18,723	401	12,350	25,138	11,048
5	65,913	14,053	0	31,937	18,762	455	18,709	29,773	14,276
6	37,953	25,315	0	18,547	25,085	6,494	10,990	17,962	6,927
7	82,098	25,606	1,989	55,116	25,532	3,469	38,292	28,769	4,824
8	22,792	7,652	0	15,650	7,705	0	12,273	7,867	0
9	7,839	5,235	0	5,520	6,844	1,330	4,153	6,032	1,879
10	1,006	808	10	610	1,097	487	383	1,773	1,390
11	3,507	2,382	0	2,799	3,507	1,122	1,693	4,320	2,642
14	61,526	27,019	26	42,990	25,462	193	30,859	36,221	10,671
15	33,163	16,946	0	23,146	20,862	832	18,309	18,535	1,105
16	150,305	60,546	0	110,782	61,924	0	90,754	66,205	0
17	28,698	11,014	0	17,310	12,589	215	17,590	11,536	100
Blantyre	659,927	3,327	0	599,640	3,220	0	562,306	3,327	0

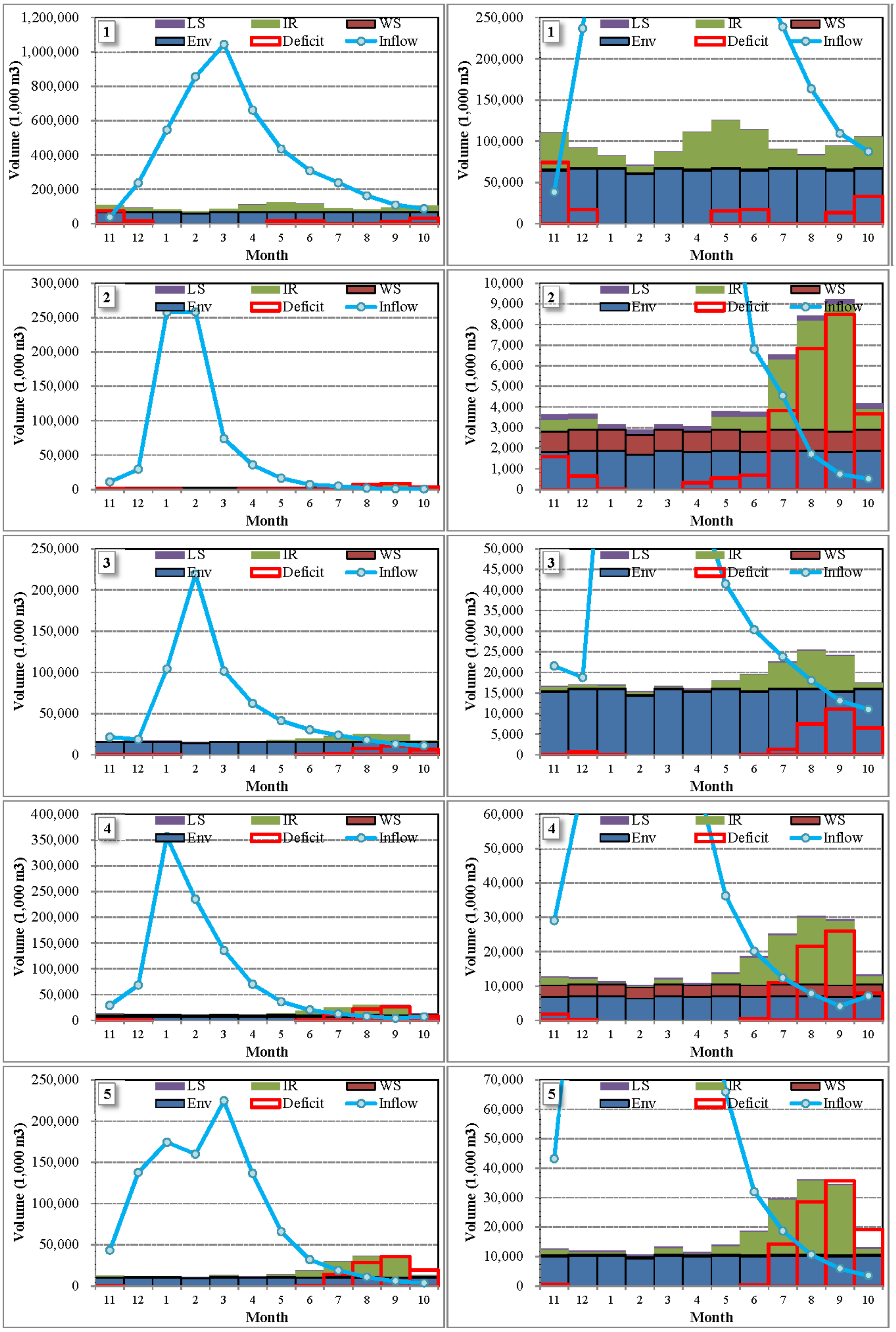
Source: Project Team

Table 6.5.26 Monthly Water Balance (Aug-Oct) by WRA (10-Year Drought)

(1,000m^3/month)

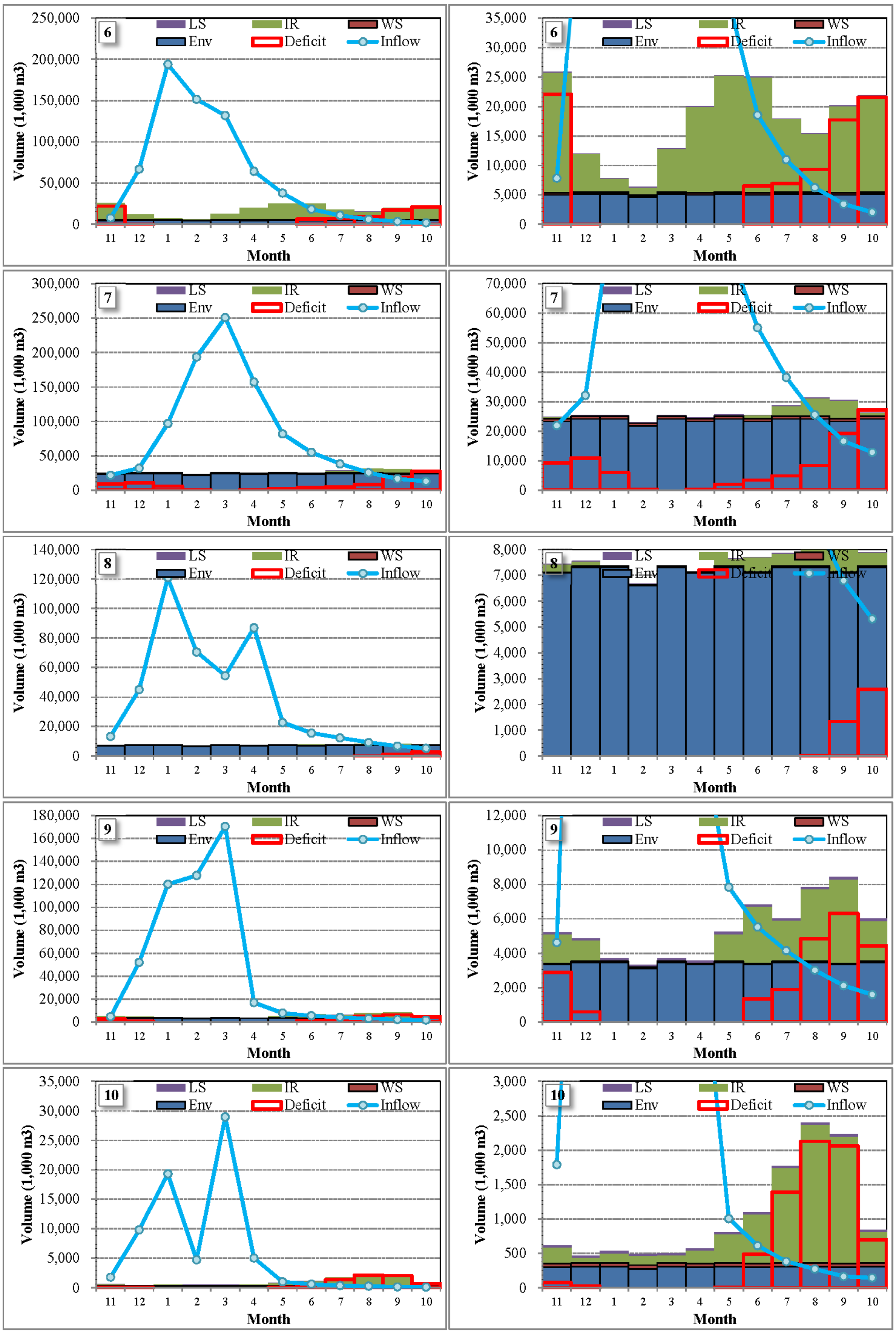
WRA	8			9			10		
	Inflow	Demand	Deficit	Inflow	Demand	Deficit	Inflow	Demand	Deficit
1	163,507	83,983	294	109,640	94,992	13,443	87,360	106,229	33,031
2	1,713	8,438	6,835	740	9,230	8,490	507	4,164	3,674
3	18,014	25,505	7,507	13,135	24,209	11,073	11,027	17,581	6,554
4	7,796	30,322	21,621	4,138	29,465	26,017	7,109	13,233	7,985
5	10,658	36,294	28,534	5,904	34,703	35,690	3,504	13,129	19,231
6	6,246	15,426	9,349	3,465	20,143	17,730	2,081	21,902	21,515
7	25,575	31,369	8,358	16,670	30,544	19,230	12,861	26,345	27,237
8	9,226	8,238	14	6,801	8,140	1,339	5,317	7,903	2,586
9	3,007	7,841	4,833	2,118	8,427	6,309	1,594	6,019	4,426
10	274	2,402	2,128	166	2,229	2,063	145	844	698
11	1,044	5,715	4,670	701	5,400	4,699	391	2,145	1,754
14	18,516	42,080	28,628	11,781	47,759	45,989	9,106	37,594	41,931
15	13,724	19,139	5,495	9,973	20,573	10,600	8,872	20,903	12,337
16	69,296	70,700	3,619	52,004	68,240	16,236	41,681	62,465	20,784
17	10,966	12,628	1,863	8,031	12,442	4,411	6,283	10,697	4,414
Blantyre	512,799	3,327	0	438,252	3,220	0	374,179	3,327	0

Source: Project Team



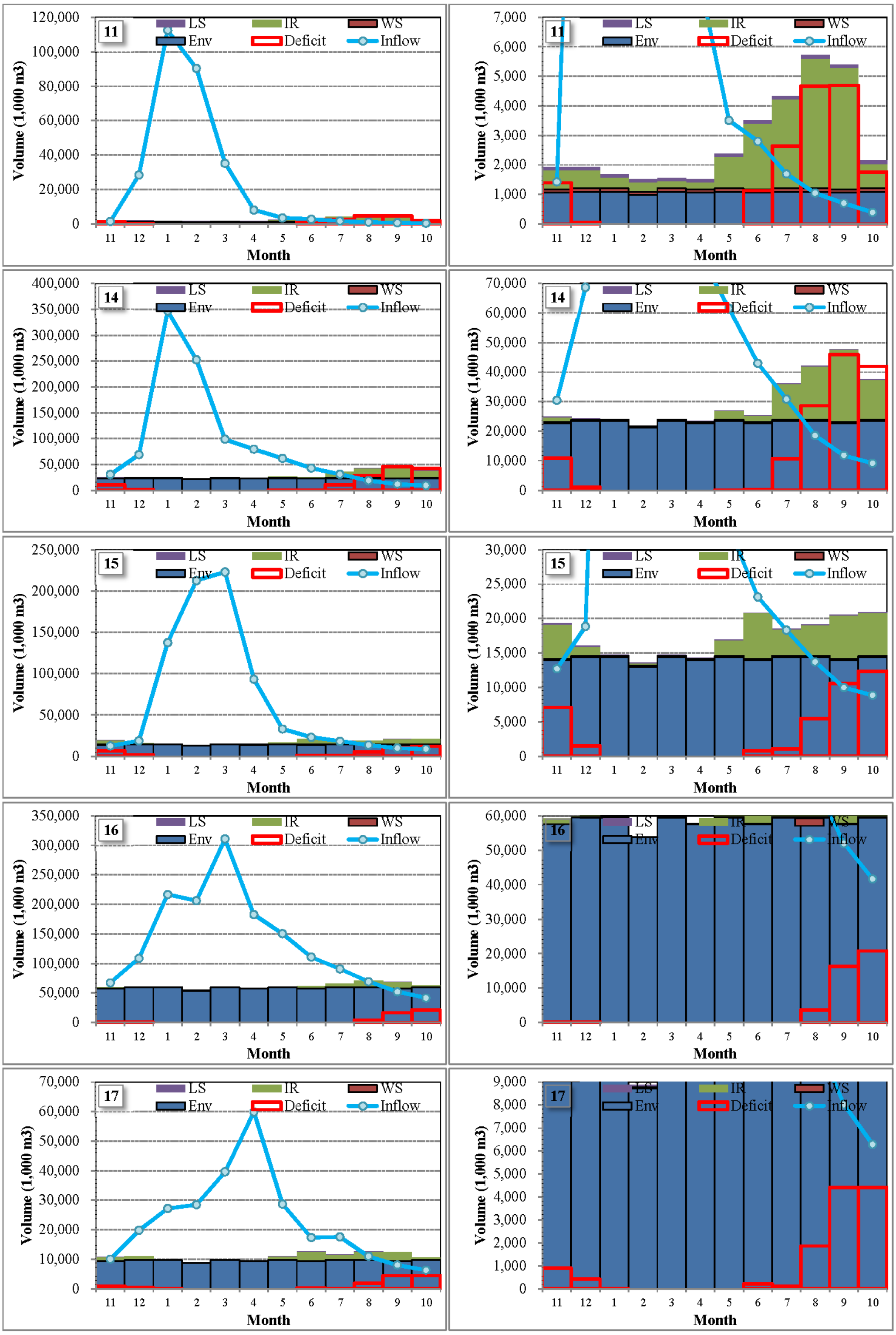
Source: Project Team

Figure 6.5.45 Water Balance by WRA (10-Year Drought) (1/4)



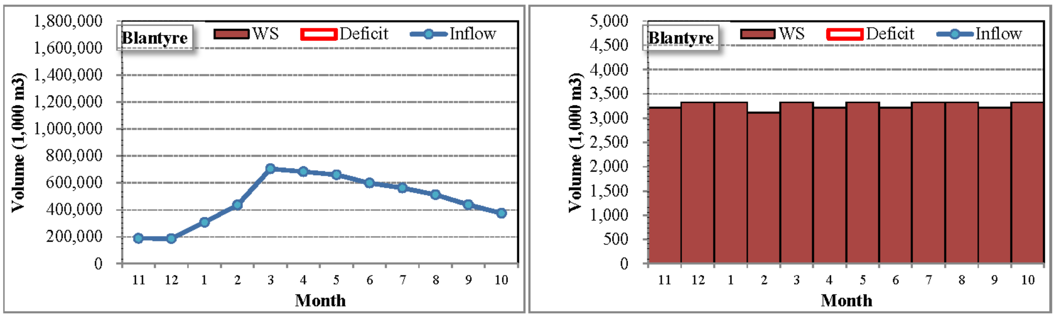
Source: Project Team

Figure 6.5.46 Water Balance by WRA (10-Year Drought) (2/4)



Source: Project Team

Figure 6.5.47 Water Balance by WRA (10-Year Drought) (3/4)



Source: Project Team

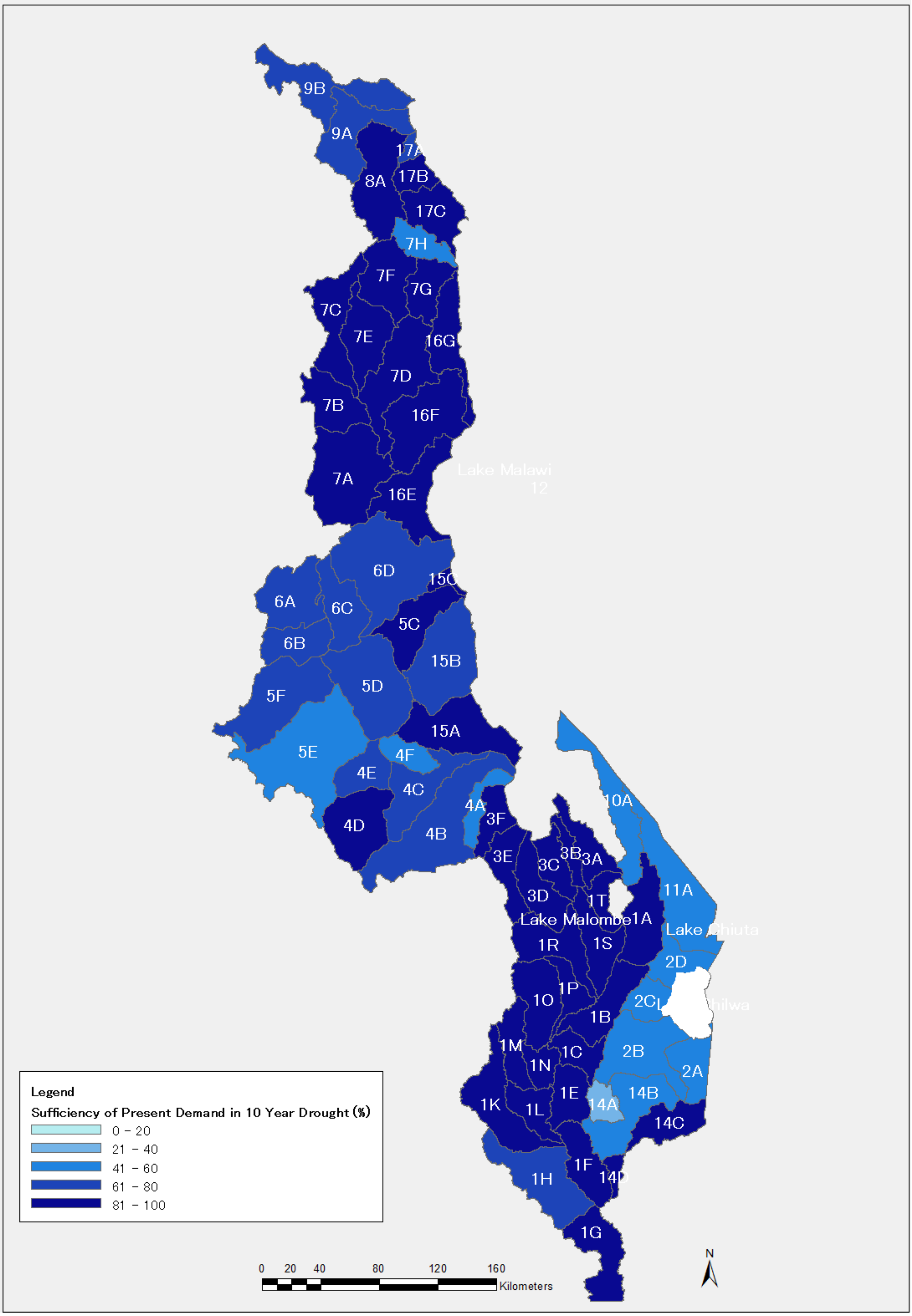
Figure 6.5.48 Water Balance by WRA (10-Year Drought) (4/4)

Table 6.5.27 Deficit of 10- and 2-Year Drought

Deficit (1,000 m3)

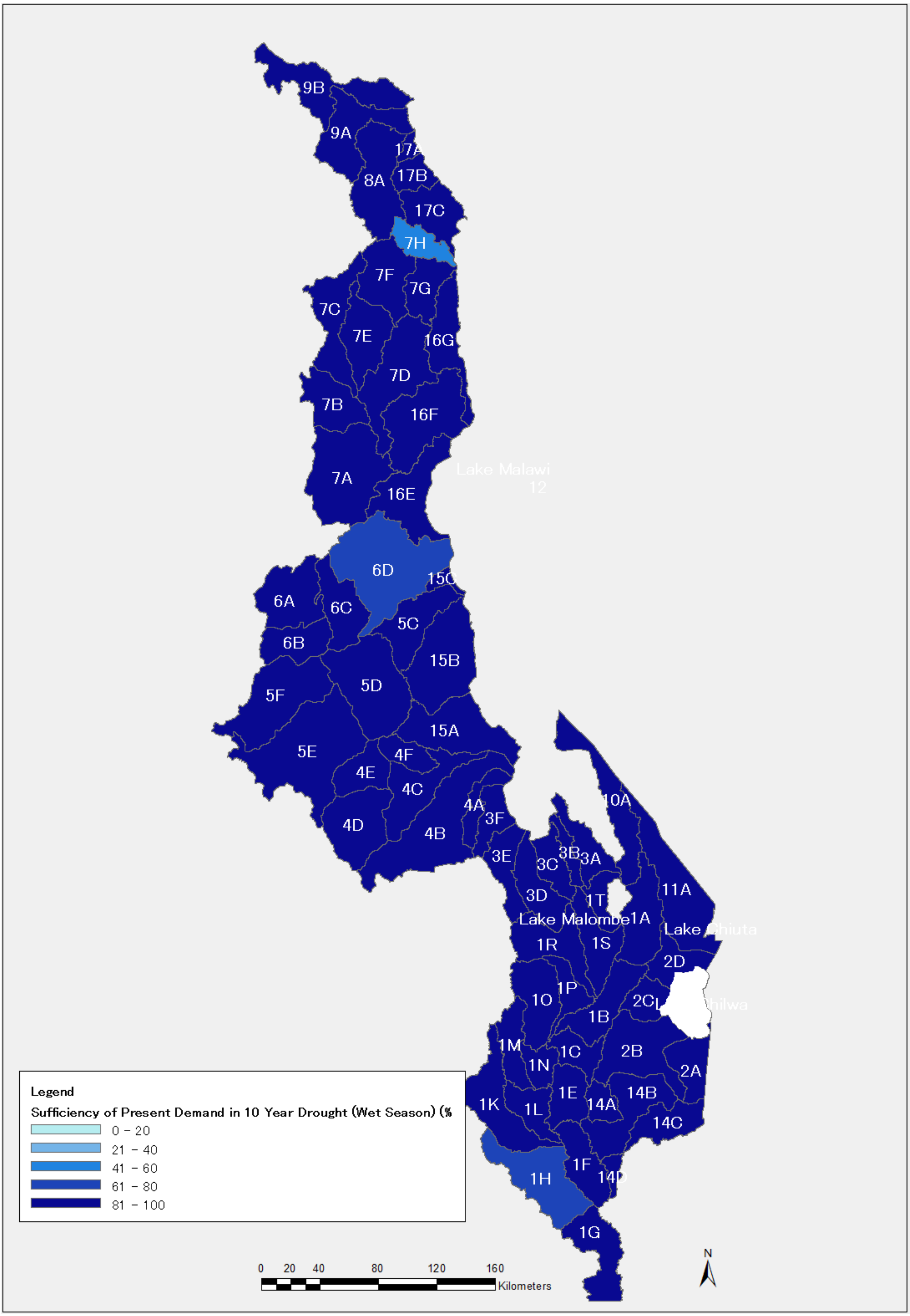
WRA	1/10		1/2	
1	1995/1996	170,512	2009/2010	298,648
2	1994/1995	26,672	2000/2001	7,988
3	1993/1994	27,200	1989/1990	4,873
4	1993/1994	69,104	1982/1983	43,939
5	1991/1992	98,650	1987/1988	56,149
6	1994/1995	84,094	1992/1993	64,296
7	1999/2000	92,189	2000/2001	39,918
8	2002/2003	3,940	1984/1985	2,006
9	2007/2008	22,262	2003/2004	16,225
10	1991/1992	6,881	1999/2000	4,838
11	1994/1995	16,337	2008/2009	9,374
14	1994/1995	139,393	1992/1993	80,822
15	1999/2000	39,008	2006/2007	10,905
16	2004/2005	41,011	1997/1998	16,376
17	1996/1997	12,322	2001/2002	8,648
Blantyre	1995/1996	0	2009/2010	0
Total		849,573		665,005

Source: Project Team



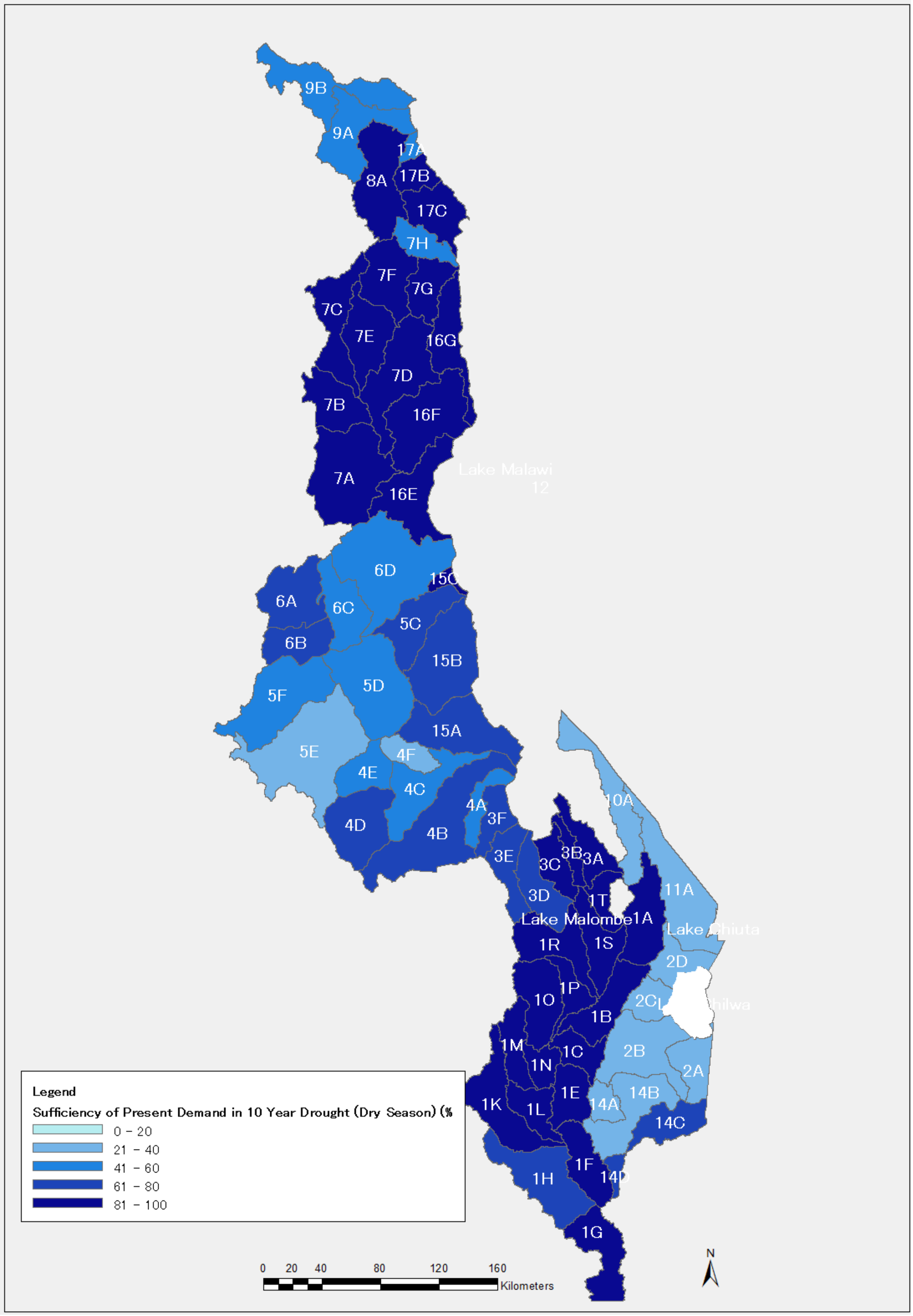
Source: Project Team

Figure 6.5.49 Sufficiency of Water Demand by WRU at Present Condition in 10-Year Drought



Source: Project Team

Figure 6.5.50 Sufficiency of Water Demand by WRU at Present Condition in Wet Season of 10-Year Drought



Source: Project Team

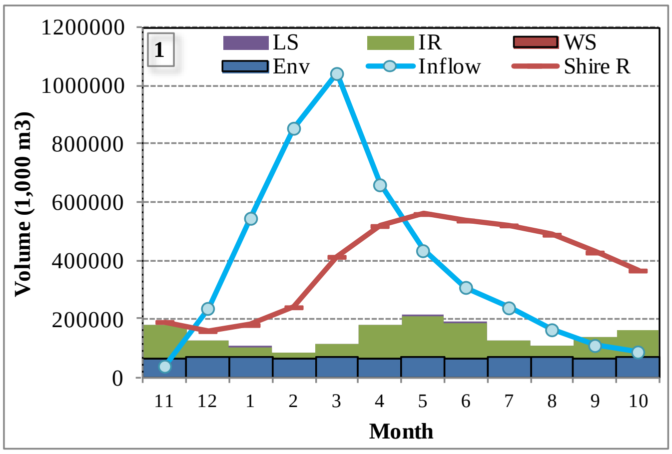
Figure 6.5.51 Sufficiency of Water Demand by WRU at Present Condition in Dry Season of 10-Year Drought

(5) Surface Water Balance in Future

The water balance in 2035 which is the target year of the Project and in 2025 which is the intermediate time is studied. The water demand in 2025 and 2035 is 1.9 and 2.4 times of present water demand excluding environmental flow. Environmental flow is constant.

The results are shown in **Table 6.5.28**, **Figure 6.5.53** and **Figure 6.5.54**. The deficit increases with increasing water demand.

The water balance in WRA1 is studied by considering water intake from the Shire River. If the water can be conveyed from the Shire River to branch river basins, water demands are surely satisfied in the branch river basins. Flow of the Shire River is high in dry season and lowest flow occurs in December. At that time, flow of each WRU is increasing. (**Figure 6.5.52**)



Source: Project Team
Note: Shire R means flow discharge of the Shire River, inflow means flow discharge excluding that of the Shire River.

Figure 6.5.52 Water Balance of WRA1 Considering Intake from the Shire River in 2035

Table 6.5.28 Water Demand in Present

Present (1,000m^3/year)

WRA	Env	WS	IR	LS
1	784,714	15,519	361,261	11,363
2	22,061	12,039	18,185	3,260
3	186,195	2,675	34,652	2,890
4	82,722	40,842	71,022	6,476
5	120,392	7,036	84,444	6,997
6	60,893	3,981	143,939	2,216
7	284,171	12,011	17,331	3,700
8	86,221	446	4,089	390
9	40,696	814	21,354	1,935
10	3,607	668	7,608	449
11	12,840	1,268	18,004	1,485
14	276,041	5,058	74,010	3,857
15	169,465	2,219	35,971	2,002
16	700,959	1,608	37,967	524
17	113,863	445	15,278	998
Blantyre	0	39,284	0	0
Total	2,944,842	145,913	945,114	48,542

Source: Project Team

Table 6.5.29 Water Demand in 2025

2025 (1,000m^3/year)

WRA	Env	WS	IR	LS
1	784,714	13,780	687,791	15,463
2	22,061	21,771	35,056	4,452
3	186,195	1,756	70,405	3,044
4	82,722	75,085	74,236	14,679
5	120,392	2,714	174,398	12,655
6	60,893	2,824	232,196	2,853
7	284,171	23,297	29,286	20,758
8	86,221	378	7,350	574
9	40,696	679	32,248	2,656
10	3,607	430	11,459	744
11	12,840	939	49,668	1,356
14	276,041	4,132	120,400	4,937
15	169,465	948	43,669	2,942
16	700,959	1,117	64,422	1,154
17	113,863	358	99,553	1,535
Blantyre	0	54,301	0	0
Total	2,944,842	204,509	1,732,138	89,801

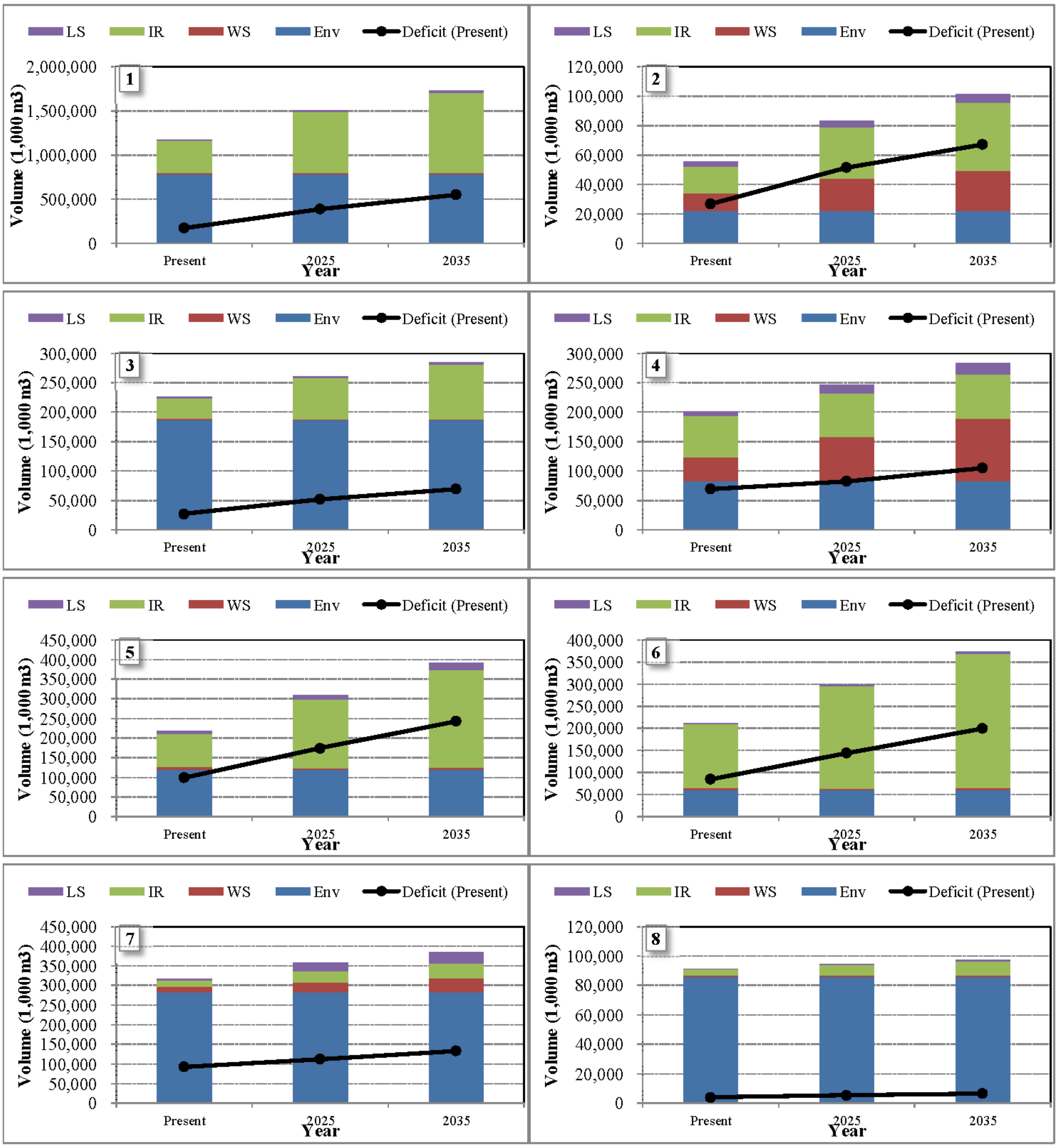
Source: Project Team

Table 6.5.30 Water Demand in 2035

2035 (1,000m^3/year)

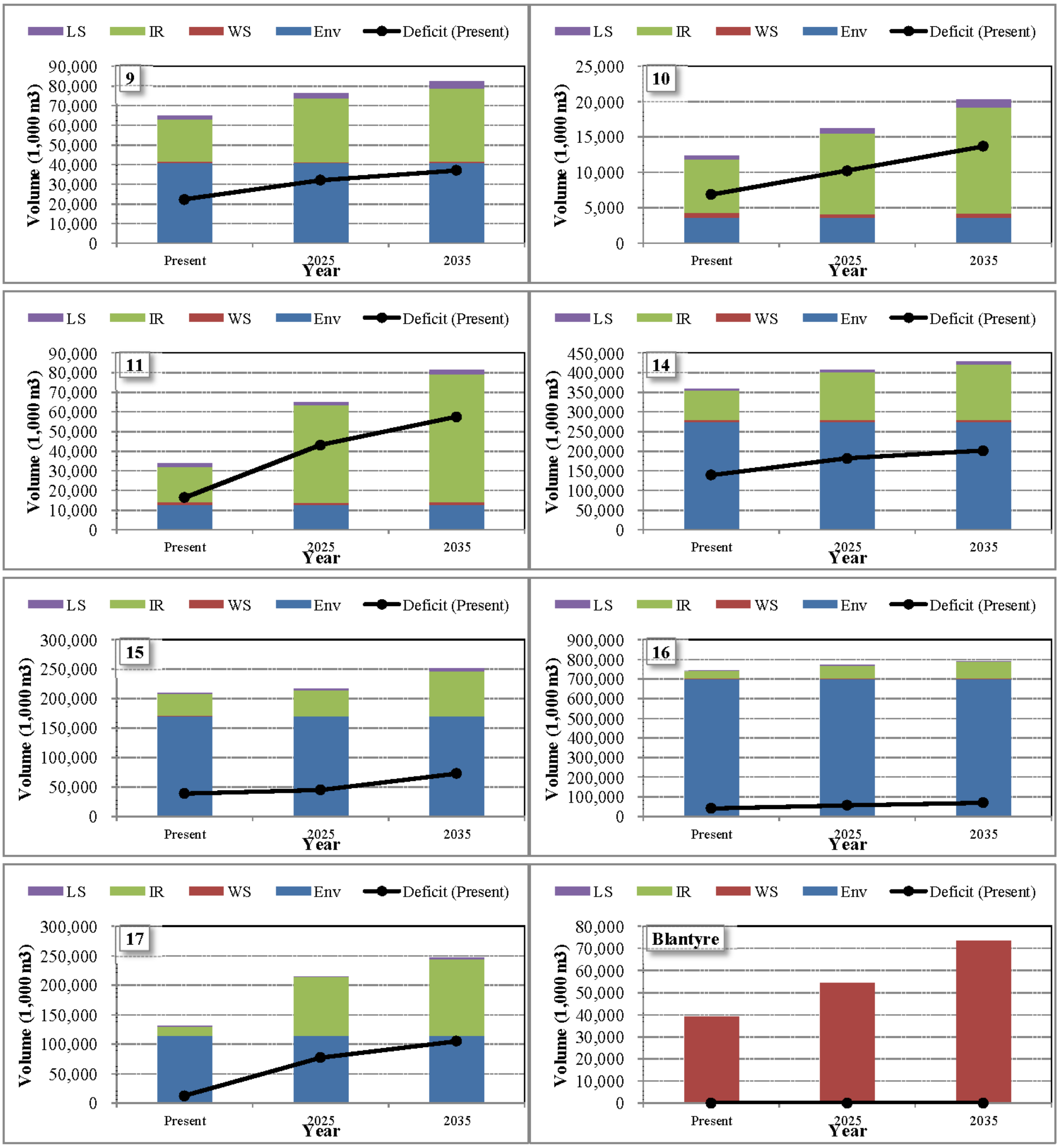
WRA	Env	WS	IR	LS
1	784,714	16,771	902,726	20,711
2	22,061	27,542	46,015	5,789
3	186,195	2,330	92,455	4,117
4	82,722	106,728	74,433	20,024
5	120,392	3,821	249,628	17,408
6	60,893	3,939	304,758	3,982
7	284,171	33,960	38,438	27,913
8	86,221	485	9,647	758
9	40,696	865	37,287	3,518
10	3,607	614	15,041	1,032
11	12,840	1,312	65,189	1,872
14	276,041	4,831	140,974	6,264
15	169,465	1,299	75,877	4,038
16	700,959	1,488	85,510	1,556
17	113,863	477	130,663	2,067
Blantyre	0	73,580	0	0
Total	2,944,842	280,041	2,268,641	121,049

Source: Project Team



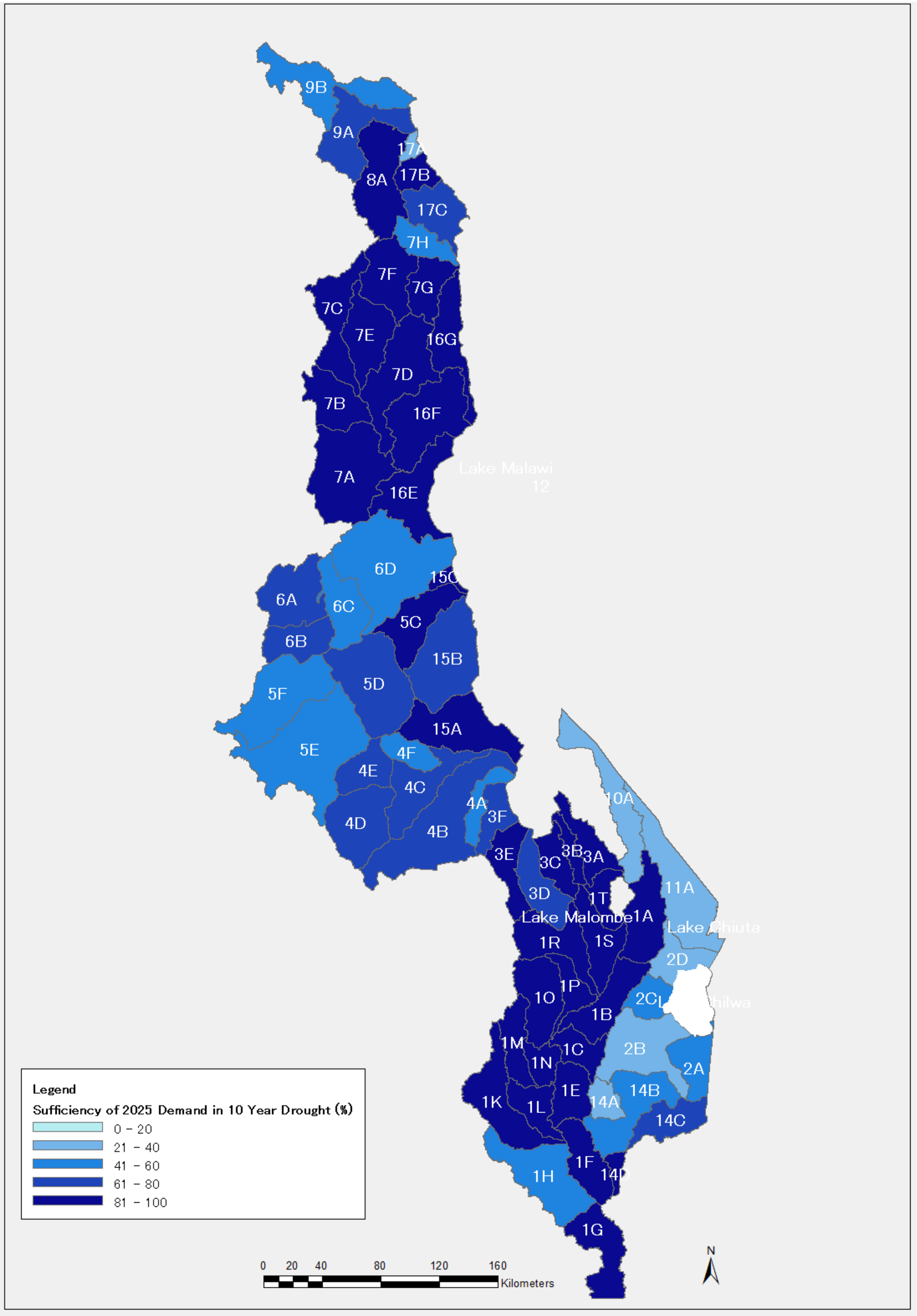
Source: Project Team

Figure 6.5.53 Water Demand and Deficit (1/2)



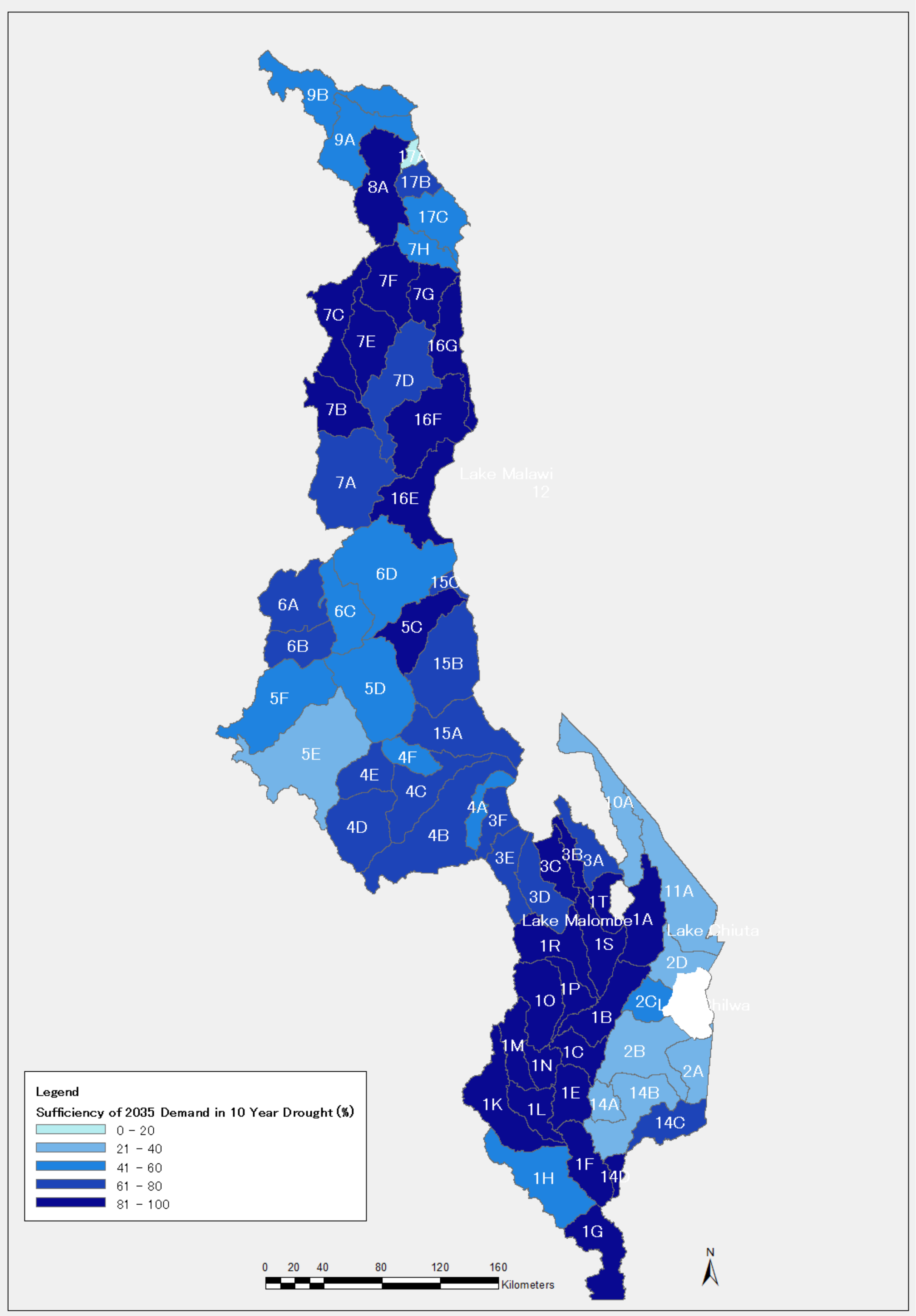
Source: Project Team

Figure 6.5.54 Water Demand and Deficit (2/2)



Source: Project Team

Figure 6.5.55 Sufficiency of Water Demand by WRU in 2025



Source: Project Team

Figure 6.5.56 Sufficiency of Water Demand by WRU in 2035

(6) Groundwater Balance

The groundwater balance is studied annually to evaluate the sustainability of water intake of groundwater comparing recharge and groundwater demand. The monthly balance is not studied because if recharge is smaller than water demand in one month, there is water resources in ground recharged over a long time.

The groundwater demand is for water supply and irrigation. The groundwater demand for water supply occupies 99%. The groundwater demand for water supply is estimated by population and the future demand increases with increasing population. The groundwater demand for irrigation is estimated from water-rights and constant in the future.

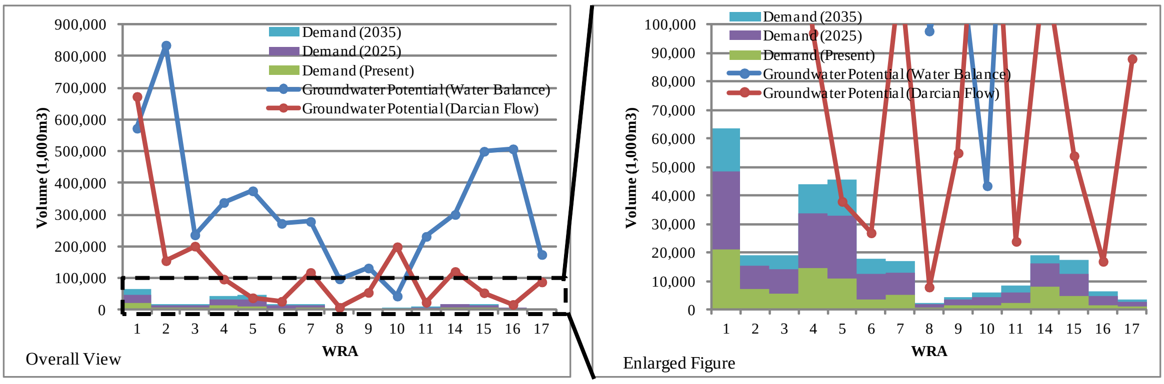
The recharge is estimated by water balance calculated by the rainfall runoff model and by Darcian flow. The recharge of water balance is assumed as the remainder obtained by subtracting evapotranspiration and river flow from rainfall. The recharge of Darcian flow is estimated by geological characteristics. The recharge is assumed as same as the groundwater flow volume. It is estimated under steady state condition and rainfall is not considered. The comparison between them is shown in **Table 6.5.31**. The recharge of water balance and Darcian flow is nearly the same and that of water balance is almost in the range of that of Darcian flow.

Here, the recharge estimated by Darcian flow is applied considering risk side because it is a little smaller than that of water balance. There is a possibility that extent WRU groundwater basin and groundwater balance is studied by WRA. The result is shown in **Table 6.5.32**. The groundwater resources is larger than water demand even in 2035 except of WRA5.

Table 6.5.31 Comparison of Groundwater Volume by Methods

WRAs	Approach	Recharge Estimates (mm/year)
1	Darcian Flow	Ave: 61mm Range: 1 - 983mm
	Water Balance	30mm
2	Darcian Flow	Ave: 40mm Range: 4 - 739mm
	Water Balance	183mm
3	Darcian Flow	Ave: 67mm Range: 1 - 383mm
	Water Balance	47mm
4	Darcian Flow	Ave: 16mm Range: 1 - 208mm
	Water Balance	38mm
5	Darcian Flow	Ave: 4mm Range: 0 - 47mm
	Water Balance	35mm
6	Darcian Flow	Ave: 5mm Range: 0 - 26mm
	Water Balance	35mm
7	Darcian Flow	Ave: 17mm Range: 1 - 348mm
	Water Balance	22mm
8	Darcian Flow	Ave: 48mm Range: 1 - 180mm
	Water Balance	47mm
9	Darcian Flow	Ave: 43mm Range: 4 - 412mm
	Water Balance	35mm
10	Darcian Flow	Ave: 201mm Range: 1 - 1,025mm
	Water Balance	26mm
11	Darcian Flow	Ave: 15mm Range: 2 - 111mm
	Water Balance	95mm
14	Darcian Flow	Ave: 51mm Range: 1 - 391mm
	Water Balance	85mm
15	Darcian Flow	Ave: 24mm Range: 1 - 207mm
	Water Balance	104mm
16	Darcian Flow	Ave: 17mm Range: 0 - 80mm
	Water Balance	92mm
17	Darcian Flow	Ave: 104mm Range: 5 - 593mm
	Water Balance	90mm
The Whole	Darcian Flow	48mm (Average in WRAs)
	Water Balance	53mm (Average in WRAs)
	NWRMP,1986	Range: 3 - 96mm
	SADC Recharge Map	Range: 100 - 300mm

Source: Project Team



Source: Project Team

Figure 6.5.57 Groundwater Balance

Table 6.5.32 Groundwater Balance

WRA	Area (km2)	Recharge (Water Balance) (mm)	Recharge (Darcian Flow) (mm)	Groundwater Volume (Water Balance) (1,000m3)	Groundwater Volume (Darcian Flow) (1,000m3)	Demand Present (1,000m3)	Demand 2025 (1,000m3)	Demand 2035 (1,000m3)
1	18,911	30	61	572,906	673,000	21,315	48,505	63,564
2	4,568	183	40	834,769	155,000	7,266	15,284	18,903
3	4,998	47	67	236,510	201,000	5,772	14,182	18,926
4	8,885	38	16	338,606	97,000	14,639	33,831	43,791
5	10,658	35	4	375,403	38,000	10,810	32,911	45,598
6	7,750	35	5	272,781	27,000	3,650	12,678	17,987
7	12,719	22	17	278,870	118,000	5,091	12,780	17,038
8	2,088	47	48	97,733	8,000	667	1,753	2,280
9	3,730	35	43	131,813	55,000	1,499	3,507	4,492
10	1,659	26	201	43,481	199,000	1,534	4,216	6,015
11	2,443	95	15	231,727	24,000	2,217	6,152	8,631
14	3,519	85	51	300,861	121,000	7,988	16,263	19,141
15	4,819	104	24	500,269	54,000	4,730	12,740	17,418
16	5,533	92	17	507,749	17,000	1,454	4,946	6,599
17	1,945	90	104	174,546	88,000	1,113	2,609	3,485
Total	94,224	-		4,898,025	1,875,000	89,746	222,359	293,869

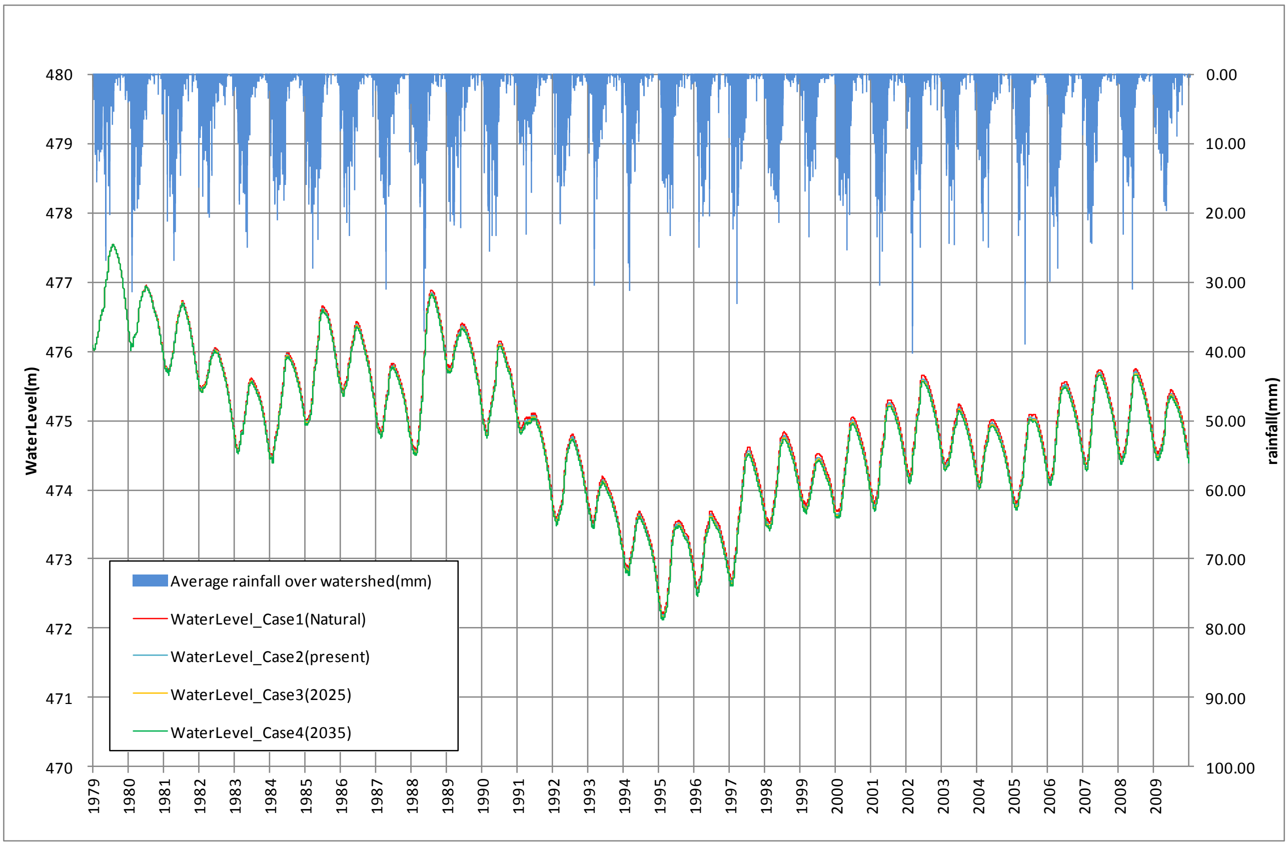
*Estimated by AL and WB area

Source: Project Team

(7) Water Balance in Lake Malawi

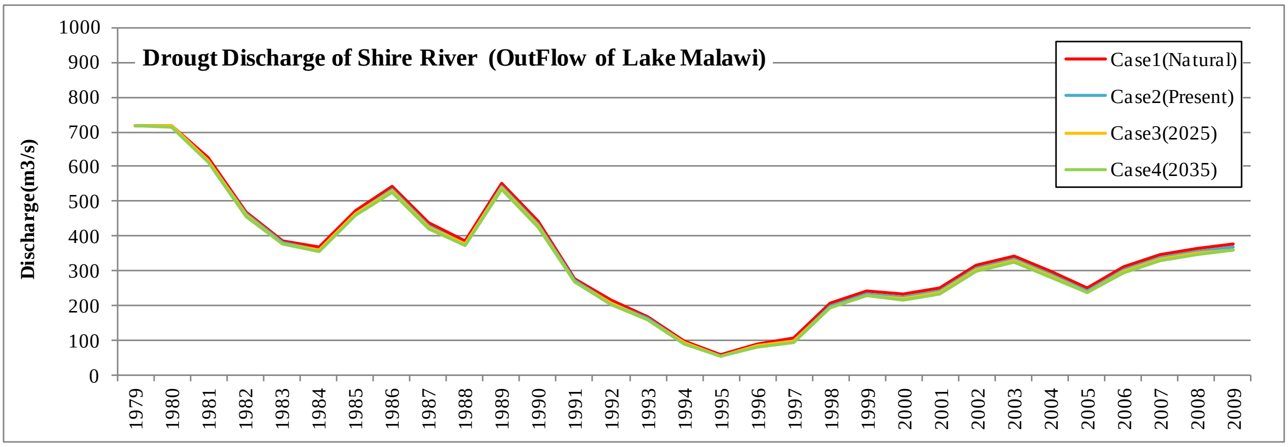
Water balance in Lake Malawi at present and in the future (2025, 2035) has been studied. The impact is evaluated by summarizing the water level in Lake Malawi and drought discharge of the Shire River (outflow of Lake Malawi).

Figure 6.5.58 and **Figure 6.5.59** show the impact of water intake on water level and outflow.



Source: Project Team

Figure 6.5.58 Water Balance of Lake Malawi in Consideration of Water Intake



Source: Project Team

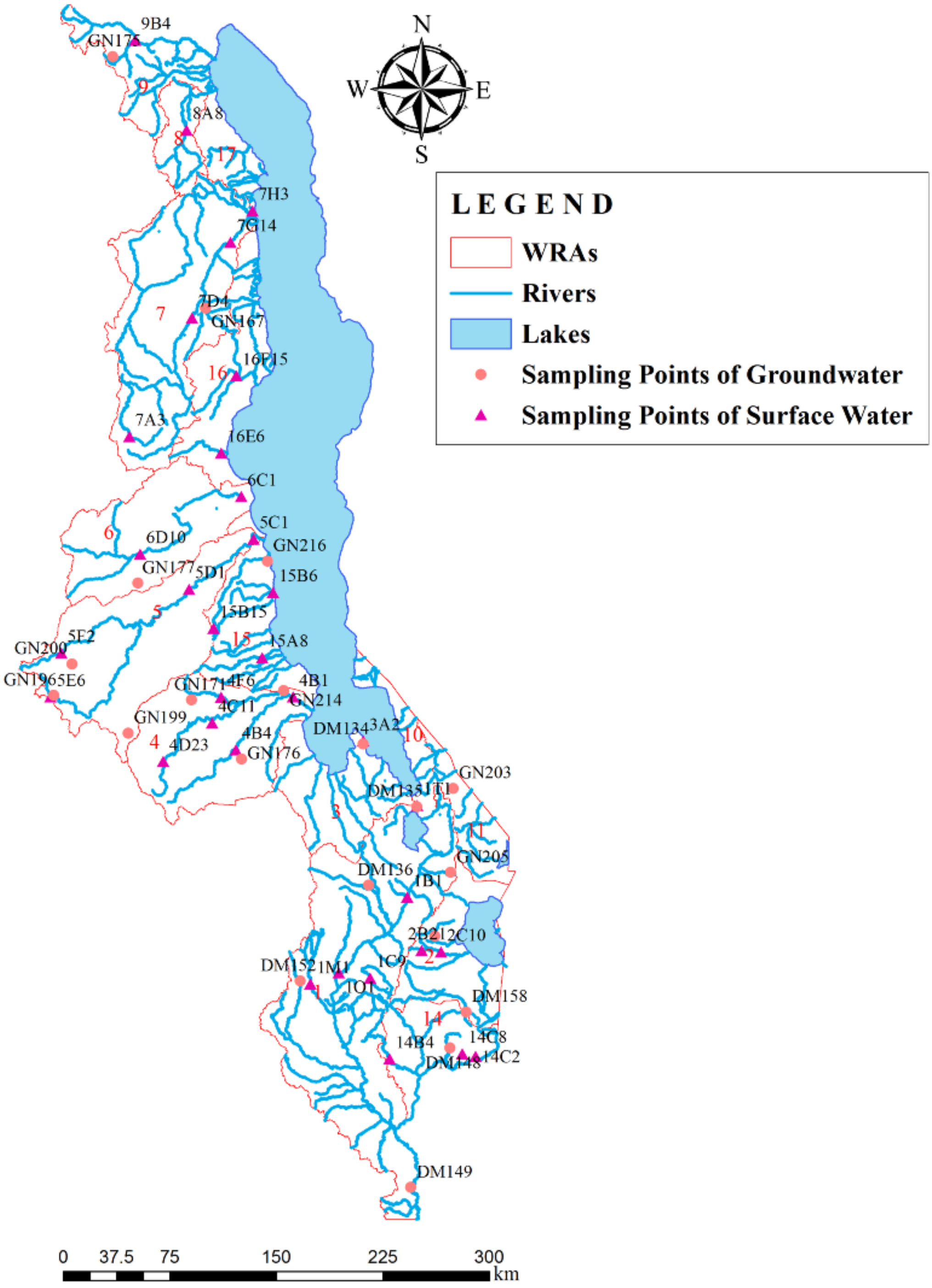
Figure 6.5.59 Drought Discharge of the Shire River (Outflow of Lake Malawi)

6.6 Water Quality

6.6.1 Water Quality Monitoring

(1) Locations and Site Conditions

In Malawi, a cross-sectional nationwide study and regular monitoring regarding water quality has not been done yet although many monitoring points were selected from hydrological stations and monitoring wells in the past plan. One of the reasons is that there is only one laboratory in Malawi; namely, the central water laboratory belonging to MoAIWD. Nevertheless, the laboratory was not able to handle the monitoring project due to severe budgetary constraints. In order to break through this obstacle and come up with the real state of water quality in Malawi, the project had chosen 54 water quality monitoring points among the 195 points decided by the project of Strengthening of the Water Resources Board (MoIWD, 2003), to analyze the water quality in accordance with the parameters shown in **Table 6.6.3**. The water samples were collected at each monitoring point twice, in rainy season and dry season during 2013. The monitoring locations are shown in **Figure 6.6.1** and in **Table 6.6.1** and **Table 6.6.2** which summarize the condition at each monitoring point. This report describe the results of monitoring and regional trends of water quality.



Source: Project Team

Figure 6.6.1 Location Map of Water Quality Monitoring in 2013

Table 6.6.1 Conditions of Monitoring Points for Groundwater

No.	Well ID.	Coordinates		WRAs	District	Location	Sampling Date		Remarks
		East	South				Rainy Season	Dry Season	
1	GN205	768386	8350760	1	Machinga	Kawombe Dam	15-Mar-13	31-Jul-13	
2	DM149	740434	8127713	1	Nsanje	Nsanje Water Office	16-Mar-13	2-Aug-13	
3	DM152	662536	8273903	1	Mwanza	Mwanza Prison	17-Mar-13	3-Aug-13	
4	DM136	710733	8341554	1	Balaka	Balaka Water Office	17-Mar-13	3-Aug-13	
5	DM147	757273	8305850	2	Zomba	Songani Water Office	16-Mar-13	31-Jul-13	
6	DM158	779285	8252143	2	Phalombe	Nansambo Full Primary School	16-Mar-13	31-Jul-13	
7	DM134	707023	8441620	3	Mangochi	Monkey Bay	15-Mar-13	30-Jul-13	
8	DM135	744587	8397411	3	Mangochi	Mangochi Water Office	15-Mar-13	30-Jul-13	
9	GN176	621291	8430906	4	Dedza	Linthipe Water Office	1-Mar-13	6-Aug-13	
10	GN171	586173	8472734	4	Lilongwe	Mlezi F.P. School	4-Mar-13	-	The key of monhole locking was broken up to the monitoring in dry season (No data in dry season)
11	GN214	650938	8479327	4	Salima	Kambwiei Sere Irrigation Scheme	27-Feb-13	8-Aug-13	
12	GN199	541292	8449352	5	Lilongwe	Kakuyu Dam	10-Feb-13	12-Oct-13	
13	GN196	489149	8476038	5	Mchinji	Mchinji Water Office	10-Feb-13	6-Aug-13	
14	GN200	501817	8498219	5	Mchinji	Rusa Dam	10-Feb-13	-	The monitoring well was vandalized up to the monitoring in dry season (No data in dry season)
15	GN177	548248	8555426	6	Kasungu	Mwalayawanyenje	14-Mar-13	6-Aug-13	
16	GN167	596026	8749943	7	Mzimba	Endiongololeni F.P. School	7-Mar-13	13-Aug-13	
17	GN175	530654	8928214	9	Chitipa	Chitip Well Field	6-Mar-13	15-Aug-13	
18	GN203	77252	8410221	11	Mangochi	Namwera Well Field	15-Mar-13	31-Jul-13	
19	DM148	767925	8226727	14	Mulanje	Mulanje Water Office	16-Mar-13	1-Aug-13	
20	GN216	639552	8571046	15	Nkhotakota	Nkhotakota Water Office	27-Feb-13	7-Aug-13	

Source: Project Team

Table 6.6.2 Conditions of Monitoring Points for Surface Water

No.	Station ID.	Coordinates		WRAs	District	Location	Sampling Date		Remarks
		East	South				Rainy Season	Dry Season	
1	1B1	738013	8333048	1	Machinga	Shire River at Liwonde Railway Bridge	15-Apr-13	31-Jul-13	The gauged W.L was 4.7m in rainy season
2	1C9	748090	8295492	1	Blantyre	Lunzu River at M1 Road Bridge	16-Mar-13	2-Aug-13	
3	1O1	689811	7279663	1	Neno	Lisungwi River at Mwanza/Neno Road Bridge	16-Mar-13	3-Aug-13	
4	1M1	669895	8271756	1	Mwanza	Nkulumadzi River at M1 Mwanza Road Bridge	16-Mar-13	2-Aug-13	The gauged W.L was 1.96m in rainy season
5	2B21	748090	8295492	2	Zomba	Kujabgaka River at ZA/BT Road Bridge	16-Mar-13	31-Jul-13	
6	2C10	761725	8294441	2	Zomba	Likangala River at Kachulu Bridge	16-Mar-13	31-Jul-13	The gauged W.L was 0.64m in rainy season
7	3A2	707017	8443761	3	Mangochi	Lake Malwi at Monkey Bay Guaging Station	15-Mar-13	30-Jul-13	The gauged W.L was 6.75m in rainy season. Oil & grease were adrift on the water in dry season
8	1T1	745022	8398070	3	Mangochi	Shire River at Mangochi Road Bridge	15-Mar-13	31-Jul-13	The gauged W.L was 7.0m in rainy season
9	4D23	566170	8429294	4	Lilongwe	Lilongwe River Upstream the confluence with Katete River	1-Mar-13	5-Aug-13	
10	4B4	617366	8437453	4	Lilongwe	Diamphwe river at M1 Road Bridge	1-Mar-13	5-Aug-13	The gauged W.L was 0.3m in dry season
11	4C11	600573	8456585	4	Lilongwe	Nanjiri River at Kadzizila Village	1-Mar-13	5-Aug-13	The gauged W.L was 1.20m in rainy season, 0.51m in dry season
12	4F6	606979	8474716	4	Lilongwe	Lumbadzi River Upstream LL/SA Road Bridge	1-Mar-13	8-Aug-13	
13	4B1	657741	8474825	4	Salima	Linthipe River at Railway Bridge Gauging Station	13-Mar-13	8-Aug-13	The gauged W.L was 2.32m in rainy season
14	5E6	486950	8474847	5	Mchinji	Bua River at Foot Path to Customs Office	10-Feb-13	6-Aug-13	The gauged W.L was 1.17m in rainy season, 0.6m in dry season
15	5F2	494482	8505939	5	Mchinji	Liwerezi River at the Road Bridge	10-Feb-13	6-Aug-13	No access to the gauging station
16	5C1	629637	8586651	5	Nkhotakota	Bua River at Old Bridge	27-Feb-13	7-Aug-13	The gauged W.L was 0.97m in dry season
17	5D1	584455	8551196	5	Kasungu	Bua River at KU/KK Road Bridge	27-Mar-13	6-Aug-13	The gauge plates have been vandalized
18	6D10	5499167	8576066	6	Kasungu	Dwangwa Rivr at M1 Road Bridge	10-Feb-13	6-Aug-13	The gauged W.L was 1.93m in rainy season
19	6C1	621152	8616683	6	Nkhotakota	Dwangwa River downstream Road Bridge	27-Feb-13	7-Aug-13	The gauged W.L was 0.74m in rainy season, 0.13m in dry season
20	7H3	628913	8818913	7	Rumphi	North Rumphi River at M1 Road Bridge	7-Mar-13	14-Aug-13	
21	7G14	613678	8796612	7	Rumphi	South Rukulu River at M1 Road Bridge	7-Mar-13	14-Aug-13	
22	7D4	586400	8742996	7	Mzimba	Kasitu River at Edundu	7-Mar-13	-	The river was dried up in the dry season (No data in dry season)
23	7A3	542152	8659287	7	Mzimba	South Rukulu River at Chimsewezo	7-Mar-13	16-Aug-13	
24	8A8	582646	8876121	8	Chitipa	North Rukuru River at Uledi Gauging Station	6-Mar-13	14-Aug-13	
25	9B4	546347	8939770	9	Chitipa	Songwe River Water Guaging Station	6-Mar-13	15-Aug-13	
26	14C2	786025	8220402	14	Mulanje	Ruo River at Trading Centre Old Road Bridge	16-Mar-13	1-Aug-13	The gauged W.L was 1.27m in rainy season
27	14C8	776720	8222475	14	Mulanje	Lichenya River Upstream Mulanje Road Bridge	16-Mar-13	1-Aug-13	
28	14B4	725502	8218693	14	Thyolo	Nsuwadzi River Upstream Water Suplly Intake	16-Mar-13	1-Aug-13	
29	15B15	601644	8523354	15	Ntchisi	Kaombe River at Water Supply Intake	27-Feb-13	7-Aug-13	
30	15A8	635882	8502696	15	Salima	Lingadzi River at Kaniche	27-Mar-13	7-Aug-13	
31	15B6	643360	8548823	15	Nkhotakota	Chia Lagoon at Gauging Station	27-Mar-13	7-Aug-13	The gauged W.L was 1.32m in rainy season, 0.97m in dry season
32	16E6	606942	8647516	16	Nkhotakota	Dwambazi River at Nkhotakota/Nkhata Bay	5-Mar-13	13-Aug-13	It was difficult to access the gauging station due to bushy surroundings
33	16F15	617725	87021928	16	Nktata Bay	Luweya River at Mzwnga Village	5-Mar-13	13-Aug-13	

Source: Project Team

Table 6.6.3 Constituents Analyzed for the Water Quality Monitoring

Constituents
pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Carbonate, Bicarbonate, Chloride, Sulphate, Nitrate, Fluoride, Sodium, Potassium, Calcium, Magnesium, Total Iron, Manganese, Turbidity, Suspended Solids (SS), Total Hardness, Total Alkalinity, Copper, Phosphate, Dissolved oxygen (DO), Chemeical Oxygen demand (COD), Biochemical xygen demand (BOD), Faecal coliforms, Faecal streptococci. (26 parameters in total)

Source: Project Team

(2) Results of Water Quality Analysis

Results of the water quality analysis in the Project are tabulated in **Table 6.6.4** through **Table 6.6.7** for groundwater, and **Table 6.6.8** through **Table 6.6.13** for surface water.

Table 6.6.4 Summary of Water Quality for Groundwater (1/4)

Constituents	Unit	Sampling Season	GN205		DM149		DM152		DM136		DM147		**MBS: MS733 (Borehole & Shallow wells)**	**MBS: MS691 (Domestic / Sewage elluents)**
			Kawombe Dam		Nsanje Water Office		Mwanza Prison		Balaka Water Office		Songani Water Office			
pH	-	Rainy	7.9	○	7.8	○	7.5	○	7.9	○	7.4	○	**6.0 - 9.5**	**6.5 - 9.0**
		Dry	6.52	○	7.22	○	7.14	○	7.46	○	6.62	○		
Temperature	ºC	Rainy	25.7		27.2		27.2		28.9		25.1		**-**	**-**
		Dry	25.4		26.3		29.9		27.8		24.2			
Electrical Conductivity (EC)	μs/cm	Rainy	261	○	383	○	152	○	418	○	115	○	**3,500**	**-**
		Dry	286	○	363	○	143	○	438	○	119	○		
Total Dissolved Solids (TDS)	mg/l	Rainy	117	○	180	○	76	○	202	○	58	○	**2,000**	**500**
		Dry	158	○	201	○	83	○	245	○	73	○		
Carbonate as CO_3^{2-}	mg/l	Rainy	19		19		0		20		0		**-**	**-**
		Dry	0.00		0		0.00		0.00		0.00			
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	95		125		52		84		50		**-**	**-**
		Dry	154		159		55		184		37			
Chloride as Cl^-	mg/l	Rainy	8.6	○	27.1	○	17.5	○	32.1	○	10.4	○	**750**	**-**
		Dry	11.0	○	27.5	○	11.6	○	25.8	○	12.9	○		
Sulphate as SO_4^{2-}	mg/l	Rainy	0.1	○	3.2	○	3.5	○	32.4	○	0.1	○	**800**	**-**
		Dry	3.94	○	8.83	○	6.15	○	24.4	○	5.56	○		
Nitrate as NO_3^-	mg/l	Rainy	0.035	○	0.188	○	0.295	○	0.817	○	0.127	○	**45**	**-**
		Dry	0.001	○	0.083	○	0.055	○	0.502	○	0.097	○		
Fluoride as F^-	mg/l	Rainy	0.36	○	0.68	○	0.04	○	0.47	○	0.34	○	**6**	**2**
		Dry	1	○	1.41	Δ	0.31	○	0.98	○	0.64	○		
Sodium as Na^+	mg/l	Rainy	8	○	24	○	16	○	44	○	10	○	**500**	**-**
		Dry	8	○	22	○	11	○	38	○	9	○		
Potassium as K^+	mg/l	Rainy	2.1		1.4		3.6		3.7		2.4		**-**	**-**
		Dry	1.6		1.7		3.4		3.4		2.4			
Calcium as Ca^{2+}	mg/l	Rainy	20	○	30.6	○	9.3	○	20	○	7.6	○	**250**	**-**
		Dry	29.8	○	29.8	○	8.6	○	30	○	7.2	○		
Magnesium as Mg^{2+}	mg/l	Rainy	12.6	○	11.9	○	3	○	7.9	○	3	○	**200**	**-**
		Dry	13.1	○	13	○	4.5	○	12.7	○	3.8	○		
Iron as Fe^{2+}	mg/l	Rainy	0.007	○	0.008	○	0.009	○	0.003	○	0.069	○	**3**	**-**
		Dry	0.001	○	0.01	○	0.001	○	0.001	○	0.001	○		
Manganse as Mn^{2+}	mg/l	Rainy	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○	**1.5**	**-**
		Dry	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○		
Hardness as $CaCO_3$	mg/l	Rainy	101	○	123	○	35	○	82	○	31	○	**800**	**-**
		Dry	128	○	127	○	39	○	127	○	33	○		
Alkalinity as $CaCO_3$	mg/l	Rainy	109		134		42		102		41		**-**	**-**
		Dry	125		130		45		150		30			
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		**-**	**-**
		Dry	15		19		11		19		14			
Turbidity	NTU	Rainy	5	○	14	○	1	○	5	○	5	○	**25**	**25**
		Dry	3.2	○	10	○	1.4	○	0.8	○	1.8	○		
Suspended Solids (SS)	mg/l	Rainy	4	○	13	○	0.1	○	3	○	3	○	**-**	**30**
		Dry	1	○	7	○	0.1	○	0.1	○	0.1	○		
Phosphate as PO_4^{3-}	mg/l	Rainy	-		-		-		-		-		**-**	**0.15**
		Dry	0.008	○	0.001	○	0.041	○	0.295	×	0.103	○		
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		**0.05**	**0.05**
		Dry	0.005	○	0.046	○	0.013	○	0.035	○	0.013	○		
Copper as Cu^{2+}	mg/l	Rainy	0.005	○	0.007	○	0.012	○	0.01	○	0.008	○	**2**	**2**
		Dry	0.003	○	0.001	○	0.001	○	0.001	○	0.001	○		
Dissolved Oxygen (DO)	mg/l	Rainy	7.5		3.9		4.9		5.1		7.2		**-**	**-**
		Dry	1.9		3.1		3.9		1.3		3.9			
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	3	○	3	○	5	○	4	○	1	○	**-**	**20**
		Dry	27.5	×	32.1	×	20.6	×	25.5	×	30.6	×		
Chemical Oxygen Demand (COD)	mg/l	Rainy	9	○	12	○	42	○	29	○	7	○	**-**	**60**
		Dry	98	×	87.8	×	86.2	×	110	×	94.1	×		
Faecal Coliform	Count/100ml	Rainy	12	○	60	×	50	Δ	25	○	10	○	**50**	**-**
		Dry	0	○	1608	×	12	○	4	○	4	○		
Faecal Streptococci	Count/100ml	Rainy	121	×	12	×	103	×	10	×	80	×	**0**	**-**
		Dry	8	×	404	×	28	×	12	×	4	×		

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.

Δ: the value is close to the upper limit.

×: the value exceeds over the upper limit.

Source: Project Team

Table 6.6.5 Summary of Water Quality for Groundwater (2/4)

Constituents	Unit	Sampling Season	DM158		DM134		DM135		GN176		GN171		**MBS: MS733 (Borehole & Shallow wells)**	**MBS: MS691 (Domestic / Sewage elluents)**
			Nansambo Full Primary School		Monkey Bay		Mangochi Water Office		Linthipe Water Office		Mlezi F.P. School			
pH	-	Rainy	7.49	○	7.91	○	7.8	○	7.1	○	8.1	○	**6.0 - 9.5**	**6.5 - 9.0**
		Dry	7.92	○	6.91	○	7.37	○	6.94	○	-			
Temperature	ºC	Rainy	28		31.7		28.9		25.2		25.9		-	-
		Dry	27		30		28.6		26.8		-			
Electrical Conductivity (EC)	μs/cm	Rainy	220	○	3120	Δ	892	○	90	○	500	○	**3,500**	-
		Dry	227	○	5510	×	962	○	99	○	-			
Total Dissolved Solids (TDS)	mg/l	Rainy	110	○	1401	Δ	423	○	48	○	254	○	**2,000**	**500**
		Dry	120	○	2586	×	512	○	50	○	-			
Carbonate as CO_3^{2-}	mg/l	Rainy	0		19		37		0		19		-	-
		Dry	7.2		0.00		0.00		0.00		-			
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	104		144		203		35		150		-	-
		Dry	52		870		375		18		-			
Chloride as Cl^-	mg/l	Rainy	16.9	○	753	×	103	○	6.8	○	15.2	○	**750**	-
		Dry	20	○	1,170	×	92	○	9.0	○	-			
Sulphate as SO_4^{2-}	mg/l	Rainy	0.1	○	39.7	○	17.8	○	3.3	○	51	○	**800**	-
		Dry	14.8	○	4.33	○	22.7	○	16.1	○	-			
Nitrate as NO_3^-	mg/l	Rainy	0.114	○	0.094	○	0.04	○	0.137	○	0.046	○	**45**	-
		Dry	0.291	○	0.001	○	0.001	○	0.069	○	-			
Fluoride as F^-	mg/l	Rainy	0.31	○	0.65	○	0.54	○	1.57	Δ	1.77	Δ	**6**	**2**
		Dry	0.9	○	1.32	Δ	1.35	Δ	0.27	○	-			
Sodium as Na^+	mg/l	Rainy	22	○	174	○	90	○	9	○	37	○	**500**	-
		Dry	16	○	360	○	87	○	7	○	-			
Potassium as K^+	mg/l	Rainy	0.7		14.8		9.8		1.2		8.8		-	-
		Dry	5.3		59		8.8		1.5		-			
Calcium as Ca^{2+}	mg/l	Rainy	13	○	300	×	50	○	6	○	36.8	○	**250**	-
		Dry	17	○	387	×	60	○	5	○	-			
Magnesium as Mg^{2+}	mg/l	Rainy	7.2	○	30.1	○	14.3	○	2.3	○	10.6	○	**200**	-
		Dry	4.5	○	130	○	27.6	○	3	○	-			
Iron as Fe^{2+}	mg/l	Rainy	0.004	○	0.013	○	0.497	○	0.258	○	0.001	○	**3**	-
		Dry	0.001	○	3.43	×	0.379	○	0.001	○	-			
Manganse as Mn^{2+}	mg/l	Rainy	-	○	0.001	○	0.001	○	0.001	○	0.001	○	**1.5**	-
		Dry	0.001	○	2.85	×	0.001	○	0.001	○	-			
Hardness as $CaCO_3$	mg/l	Rainy	62	○	871	×	184	○	24	○	133	○	**800**	-
		Dry	61	○	1507	×	264	○	24	○	-			
Alkalinity as $CaCO_3$	mg/l	Rainy	85		149		228		28		134		-	-
		Dry	55		713		307		14		-			
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		-	-
		Dry	11		23		28		11		-			
Turbidity	NTU	Rainy	4	○	7	○	70	×	1.2	○	0.8	○	**25**	**25**
		Dry	1.2	○	180	×	7.8	○	4	○	-			
Suspended Solids (SS)	mg/l	Rainy	205	○	6	○	68	×	1	○	0.1	○	-	**30**
		Dry	0.1	○	140	×	5	○	2	○	-			
Phosphate as PO_4^{3-}	mg/l	Rainy	-		-		-		-		-		-	**0.15**
		Dry	0.453	×	0.598	×	0.016	○	0.242	×	-			
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		**0.05**	**0.05**
		Dry	0.021	○	0.001	○	0.02	○	0.035	○	-			
Copper as Cu^{2+}	mg/l	Rainy	0.006	○	0.005	○	0.007	○	0.002	○	0.001	○	**2**	**2**
		Dry	0.013	○	0.001	○	0.001	○	0.024	○	-			
Dissolved Oxygen (DO)	mg/l	Rainy	4.6		0.8		8.3		4.5		3.6		-	-
		Dry	4.4		1.3		1.9		8.9		-			
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	4	○	4	○	4	○	4	○	4	○	-	**20**
		Dry	24.4	×	63	×	44.5	×	1.3	○	-			
Chemical Oxygen Demand (COD)	mg/l	Rainy	36	○	55	Δ	51	Δ	14	○	13	○	-	**60**
		Dry	78.4	×	12.9	○	122	×	8.6	○	-			
Faecal Coliform	Count/100ml	Rainy	41	Δ	552	×	40	Δ	0	○	25	○	**50**	-
		Dry	0	○	110	×	44	○	0	○	-			
Faecal Streptococci	Count/100ml	Rainy	3	×	12	×	60	×	10	×	5	×	**0**	-
		Dry	132	×	120	×	8	×	0	○	-			

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.

Δ: the value is close to the upper limit.

×: the value exceeds over the upper limit.

Source: Project Team

Table 6.6.6 Summary of Water Quality for Groundwater (3/4)

Constituents	Unit	Sampling Season	GN214		GN199		GN196		GN200		GN177		MBS: MS733 (Borehole & Shallow wells)	MBS: MS691 (Domestic / Sewage elluents)
			Kambwiei Sere Irrigation Scheme		Kakuyu Dam		Mchinji Water Office		Rusa Dam		Mwalayawan yenje			
pH	-	Rainy	7.9	○	7.9	○	8.1	○	8.3	○	8.46	○	**6.0 - 9.5**	**6.5 - 9.0**
		Dry	6.95	○	7.89	○	6.77	○	-		7.71	○		
Temperature	ºC	Rainy	28.5		24.3		26.3		25.7		25.1		**-**	**-**
		Dry	25.7		29.7		23.1		-		25.8			
Electrical Conductivity (EC)	μs/cm	Rainy	1209	○	240	○	220	○	640	○	280	○	**3,500**	**-**
		Dry	1164	○	370	○	238	○	-		349	○		
Total Dissolved Solids (TDS)	mg/l	Rainy	624	Δ	113	○	106	○	296	○	140	○	**2,000**	**500**
		Dry	597	○	186	○	130	○	-		179	○		
Carbonate as CO_3^{2-}	mg/l	Rainy	29		14		11		52		15		**-**	**-**
		Dry	0		11		0		-		11			
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	405		69		40		212		81		**-**	**-**
		Dry	638		120		67		-		109			
Chloride as Cl^-	mg/l	Rainy	45.7	○	15.2	○	13.5	○	15.2	○	20.7	○	**750**	**-**
		Dry	36.2	○	5.1	○	9	○	-		7.2	○		
Sulphate as SO_4^{2-}	mg/l	Rainy	97.5	○	6.31	○	23.5	○	9.7	○	4.78	○	**800**	**-**
		Dry	17.2	○	49	○	38.7	○	-		34.3	○		
Nitrate as NO_3^-	mg/l	Rainy	0.154	○	0.001	○	0.001	○	0.001	○	0.128	○	**45**	**-**
		Dry	0.061	○	0.014	○	0.099	○	-		0.027	○		
Fluoride as F^-	mg/l	Rainy	0.86	○	0.43	○	0.41	○	0.54	○	1.23	Δ	**6**	**2**
		Dry	0.74	○	0.54	○	0.14	○	-		0.55	○		
Sodium as Na^+	mg/l	Rainy	100	○	10	○	10	○	16	○	19	○	**500**	**-**
		Dry	41	○	19	○	10	○	-		33	○		
Potassium as K^+	mg/l	Rainy	39.8		1.1		1.4		3.3		5.1		**-**	**-**
		Dry	3.4		3.1		5.9		-		10.2			
Calcium as Ca^{2+}	mg/l	Rainy	100	○	23	○	18	○	84	○	17	○	**250**	**-**
		Dry	62.5	○	28	○	19	○	-		20	○		
Magnesium as Mg^{2+}	mg/l	Rainy	11.4	○	6.8	○	6.7	○	9.7	○	9	○	**200**	**-**
		Dry	23	○	13.6	○	8	○	-		7.6	○		
Iron as Fe^{2+}	mg/l	Rainy	0.115	○	0.396	○	0.342	○	0.618	○	0.001	○	**3**	**-**
		Dry	0.001	○	1.7	○	0.001	○	-		0.001	○		
Manganse as Mn^{2+}	mg/l	Rainy	0.001	○	0.001	○	0.001	○	0.004	○	0.001	○	**1.5**	**-**
		Dry	0.001	○	0.31	○	0.001	○	-		0.001	○		
Hardness as $CaCO_3$	mg/l	Rainy	296	○	86	○	73	○	250	○	79	○	**800**	**-**
		Dry	500	○	127	○	80	○	-		81	○		
Alkalinity as CaCO3	mg/l	Rainy	380		79		51		260		91		**-**	**-**
		Dry	523		116		54		-		109			
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		**-**	**-**
		Dry	8		15		8		-		10			
Turbidity	NTU	Rainy	5	○	12	○	54	×	140	×	1.2	○	**25**	**25**
		Dry	4	○	7	○	6.1	○	-		4	○		
Suspended Solids (SS)	mg/l	Rainy	3	○	10	○	20	○	136	×	0.1	○	**-**	**30**
		Dry	2	○	3	○	4	○	-		2	○		
Phosphate as PO_4^{3-}	mg/l	Rainy	-		-		-		-		-		**-**	**0.15**
		Dry	1.63	×	0.056	○	0.209	×	-		0.821	×		
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		**0.05**	**0.05**
		Dry	0.027	○	0.007	○	0.008	○	-		0.012	○		
Copper as Cu^{2+}	mg/l	Rainy	0.006	○	0.002	○	0.001	○	0.001	○	0.002	○	**2**	**2**
		Dry	0.002	○	0.004	○	0.023	○	-		0.015	○		
Dissolved Oxygen (DO)	mg/l	Rainy	5.6		7.1		1.4		0.3		8.5		**-**	**-**
		Dry	9.1		6.2		9		-		8.8			
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	3	○	3	○	3	○	70	×	9	○	**-**	**20**
		Dry	10.9	○	4	○	10.6	○	-		4.5	○		
Chemical Oxygen Demand (COD)	mg/l	Rainy	45	○	14	○	99	×	549	×	15	○	**-**	**60**
		Dry	43.1	○	16	○	65.1	×	-		11.7	○		
Faecal Coliform	Count/100ml	Rainy	10	○	2448	×	16	○	2300	×	20	○	**50**	**-**
		Dry	0	○	13	○	0	○	-		0	○		
Faecal Streptococci	Count/100ml	Rainy	0	○	24	×	2	×	700	×	5	×	**0**	**-**
		Dry	0	○	1	×	0	○	-		0	○		

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.
Δ: the value is close to the upper limit.
×: the value exceeds over the upper limit.

Source: Project Team

Table 6.6.7 Summary of Water Quality for Groundwater (4/4)

Constituents	Unit	Sampling Season	GN167		GN175		GN203		DM148		GN216		**MBS: MS733 (Borehole & Shallow wells)**	**MBS: MS691 (Domestic / Sewage elluents)**
			Endiongololeni F.P. School		Chitip Well Field		Namwera Well Field		Mulanje Water Office		Nkhotakota Water Office			
pH	-	Rainy	6.8	○	6	Δ	7.4	○	7.4	○	6.3	Δ	**6.0 - 9.5**	**6.5 - 9.0**
		Dry	7.12	○	6.94	○	7.63	○	6.9	○	5.95	×		
Temperature	ºC	Rainy	26.3		25.6		25.6		24.7		28.1		-	-
		Dry	23.6		24.2		24.9		26.3		28.9			
Electrical Conductivity (EC)	μs/cm	Rainy	2300	○	78	○	113	○	130	○	130	○	**3,500**	-
		Dry	2157	○	99	○	126	○	134	○	88	○		
Total Dissolved Solids (TDS)	mg/l	Rainy	1160	Δ	39	○	59	○	67	○	67	○	**2,000**	**500**
		Dry	1015	○	53	○	70	○	83	○	46	○		
Carbonate as CO_3^{2-}	mg/l	Rainy	0		0		0		0		0		-	-
		Dry	0		0		7.2		0		0			
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	550		17		55		58		68		-	-
		Dry	500		32		44		49		25			
Chloride as Cl^-	mg/l	Rainy	397	○	10.8	○	6.9	○	11.8	○	7.1	○	**750**	-
		Dry	376	○	9.9	○	3.4	○	6.9	○	8.1	○		
Sulphate as SO_4^{2-}	mg/l	Rainy	11.5	○	5.05	○	0.1	○	0.1	○	0.1	○	**800**	-
		Dry	11.5	○	5.07	○	3.51	○	11.7	○	8.03	○		
Nitrate as NO_3^-	mg/l	Rainy	1.348	○	0.092	○	0.065	○	0.083	○	0.044	○	**45**	-
		Dry	1.88	○	0.001	○	0.001	○	0.001	○	0.221	○		
Fluoride as F^-	mg/l	Rainy	0.75	○	0.58	○	0.12	○	0.18	○	0.54	○	**6**	**2**
		Dry	0.32	○	0.6	○	0.64	○	1.21	Δ	0.36	○		
Sodium as Na^+	mg/l	Rainy	77	○	9	○	3	○	10	○	8	○	**500**	-
		Dry	68	○	9	○	4	○	8	○	8	○		
Potassium as K^+	mg/l	Rainy	9.8		0.4		8.5		3.4		0.8		-	-
		Dry	9.6		5.8		8.4		3		0.6			
Calcium as Ca^{2+}	mg/l	Rainy	238	Δ	4	○	9.3	○	8.1	○	10.2	○	**250**	-
		Dry	267	×	5	○	8.8	○	10.8	○	6	○		
Magnesium as Mg^{2+}	mg/l	Rainy	62.2	○	1.2	○	3.5	○	4	○	5.6	○	**200**	-
		Dry	31	○	1	○	4.2	○	4.2	○	2	○		
Iron as Fe^{2+}	mg/l	Rainy	0.003	○	0.026	○	0.001	○	0.036	○	0.056	○	**3**	-
		Dry	0.072	○	1.43	○	0.001	○	0.001	○	0.001	○		
Manganse as Mn^{2+}	mg/l	Rainy	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○	**1.5**	-
		Dry	0.001	○	0.42	○	0.001	○	0.001	○	0.001	○		
Hardness as $CaCO_3$	mg/l	Rainy	850	×	14	○	37	○	36	○	48	○	**800**	-
		Dry	794	○	19	○	39	○	44	○	23	○		
Alkalinity as CaCO3	mg/l	Rainy	451		13		45		47		56		-	-
		Dry	410		16		47		40		20			
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		-	-
		Dry	2.7		1		9		14		10			
Turbidity	NTU	Rainy	2	○	2	○	4	○	3	○	6	○	**25**	**25**
		Dry	1	○	1	○	0.7	○	2	○	2.1	○		
Suspended Solids (SS)	mg/l	Rainy	0.1	○	0.1	○	3	○	2	○	6	○	-	**30**
		Dry	6	○	14	○	0.1	○	2	○	2	○		
Phosphate as PO_4^{3-}	mg/l	Rainy	0.008	○	0.014	○	-		-		-		-	**0.15**
		Dry	0.66	×	0.582	×	0.187	×	0.071	○	0.551	×		
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		**0.05**	**0.05**
		Dry	0.024	○	0.012	○	0.001	○	0.001	○	0.037	○		
Copper as Cu^{2+}	mg/l	Rainy	0.004	○	0.004	○	0.006	○	0.005	○	0.005	○	**2**	**2**
		Dry	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○		
Dissolved Oxygen (DO)	mg/l	Rainy	2.2		4.8		4.8		4.2		4		-	-
		Dry	6.1		6.8		3.2		2.5		8.9			
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	6.5	○	3.1	○	2	○	1	○	3	○	-	**20**
		Dry	4.1	○	5.1	○	21	×	45	×	3.8	○		
Chemical Oxygen Demand (COD)	mg/l	Rainy	31	○	9	○	9	○	8	○	11	○	-	**60**
		Dry	14.1	○	19.6	○	74.5	×	110	×	11.8	○		
Faecal Coliform	Count/100ml	Rainy	0	○	98	×	212	×	89	×	200	×	**50**	-
		Dry	0	○	2	○	0	○	172	×	0	○		
Faecal Streptococci	Count/100ml	Rainy	0	○	50	×	9	×	5	×	70	×	**0**	-
		Dry	0	○	0	○	0	○	16	×	0	○		

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.

Δ: the value is close to the upper limit.

×: the value exceeds over the upper limit.

Source: Project Team

Table 6.6.8 Summary of Water Quality for Surface Water (1/6)

Constituents	Unit	Sampling Season	1B1		1C9		1O1		1M1		2B21		WHO-2011	MBS: MS214 (Drinking Water)	MBS: MS691 (Domestic / Sewage elluents)
			Shire River at Liwonde Railway Bridge		Lunzu River at M1 Road Bridge		Lisungwi River at Mwanza/Neno Road Bridge		Nkulumadzi River at M1 Mwanza Road Bridge		Kujabgaka River at ZA/BT Road Bridge				
pH	-	Rainy	7.9	○	7.47	○	7.45	○	7.46	○	7.2	○	**6.5-8.5**	**5.0 - 9.5**	**6.5 - 9.0**
		Dry	8.55	○	8.36	○	7.92	○	8.06	○	7.45	○			
Temperature	ºC	Rainy	25.5		21.4		22.5		23.1		21.4		**-**	**-**	**-**
		Dry	26.5		24.2		21.2		21.1		20.4				
Electrical Conductivity (EC)	μs/cm	Rainy	260	×	376	×	138	○	136	○	73	○	**-**	**150**	**-**
		Dry	277	×	546	×	187	×	118	○	96	○			
Total Dissolved Solids (TDS)	mg/l	Rainy	120	○	195	○	69	○	68	○	37	○	**-**	**1,000**	**500**
		Dry	141	○	270	○	98	○	70	○	60	○			
Carbonate as CO_3^{2-}	mg/l	Rainy	19		0		0		0		0		**-**	**-**	**-**
		Dry	14.4		28.8		9.6		4.8		0				
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	53		214		60		54		28		**-**	**-**	**-**
		Dry	98		202		50		38		42				
Chloride as Cl^-	mg/l	Rainy	25.4	○	8.5	○	12.6	○	15	○	8.6	○	**250**	**200**	**-**
		Dry	12	○	20.6	○	12.2	○	6.1	○	5	○			
Sulphate as SO_4^{2-}	mg/l	Rainy	3.1	○	6.2	○	1.1	○	0.022	○	0.78	○	**400**	**400**	**-**
		Dry	5.38	○	11.9	○	8.31	○	6.19	○	5.14	○			
Nitrate as NO_3^-	mg/l	Rainy	0.017	○	0.381	○	0.043	○	0.013	○	0.001	○	**50**	**10**	**-**
		Dry	0.001	○	0.001	○	0.001	○	0.006	○	0.001	○			
Fluoride as F^-	mg/l	Rainy	0.74	○	0.48	○	0.1	○	0.01	○	0.04	○	**1.5**	**1**	**2**
		Dry	1.28	×	1.34	×	0.59	○	0.65	○	0.71	○			
Sodium as Na^+	mg/l	Rainy	26	○	23	○	12	○	14	○	8	○	**200**	**200**	**-**
		Dry	21	○	25	○	13	○	8	○	6	○			
Potassium as K^+	mg/l	Rainy	5.7		1.8		2.1		2.1		0.7		**-**	**-**	**-**
		Dry	57		1.2		1.8		1.4		1				
Calcium as Ca^{2+}	mg/l	Rainy	11	○	35.1	○	10.1	○	9	○	4.2	○	**200**	**150**	**-**
		Dry	16	○	47.2	○	11.6	○	8	○	6.6	○			
Magnesium as Mg^{2+}	mg/l	Rainy	5.2	○	13.5	○	3.2	○	2.2	○	1.4	○	**150**	**70**	**-**
		Dry	9.6	○	20.6	○	6.1	○	3.6	○	4.2	○			
Iron as Fe^{2+}	mg/l	Rainy	0.002	○	0.006	○	0.032	○	0.057	○	0.438	×	**1.5**	**0.2**	**-**
		Dry	0.001	○	0.001	○	0.001	○	0.727	×	0.001	○			
Manganse as Mn^{2+}	mg/l	Rainy	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○	**0.5**	**0.1**	**-**
		Dry	0.001	○	0.001	○	0.001	○	0.205	×	0.001	○			
Hardness as $CaCO_3$	mg/l	Rainy	48		143		38		31		17		**-**	**-**	**-**
		Dry	79		202		54		36		33				
Alkalinity as CaCO3	mg/l	Rainy	75		175		49		44		22		**-**	**-**	**-**
		Dry	108		214		57		39		34				
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		**-**	**-**	**-**
		Dry	8		14		10		12		11				
Turbidity	NTU	Rainy	14	×	17	×	500	×	230	×	24	×	**5**	**1**	**25**
		Dry	22	×	4	×	22	×	24	×	12	×			
Suspended Solids (SS)	mg/l	Rainy	13	○	15	○	489	×	200	×	20	○	**-**	**-**	**30**
		Dry	18	○	2	○	20	○	20	○	8	○			
Phosphate as PO_4^{3-}	mg/l	Rainy	0.001	○	0.081	○	0.197	×	0.113	Δ	0.001	○	**-**	**-**	**0.15**
		Dry	0.001	○	0.02	○	0.015	○	0.011	○	0.01	○			
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		**0.01**	**0.05**	**0.05**
		Dry	0.013	○	0.027	○	0.009	○	0.04	○	0.022	○			
Copper as Cu^{2+}	mg/l	Rainy	0.006	○	0.01	○	0.011	○	0.01	○	0.005	○	**2**	**1**	**2**
		Dry	0.001	○	0.001	○	0.001	○	0.001	○	0.041	○			
Dissolved Oxygen (DO)	mg/l	Rainy	6.2		8.7		5.2		6.2		8.7		**-**	**-**	**-**
		Dry	6		6.2		6.8		5.3		8.2				
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	1	○	5	○	8	○	5	○	5	○	**-**	**-**	**20**
		Dry	9.15	○	6.7	○	6.85	○	8.9	○	9.7	○			
Chemical Oxygen Demand (COD)	mg/l	Rainy	4	○	45	○	63	×	37	○	28	○	**-**	**-**	**60**
		Dry	29.4	○	25.1	○	15.2	○	21.6	○	27.1	○			
Faecal Coliform	Count/100ml	Rainy	60	×	90	×	12	×	42	×	4680	×	**0**	**0**	**-**
		Dry	48	×	872	×	556	×	908	×	1620	×			
Faecal Streptococci	Count/100ml	Rainy	4	×	42	×	90	×	20	×	1060	×	**0**	**0**	**-**
		Dry	28	×	480	×	408	×	100	×	672	×			

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.
Δ: the value is close to the upper limit.
×: the value exceeds over the upper limit.

Source: Project Team

Table 6.6.9 Summary of Water Quality for Surface Water (2/6)

Constituents	Unit	Sampling Season	2C10		3A2		1T1		4D23		4B4		WHO-2011	MBS: MS214 (Drinking Water)	MBS: MS691 (Domestic / Sewage elluents)
			Likangala River at Kachulu Bridge		Lake Malwi at Monkey Bay Guaging Station		Shire River at Mangochi Road Bridge		Lilongwe River Upstream the confluence with Katete River		Diamphwe river at M1 Road Bridge				
pH	-	Rainy	7.54	○	8.2	○	7.7	○	7.4	○	7.3	○	6.5-8.5	5.0 - 9.5	6.5 - 9.0
		Dry	7.53	○	8.78	○	8.32	○	7.6	○	7.89	○			
Temperature	ºC	Rainy	22.4		28.3		28.2		26.3		24.9		-	-	-
		Dry	20.4		27.4		26.2		27.4		26.2				
Electrical Conductivity (EC)	µs/cm	Rainy	105	○	249	×	252	×	70	○	100	○	-	150	-
		Dry	134	○	250	×	256	×	77	○	226	×			
Total Dissolved Solids (TDS)	mg/l	Rainy	51	○	120	○	117	○	37	○	52	○	-	1,000	500
		Dry	76	○	126	○	131	○	45	○	113	○			
Carbonate as CO_3^{2-}	mg/l	Rainy	4		9		14		0		0		-	-	-
		Dry	4.8		14.4		19.2		0		9				
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	36		80		58		27		42		-	-	-
		Dry	42		90		72		15		55				
Chloride as Cl^-	mg/l	Rainy	8.6	○	22	○	27.1	○	3.5	○	6	○	250	200	-
		Dry	8.8	○	11.5	○	10.3	○	5.2	○	1.8	○			
Sulphate as SO_4^{2-}	mg/l	Rainy	1.2	○	1.2	○	2.3	○	4.1	○	4	○	400	400	-
		Dry	5.96	○	1.34	○	7.91	○	12	○	37.9	○			
Nitrate as NO_3^-	mg/l	Rainy	0.013	○	0.001	○	0.023	○	0.052	○	0.44	○	50	10	-
		Dry	0.008	○	0.001	○	0.001	○	0.054	○	0.101	○			
Fluoride as F^-	mg/l	Rainy	0.52	○	0.48	○	0.55	○	1.93	×	1.69	×	1.5	1	2
		Dry	0.68	○	0.82	○	1.14	×	1.8	×	0.27	○			
Sodium as Na^+	mg/l	Rainy	10	○	22	○	20	○	4	○	5	○	200	200	-
		Dry	9	○	17	○	20	○	3.2	○	8	○			
Potassium as K^+	mg/l	Rainy	0.8		6.1		6.2		1.3		1.1		-	-	-
		Dry	1.9		5.9		5.9		0.7		0.4				
Calcium as Ca^{2+}	mg/l	Rainy	5.8	○	14	○	13.2	○	7	○	9	○	200	150	-
		Dry	8.4	○	14.9	○	15	○	7.6	○	20	○			
Magnesium as Mg^{2+}	mg/l	Rainy	3.1	○	6.5	○	6.5	○	2	○	4.3	○	150	70	-
		Dry	4.6	○	9.1	○	6.8	○	2	○	7.7	○			
Iron as Fe^{2+}	mg/l	Rainy	0.003	○	0.001	○	0.11	○	0.374	×	0.293	×	1.5	0.2	-
		Dry	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○			
Manganse as Mn^{2+}	mg/l	Rainy	0.001	○	0.001	○	0.001	○	0.002	○	0.001	○	0.5	0.1	-
		Dry	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○			
Hardness as $CaCO_3$	mg/l	Rainy	27		61		59		26		40		-	-	-
		Dry	39		73		65		27		81				
Alkalinity as CaCO3	mg/l	Rainy	36		80		70		22		34		-	-	-
		Dry	42		97		90		12		60				
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		-	-	-
		Dry	11		8		8		10		7				
Turbidity	NTU	Rainy	58	×	6	×	4	×	18	×	50	×	5	1	25
		Dry	18	×	2.8	×	1.8	×	6	×	2.5	×			
Suspended Solids (SS)	mg/l	Rainy	55	×	6	○	2.5	○	16	○	47	×	-	-	30
		Dry	15	○	2	○	0.1	○	2.5	○	0.1	○			
Phosphate as PO_4^{3-}	mg/l	Rainy	0.001	○	0.001	○	0.001	○	0.081	○	0.74	×	-	-	0.15
		Dry	0.061	○	0.001	○	0.001	○	0.845	×	0.848	×			
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		0.01	0.05	0.05
		Dry	0.007	○	0.02	○	0.008	○	0.015	○	0.014	○			
Copper as Cu^{2+}	mg/l	Rainy	0.009	○	0.004	○	0.005	○	0.001	○	0.001	○	2	1	2
		Dry	0.001	○	0.011	○	0.001	○	0.001	×	0.001	×			
Dissolved Oxygen (DO)	mg/l	Rainy	8.3		7.4		6.6		5.3		5.1		-	-	-
		Dry	6.5		7.4		5.9		8.6		9.3				
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	3	○	4	○	2	○	5	○	5	○	-	-	20
		Dry	10.4	○	4.5	○	8.45	○	2.1	○	0.9	○			
Chemical Oxygen Demand (COD)	mg/l	Rainy	10	○	27	○	10	○	14	○	113	×	-	-	60
		Dry	33.7	○	12.9	○	13.3	○	7.8	○	4.4	○			
Faecal Coliform	Count/100ml	Rainy	2055	×	100	×	20	×	1050	×	760	×	0	0	-
		Dry	1620	×	56	×	48	×	55	×	40	×			
Faecal Streptococci	Count/100ml	Rainy	1380	×	4	×	4	×	420	×	105	×	0	0	-
		Dry	672	×	8	×	0	○	8	×	8	×			

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.

Δ: the value is close to the upper limit.

×: the value exceeds over the upper limit.

Source: Project Team

Table 6.6.10 Summary of Water Quality for Surface Water (3/6)

Constituents	Unit	Sampling Season	4C11		4F6		4B1		5E6		5F2		WHO-2011	MBS: MS214 (Drinking Water)	MBS: MS691 (Domestic / Sewage elluents)
			Nanjiri River at Kadzizila Village		Lumbadzi River Upstream LL/SA Road Bridge		Linthipe River at Railway Bridge Gauging Station		Bua River at Foot Path to Customs Office		Liwerezi River at the Road Bridge				
pH	-	Rainy	7.45	○	7.47	○	8.2	○	7.49	○	7.4	○	**6.5-8.5**	**5.0 - 9.5**	**6.5 - 9.0**
		Dry	7.75	○	8.98	○	7.74	○	7.72	○	6.68	○			
Temperature	ºC	Rainy	25.2		24.5		27.3		22.9		24.1		**-**	**-**	**-**
		Dry	24.3		27.2		25.2		22.7		26.9				
Electrical Conductivity (EC)	μs/cm	Rainy	300	×	300	×	307	×	69	○	70	○	**-**	**150**	**-**
		Dry	680	×	674	×	779	×	120	○	99	○			
Total Dissolved Solids (TDS)	mg/l	Rainy	150	○	155	○	150	○	36	○	36	○	**-**	**1,000**	**500**
		Dry	340	○	318	○	383	○	58	○	50	○			
Carbonate as CO_3^{2-}	mg/l	Rainy	0		0		12		0		0		**-**	**-**	**-**
		Dry	18		54		36		4		0				
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	86		102		70		14		15		**-**	**-**	**-**
		Dry	255		131		99		30		27.8				
Chloride as Cl^-	mg/l	Rainy	32.1	○	18.6	○	15.5	○	8	○	8	○	**250**	**200**	**-**
		Dry	18.1	○	12.7	○	54.3	○	3.7	○	7.2	○			
Sulphate as SO_4^{2-}	mg/l	Rainy	19.2	○	29.2	○	33.9	○	6.09	○	6.51	○	**400**	**400**	**-**
		Dry	53.3	○	70.2	○	104	○	16.3	○	12.2	○			
Nitrate as NO_3^-	mg/l	Rainy	0.032	○	0.001	○	0.024	○	0.047	○	0.001	○	**50**	**10**	**-**
		Dry	0.057	○	0.085	○	0.155	○	0.061	○	0.068	○			
Fluoride as F^-	mg/l	Rainy	1.64	×	1.42	×	0.31	○	0.49	○	0.41	○	**1.5**	**1**	**2**
		Dry	0.66	○	0.59	○	0.81	○	0.1	○	0.62	○			
Sodium as Na^+	mg/l	Rainy	15	○	20	○	14	○	8	○	7	○	**200**	**200**	**-**
		Dry	33	○	42	○	80	○	4	○	4	○			
Potassium as K^+	mg/l	Rainy	2.3		3.2		2.2		0.7		1.7		**-**	**-**	**-**
		Dry	1.3		2.8		9.6		1		0.3				
Calcium as Ca^{2+}	mg/l	Rainy	26	○	23.2	○	27.3	○	4	○	3.7	○	**200**	**150**	**-**
		Dry	77	○	60	○	40	○	10	○	8	○			
Magnesium as Mg^{2+}	mg/l	Rainy	9.72	○	8.7	○	8.6	○	1	○	1	○	**150**	**70**	**-**
		Dry	14	○	11.2	○	10.2	○	4.7	○	3.8	○			
Iron as Fe^{2+}	mg/l	Rainy	0.408	×	0.555	×	0.026	○	0.047	○	0.372	×	**1.5**	**0.2**	**-**
		Dry	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○			
Manganse as Mn^{2+}	mg/l	Rainy	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○	**0.5**	**0.1**	**-**
		Dry	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○			
Hardness as $CaCO_3$	mg/l	Rainy	105		94		104		14		14		**-**	**-**	**-**
		Dry	249		195		141		44		35				
Alkalinity as CaCO3	mg/l	Rainy	70		83		57		11		12		**-**	**-**	**-**
		Dry	239		197		141		31		22				
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		**-**	**-**	**-**
		Dry	8		20		12		12		13				
Turbidity	NTU	Rainy	120	×	200	×	62	×	1.1	Δ	28	×	**5**	**1**	**25**
		Dry	4	×	4.2	×	12	×	8	×	4.2	×			
Suspended Solids (SS)	mg/l	Rainy	117	×	195	×	60	×	0.1	○	26	○	**-**	**-**	**30**
		Dry	3	○	2	○	6	○	5	○	2	○			
Phosphate as PO_4^{3-}	mg/l	Rainy	0.145	Δ	0.062	○	0.071	○	0.035	○	0.039	○	**-**	**-**	**0.15**
		Dry	0.89	×	0.589	×	0.706	×	0.623	×	0.791	×			
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		**0.01**	**0.05**	**0.05**
		Dry	0.015	○	0.015	○	0.065	×	0.047	○	0.013	○			
Copper as Cu^{2+}	mg/l	Rainy	0.002	○	0.002	○	0.003	○	0.001	○	0.002	○	**2**	**1**	**2**
		Dry	0.02	×	0.001	×	0.002	×	0.001	×	0.008	×			
Dissolved Oxygen (DO)	mg/l	Rainy	7.3		8.5		4.5		10.2		8.3		**-**	**-**	**-**
		Dry	10.1		9.6		9.1		8.3		9.2				
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	5	○	5	○	5	○	5	○	5	○	**-**	**-**	**20**
		Dry	8.2	○	4.8	○	6.6	○	5.4	○	7.1	○			
Chemical Oxygen Demand (COD)	mg/l	Rainy	72	×	20	○	31	○	97	×	46	○	**-**	**-**	**60**
		Dry	49.4	○	16.5	○	19.6	○	27.4	○	25.9	○			
Faecal Coliform	Count/100ml	Rainy	1020	×	1100	×	250	×	1520	×	1400	×	**0**	**0**	**-**
		Dry	300	×	1065	×	2355	×	1980	×	75	×			
Faecal Streptococci	Count/100ml	Rainy	40	×	150	×	40	×	500	×	1160	×	**0**	**0**	**-**
		Dry	156	×	955	×	1420	×	1220	×	60	×			

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.

Δ: the value is close to the upper limit.

×: the value exceeds over the upper limit.

Source: Project Team

Table 6.6.11 Summary of Water Quality for Surface Water (4/6)

Constituents	Unit	Sampling Season	5C1		5D1		6D10		6C1		7H3		7G14		WHO-2011	MBS: MS214 (Drinking Water)	MBS: MS691 (Domestic / Sewage elluents)
			Bua River at Old Bridge		Bua River at KU/KK Road Bridge		Dwangwa Rivr at M1 Road Bridge		Dwangwa River downstream Road Bridge		North Rumphi River at M1 Road Bridge		South Rukulu River at M1 Road Bridge				
pH	-	Rainy	7.5	○	8.25	○	7.1	○	7.85	○	7.69	○	7.68	○	**6.5-8.5**	**5.0 - 9.5**	**6.5 - 9.0**
		Dry	7.37	○	8.94	○	8.72	○	6.92	○	7.34	○	7.38	○			
Temperature	ºC	Rainy	28.6		28.3		24.8		27.2		25.1		27.2		**-**	**-**	**-**
		Dry	29.7		24.6		25.3		29.3		16.4		16.1				
Electrical Conductivity (EC)	µs/cm	Rainy	244	×	198	×	190	×	196	×	51	○	109	○	**-**	**150**	**-**
		Dry	297	×	346	×	649	×	93	○	32	○	87	○			
Total Dissolved Solids (TDS)	mg/l	Rainy	127	○	94	○	92	○	92	○	25	○	55	○	**-**	**1,000**	**500**
		Dry	153	○	168	○	320	○	47	○	16	○	44	○			
Carbonate as CO_3^{2-}	mg/l	Rainy	0		10		0		12		0		0		**-**	**-**	**-**
		Dry	0		12		20		0		0		0				
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	70		66		81		62		11		38		**-**	**-**	**-**
		Dry	109		62		142		20		7		17				
Chloride as Cl^-	mg/l	Rainy	10.1	○	10.4	○	8.8	○	10.8	○	5.4	○	12.5	○	**250**	**200**	**-**
		Dry	10.9	○	23.5	○	61.5	○	9	○	3.3	○	9.9	○			
Sulphate as SO_4^{2-}	mg/l	Rainy	39.4	○	6.2	○	6.31	○	5.2	○	5.41	○	2.19	○	**400**	**400**	**-**
		Dry	34.6	○	45.7	○	46.3	○	11.9	○	3.84	○	12.2	○			
Nitrate as NO_3^-	mg/l	Rainy	0.053	○	0.001	○	0.004	○	0.001	○	0.035	○	0.001	○	**50**	**10**	**-**
		Dry	0.074	○	0.083	○	0.079	○	0.079	○	0.001	○	0.063	○			
Fluoride as F^-	mg/l	Rainy	0.41	○	0.12	○	0.46	○	0.22	○	0.6	○	0.38	○	**1.5**	**1**	**2**
		Dry	0.37	○	0.11	○	0.5	○	0.18	○	0.14	○	0.15	○			
Sodium as Na^+	mg/l	Rainy	15	○	11	○	7	○	8	○	5	○	11	○	**200**	**200**	**-**
		Dry	10	○	18	○	71	○	6	○	2	○	7	○			
Potassium as K^+	mg/l	Rainy	2		1.7		2.8		2.9		1		2.9		**-**	**-**	**-**
		Dry	1.9		1.5		4.7		2		0.9		1.4				
Calcium as Ca^{2+}	mg/l	Rainy	16.3	○	13.5	○	20	○	21	○	3	○	6	○	**200**	**150**	**-**
		Dry	33	○	26	○	38	○	6	○	2.2	○	5.1	○			
Magnesium as Mg^{2+}	mg/l	Rainy	8.8	○	7.6	○	6.4	○	6.4	○	1	○	2.1	○	**150**	**70**	**-**
		Dry	8.4	○	11	○	7.8	○	2.6	○	0.9	○	2	○			
Iron as Fe^{2+}	mg/l	Rainy	0.298	×	0.193	Δ	0.562	×	0.507	×	0.291	×	0.787	×	**1.5**	**0.2**	**-**
		Dry	0.001	○	0.001	○	0.001	○	0.155	○	0.001	○	0.31	×			
Manganse as Mn^{2+}	mg/l	Rainy	0.001	○	0.001	○	0.003	○	0.002	○	0.001	○	0.006	○	**0.5**	**0.1**	**-**
		Dry	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○			
Hardness as $CaCO_3$	mg/l	Rainy	77		65		77		80		12		25		**-**	**-**	**-**
		Dry	116		110		126		25		9		22				
Alkalinity as CaCO3	mg/l	Rainy	57		70		66		71		9		31		**-**	**-**	**-**
		Dry	89		70		149		16		5		13				
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		-		**-**	**-**	**-**
		Dry	6		11		9		10		0.1		0.1				
Turbidity	NTU	Rainy	60	×	38	×	50	×	160	×	10	×	120	×	**5**	**1**	**25**
		Dry	6	×	4	×	6	×	8	×	0.8	○	15	×			
Suspended Solids (SS)	mg/l	Rainy	56	×	37	×	46	×	156	×	5	○	50	×	**-**	**-**	**30**
		Dry	3	○	3	○	4	○	4	○	6	○	14	○			
Phosphate as PO_4^{3-}	mg/l	Rainy	0.051	○	0.031	○	0.103	○	0.157	×	0.007	○	0.136	Δ	**-**	**-**	**0.15**
		Dry	0.789	×	0.833	×	0.751	×	0.498	×	0.755	×	0.57	×			
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		-		**0.01**	**0.05**	**0.05**
		Dry	0.034	○	0.004	○	0.01	○	0.012	○	0.013	○	0.023	○			
Copper as Cu^{2+}	mg/l	Rainy	0.003	○	0.004	○	0.001	○	0.007	○	0.003	○	0.002	○	**2**	**1**	**2**
		Dry	0.013	×	0.001	○	0.001	○	0.011	○	0.001	○	0.001	○			
Dissolved Oxygen (DO)	mg/l	Rainy	6.8		5.2		5.4		4.6		7.1		6.2		**-**	**-**	**-**
		Dry	8.9		9.3		4.7		8.9		7.1		7				
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	4	○	4	○	5	○	5	○	1.9	○	1.9	○	**-**	**-**	**20**
		Dry	5.2	○	7.6	○	6.1	○	0.9	○	3.6	○	5.8	○			
Chemical Oxygen Demand (COD)	mg/l	Rainy	125	×	90	×	82	×	135	×	60	Δ	11	○	**-**	**-**	**60**
		Dry	31.4	○	61.2	×	111	×	2.9	○	8.6	○	14.1	○			
Faecal Coliform	Count/100ml	Rainy	820	×	200	×	1120	×	1760	×	1240	×	270	×	**0**	**0**	**-**
		Dry	125	×	500	×	1850	×	120	×	0	○	2350	×			
Faecal Streptococci	Count/100ml	Rainy	105	×	75	×	660	×	575	×	250	×	100	×	**0**	**0**	**-**
		Dry	25	×	130	×	125	×	20	×	200	×	0	○			

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.
Δ: the value is close to the upper limit.
×: the value exceeds over the upper limit.

Source: Project Team

Table 6.6.12 Summary of Water Quality for Surface Water (5/6)

Constituents	Unit	Sampling Season	7D4		7A3		8A8		9B4		14C2		14C8		**WHO-2011**	**MBS: MS214 (Drinking Water)**	**MBS: MS691 (Domestic / Sewage elluents)**
			Kasitu River at Edundu		South Rukulu River at Chimsewezo		North Rukuru River at Uledi Gauging Station		Songwe River Water Guaging Station		Ruo River at Trading Centre Old Road Bridge		Lichenya River Upstream Mulanje Road Bridge				
pH	-	Rainy	8.03	○	7.27	○	7.69	○	7.43	○	7	○	7.4	○	**6.5-8.5**	**5.0 - 9.5**	**6.5 - 9.0**
		Dry	-		8.03	○	7.29	○	7.31	○	7.8	○	8.44	○			
Temperature	ºC	Rainy	29.3		24		25.7		28.5		24.9		23.8		-	-	-
		Dry	-		17		22.2		17.4		21.2		20.2				
Electrical Conductivity (EC)	μs/cm	Rainy	198	×	154	×	47	○	83	○	27	○	48	○	-	**150**	-
		Dry	-		201	×	38	○	97	○	29	○	51	○			
Total Dissolved Solids (TDS)	mg/l	Rainy	99	○	79	○	24	○	42	○	14	○	24	○	-	**1,000**	**500**
		Dry	-		97	○	19	○	50	○	18	○	26	○			
Carbonate as CO_3^{2-}	mg/l	Rainy	10		0		0		0		0		0		-	-	-
		Dry	-		9		0		0		1.2		1.8				
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	77		69		9		13		9		14		-	-	-
		Dry	-		71		12		33		4		10				
Chloride as Cl^-	mg/l	Rainy	6	○	8.9	○	7	○	10	○	3.5	○	7.2	○	**250**	**200**	-
		Dry	-		9.9	○	3.6	○	6.6	○	3.2	○	7.8	○			
Sulphate as SO_4^{2-}	mg/l	Rainy	4.01	○	5.81	○	3.1	○	10.3	○	0.56	○	0.38	○	**400**	**400**	-
		Dry	-		5.86	○	2.98	○	8.45	○	2.1	○	0.7	○			
Nitrate as NO_3^-	mg/l	Rainy	0.017	○	0.03	○	0.001	○	0.038	○	0.001	○	0.012	○	**50**	**10**	-
		Dry	-		0.001	○	0.001	○	0.001	○	0.28	○	0.001	○			
Fluoride as F^-	mg/l	Rainy	0.57	○	0.63	○	0.32	○	0.41	○	0.1	○	0.44	○	**1.5**	**1**	**2**
		Dry	-		0.57	○	0.9	○	0.69	○	0.19	○	0.15	○			
Sodium as Na^+	mg/l	Rainy	12	○	12	○	3	○	8	○	2	○	6	○	**200**	**200**	-
		Dry	-		14	○	2	○	7	○	1.8	○	4.3	○			
Potassium as K^+	mg/l	Rainy	4		4		1		2.8		0.4		0.3		-	-	-
		Dry	-		2.9		0.7		2.3		0.8		0.58				
Calcium as Ca^{2+}	mg/l	Rainy	15	○	11.2	○	3.4	○	4	○	2	○	2.5	○	**200**	**150**	-
		Dry	-		13	○	3.2	○	7	○	2.6	○	3.9	○			
Magnesium as Mg^{2+}	mg/l	Rainy	6.3	○	4	○	1	○	1	○	0.8	○	0.8	○	**150**	**70**	-
		Dry	-		6.8	○	1	○	2.5	○	0.2	○	1	○			
Iron as Fe^{2+}	mg/l	Rainy	0.367	×	0.843	×	0.413	×	1.19	×	0.018	○	0.063	○	**1.5**	**0.2**	-
		Dry	-		0.87	×	0.001	○	0.038	○	0.56	×	0.001	○			
Manganse as Mn^{2+}	mg/l	Rainy	0.001	○	0.003	○	0.001	○	0.001	○	0.001	○	0.001	○	**0.5**	**0.1**	-
		Dry	-		0.001	○	0.001	○	0.001	○	0.001	○	0.001	○			
Hardness as $CaCO_3$	mg/l	Rainy	64		45		13		16		8		9		-	-	-
		Dry	-		62		12		27		8.8		14				
Alkalinity as $CaCO_3$	mg/l	Rainy	79		56		7		11		7		11		-	-	-
		Dry	-		73		9		27		6.1		11				
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		-		-	-	-
		Dry	-		0.1		0.3		0.4		5		4				
Turbidity	NTU	Rainy	20	×	2	×	60	×	120	×	8	×	6	×	**5**	**1**	**25**
		Dry	-		0.6	○	0.4	○	14	×	2	×	0.8	○			
Suspended Solids (SS)	mg/l	Rainy	13	○	0.1	○	25	○	59	×	7	○	5	○	-	-	**30**
		Dry	-		1	○	6	○	24	○	1	○	0.1	○			
Phosphate as PO_4^{3-}	mg/l	Rainy	0.035	○	0.042	○	0.049	○	0.111	○	0.001	○	0.001	○	-	-	**0.15**
		Dry	-		0.569	×	1.089	×	1.185	×	0.068	○	0.001	○			
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		-		**0.01**	**0.05**	**0.05**
		Dry	-		0.001	○	0.01	○	0.008	○	0.001	○	0.001	○			
Copper as Cu^{2+}	mg/l	Rainy	0.003	○	0.004	○	0.004	○	0.003	○	0.007	○	0.007	○	**2**	**1**	**2**
		Dry	-		0.001	○	0.001	○	0.001	○	0.001	○	0.001	○			
Dissolved Oxygen (DO)	mg/l	Rainy	5.1		4.1		5.7		6		7.3		6		-	-	-
		Dry	-		6.9		7.2		6.6		6.8		8.6				
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	2.2	○	2.2	○	2.6	○	2.2	○	3	○	3	○	-	-	**20**
		Dry	-		3	○	9.5	○	0.8	○	6.35	○	6.25	○			
Chemical Oxygen Demand (COD)	mg/l	Rainy	29	○	43	○	86	×	70	×	11	○	10	○	-	-	**60**
		Dry	-		44.7	○	22.7	○	2.4	○	18.8	○	14.9	○			
Faecal Coliform	Count/100ml	Rainy	1060	×	900	×	2220	×	3450	×	2400	×	1480	×	**0**	**0**	-
		Dry	-		1700	×	150	×	520	×	432	×	28	×			
Faecal Streptococci	Count/100ml	Rainy	990	×	80	×	960	×	370	×	170	×	225	×	**0**	**0**	-
		Dry	-		0	○	50	×	80	×	176	×	4	×			

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.

Δ: the value is close to the upper limit.

×: the value exceeds over the upper limit.

Source: Project Team

Table 6.6.13 Summary of Water Quality for Surface Water (6/6)

Constituents	Unit	Sampling Season	14B4		15B15		15A8		15B6		16E6		16F15		WHO-2011	MBS: MS214 (Drinking Water)	MBS: MS691 (Domestic / Sewage elluents)
			Nsuwadzi River Upstream Water Suplly Intake		Kaombe River at Water Supply Intake		Lingadzi River at Kaniche		Chia Lagoon at Gauging Station		Dwambazi River at Nkhotakota/Nkhata Bay		Luweya River at Mzwnga Village				
pH	-	Rainy	7.4	○	7.47	○	7.37	○	7.39	○	7.94	○	7.87	○	**6.5-8.5**	**5.0 - 9.5**	**6.5 - 9.0**
		Dry	7.23	○	6.94	○	7.85	○	8.04	○	7.28	○	8.16	○			
Temperature	ºC	Rainy	24.1		20.3		27.8		29.4		22.4		25.4		**-**	**-**	**-**
		Dry	23.4		24.2		26.8		29.1		18.1		20				
Electrical Conductivity (EC)	μs/cm	Rainy	150	Δ	156	Δ	203	×	121	○	65	○	76	○	**-**	**150**	**-**
		Dry	144	○	154	×	273	×	192	×	62	○	82	○			
Total Dissolved Solids (TDS)	mg/l	Rainy	74	○	93	○	102	○	61	○	33	○	40	○	**-**	**1,000**	**500**
		Dry	84	○	77	○	127	○	90	○	31	○	43	○			
Carbonate as CO_3^{2-}	mg/l	Rainy	0		0		0		0		2.4		2.4		**-**	**-**	**-**
		Dry	7.2		0		16		13		0		4				
Bicarbonate as HCO_3^{2-}	mg/l	Rainy	52		92		86		50		14		17		**-**	**-**	**-**
		Dry	48		46		83.1		50		16		23				
Chloride as Cl^-	mg/l	Rainy	20.3	○	12.1	○	10.6	○	8.6	○	6.1	○	1.7	○	**250**	**200**	**-**
		Dry	6	○	9.9	○	14.9	○	11.7	○	6.6	○	3.3	○			
Sulphate as SO_4^{2-}	mg/l	Rainy	1.6	○	0.61	○	12.5	○	0.8	○	5.04	○	6.4	○	**400**	**400**	**-**
		Dry	6.41	○	18.9	○	8.63	○	4.2	○	5.08	○	6.31	○			
Nitrate as NO_3^-	mg/l	Rainy	0.006	○	0.006	○	0.013	○	0.001	○	0.001	○	0.005	○	**50**	**10**	**-**
		Dry	0.001	○	0.071	○	0.157	○	0.169	○	0.001	○	0.001	○			
Fluoride as F^-	mg/l	Rainy	0.01	○	0.12	○	0.37	○	0.17	○	0.47	○	0.52	○	**1.5**	**1**	**2**
		Dry	0.49	○	0.42	○	0.59	○	0.53	○	0.14	○	0.16	○			
Sodium as Na^+	mg/l	Rainy	12	○	8	○	10	○	7	○	4	○	6	○	**200**	**200**	**-**
		Dry	8	○	5	○	13	○	13	○	5	○	7	○			
Potassium as K^+	mg/l	Rainy	1.4		1.3		2.8		3.8		1.4		2.2		**-**	**-**	**-**
		Dry	1.3		1		2.3		3.8		1.1		1.1				
Calcium as Ca^{2+}	mg/l	Rainy	10	○	17.1	○	17	○	9	○	5	○	5	○	**200**	**150**	**-**
		Dry	11.4	○	12.4	○	23	○	12	○	4	○	6	○			
Magnesium as Mg^{2+}	mg/l	Rainy	4	○	7.7	○	7.6	○	4	○	1.2	○	1.1	○	**150**	**70**	**-**
		Dry	5	○	6.8	○	8.8	○	6	○	1.2	○	1.2	○			
Iron as Fe^{2+}	mg/l	Rainy	1.42	×	0.418	×	0.647	×	0.399	×	0.585	×	1.22	×	**1.5**	**0.2**	**-**
		Dry	0.001	○	0.819	×	0.001	○	0.001	○	0.026	○	0.001	○			
Manganse as Mn^{2+}	mg/l	Rainy	0.001	○	0.001	○	0.004	○	0.001	○	0.003	○	0.345	×	**0.5**	**0.1**	**-**
		Dry	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○	0.001	○			
Hardness as $CaCO_3$	mg/l	Rainy	43		75		74		39		18		19		**-**	**-**	**-**
		Dry	49		60		93		54		14		19				
Alkalinity as $CaCO_3$	mg/l	Rainy	42		75		70		41		14		17		**-**	**-**	**-**
		Dry	51		37		94		62		13		25				
Silica as SiO_2	mg/l	Rainy	-		-		-		-		-		-		**-**	**-**	**-**
		Dry	15		7		10		9		0.1		1.8				
Turbidity	NTU	Rainy	270	×	10	×	120	×	100	×	4	×	40	×	**5**	**1**	**25**
		Dry	18	×	20	×	6	×	12	×	0.6	○	6	×			
Suspended Solids (SS)	mg/l	Rainy	267	×	8	○	117	×	96	×	1	○	19	○	**-**	**-**	**30**
		Dry	12	○	13	○	3.1	○	7	○	4	○	6	○			
Phosphate as PO_4^{3-}	mg/l	Rainy	0.077	○	0.016	○	0.085	○	0.189	×	0.006	○	0.063	○	**-**	**-**	**0.15**
		Dry	0.001	○	0.325	×	0.7	×	0.632	×	0.311	×	0.685	×			
Lead as Pb^{2+}	mg/l	Rainy	-		-		-		-		-		-		**0.01**	**0.05**	**0.05**
		Dry	0.013	○	0.029	○	0.04	○	0.044	○	0.016	○	0.032	○			
Copper as Cu^{2+}	mg/l	Rainy	0.007	○	0.004	○	0.004	○	0.005	○	0.002	○	0.002	○	**2**	**1**	**2**
		Dry	0.001	○	0.001	○	0.001	○	0.009	○	0.001	○	0.001	○			
Dissolved Oxygen (DO)	mg/l	Rainy	8		5.8		5.6		3.9		5.6		5.8		**-**	**-**	**-**
		Dry	7.2		9.8		8.1		11.2		9.2		9.4				
Biochemical Oxygen Demand (BOD)	mg/l	Rainy	6	○	3	○	4	○	4	○	4.1	○	5.8	○	**-**	**-**	**20**
		Dry	8.2	○	0.7	○	9	○	5.9	○	3.4	○	3.5	○			
Chemical Oxygen Demand (COD)	mg/l	Rainy	60	Δ	44	○	111	×	91	×	89	×	129	×	**-**	**-**	**60**
		Dry	27.8	○	3.8	○	22.7	○	16.5	○	14.9	○	11.8	○			
Faecal Coliform	Count/100ml	Rainy	1020	×	200	×	160	×	105	×	1660	×	1990	×	**0**	**0**	**-**
		Dry	1132	×	120	×	150	×	1600	×	250	×	150	×			
Faecal Streptococci	Count/100ml	Rainy	520	×	25	×	48	×	10	×	350	×	1140	×	**0**	**0**	**-**
		Dry	120	×	115	×	45	×	100	×	100	×	100	×			

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.

Δ: the value is close to the upper limit.

×: the value exceeds over the upper limit.

Source: Project Team

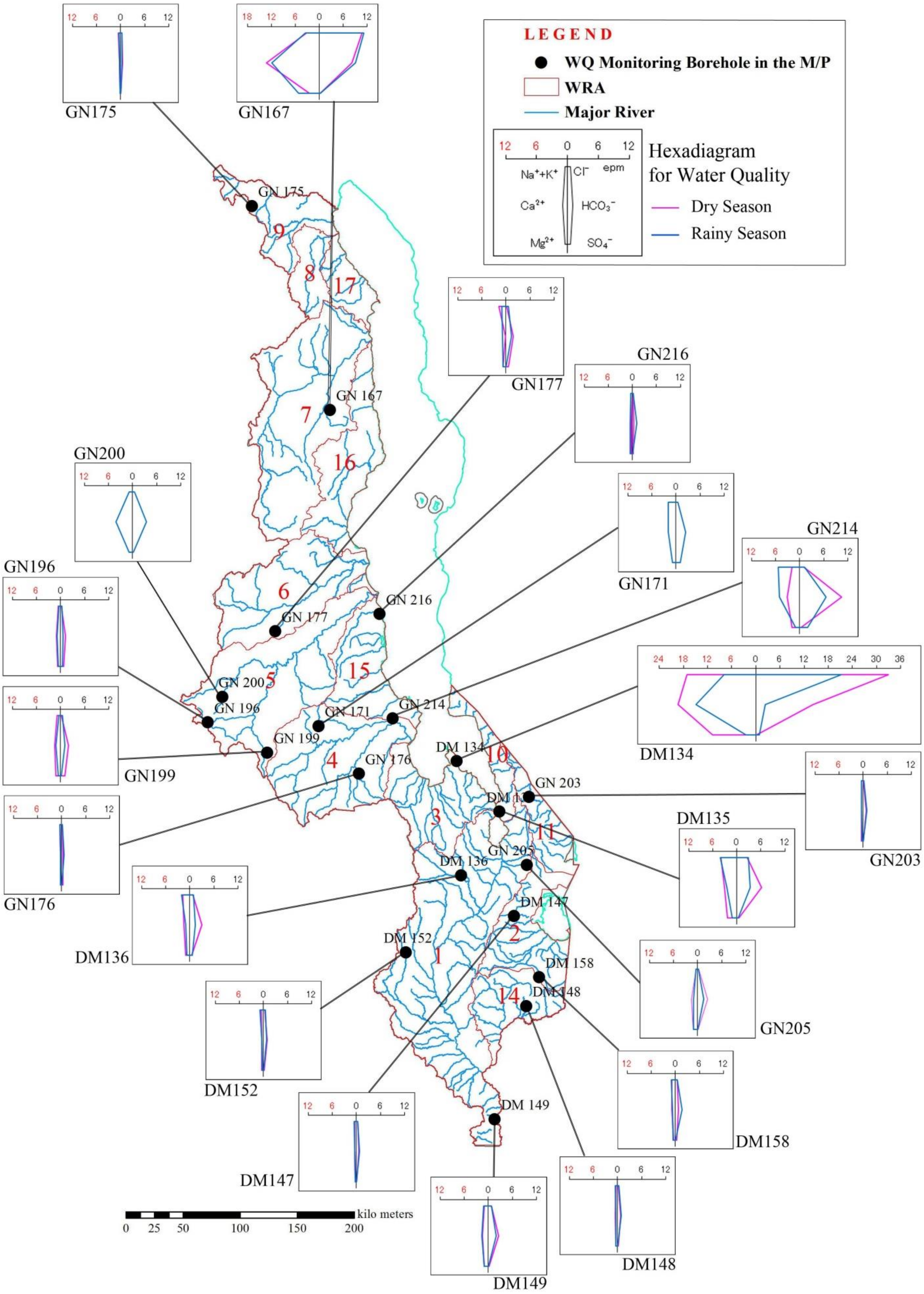
6.6.2 Findings of the Monitoring

(1) Trends of Dissolved Ions in Water

The chemical composition of land surface water (river, lake, wetland, artificial pond and groundwater) is usually classified under six (6) headings; namely, main ions, dissolved gases, biogenic substances, organic substances, microelements and pollutants. Components of main ions, especially, including Sodium (Na^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}) as cations, and Chloride (Cl^-), Sulfate (SO_4^{2-}) Bicarbonate (HCO_3^{2-}) as anions greatly help us to understand aqueous evolutionary paths upon water cycle and make predictions about future conditions of water bodies. Stiff diagram and Piper diagram give graphical and statistical interpretation with equivalents of these seven (7) ions.

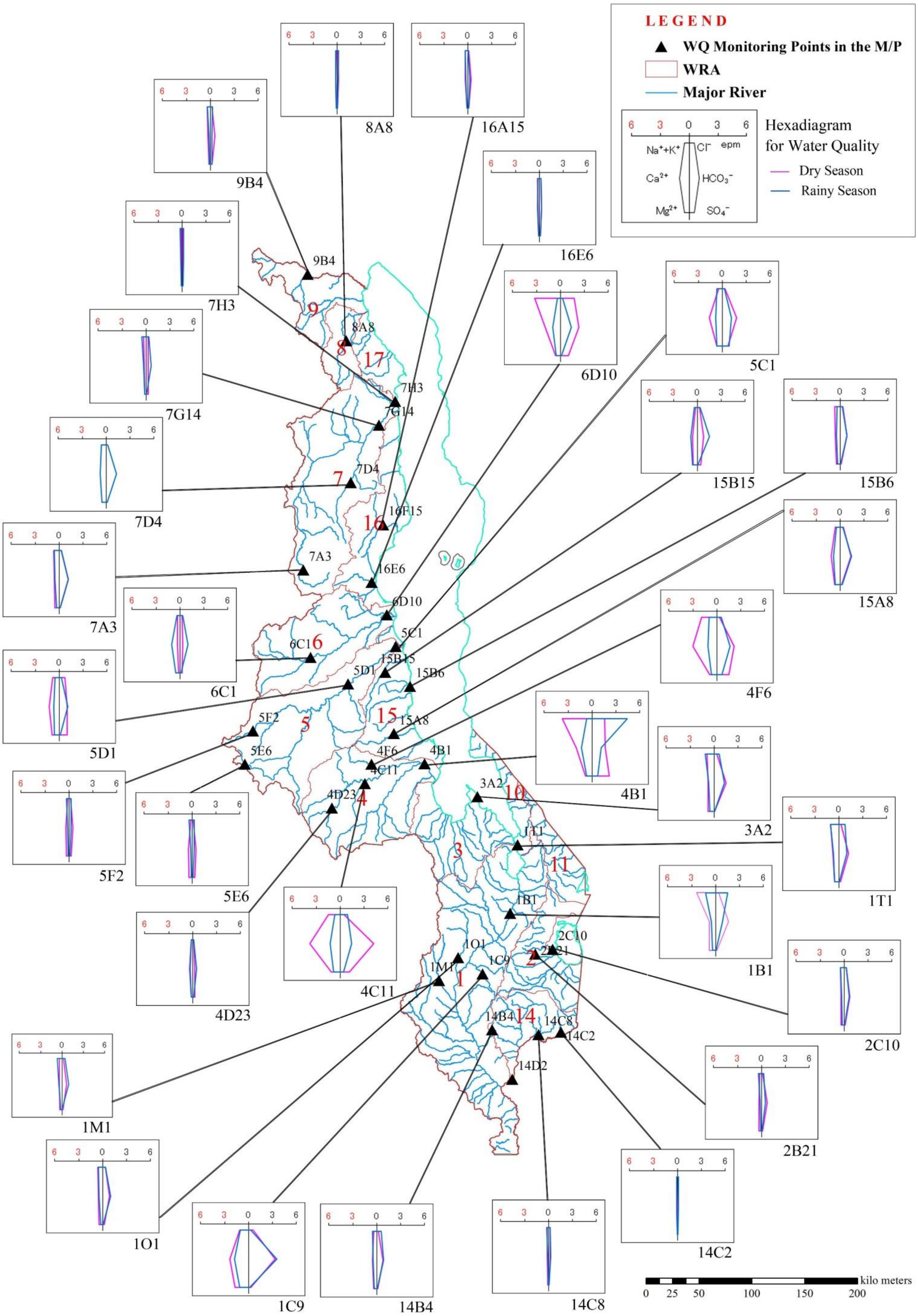
Stiff diagram, or Hexadiagram, is widely utilized to display the major ion concentration of a water sample. A polygonal shape is created from four parallel horizontal axes extending on either side of a vertical zero axis. Cations are plotted on the left side of the zero axis, one to each horizontal axis, and anions are plotted on the right side. Stiff diagrams stuck on a dimensional plane are very helpful to make a rapid visual comparison between different water sources and understand aqueous evolution. **Figure 6.6.2** shows stiff diagrams at all monitoring points of groundwater, and **Figure 6.6.3** shows those of surface water.

Piper diagram, or Tri-linear diagram, is combined with one diamond shaped field and two ternary fields which have apexes peaked at 0% or 100% of equivalent ratios among the main ions. The diagram can statistically sort large groups of data and classify water types based on origin (Type I through VI) although it cannot show ion concentration. **Figure 6.6.4** shows piper diagram plotted with groundwater, and **Figure 6.6.5** shows those of surface water.



Source: Project Team

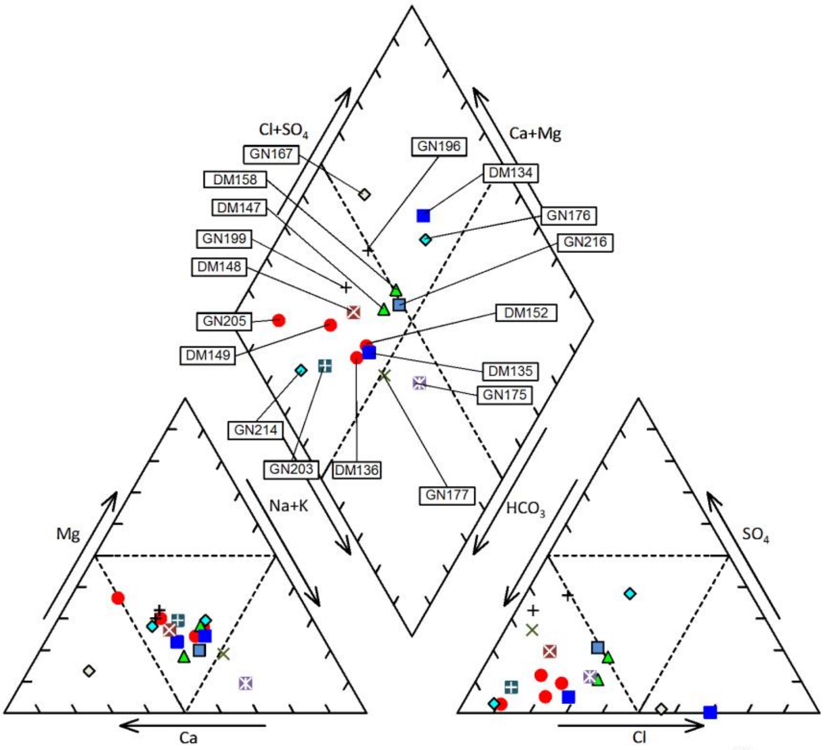
Figure 6.6.2 Stiff Diagram at Monitoring Points of Groundwater in the Whole of Malawi



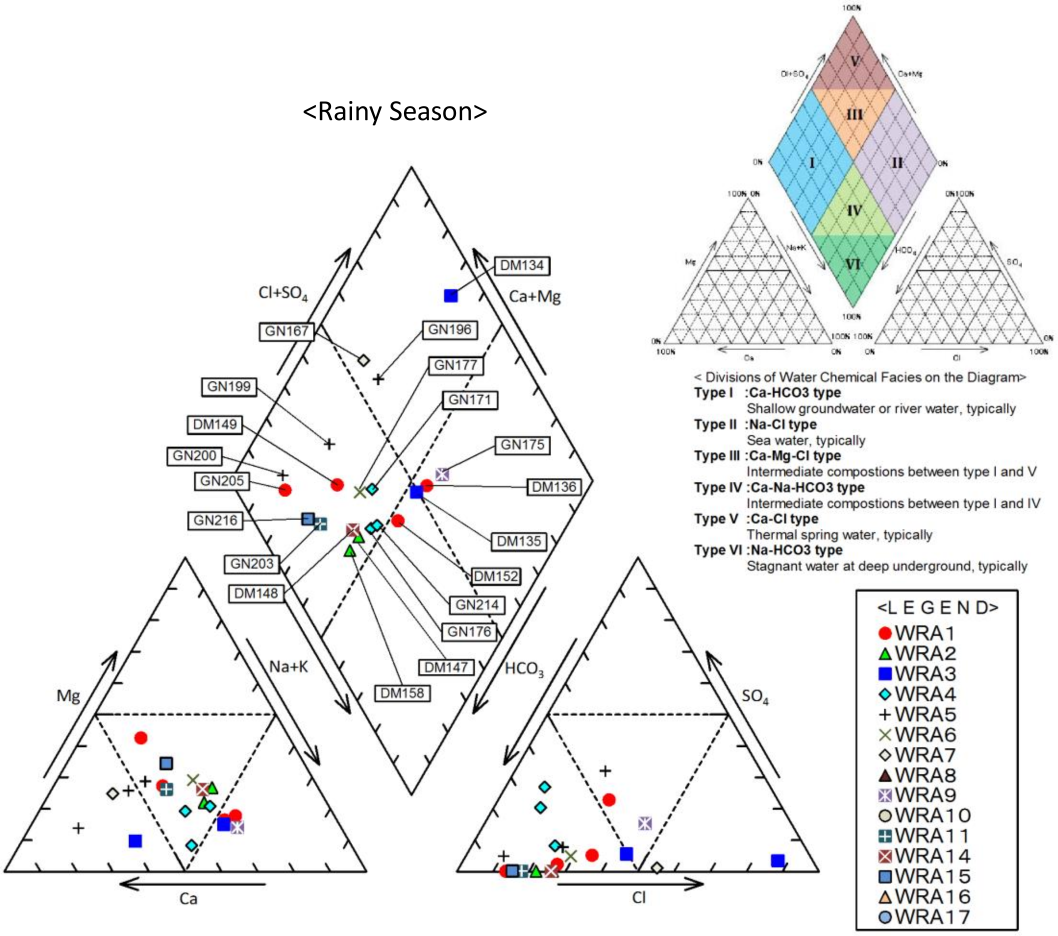
Source: Project Team

Figure 6.6.3 Stiff Diagram at Monitoring Points of Surface Water in the Whole of Malawi

<Dry Season>



<Rainy Season>



< Divisions of Water Chemical Facies on the Diagram>

Type I **:Ca-HCO3 type**
Shallow groundwater or river water, typically

Type II **:Na-Cl type**
Sea water, typically

Type III **:Ca-Mg-Cl type**
Intermediate compostions between type I and V

Type IV **:Ca-Na-HCO3 type**
Intermediate compostions between type I and IV

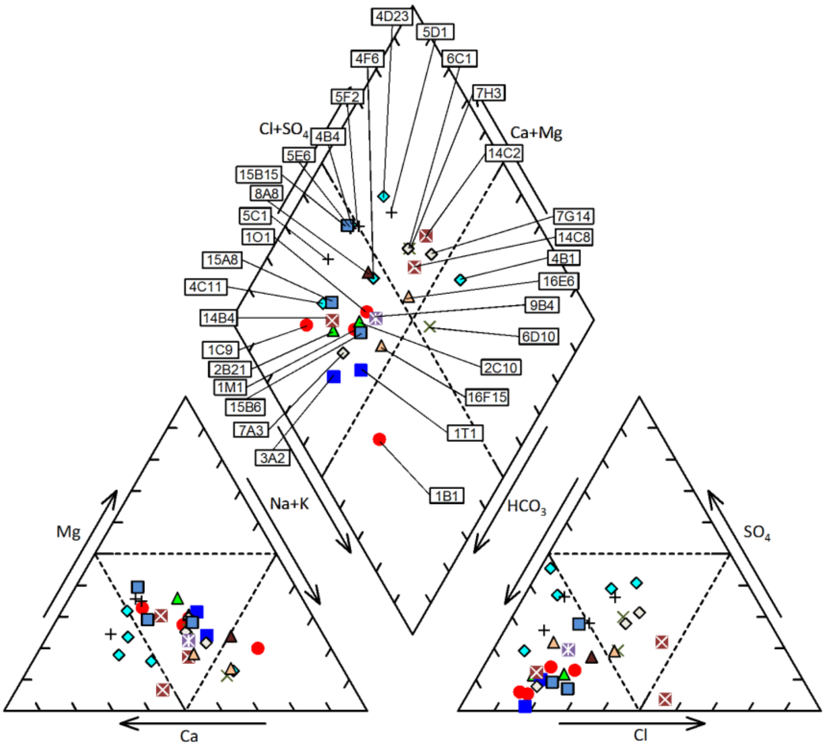
Type V **:Ca-Cl type**
Thermal spring water, typically

Type VI **:Na-HCO3 type**
Stagnant water at deep underground, typically

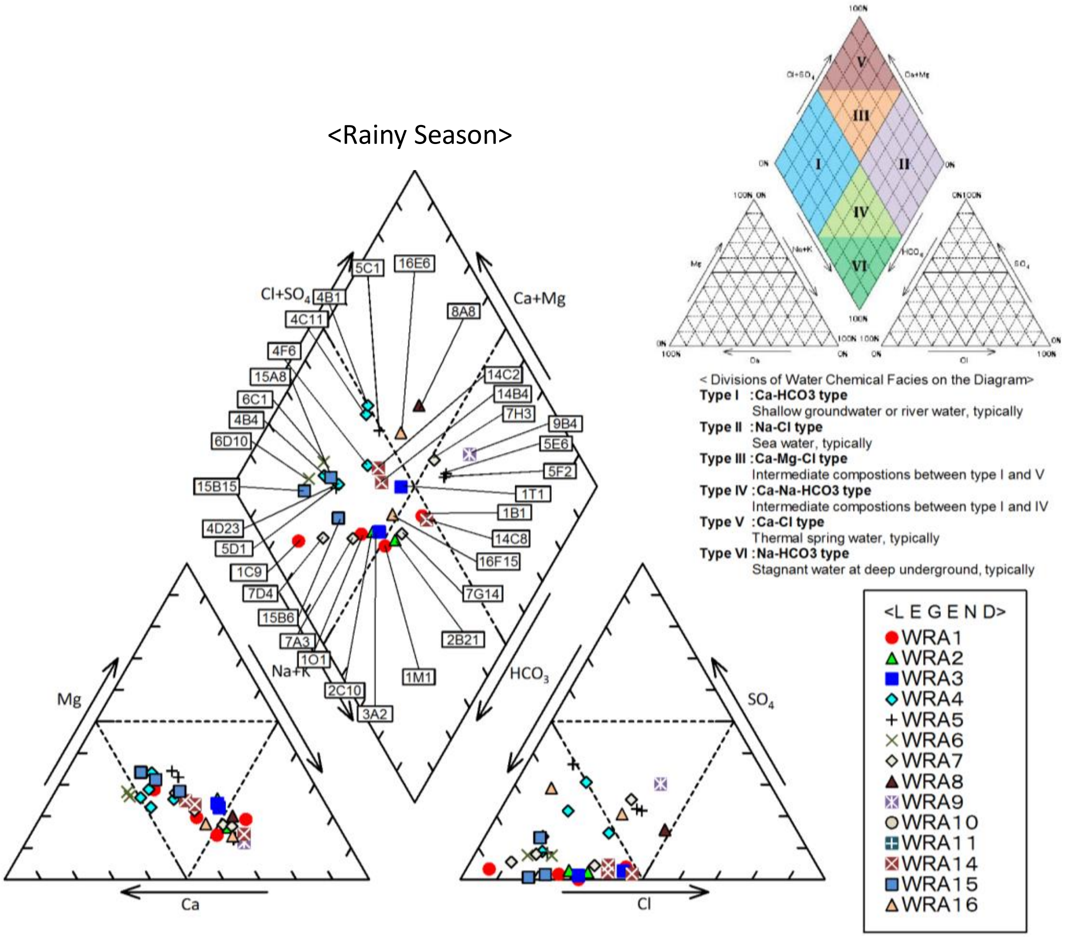
Source: Project Team

Figure 6.6.4 Piper Diagram for Monitoring Data of Groundwater in the Whole of Malawi

<Dry Season>



<Rainy Season>



< Divisions of Water Chemical Facies on the Diagram>

Type I :**Ca-HCO3 type**
Shallow groundwater or river water, typically

Type II :**Na-Cl type**
Sea water, typically

Type III :**Ca-Mg-Cl type**
Intermediate compostions between type I and V

Type IV :**Ca-Na-HCO3 type**
Intermediate compositions between type I and IV

Type V :**Ca-Cl type**
Thermal spring water, typically

Type VI :**Na-HCO3 type**
Stagnant water at deep underground, typically

<L E G E N D>
- ● WRA1
- ▲ WRA2
- ■ WRA3
- ◆ WRA4
- + WRA5
- × WRA6
- ◇ WRA7
- ▲ WRA8
- ☒ WRA9
- ○ WRA10
- ⊞ WRA11
- ☒ WRA14
- ■ WRA15
- △ WRA16

Source: Project Team

Figure 6.6.5 Piper Diagram for Monitoring Data of Surface Water in the Whole of Malawi

1) Groundwater

On the piper diagram, most of samples are plotted in the domain of Ca-HCO_3 type which means typical shallow groundwater or freshwater. It seems that groundwater in Malawi tends to be generally rapidly reshuffled due to active recharge, and seasonal fluctuations of groundwater table in each monitoring well support the trend. Some of the samples show high concentration of main ions on the stiff patterns (see **Figure 6.6.2**). The sample at GN177 among these indicates small variations of chemical components and also small fluctuations through a year. It is thought that the stiff pattern strongly reflects being derived from mineral composition of basement rocks. On the other hand, the sample collected at DM134 indicates far elevated concentration of chloride ion than the other samples. What is more remarkable is that the water has higher electrical conductivity than 3,000 μm/cm which corresponds to brackish water although the monitoring well is located adjacent to Lake Malawi. The water quality of Lake Malawi is clearly prone to freshwater in accordance with data of the gauging station at Monkey Bay (3A2), hence the different trends show that the percolation path of groundwater at DM134 is not related to Lake Malawi at all.

In general, chloride is in poor concentration in land water because the supply from the earth crust is extremely low amount except in some kinds of volcanic or sedimentary rock. However, chloride is one of essential elements for human health and humans absorb it as salt (NaCl) and scatter it as urine into the earth. The monitoring well of DM134 is located on the premises of a primary school and the groundwater table is relatively shallow (annual fluctuation: 2.0-2.5m in depth). Therefore, human wastes from the school might make a contribution to elevate chloride concentration and electrical conductivity in water body at DM134.

2) Surface Water

Most of the samples are plotted in the domain of Ca-HCO_3 type water on the piper diagram and the stiff patterns do not show data which have remarkably high concentration of ions. However, chemical compositions of some of the samples dramatically vary in seasons, on the plateau areas (WRA 4, 5, 6) especially. In focusing on samples at 6D10 and 4B1 on the piper diagram, both samples are plotted in the domain of Na-Cl type which means typical seawater in rainy season where these are plotted in the domain of Ca-HCO_3 type. The stiff diagrams of these commonly show that main ions in dry season are more enriched than in rainy season.

Major rivers flowing on the plateau areas such as the Linthipe River (WRA 4), the Bua River (WRA 5) and the Dwange River (WRA 6) dramatically decrease their flow rate down to almost zero in dry season when parts of these river channel sare completely dried up (see **Figure 6.6.6**). In the river channel cut off into many puddles, water become stagnant and puddles are downsized more and more until start of rainy season. As an inevitable consequence of drying up of river, the concentration of main ions rises up. The drought along river channels make saline dissolved in water precipitate out in soil and salty pollution brings harmful effects to vegetable growth.

Left picture: in rainy season (March, 2013) Right picture: in dry season (October, 2013)

Source: Project Team

Figure 6.6.6 Seasonal Comparison of River Regimes on the Rusa River (WRA 5)

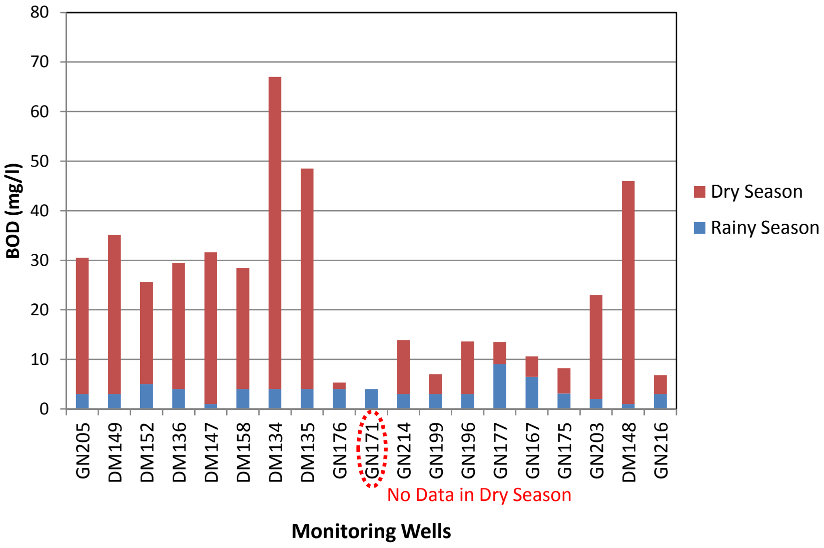
(2) Pollution of Groundwater

Biochemical oxygen demand (BOD), chemical oxygen demand (COD) and dissolved oxygen (DO) as organic pollution indicators were determined for all water samples. BOD is the amount of oxygen required by microorganisms to consume organic compounds, and it can be used as a gauge of nutrient pollution by effluent wastewater. COD is a similar indicator to BOD, they both measure the amount of organic compounds in water. However, COD is less specific, since it measures everything that can be chemically oxidized rather than just levels of biologically active organic matter. DO is a relative measure of the amount of oxygen in water, and generally it is often used for gauging nutrient pollution as same as BOD or COD. Low DO value tends to show as an influence to pollution since insufficient oxygen often caused by the decomposition of organic matter may occur in water body.

For the standards of these pollution indicators, most pristine rivers will have a BOD below 1mg/l, and moderately polluted rivers may have a BOD value in the range of 2 to 8 mg/l. Municipal sewage that is efficiently treated would have a value of about 20 mg/l or less. The optimal levels for DO are higher than 5mg/l in general.

Generally, Organic pollution never occurs in relatively deep aquifer below tens of meters in depth because almost all organic matters are completely lost by biodegradation in subsurface during percolation of surface water into underground. However, half of the sampling points show higher BOD than the pollution level (>20 mg/l) in dry season although most of the BOD in rainy season were less than 5 mg/l as shown **Figure 6.6.7**.

The COD values in dry season tend to be higher than in rainy season and correlate with BOD as shown in **Figure 6.6.8**, hence these seem to be plausible and mean that organic pollutions were induced at monitoring wells where BOD rose in dry season.



Source: Project Team

Figure 6.6.7 Seasonal Comparison on BOD each Groundwater Monitoring Point

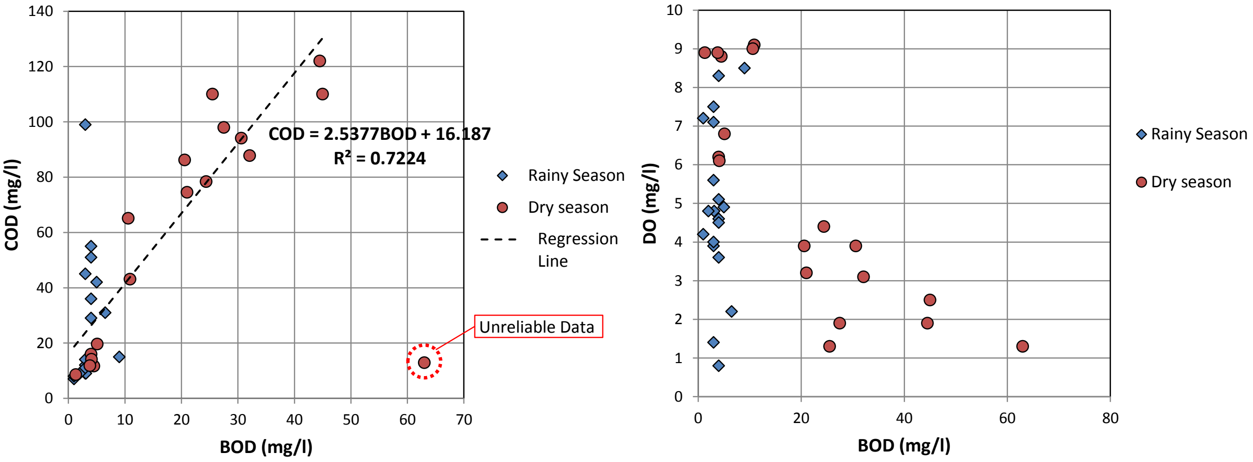
Turbidity and amounts of suspended solids were generally less than the designated threshold except some samples and did not rise as a result of the rising of BOD, thus organic matters might exist as basically soluble substance in the water body, in dry season.

According to the relationship between BOD and DO, DO values roughly tend to decrease in response to the rising of BOD (see **Figure 6.6.8**).

As above mentioned, one reason of BOD rising at monitoring wells in dry season is hypothesized as follows:

- In rainy season, surface water containing soluble organic matters easily flowed into monitoring wells because the seal surrounding the well did not function. However, rich oxygen accompanied with the inflow was brought to groundwater and it oxidized organic matters in water body. Thus it ended up low BOD values.
- In dry season, the supply water with oxygen was extinguished and groundwater in the wells was prone to be reduced. Thus oxygen concentration decreased and soluble organic matters which avoided oxidation were concentrated by a drop in groundwater table.

For whatever reasons, most of monitoring wells are clearly contaminated by direct inflow from surface due to inadequate well structure. Therefore, the monitored water quality at the monitoring wells do not represent primary conditions of deep aquifer. On the other hand, most of water prior to percolating into underground is generally polluted by human activities, thus it should be considered that shallow groundwater struck within 5m in depth are not safe to drink.



Source: Project Team

Figure 6.6.8 Relationship between BOD and COD, DO

(3) Pollution of Surface Water

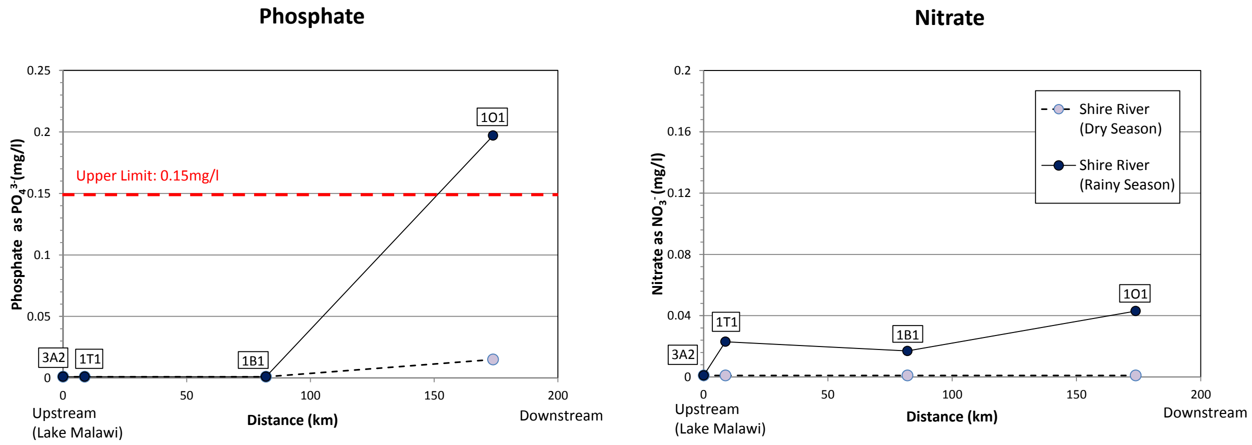
Nitrate and phosphorous compounds called nutritive salts are essential elements for living beings, but too much of these can cause negative results such as eutrophication in the water environment. A regional ecosystem sensitively responds to the addition of artificial substances including nitrate and phosphorous compounds from fertilizer or sewage, and causes the blooming of phytoplankton in the water body in proportion to increased level of the nutritive salts. The high increase of planktons results in an enormous amount of their corpses, and finally induces an anoxic water environment in and reductions in the population of certain fish and other animal populations.

1) Groundwater

Trends of concentration in nutritive salts were quite different between the rainy and dry seasons. According to the concentrations of phosphate and nitrate in water samples collected from the Shire River, the concentration of phosphate downstream was especially high and exceeds the upper limit defined by the Malawi standard in rainy season. Although all nitrate concentrations are very low and below the threshold (50 mg/l), these tend to increase slightly heading downstream in the rainy season.

In the dry season, both nutritive salts were very weak throughout the entire river (see **Figure 6.6.9**). The trends of BOD on the Shire River were reversed between the rainy and dry seasons, that is to say, the BODs in the dry season were higher than the rainy season. DO values were almost horizontal in both seasons, but these in the rainy season slightly decreased heading downstream (see **Figure 6.6.11**). These indicators show that eutrophication may have progressed downstream of the Shire River in the rainy season, especially.

On the highland areas in central Malawi, the concentration of phosphate in the dry season on the main rivers was much higher than in the rainy season. This phenomenon implies that soluble substances might be concentrated in the river due to the remarkable drop of flow rate. One water sample on the Nanjiri River branching from the Lilongwe River (4C11 gauging station) shows that the concentration of phosphate and nitrate protrude beyond the ones at the other monitoring stations in the rainy season. It is doubtful that eutrophication might happen on the Nanjiri River in the rainy season although the BOD and DO values of each sample lie on the safe side of the threshold.

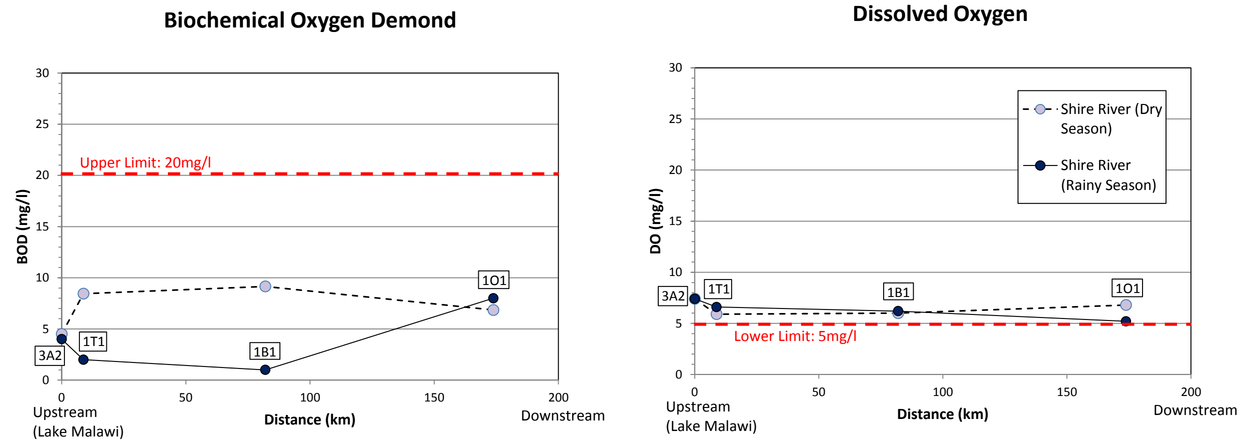


Phosphate

Nitrate

Source: Project Team

Figure 6.6.9 The Change in Nutritive Salts from Upstream to Downstream in the Shire River

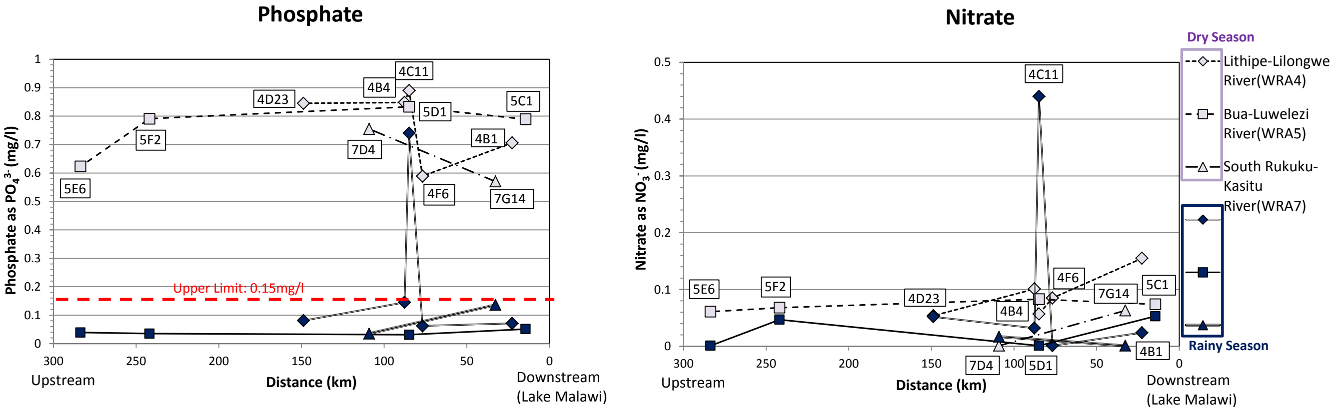


Biochemical Oxygen Demond

Dissolved Oxygen

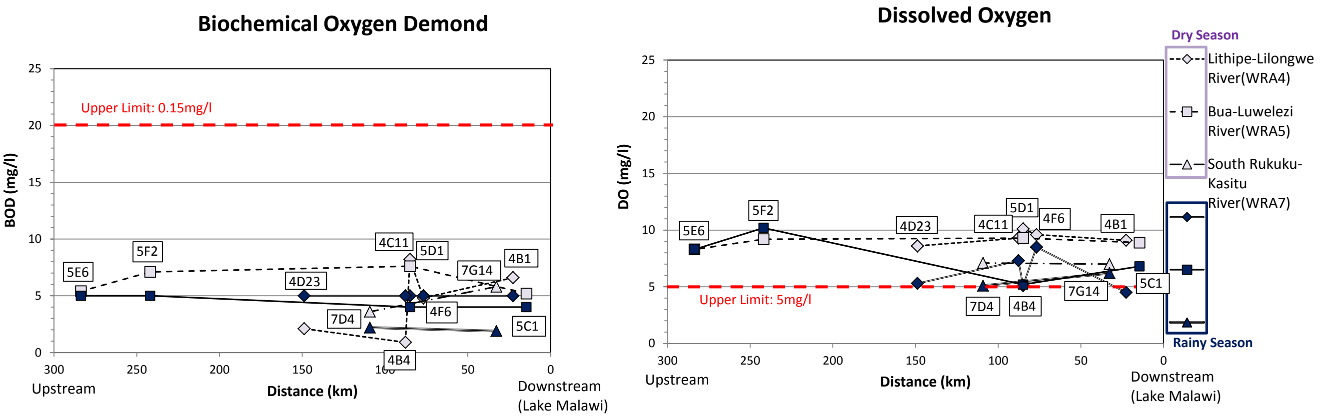
Source: Project Team

Figure 6.6.10 The Change in BOD and DO from Upstream to Downstream in the Shire River



Source: Project Team

Figure 6.6.11 The Change in Nutritive Salts from Upstream to Downstream in the Main Rivers on the High Land



Source: Project Team

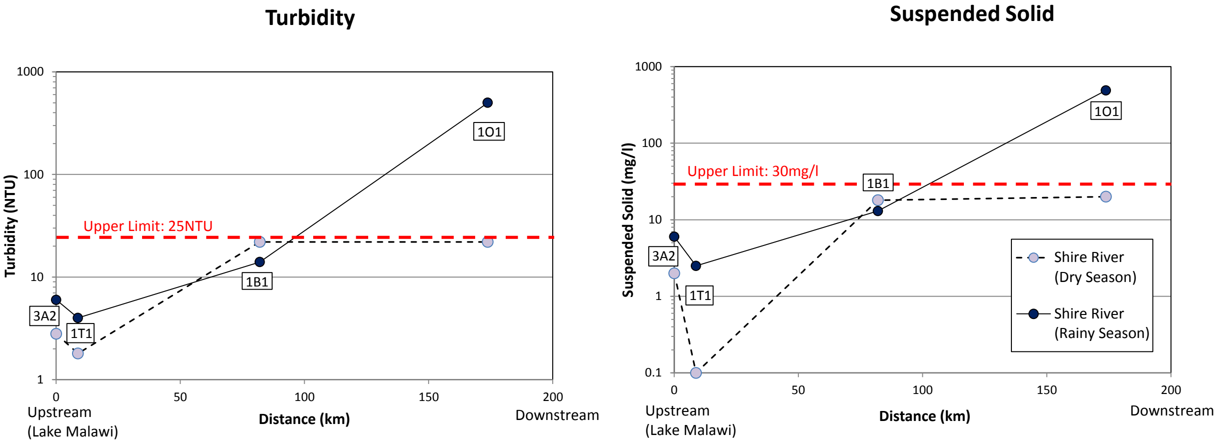
Figure 6.6.12 The Change of BOD and DO from Upstream to Downstream in the Main Rivers on the High Land

2) Trend of Land Erosion

The indicator of turbidity in water shows that it is caused by suspended particles or colloidal matter that obstructs light transmission through the water. It may be caused by inorganic or organic matter or a combination of the two. The indicator of suspended solids (SS) is what weighs these particles inducing turbidity, hence there is very high correlation between both indicators. High concentrations of suspended solids or high degrees of turbidity can lower water quality because parts of suspended particles are derived from pollution sources, and aquatic plants also receive less light, photosynthesis decreases and less oxygen is produced in a water body. Turbidity and suspended solids are also used as a measure of land erosion caused by disorderly deforestation or cultivation.

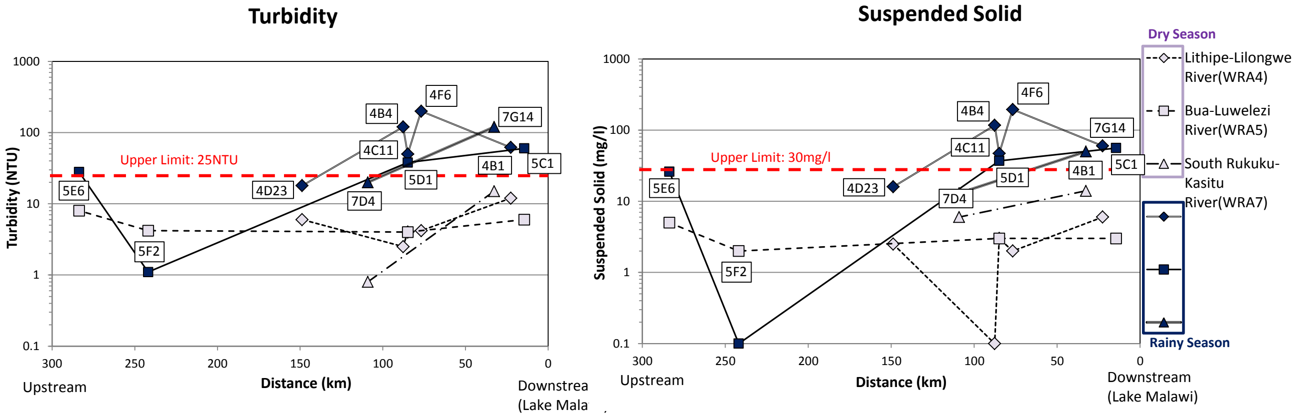
On Shire River, the two indicators at 1O1 gauging station located downstream went over the thresholds by a large amount in the rainy season, and are approx. fifty times as high as the values at the other monitoring points upstream. It strongly suggests that in the rainy season land erosions occurred on a serious level on the watershed across the Balaka, Zomba, Mwanza and Blantyre districts.

On the highland area, the three main rivers, Lithipe-Lilongwe River, Bua-Luwelezi River and South Rukuku-Kasitu River show almost the same trends as at Shire River, that is, the concentrations of suspended solids and turbidity tended to be higher at the monitoring stations closer to the discharge basin. On Lithipe-Lilongwe River, the highest concentration resulted midstream at 4B4 and 4F6 in the rainy season. It is considered that agricultural developments may have proceeded particularly in the central areas of the Lilongwe district.



Source: Project Team

Figure 6.6.13 The Change of Turbidity and SS from Upstream to Downstream in the Shire River



Source: Project Team

Figure 6.6.14 The Change of Turbidity and SS from Upstream to Downstream in the Main Rivers on the High Land

3) Local Trend in Urban Area

The monitoring scheme of the Project was performed for discovering wide areal trends of water quality throughout the whole of Malawi, but it did not pick out local trends in specific areas, such as urban areas. This report verifies the facts of pollution in urban areas using the latest of the previous studies.

In Malawi, there are three (3) major cities; namely, Lilongwe, Blantyre and Mzuzu. Blantyre City is among the most industrialized cities in Malawi. On the other hand, it has been concluded that rapid industrialization and population growth burdens the aqueous environment. According to a study executed by Tananga, et.al[11] from the Southern Region Water Development Office, the settlement of migrants and location of factories have been increasing along the Mudi River tributary in the watershed of the Shire River as a result of which there is obvious deterioration in the river which has grown more serious as shown in **Figure 6.6.15**. Actually, organic pollution indicators of DO and BOD showed worse values than the designated thresholds on most of the water samples in the Mudi River (see **Table 6.6.14**). These pollution sources are mainly household effluents which get rid of sewage treatments but not many industrial effluents. However, the proportion of effluents from heavy industry will increase and the residents nearby the shore of the Mudi River or more downstream areas will be exposed to a more serious health crisis if industrialization develops without mitigation of aqueous deterioration in Blantyre City. In spite of no similar studies in the other cities, the pollution problems must have created increasingly worse situations as found in Blantyre.

Source: Water Quality Report of Mudi River Mlambalala and Naperi Streams in Blantyre District

Figure 6.6.15 Dump of Solid Waste at Victoria Avenue Bridge in the Mudi River

Table 6.6.14 Results of Water Quality Testing in the Mudi River

Sample Sources/Locations	Parameters Tested							
	pH		Electrical Conductivity		DO		BOD	
	(-)		(µs/cm)		(mg/l)		(mg/l)	
MBS: MS691 (Domestic Sewage Elluents)	**6.5 - 7.0**		**-**		**-**		**< 20**	
Mudi Upstream at Makata	6.4	Δ	406	-	6.85	-	9.2	○
Anchor Indu. Drain Water	6.25	Δ	541	-	3.76	-	33	×
Mudi Upstream of Mudi / Nasolo Confluence	5.6	×	480	-	3.81	-	19.5	Δ
Mudi / Nasolo Confluence	5.2	×	494	-	4.2	-	29	×
Mudi Victoria Avenue	6.2	Δ	452	-	4.1	-	30	×
Blantyre Waste Water from Treatment Paper on the Mudi Downstream	6.4	Δ	401	-	4.6	-	26.5	×
Drain water emptying into Nasolo	5.8	×	834	-	2.3	-	172	×

Note: Symbols neighboring each result value mean the following;

○: the value lies on the safe side of the upper limit designated by the water quality standards in Malawi.

Δ: the value is close to the designated threshold.

×: the value exceeds over designated threshold.

Source: Water Quality Report of Mudi River Mlambalala and Naperi Streams in Blantyre District

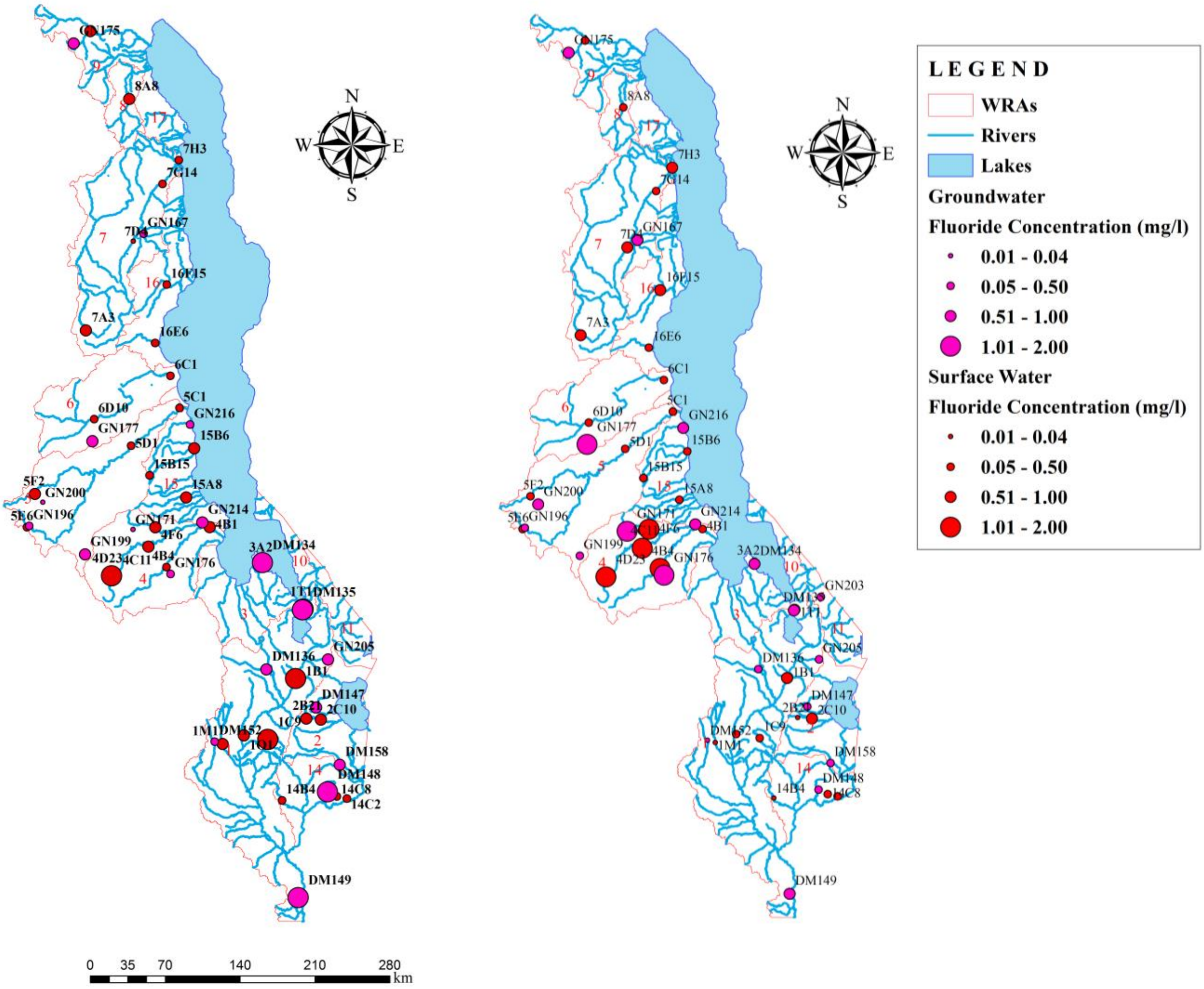
4) Fluoride

Fluoride is a common element that is widely distributed in the Earth's crust and exists in the form of fluorides in a number of minerals. Fluoride is a beneficial element with regard to the prevention of dental caries, and is taken with drinking water for dental protection. The amounts added to drinking water are usually between 0.5 and 1mg/l. On the other hand, elevated fluoride intakes can have serious effects on skeletal tissues. Skeletal fluorosis, with adverse changes in bone structure, may be observed when drinking water contains 3 to 6 mg/l of fluoride concentration, particularly with high water consumption. Crippling skeletal fluorosis usually develops only where drinking water contains over 10mg/l of fluoride[12].

The trends of fluoride concentration seem to vary between the rainy and dry seasons. In the rainy season, the watershed of Lithipe-Lilongwe River (WRA 4) had a higher concentration of fluoride than the threshold 1.0 to 1.5 defined by MBS and WHO standards, except in the downstream area. The monitoring wells (GN171 and GN176) neighboring the midstream of Lilongwe River and Lithipe River also indicated an excess of 1mg/l of fluoride. On the contrary, such high fluoride concentrations do not appear to be common in the alluvial areas, e.g., the watershed of Shire River (WRA 1). However, a very interesting trend was revealed that in the dry season the fluoride concentration of the Shire River watershed became higher than the watersheds on the highland (see **Figure 6.6.16**).

The sources of fluoride have not been identified correctly, but a previous chemical analysis of thermal springs in the Nkhotakota district have revealed fluoride concentrations as high as 16mg/l[13], thus it seems that one of the sources of fluoride may be derived from hydrothermal vents in fractures inside the basement rocks. The interpretation of seasonal variations of fluoride concentration needs further monitoring and basic study.

The fluoride concentrations monitored in the project are not at a serious level for human health, although several water samples exceed the threshold, and serious injuries caused by skeletal fluorosis have not been reported until now. However, further studies should be done to lower the health risk in growing populations.



<Dry Season>

<Rainy Season>

Source: Project Team

Figure 6.6.16 Fluoride Concentration in Malawi

6.6.3 Issues of Water Quality

A part of the water environment in Malawi has been cleared by water quality monitoring in the Project despite there being only a few monitoring stations. This report will mention some issues found in the monitoring throughout the country as mentioned below.

- ✓ Most of the monitoring wells were contaminated with human wastes, feces and urine probably, but the contamination into groundwater was not under natural conditions, rather it was caused by dirty water directly flowing into wells from the surface due to the failure of well structures. In order to measure true underground aqueous conditions, firm seal structures to prevent flowing surface water must be built up to deep aquifer in monitoring wells.

- ✓ Shallow groundwater struck within 5m deep is generally not safe to drink, thus groundwater development should aim at deeper aquifer than 15m in which human's contamination from surface can be avoided.

- ✓ Trends of concentration of nutritive salts were quite different between the rainy and dry season. On the highland areas, that may be a reason why soluble substances might be concentrated in the river due to the remarkable drop of the flow rate in the dry season. In the rainy season, possible eutrophication was identified mid or downstream of major rivers in both the low and high land areas. The eutrophication might be brought about by the discharge of untreated waste water from sewage works or irrigation facilities.

- ✓ In the rainy season, turbidity tends to be higher further downstream, particularly on the Shire River and the Lithipe-Lilongwe River. The rise in the degree of turbidity appears to show evidence of land erosion caused by an expansion of disorderly deforestation or cultivation.

- ✓ In urban areas, deterioration of aqueous environments was clearly recognized via both visual checking and water quality testing. Currently, most of the pollutants originate from household effluents, but in future heavy metals or organic solvents will cause serious health problems to water users on the downstream areas from effluent sources, coinciding with further industrialization.

- ✓ High concentrations of fluoride derived from hydrothermal or other geological factors appeared in the watersheds of the Lithipe River and the Shire River although the trends varied seasonally. They are not serious threats to human health now, but the water sources containing such high concentrations of fluoride (>10mg/l) could cause harmful injuries to human existence in Malawi. These dangerous water sources must be avoided by specifying the origins and mechanisms of concentrating fluoride compounds in nature.

6.7 Tendency of Climate Change Impact

Climate Change that accompanies global warming is now becoming a serious concern to be shared by all people in the world. The 4th Assessment Report that was published in 2007 by the Intergovernmental Panel on Climate Change (IPCC) shows more realistic impacts of climate change, as presented below.

- By 2020, between 75 and 250 million people are projected to be exposed to increased water stress due to climate change.
- By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50%. Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition.
- Towards the end of the 21st century, projected sea level rise will affect low-lying coastal areas with large populations. The cost of adaptation could amount to at least 5 to 10% of GDP.
- By 2080, an increase of 5 to 8% of arid and semi-arid land in Africa is projected under a range of climate scenarios (high confidence).

As for Malawi, UNDP discloses simulation results of GCM (General Circulation Model) as a country report which describes climate change impacts in temperature and rainfall as shown in the table below.

Table 6.7.1 GCM Projections of Future Climate in Malawi

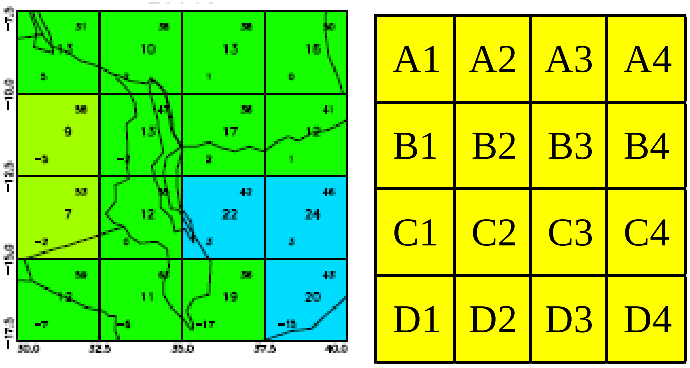
Item	Projection
Temperature	(1) The mean annual temperature is projected to increase by 1.1 to 3.0℃ by the 2060s, and 1.5 to 5.0℃ by the 2090s. Under a single emissions scenario, the projected changes from different models span a range of up to 2.1℃ (2) All projections indicate substantial increases in the frequency of days and nights that are considered 'hot' in current climate. (3) All projections indicate decreases in the frequency of days and nights that are considered 'cold' in current climate. These events are expected to become exceedingly rare, and do not occur at all under the highest emissions scenario (A2) by the 2090s.
Precipitation	(1) Projections of mean rainfall do not indicate substantial changes in annual rainfall. The range of projections from different models is large and straddles both negative and positive changes (-13% to +32%). Seasonally, the projections tend towards decreases in dry season rainfall (JJAand SON), and increases in wet season rainfall (DJF and MAM) (2) Overall, the models consistently project increases in the proportion of rainfall that falls in heavy events in the annual average under the higher emissions scenarios (A2 and A1B), of up to 19% by the 2090s. These increases mainly arise from increases in heavy events in the wet -seasons, DJF and MAM, and are partially offset by decreases in JJA and SON. (3) The models consistently project increases in 1-and 5-day rainfall maxima by the 2090s under the higher emissions scenarios, of up to 26mm in 1-day events, and 39mm in 5-day events. These also generally increase in DJF and MAM, but decrease in JJA and SON.

To cope with these impacts, JICA and UNDP conducted Africa Adaptation Program (APP) which was established under the Japan-UNDP Joint Framework for Building Partnership to Address Climate Change in Africa founded at the Fourth Tokyo International Conference on African Development (TICAD) in May 2008, focusing on the creation of an environment in which more appropriate adaptation decisions and practices are made.

6.7.1 Arrangement of Increment and Decrease Ratio

(1) Condition of Grid

The climate models are 15 model ensembles used by the Intergovernmental Panel on Climate Change (IPCC) for their fourth assessment report published in 2007. Then, UNDP updates simulated time series data and calculation results by ensemble method in the WEB Site for IPCC emission scenario: A2, A1B and B2. In addition, UNDP summarized the monthly projection outputs from the daily data of the GCMs until the end of the 21st century to monthly data. The horizontal resolutions of the GCMs are as coarse as 0.2° x 0.2° to 5° x 5° grid; however, the global data field is re-gridded as a common 2.5° by 2.5° grid and monthly time series at each grid box are averaged to annual and seasonal values for each model. The Project Team used the re-gridded data by UNDP to investigate the tendency of climate change impact in Malawi.



A1	A2	A3	A4
B1	B2	B3	B4
C1	C2	C3	C4
D1	D2	D3	D4

Left: grid condition by UNDP, Right: Numbering of Grid in the Study
Source: UNDP and project Team

Figure 6.7.1 Grid Condition arranged by UNDP

(2) Increment and Diminution in Rainfall and Temperature for Year 2035

Table 6.7.2 and Table 6.7.3 show increment values as to rainfall and temperature in 2035 from present condition by grid, which were obtained through UNDP arrangement information. The values of tables indicate seasonal variation (DJF: December, January, February, MAM: March, April and May; JJA: June, July and August; SON: September, October and November) in Rainfall and Temperature. The temperature has a clear incremental tendency over scenarios and seasons compared with present condition, while rainfall has both increment and diminution tendency.

Table 6.7.2 Monthly Rainfall Increment (from present to 2035)

	Scenario A2 (mm)				Scenario A1B (mm)				Scenario B1 (mm)			
DJF	8.60	8.68	11.72	12.73	5.36	7.31	9.25	2.29	5.04	6.93	7.61	9.51
	4.78	10.20	9.03	7.43	2.22	3.75	11.83	8.29	-2.49	1.07	3.76	7.36
	-1.07	1.41	4.89	3.08	-4.88	0.24	3.19	3.41	-4.39	-4.53	-0.10	1.06
	-10.37	-0.18	-2.12	4.93	-0.67	2.18	6.34	3.20	-1.39	-4.52	-2.96	0.07
MAM	4.15	4.96	6.30	4.62	5.78	5.88	8.82	4.09	3.03	4.95	8.93	11.34
	-1.76	3.42	3.05	8.80	-1.24	3.53	6.79	5.02	4.86	5.31	9.62	10.65
	0.60	3.34	4.93	6.43	-2.55	-1.22	3.55	0.72	2.73	6.30	6.65	7.22
	-0.91	-0.19	1.96	6.51	-1.70	-2.22	-0.30	0.10	-0.88	3.02	6.63	3.64
JJA	-0.05	-0.21	0.16	-0.35	-0.20	-0.10	-0.16	-1.18	-0.07	-0.14	-0.79	-1.00
	-0.17	-0.16	-0.17	-0.17	-0.14	0.11	0.25	-0.39	-0.17	-0.26	-0.71	-1.38
	-0.35	-0.23	-0.26	-0.22	0.16	0.54	0.63	0.03	-0.07	-0.23	-0.98	-1.99
	-0.47	-0.44	-0.27	-0.13	0.42	1.31	1.42	0.28	-0.28	-0.51	-1.05	-2.33
SON	-2.40	2.18	1.12	-1.07	-4.57	-1.05	-3.33	-2.26	-0.17	-1.63	0.43	0.82
	-1.17	0.54	-0.26	-1.20	-2.34	-2.53	-1.22	-1.51	-0.76	-1.63	-1.02	-0.98
	-2.01	-2.23	-0.63	-1.27	-3.02	-2.92	-2.83	-2.88	-0.01	0.47	-1.57	-2.50
	-3.44	-5.05	-6.02	-2.96	-6.11	-7.07	-3.78	-4.76	-0.36	-4.11	-2.63	-4.17

Source: UNDP

Table 6.7.3 Monthly Temperature Increment (from present to 2035)

	Scenario A2 (Celsius)				Scenario A1B (Celcius)				Scenario B1 (Celsius)			
DJF	1.20	1.15	1.17	1.01	1.22	1.20	1.09	1.00	1.00	0.99	0.92	0.85
	1.18	1.09	1.02	1.00	1.32	1.24	1.19	1.06	1.00	0.96	0.96	0.89
	1.23	1.08	0.98	1.01	1.36	1.29	1.20	1.11	1.01	1.06	1.01	0.94
	1.29	1.10	1.03	1.01	1.37	1.31	1.13	1.05	1.02	1.03	0.97	0.85
MAM	1.32	1.27	1.16	1.06	1.40	1.27	1.23	1.05	1.02	0.99	0.96	0.86
	1.40	1.32	1.21	1.06	1.46	1.46	1.31	1.18	0.97	0.94	0.92	0.89
	1.50	1.39	1.25	1.07	1.56	1.49	1.41	1.23	1.00	0.90	0.89	0.85
	1.47	1.38	1.17	1.07	1.54	1.49	1.37	1.12	0.99	0.85	0.84	0.76
JJA	1.52	1.48	1.28	1.09	1.50	1.43	1.32	1.21	1.12	1.13	1.04	0.95
	1.47	1.46	1.27	1.14	1.56	1.50	1.37	1.22	1.17	1.16	1.06	0.98
	1.40	1.40	1.32	1.20	1.55	1.54	1.39	1.21	1.07	1.10	1.13	1.02
	1.37	1.38	1.28	1.16	1.49	1.48	1.33	1.19	0.98	1.00	1.02	0.96
SON	1.36	1.39	1.20	1.10	1.42	1.38	1.29	1.19	1.19	1.16	1.06	0.97
	1.38	1.37	1.19	1.04	1.52	1.41	1.32	1.16	1.13	1.10	1.05	0.97
	1.45	1.33	1.26	1.07	1.62	1.45	1.30	1.16	1.12	1.11	1.09	0.99
	1.65	1.68	1.39	1.15	1.73	1.59	1.38	1.15	1.15	1.13	1.08	0.92

Source: UNDP

(3) Increment and Diminution in Rainfall and Temperature for Year 2035

Table 6.7.2 and Table 6.7.3, seasonal increment and diminution ratios by WRAs were as estimated in **Table 6.7.4** and Table 6.7.5 for each scenario, using GIS functions. These ratios have been multiplied by basin mean rainfall and evapotranspiration which are input to the water balance simulation model by MIKE SHE (see previous sections) to confirm tendencies of climate change impacts.

Table 6.7.4 Seasonal Incremental Ratio of Rainfall in WRAs by Scenario

	A2				A1B				B1			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
1	1.00	1.01	0.95	0.87	1.02	0.99	1.15	0.84	0.98	1.04	0.91	0.91
2	0.99	1.02	0.97	0.83	1.03	1.00	1.17	0.89	0.99	1.06	0.87	0.92
3	1.01	1.03	0.97	0.94	1.00	0.99	1.07	0.91	0.98	1.06	0.96	1.01
4	1.01	1.03	0.97	0.93	1.00	0.99	1.07	0.91	0.98	1.06	0.97	1.01
5	1.01	1.03	0.97	0.93	1.00	0.99	1.07	0.91	0.98	1.06	0.97	1.01
6	1.01	1.03	0.97	0.95	1.00	1.00	1.06	0.91	0.98	1.06	0.97	1.00
7	1.05	1.03	0.98	1.02	1.02	1.03	1.01	0.92	1.00	1.05	0.97	0.95
8	1.05	1.03	0.98	1.03	1.02	1.04	1.01	0.93	1.01	1.05	0.97	0.95
9	1.04	1.04	0.97	1.06	1.03	1.05	0.99	0.96	1.03	1.05	0.98	0.95
10	1.02	1.04	0.97	0.97	1.01	1.02	1.08	0.91	1.00	1.06	0.89	0.96
11	1.02	1.05	0.97	0.98	1.01	1.03	1.08	0.91	1.00	1.06	0.87	0.95
12	1.05	1.03	0.98	1.02	1.02	1.03	1.01	0.92	1.00	1.05	0.97	0.95
13	1.05	1.03	0.98	1.02	1.02	1.03	1.01	0.92	1.00	1.05	0.97	0.95
14	0.99	1.02	0.96	0.82	1.03	1.00	1.18	0.89	0.99	1.06	0.86	0.92
15	1.01	1.03	0.97	0.93	1.00	0.99	1.07	0.91	0.98	1.06	0.97	1.01
16	1.05	1.03	0.98	1.02	1.02	1.03	1.01	0.92	1.00	1.05	0.97	0.95
17	1.05	1.03	0.98	1.02	1.02	1.03	1.01	0.93	1.01	1.05	0.97	0.95
Min.	0.99	1.01	0.95	0.82	1.00	0.99	0.99	0.84	0.98	1.04	0.86	0.91
Max.	1.05	1.05	0.98	1.06	1.03	1.05	1.18	0.96	1.03	1.06	0.98	1.01
Avg.	1.02	1.03	0.97	0.96	1.01	1.02	1.06	0.91	1.00	1.05	0.94	0.96

Source: Project Team

Table 6.7.5 Seasonal Incremental Ratio of Evapotranspiration in WRAs by Scenario

	A2				A1B				B1			
	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON	DJF	MAM	JJA	SON
1	1.07	1.08	1.09	1.10	1.08	1.09	1.09	1.10	1.06	1.05	1.07	1.07
2	1.07	1.08	1.08	1.09	1.07	1.09	1.09	1.09	1.06	1.05	1.07	1.07
3	1.07	1.09	1.09	1.09	1.08	1.10	1.10	1.09	1.07	1.06	1.07	1.07
4	1.07	1.09	1.09	1.09	1.08	1.10	1.10	1.09	1.07	1.06	1.07	1.07
5	1.07	1.09	1.09	1.09	1.08	1.10	1.10	1.09	1.07	1.06	1.07	1.07
6	1.07	1.09	1.09	1.09	1.08	1.10	1.10	1.09	1.07	1.06	1.07	1.07
7	1.07	1.09	1.09	1.09	1.08	1.09	1.10	1.09	1.06	1.06	1.07	1.07
8	1.07	1.08	1.10	1.09	1.08	1.09	1.10	1.09	1.06	1.06	1.07	1.07
9	1.07	1.08	1.10	1.09	1.08	1.08	1.09	1.09	1.06	1.06	1.07	1.07
10	1.06	1.08	1.09	1.08	1.08	1.09	1.09	1.09	1.07	1.06	1.07	1.07
11	1.06	1.08	1.09	1.08	1.08	1.09	1.09	1.08	1.06	1.06	1.07	1.07
12	1.07	1.09	1.09	1.09	1.08	1.09	1.10	1.09	1.06	1.06	1.07	1.07
13	1.07	1.09	1.09	1.09	1.08	1.09	1.10	1.09	1.06	1.06	1.07	1.07
14	1.06	1.07	1.08	1.09	1.07	1.09	1.08	1.09	1.06	1.05	1.06	1.07
15	1.07	1.09	1.09	1.09	1.08	1.10	1.10	1.09	1.07	1.06	1.07	1.07
16	1.07	1.09	1.09	1.09	1.08	1.09	1.10	1.09	1.06	1.06	1.07	1.07
17	1.07	1.09	1.09	1.09	1.08	1.09	1.10	1.09	1.06	1.06	1.07	1.07
Min.	1.06	1.07	1.08	1.08	1.07	1.08	1.08	1.08	1.06	1.05	1.06	1.07
Max.	1.07	1.09	1.10	1.10	1.08	1.10	1.10	1.10	1.07	1.06	1.07	1.07
Avg.	1.07	1.08	1.09	1.09	1.08	1.09	1.10	1.09	1.06	1.06	1.07	1.07

Source: Project Team

Incidentally, the ratio of evapotranspiration was converted from the change values of temperature by using Hammon's formula as shown below.

$$\frac{PET}{PET_0} = exp(0.062\Delta T)$$

PET = Potential evapotranspiration after climate change,
PET0 = Potential evapotranspiration before climate change,
ΔT = Change of temperature. (Hammon Formula)

6.7.2 Water Balance Simulation for Climate Change Tendency

Water Balance Simulation was carried out by using the ratios mentioned in **Subsection 6.7.1**. The results of the simulation are summarized by emission scenario in **Table 6.7.6**. Regardless of scenario, the rainfall and evapotranspiration demonstrate a small upward trend, while the river flow and recharge has a small decrease trend. Thus, the climate change tendency is confirmed using only the A1B emission scenario because the difference in each scenario is very small in 2035.

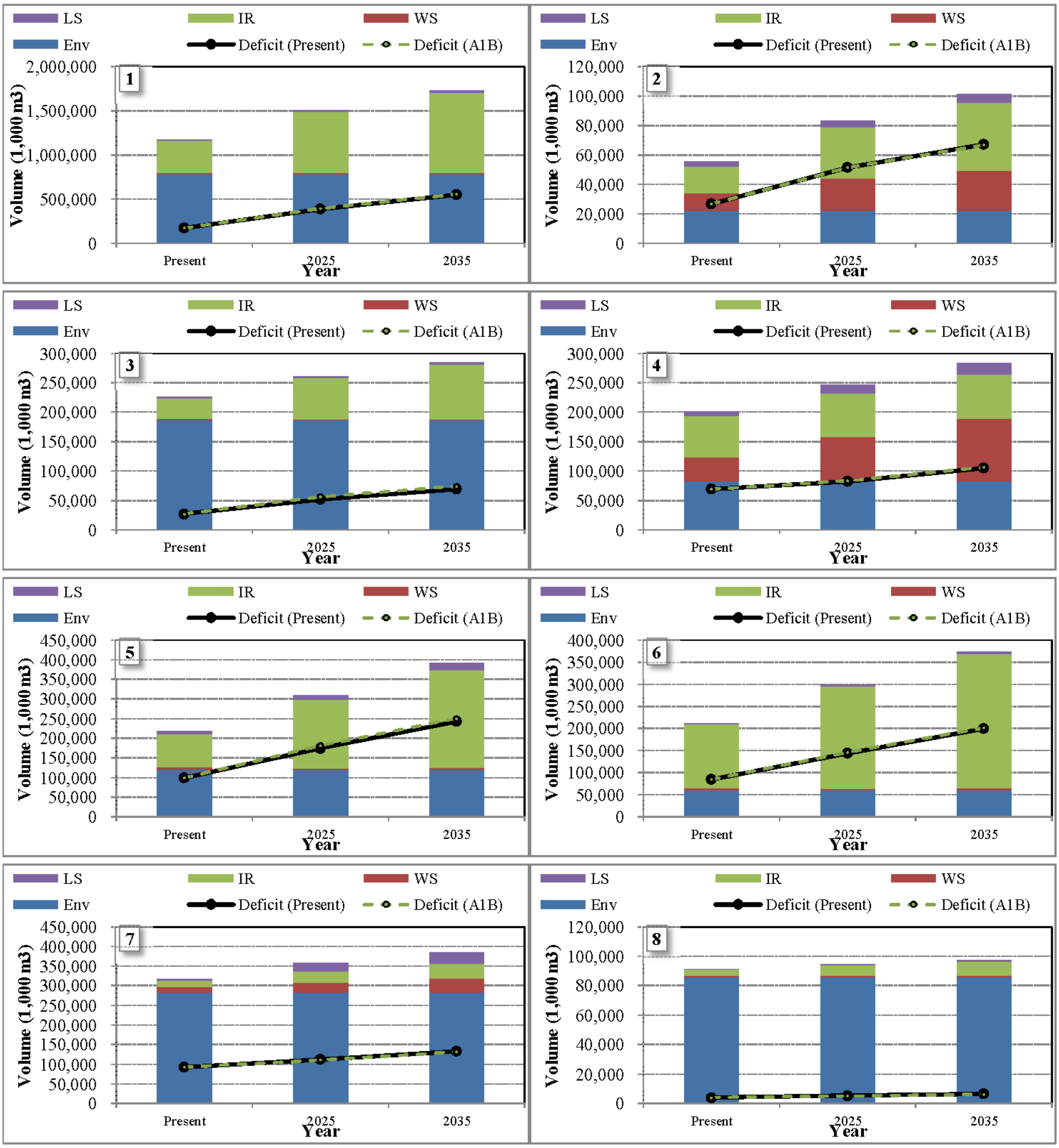
Table 6.7.6 Water Balance by Climate Change Scenario

Unit: mm

WRA	P	Ep	Q	Re	Re/P
Present	980	701	225	53	5%
B1	981	711	219	51	5%
A1B	983	714	218	51	5%
A2	989	717	221	52	5%

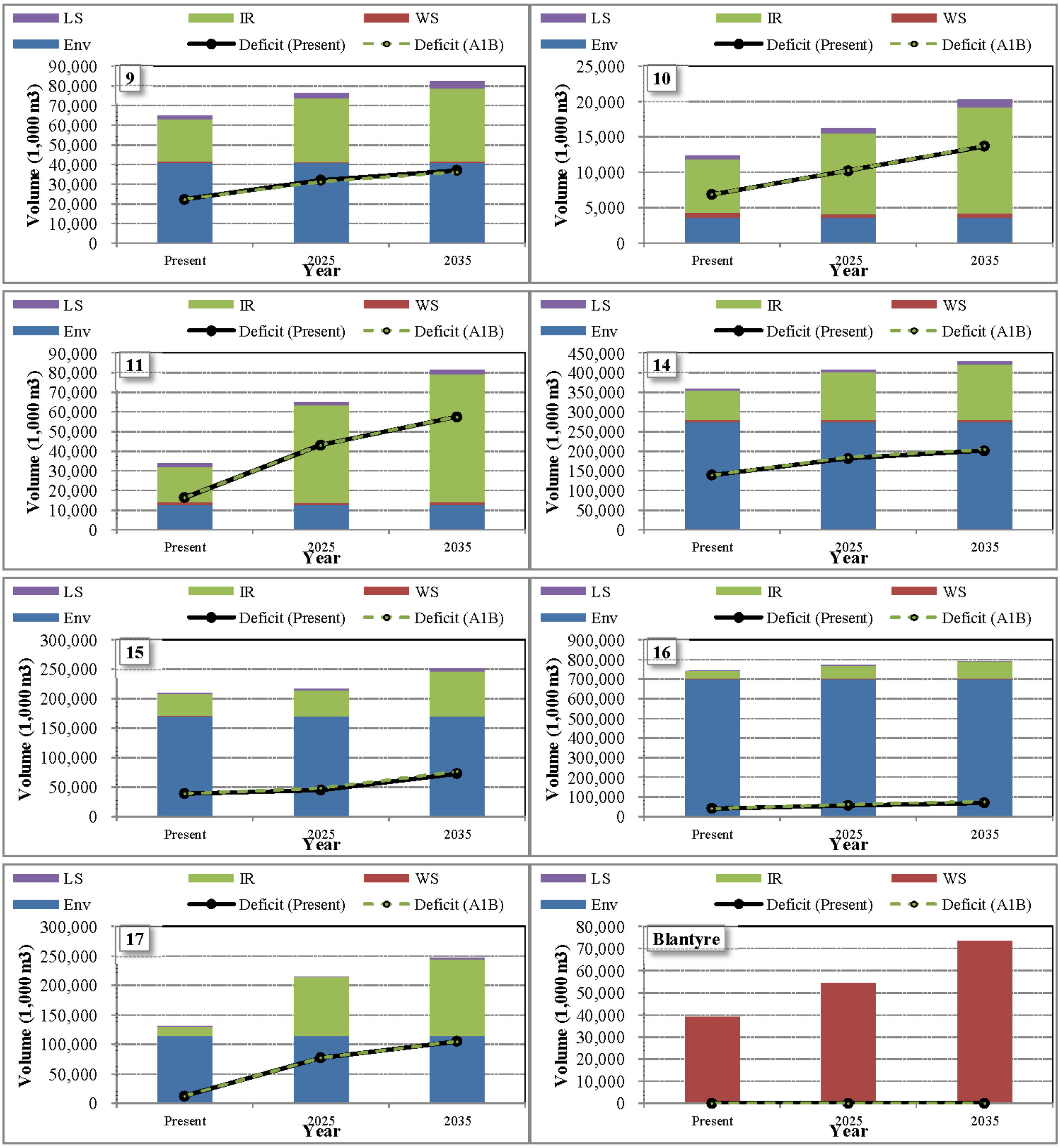
Source: Project Team

Climate change tendencies on surface water were summarized by WRA as shown in **Figure 6.7.2** and **Figure 6.7.3**. The climate change impact on the relationship between water supply and demand in 2035 is just a few percent.



Source: Project Team
(LS: Water demand for Livestock, IR: Irrigation Water Demand, WS: Water Supply Demand, Env: Required environmental flow)

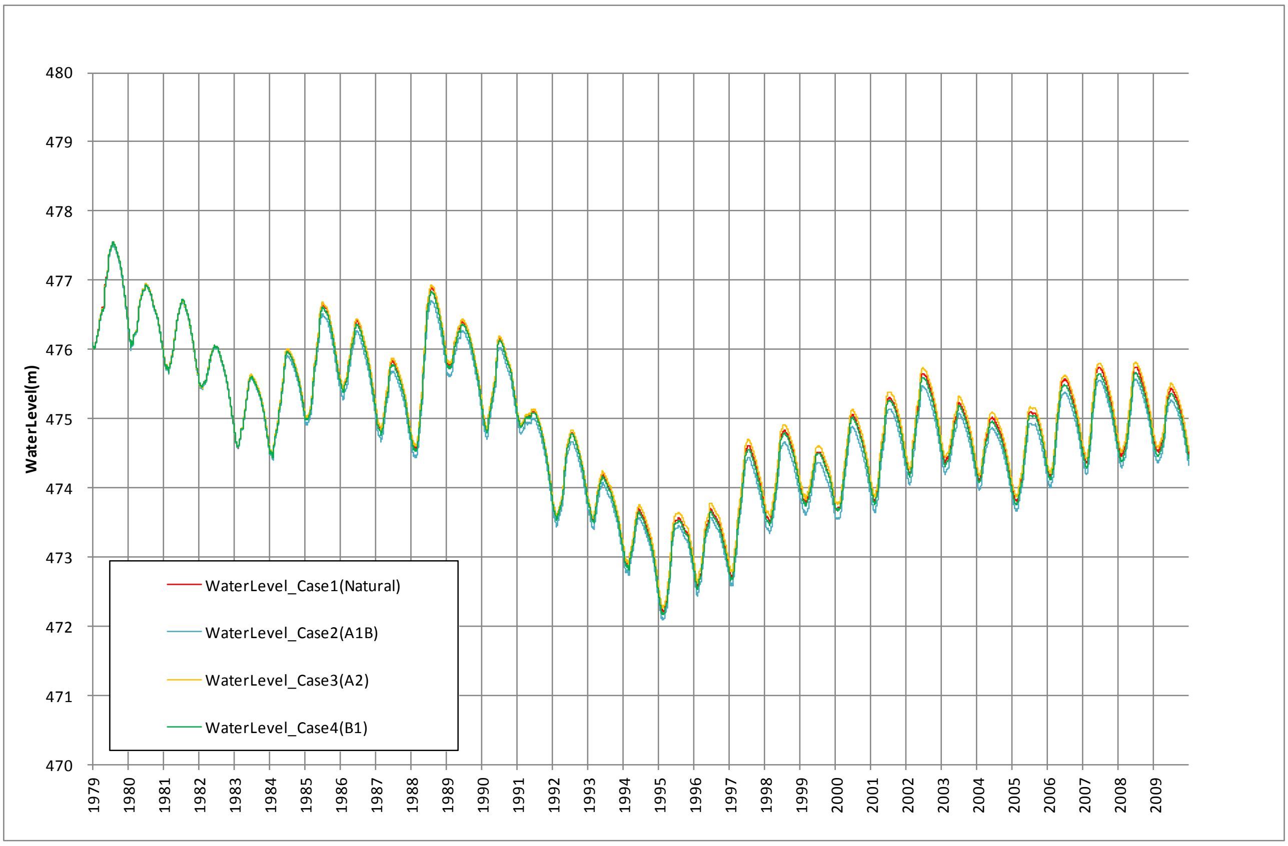
Figure 6.7.2 Changing Trend on Water Balance by Climate Change (1/2)



Source: Project Team

Figure 6.7.3 Changing Trend on Water Balance by Climate Change (2/2)

The impact on water level of Lake Malawi is also confirmed by the Lake Malawi simulation model established in the Project. The simulation result indicates that the water level changes in each scenario as shown in **Figure 6.7.4**.



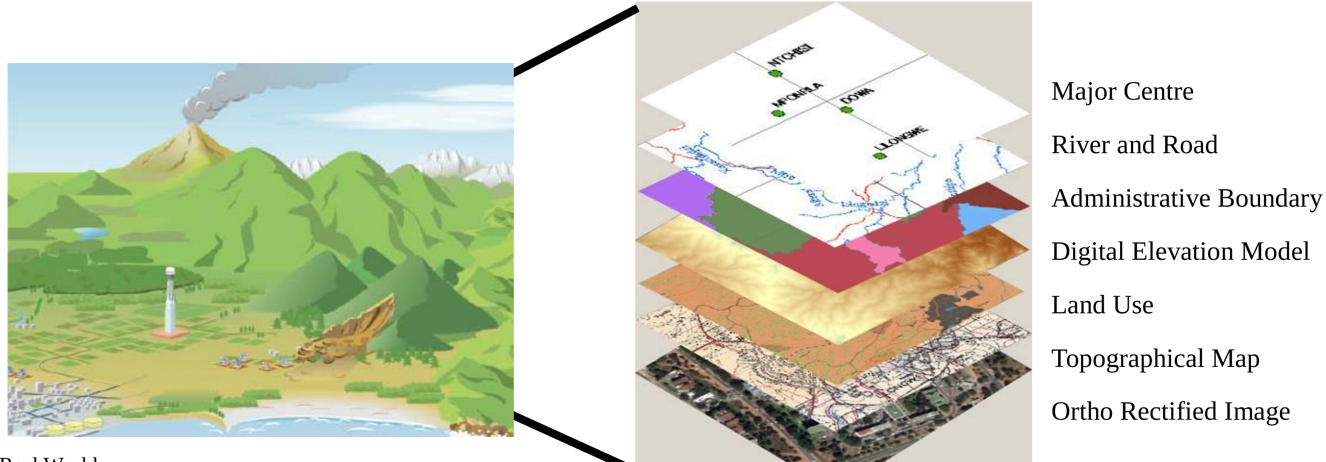
Source: Project Team

Figure 6.7.4 Changing Trend of Water Level of Lake Malawi by Climate Change

6.8 Concept of GIS

A Geographic Information System (GIS) is a system designed to produce, analyze, manage, and provide all types of geo-spatial information data. These systems incorporate the basic functions such as map representation, feature mapping/compiling, annotation editing, geo-spatial information search, spatial analysis, thematic mapping, and printing. Furthermore, GIS database adapt feature layering method (shown in **Figure 6.8.1**) to analyze and compile geospatial information data from either space and time side.

These functions and methods have efficacy for project such as facility and road management or master planning.



Source: Project Team

Figure 6.8.1 Concept of Feature Layering Method

6.8.1 Acquisition of Existing GIS Data

Information and data related to water resources were input in the GIS database using ARC GIS (Version 10) to analyze the information for the purpose of formulation of the water resources development and management master plan.

GIS data shown in **Annex 5.6.1** was acquired from the MoAIWD and relevant government authorities such as the Department of Forestry (DoF), the Ministry of Lands, Housing and Urban Development (MoLHUD), and the National Statistics Office (NSO).

For example, the GIS data listed below were collected in the Project.

- Water resources area data, Borehole data, Meteorology station data, Rainfall station data, WL-Q Station data were collected from MoAIWD.
- Aerial photo data, Topographic map data, Digital terrain model (DTM), Digital elevation Model (DEM), Land cover map data, Land use and vegetation map data were collected from DoF. The data was produced during the “Forest Resource Mapping Project under the Forest Preservation Programme”
- Topographic maps (1:50,000) were collected from MoLHUD.
- District maps were collected to find out the location of the District Center (DC) and the Village Center (VC) from NSO.

6.8.2 GIS Database Model

(1) Setting of Coordinate Reference System (CRS)

In Malawi, the CRS of UTM 36 S Clarke 1980 (Datum: Arc 1960) is used as standard. Therefore, CRS and Transformation parameter are adopted in the Project as shown in Table 6.8.1 and **Table 6.8.2**. The GIS database table is defined by five main fields (main class, sub-class, feature name, data type, annotations), which is summarized in **Annex 5.6.2**.

Table 6.8.1 Coordinate Reference System in Malawi

Projection	Universal Transverse Mercator (UTM)
Zone	36 South
Central Meridian	33 degree
Scale Factor	0.9996
Longitude of True Origin	33 degree
Latitude of True Origin	0 degree
False Easting at Origin	500,000m E
False Northing at Origin	10,000,000m N
Spheroid	Clarke 1980
Datum	Arc1960

Source: Project Team

Table 6.8.2 Transformation Parameter from WGS 84 to Clarke 1960

Major semi-axis (a)	6378249.145m
Flattening (1/f)	0.003407561
X	179.0m
Y	87.0m
Z	314.0m

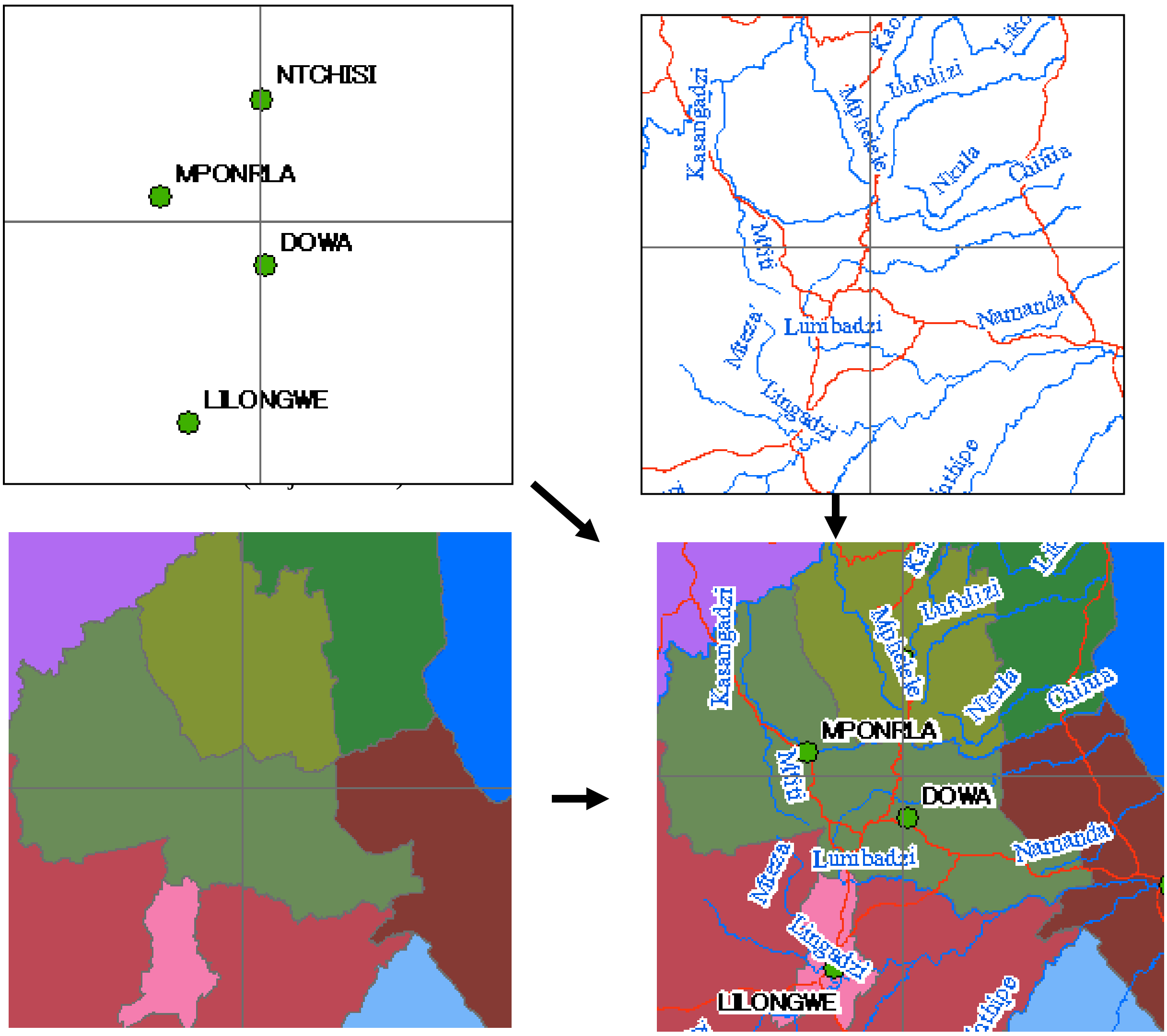
Source: Project Team

(2) Data Format and Type

Spatial features in GIS are presented in either vector or raster form. In the Project’s GIS database, both data forms are used.

The vector format represents the location and boundaries of features as sequences of x, y, (and sometimes z) coordinates.

The vector format data consists of three types of geometric features (**Table 6.8.2**): point, line, and area. Point features may be represented by a single x, y or x, y, z location such as control points, signs or utilities. Line features may be represented by a linear extent line such as center of roads or streams. Area features are called polygons. This may be represented by boundary lines that encompasses the area such as administrated areas or vegetated areas.



Area (polygon) Features (District)

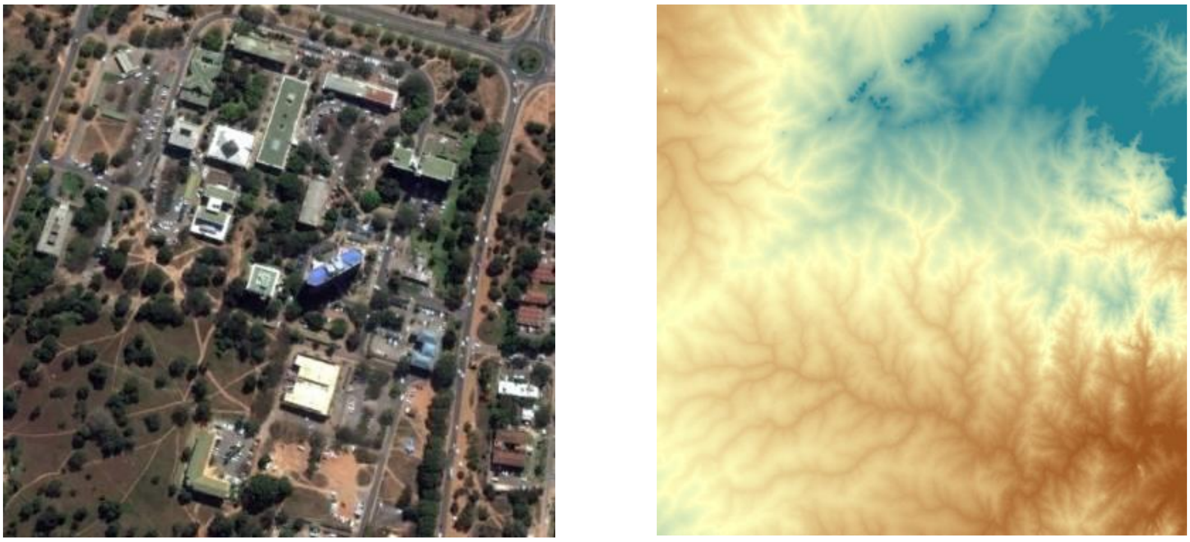
Integrated Vector Format Data

Source: Project Team

Figure 6.8.2 Three Types of Geometric Objects

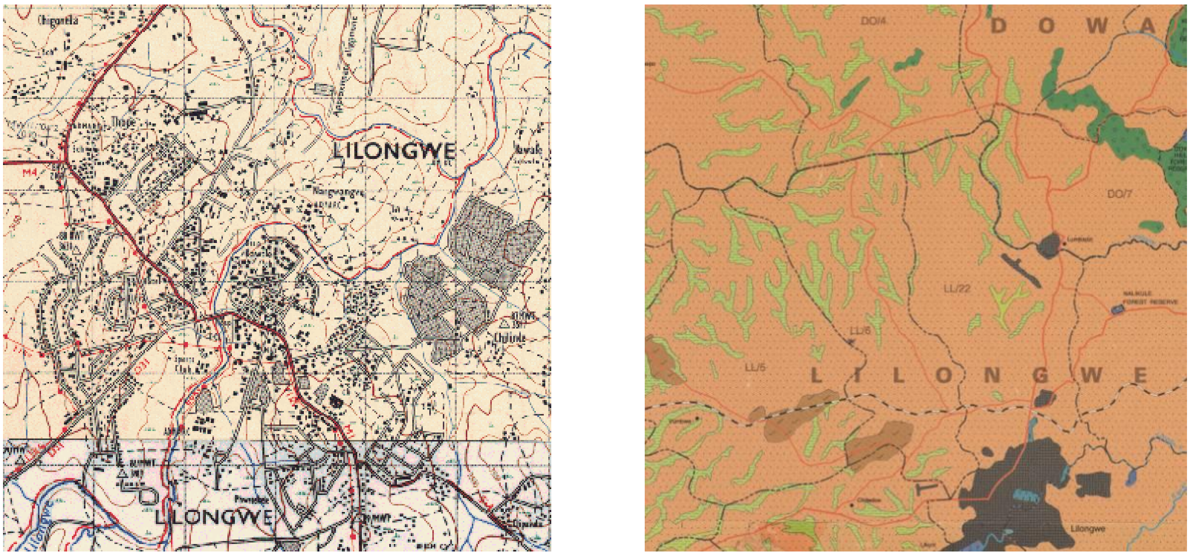
On the other hand, “Raster” or “grid-based” format represents the features as cells or pixel in a grid matrix such as ortho-rectified image, digital elevation model (DEM) and scanned maps.

Figure 6.8.3 shows typical raster or grid-based format data.



Ortho-rectified imagery
(Captured from Google Earth)

DEM generated from SRTM



Scanned topographical map (left) and land use map (right)

Source: Project Team

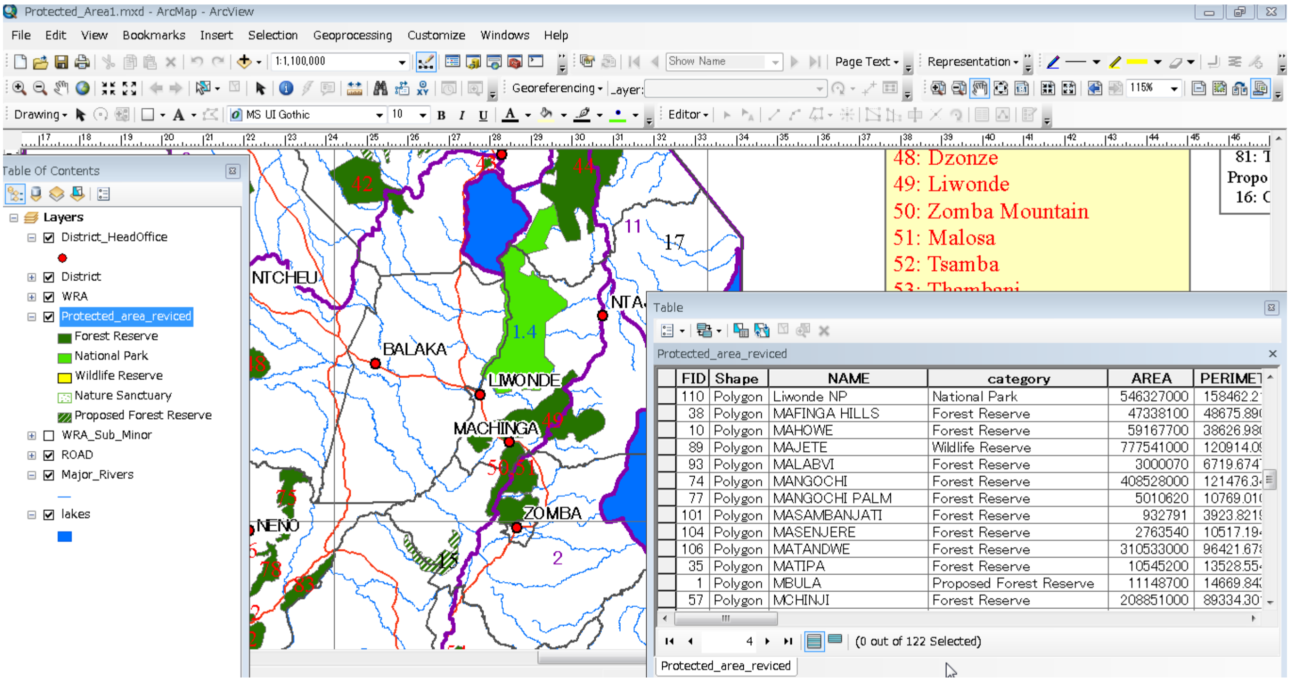
Figure 6.8.3 Typical Raster or Grid-Based Format Data

(3) Annotations

All spatial information, except those for geometry (point, line, polygon and raster), are called annotations. Feature name, area and observed value are typical information.

These information are usually used in association with geometry data, which are managed by relation database (refer to **Figure 6.8.4**).

Collected GIS data have been used for annotations without major modification. Newly created GIS data is used for annotations created based on GIS database definition.



FID	Shape	NAME	category	AREA	PERIMET
110	Polygon	Liwonde NP	National Park	546327000	158462.2
38	Polygon	MAFINGA HILLS	Forest Reserve	47338100	48675.89
10	Polygon	MAHOWE	Forest Reserve	59167700	38626.98
89	Polygon	MAJETE	Wildlife Reserve	777541000	120914.0
93	Polygon	MALABVI	Forest Reserve	3000070	6719.674
74	Polygon	MANGOCHI	Forest Reserve	408528000	121476.3
77	Polygon	MANGOCHI PALM	Forest Reserve	5010620	10769.01
101	Polygon	MASAMBANJATI	Forest Reserve	932791	3923.821
104	Polygon	MASENJERE	Forest Reserve	2763540	10517.19
106	Polygon	MATANDWE	Forest Reserve	310533000	96421.67
35	Polygon	MATIPA	Forest Reserve	10545200	13528.55
1	Polygon	MBULA	Proposed Forest Reserve	11148700	14669.84
57	Polygon	MCHINJI	Forest Reserve	208851000	89334.30

(0 out of 122 Selected)

Source: Project Team

Figure 6.8.4 Protected Area Annotation in Connection with Features

6.8.3 GIS Database Development

The GIS database was developed to conduct hydrological analysis and master planning efficiently.

In developing the GIS database, the Project made clear definitions of database table and folder framework.

(1) Database Definition

The Water Resources Master Plan (WRMP) database is created in accordance with the GIS database table (**Table 6.8.3**). This table has the following 6 items as database fields.

>Major class name: grouping sub-classes

>Sub-class name: grouping features

>Feature name: name to identify feature and equal to file name without extension

>Data type: data type of feature

>Major Annotations: annotation name that feature has

>CRS: coordinate system that feature refer

Furthermore, all data in the GIS database is in ‘shp’ format, used in ArcGIS.

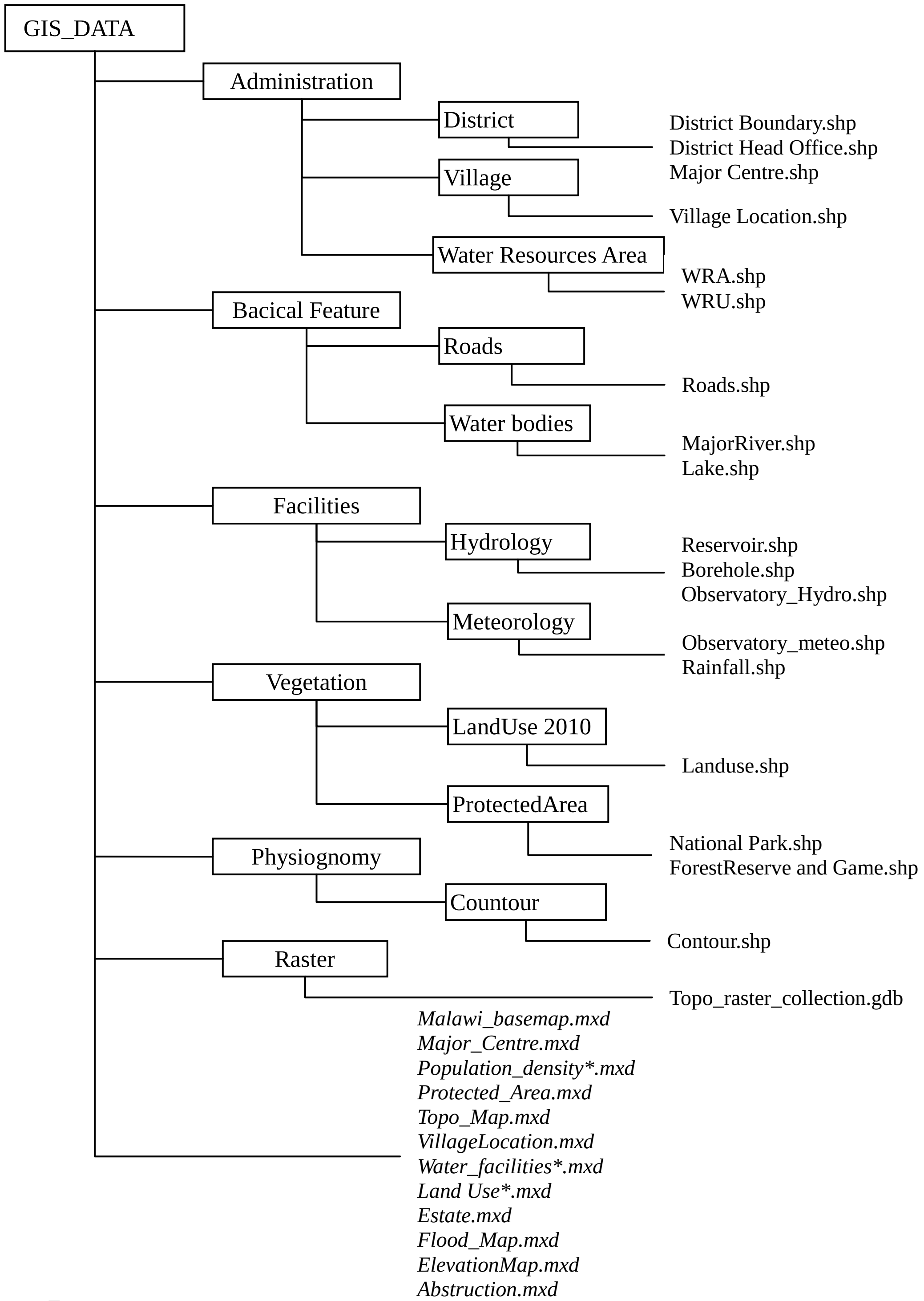
Table 6.8.3 GIS database table

Appendix B: GIS Database definition Table for Water Resources Master Plan

Major Class Name	Sub Class Name	Feature Name	Data Type	Major Annotations	CRS
Administration	District	District Boundary	Polygon	District_Nmae, Area(km2), 2008-2030 Population_density by District	Arc1960
		District Head Office	Point	Name	Arc1960
		Major Centre	Point	Name, Village, TA, District, Region, Easting, Northing	WGS84
		Major Centre Buffer 15km	Polygon	Name, Village, TA, District, Region, Easting, Northing, Buffer_Distance	WGS84
		Major Centre Buffer 25km	Polygon	Name, Village, TA, District, Region, Easting, Northing, Buffer_Distance	WGS84
	Traditional Authority	Traditional Authority Boundary	Polygon	TACode, Area(SqKm), Area(SqM), District_Name, TAName, District_Code, Perimeter, Hectares	Arc1960
		Trading Center Location	Point	ObjectID, Road Type, Road Class, Length, Enabled	WGS84
	Village	Village Location	Point	Serial_No., EA, Village, Name of PL, Feature, Earthing, Northing, Reagion, District, TA,	WGS84
	Water Resources Area	WRA	Polygon	Major_Catch(WRA No.), Name, 2008-2030 Population_density by WRA	Arc1960
		WRU	Polygon	WaterReso(WRU_No.), Area, Perimeter, Major_Catch, Minor_Catch, RiverName, Population Density by WRU	Arc1960
Bacical Features	Roads	Main Roads	Linestring	Main, Mainor, Secondary, Tertiary, District, Other road	Arc1960
	Water Bodies	MajorRiver	Linestring	River Name	Arc1960
		Lake	Polygon	Name, Area, Perimeter	Arc1960
Facilities	Hydrology	Reservoir	point	Name, RiverName, District, WRA, Category, Feature	Arc1960
		Borehole	point	Borehole_ID, Easting, Southing, district, TA_Name, WRA_Code, Aquifercode, WaterLevel, W_Strike, Depth, Yield, Lithology, PH, EC, TDS, CO3, HCO3, CL, SO4, NA, K, CA, MG, FE, MN, F, NO3, SIO2	Arc1960
		observatory	point	Code, Latitude, Longitude, X, Y, Source, open2012, Status, Number, Name	Arc1960
	Meteorology	observatory	point	Site, WMO_ID, Name, Start, Latitude, longitude, Elevation	Arc1960
		Rainfall station	point	ID, Name, Longitude, Latitude, Elevation, SFPDP, Glasgow_Un	Arc1960
Vegitation	Land Use 2010	Landuse	Polygon	ObjectID, Major_Catch(WRA_No.), Level1, Level2, length, Area	Arc1960
	Boundary	National Park	Polygon	Type_ID, Type_text, Name, Name_Low, Proteced_Date, Area(sqm,sqkm), Perimetre, Hectares, Gaz_date, Gaz_Decade, Gaz_1964, Add_date, Rational1, R1_code, Rational2, R2_code, Buffer_pop	Arc1960
		ForestReserve and Game	Polygon	Type_ID, Type_text, Name, Name_Low, Proteced_Date, Area(sqm,sqkm), Perimetre, Hectares, Gaz_date, Gaz_Decade, Gaz_1964, Add_date, Rational1, R1_code, Rational2, R2_code, Buffer_pop	Arc1960
Physiognomy	Contour	Index Contour	Linestring	Height(feet), Height(metre), Length, Fnode, Tnode	Arc1960
Raster	1:50,000 topographic map	Topo_raster_collection	Raster	Name, Length, Area	Arc1960

(2) Folder Framework

The shape files created based on the GIS database definition table are stored in the folder as follows (**Figure 6.8.5**).



Source: Project Team

Figure 6.8.5 Folder Framework of GIS Database

The main class name in **Table 6.8.3** is used as folder name of the first hierarchy. The subclass name is used as folder name of the second hierarchy.

"mxd" files in the "GIS_Data" folder are used to open the thematic map easily. When one would like to confirm, edit or print a thematic map, the selected "mxd" file shall be opened by double-clicking.

References for Chapter 6

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[2] Overseas Development Administration Institute of Geological Sciences, “Groundwater Resources of Malawi”, Department of Lands, Valuation and Water, Malawi, 1983

[3] Koken Boring Machine Co., Ltd., “The Project for Development of Groundwater in Lilongwe – Dedza, Final Report” Ministry of Water Development, Malawi, 2004

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[7] United Nations, Department of Technical Cooperation for Development, “National Water Resources Master Plan ANNEX6 Groundwater Resource of Malawi,” Ministry of Irrigation and Water Development, Malawi, 1986.

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[11] Tananga M. Nyirenda and Owen Lin-phiri, “Water Quality Report of Mudi River, Mlambalala and Naperi Streams in Blantyre District”, Southern Region Water Development Office, Malawi, 2011

[12] World Health Organization, “Guidelines for Drinking-water Quality, Fourth Edition”, 2011

[13] United Nations Development Programme (UDNP), “National Water Resources Master Plan, APPENDIX E Water Quality”, 1986

PART I

Chapter 7. CAPACITY DEVELOPMENT

CHAPTER 7. CAPACITY DEVELOPMENT

7.1 Target Organization and Department

For the implementation of effective interventions for water resources management, improvement of the performance of the related institutions is inevitable. Several efforts have been made to make positive steps; however, the water sector is still adversely affected in terms of implementation. The target will be focused on the human capacity of the Ministry of Agriculture, Irrigation and Water Development to concentrate on the management and operation of water resources for an effective intervention.

As to human capacity, the mid-term review report of May 2010 of the Second National Development Programme (NWDP-II) suggested there is a sufficient number of professionals and technicians with basic qualifications but lacking in staff with advanced qualifications for the sector to be managed efficiently and effectively.

The Human Resources Planning Unit of the Human Resource Management and Development Section has undertaken an assessment and analysis of the training needs of the department following the recommendations of the mid-term review of NWDP-II.

The study was undertaken to conduct the following activities:

- To identify skills and work experience profiles;
- To analyze the main functions/responsibilities performed by each department;
- To identify the main occupation categories and skills/work experience possessed by the current employees;
- To analyze the current staff performance problems/gaps and determine the specific deficiencies caused by lack of skills, knowledge and attitudes;
- To specify the group and individual training needs of staff;
- To determine and prioritize the most critical skill requirements in the irrigation, water and sanitation sector; and
- To prepare a training plan based on the results of the Training Needs Assessment (TNA) exercise.

The results of the study for the plan period of 5 years are compiled at the Human Resources Planning Unit (HRPU). Some training programs have already found funding and some others have not. However, the plan is treated as developmental that additional interventions can be further added upon discussion and agreement with the relevant authorities and the HRPU.

The HRPU has conducted a capacity assessment and training plan. The Project Team will review the report and conduct discussions with HRPU to further facilitate the implementation of the capacity development program outlined by the HRPU. The target organization and department will be within the Ministry of Agriculture, Irrigation and Water Development to maximize the impact of training in order to incorporate the acquired skills into the updating process of the Master Plan.

7.2 Capacity Assessment

The capacity development program will be implemented during the Phase I Project. The approach towards the capacity development in the project is to focus on drawing a master plan. Hence the training program will be planned and implemented to upgrade skills of individual staff in concordance with the assessment of the training needs and training capacity of the Project Team.

7.2.1 Methodology of Assessment

In order to plan a capacity development program, the needs for training are to be identified within the technical scope of work for each dispatched engineer. Since an extensive capacity assessment has been already carried out by the HRPU, the Project Team will use its report as a mainstream plan of training. In Phase I, the Project Team will focus on the technical aspects that are indispensable for data collection. Review of technical reports and data will lead the Project Team to identify the deficiencies and gaps of information, institutional arrangement and technical skills. The following approaches will be deployed to identify the training needs and possible training program.

(1) Consultative Meetings

The Project Team will consult closely with the HRPU to streamline the activities with the capacity development program that were already planned and propelled by the MWDI. The meetings are taken as opportunities also to gather data on the organizational and institutional structures as well as challenges that the Ministry is facing in terms of capacity development.

Exchanges of views and ideas between the HRPU and the Project Team are to be the basis for formulation of the programme to avert the implementation of programs from duplication of the already planned or implemented activities. The internal administrative procedures for selection and authorization to attend the training of the trainees will be managed by the HRPU.

(2) Reports and Data Review

Engineers dispatched by the Project Team will review the relevant reports and data to assess the current and past undertakings related to technical data collection, recording, analysis, and planning and project implementation. Through this process, the technical information gaps are to be identified in the current working practices.

(3) Interviews and Site Visit

Interviews are to be made with relevant personnel in the Ministry to collect data and information both on technical aspects and institutional arrangement. Together with the data and information collected, a further analysis is to be made to identify plausible cause of lack of information or data that should support operation and maintenance and/or project planning.

(4) Capacity Assessment Test

After identifying the needs of training, a small preliminary test will be conducted to assess the current skills and knowledge of the trainee prior to implementation of the training program. The results are taken as a baseline of skill levels to compare with the skills improved after learning.

(5) The Way Forward

After the training session, an evaluation will be made to ensure the acquisition of new knowledge and skills. The way forward will be discussed to make use of the output produced by the training in the Master Plan.

7.2.2 Results of Capacity Assessment

The HRPU conducted a Training Needs Assessment Study on Irrigation and Water Development to find out the training needs for the governmental bodies to meet the capacity requirements. A report was compiled in February 2012. The study elucidated a thorough capacity development needs by different technical and administrative subjects, by departments. A summary of the training needs are summarized as follows.

Table 7.2.1 Needs for Capacity Development Program

Proposed Training	Departments											
	Irrigation	Procurement & Supply	Water Resources (Hydrology)	Ground Water	Admin	Water supply	Finance	Internal Audit	ICT	Planning & Monitoring	HRM & D	NWDP-PMU
Technical Training in Irrigation Engineering	✓											
Data Analysis Using Computer Software Packages	✓		✓	✓						✓		
Survey, Design & Construction	✓		✓	✓		✓						
GPS/AutoCAD Training	✓			✓		✓						
Motorized Pump Maintenance	✓											
Project Management	✓		✓	✓		✓				✓		
Irrigation Research	✓											
Dam Design & Construction	✓		✓									
Water Resources Management			✓									
Borehole Drilling Training			✓	✓								
Play Pump Installation & Maintenance			✓	✓								
Field Operations and Design	✓		✓	✓		✓						
Environmental Health			✓									
Planning and analyzing	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Sanitation & Hygiene			✓			✓						
High Level Research						✓					✓	
Budgeting Skills	✓	✓	✓	✓	✓	✓	✓					
Borehole Rehabilitation & Maintenance						✓						
Management Skills & Auditing								✓				
Financial Management							✓					
International Human Resource Planning											✓	
Upgrading for Secretaries & copy Typists											✓	
Performance Mgt & Staff Appraisal											✓	
Quality Service Delivery & Productivity improvement	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Strategic Human Resource Mgt											✓	
Corporate Waste Management												
Purchasing & Inventory Control		✓										
Contemporary Human Resource Management Skills											✓	
Fleet & Distribution Management											✓	
Team building & Group Dynamics	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Capital Budgeting & Financial Management in the Public Sector							✓					
Monitoring & Evaluation										✓	✓	✓
Project Supply chain Management		✓										✓
Computer Skills	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	

Source: Report on Training Needs Assessment Study Irrigation and Water Development, February 2012

(1) Consultative Meetings

The Project Team will consult closely with the HRPU to streamline the activities with the capacity development programs that were already planned and propelled by the MoAIWD. The meetings are to be taken as opportunities also to gather data on the organizational and institutional structures as well as challenges that the Ministry is facing in terms of capacity development.

Exchanges of views and ideas between the HRPU and the Project Team are to be the basis for formulation of the program to avert the implementation of programs from duplication of the already planned or implemented activities. The internal administrative procedures for selection and authorization to attend the training of the trainees will be managed by the HRPU.

(2) Reports and Data Review

Engineers dispatched by the Project Team review the relevant reports and data to assess the current and past undertakings related to technical data collection, recording, analysis, and planning and project implementation. Through this process, the technical information gaps are to be identified in the current working practices.

7.3 Capacity Development

Particular needs for capacity development are identified along the technical study. Topical issues are summarized and contents of activities are proposed in the following sections by sector. The capacity development needs range from institutional development to skill development. The subject areas related to hydropower and disaster management are not included in this section sincethe jurisdiction of these sectors are not covered by the MoAIWD.

7.3.1 Agriculture and Irrigation

Capacity development needs in relation to agriculture and irrigation are summarized **Table 7.3.1**.

Table 7.3.1 Areas that need Capacity Building in Agriculture and Irrigation

Project Theme and Background	Project Components	Target
1.Formation of Water Users Association (WUA) for agricultural water users		
The agriculture sector is the biggest user of water. The users that use irrigation schemes are required to manage effective and efficient usage of water and abide by the obligations of the abstraction license and the effluent discharge permit in accordance with the National Water Resources Act of 2013.	1. Establishment of Water Users Association (WUA) with water users of a water scheme or irrigation scheme for irrigation. 2. Preparation of a WUA constitution in accordance with the National Water Resources Act. 3. Registration of WUA and payment of water abstraction and discharge permit.	Water Users Association; Dept. of Irrigation; NWRA
2. Promotion of water saving irrigation methods		
The production of food and cash crops is a key for improvement of living conditions in rural areas. The scarcity of available water especially during the dry season makes it difficult for small farmers to grow vegetables during the dry season. Introduction of water saving irrigation method and improved agricultural methods allows to plant crops and vegetables with less water.	1. Training on water saving irrigation methods for government officials as trainers. The government extension workers conduct training projects for farmers. 2. Investment in water saving irrigation methods. 3. Training on improved agricultural methods including strengthening farmers associations for enhancement of cash crop trade.	Farmers association Dept. of Irrigation NWRA

Source: Project Team

7.3.2 Urban Water Supply and Sanitation and Hygiene

Capacity development needs in relation to urban water supply and sanitation and hygiene are summarized in **Table 7.3.2**.

Table 7.3.2 Areas that need Capacity Building in Urban Water Supply and Sanitation and Hygiene

Project Theme and Background	Project Components	Target
1.Reduction of Non-Revenue Water (NRW)		
The urban water utilities are operating under low financial viability. Minimising non-revenue water can contribute to strengthen the financial capacity of utilities. Water Boards, however, still struggle to achieve acceptable NRW levels (33% NRW average rate, 2012-13 SPR). Weak internal policies and procedures and the lack of financial or human resource capacity contribute to rising NRW levels.	1. Improvement of metering system including: 2. Maintenance of meters, reading errors, slow running meter, tampering of meters 3. broken or no meter, illegal connection 4. Improvement of billing system including: 5. Administration of errors, data entry errors, delays 6. Loss of records 7. Reduction of leakages including: 8. Leaks from pipes, booster stations, air valves 9. Public awareness improvement including: 10. Payment, installation of meters, sanitation and hygiene	Water Boards (Lilongwe, Blantyre, Northern, Central Southern)
2. Development of Water Safety Plan		
A water safety plan is not in place for drinking water in Malawi. The WHO calls for an implementation guidelines to ensure the safety of drinking-water supply through a comprehensive risk assessment and risk management approach in the Third Edition of the WHO Guidelines for Drinking-water Quality (2004). All steps in water supply from catchment to consumer are managed through a comprehensive management system.	1. Assemble the WSP team 2. Describe the water supply system 3. Identify hazards and hazardous events and assess the risk and prioritize the risks 4. Determine and validate risk control measures and water supply system with ISO standards 5. Develop, implement and maintain an improvement/upgrade plan 6. Define monitoring of the control measures 7. Verify the effectiveness of the WSP 8. Prepare management procedures 9. Develop supporting programmes 10. Plan and carry out periodic review of the WSP	Water Boards (Lilongwe, Blantyre, Northern, Central Southern)
2.Improvement of sewage sludge collection		
For improvement of urban sanitation, the collection and disposal of sludge from on-site sanitation systems must also be considered. Latrine and septic/interceptor tank contents require attention to be properly collected before emptying and releasing to the environment.	1. Systematic planning based on stakeholder identification and coordination (integrated with urban sanitation planning) 2. Regulations on services provision and management procedures 3. Fee structuring 4. Management and regulation of emptying services by private entrepreneurs 5. Establishment of rules to secure a competitive market 6. Appropriate treatment options 7. Securing the market for biosolids sale 8. Incorporating faecal sludge management (FSM) into planning	Water Boards; Ministry of Health; MoAIWD

Source: Project Team

7.3.3 Rural Water Supply

Capacity development needs in relation to rural water supply are summarized **Table 7.3.3**.

Table 7.3.3 Areas that need Capacity Building in Rural Water Supply

Project Theme and Background	Project Components	Target
1. Development of Water Supply for Market Centers		
In order to facilitate water supply infrastructure in the market centers, the strengthening of communication about information of market centers is needed.	1.Improvement of planning capacity of water supply section in the district water office. 2. Improvement of coordination of finance for the water supply of the market centers in MoAIWD. 3. Building of awareness of Reasional Water Boards as regards participation from planning stage for water supply of the market centers	MoAIWD; MoLGRD; Local Government
2. Development of Water Supply for Market Centers		
In order to facilitate water supply infrastructure in the communities, the strengthening of communication and information sharing among related agencies is necessary.	*1. Establishment of mutual communication system among related agencies.* *2. Improvement of planning skills of District Water Office.* *3. Building of awareness of Reasional Water Boards/Local Government/WUAs of communities as regards participation from the planning stage.*	*MoAIWD;* *MoLGRD;* *Local Government*
3. Regional water supply institutional reinforcement		
For the rural market centers, gravity-fed scheme and boreholes are primarily coordinated by districts. However, the conditions and installation of the infrastructures are not systematically monitored or recorded by the authority. The Ministry has no records, so that policy interventions becomes a difficult task. Results oriented working method need to be implemented.	1. Define the Terms of Reference for the water supply department to monitor and keep records of water supply infrastructure by different water supply schemes 2. Establish regular reporting protocols between the Ministry and districts regarding the relevant information necessary for decision-making on interventions and policy formulation. 3. All interventions to use water must be registered with NWRA, for water abstruction. The Ministry and district councils inform all developers including private, non-profit and governmental agencies. 4. The progress of intervention shall be included in the sector performance report in the framework of SWAP. The water supply department prepares the sector performance report using the report submitted by the districts.	MoAIWD Water Supply Section

Source: Project Team

7.3.4 Surface Water

Capacity development needs in relation to surface water supply are summarized **Table 7.3.4**.

Table 7.3.4 Recommended Projects for Surface Water

Project Theme and Background	Project Components	Target Stakeholders
1.Classification of rivers		
For the purpose of river water management there needs to be a classification system of rivers with regulations covering – water quality standards, conservation rules, management system by classifications among others.	1. Draw a set of classification criteria 2.Draw rules and regulations according to the classification of rivers 3.Inform stakeholders of the protocols who undertake any activities related to the rivers	NRWA officials; Surface Water Section; River water users
2.Buffer zones management of rivers		
To facilitate riparian management, such as river and lake waters, buffer zones need to be set in place to avoid siltation and contamination of water by cultivation activities at riversides. However, in practice there need to be alternative ways of gardening since people are gaining food and income from such practices.	1. Draw a set of classification criteria 2. Draw rules and regulations according to the classification of rivers 3. Assist raising awareness and other means of gardening by providing water through pipes or something.	NRWA officials Dept. of Irrigation River water users

Source: Project Team

7.3.5 Groundwater

Capacity development needs in relation to groundwater supply are summarized in **Table 7.3.5**.

Table 7.3.5 Areas that need Capacity Building in Groundwater

Project Theme and Background	Project Components	Target Stakeholders
1.Hydro-geological data management		
To improve data management and processing, hydro-geological data management, evaluation and planning groundwater development.	1.Preparation of manual for collecting data from data loggers, data monitoring, collection, input, data error detection and maintenance of data logger 2.Draw rules and regulations according to the classification of rivers 3.Inform stakeholders of the protocols who undertake any activity related to the rivers	NRWA officials; Surface water section; River water users
2.Establishment of groundwater management section		
The Ministry needs to manage the data and interventions with coherence to facilitate groundwater management for adequate monitoring, analysis and evaluation and groundwater development planning	1.Set up a groundwater management section with a clear TOR and mandates 2.Consolidate the database system WISH with new borehole information, existing boreholes, monitoring information. 3.Conduct analysis and evaluation activities on statistics of borehole information, evaluation of water supply from boreholes 4.Development planning of boreholes	NRWA officials; MoAIWD officials

Source: Project Team

7.3.6 Water Resources Management

Capacity development needs in relation to water resources management are summarized **Table 7.3.6**. These activities are to be transferred to the activities of NRWA.

Table 7.3.6 Recommended Projects for Surface Water

Project Theme and Background	Project Components	Target Stakeholders
1. Catchment Area Management		
Catchment Area Management is a key to manage and supervise 17 Water Resources Areas (WRA) also indicated catchments across Malawi. A catchment area management committees will cares for 1 or more catchment areas.	1.Draw guidelines for catchment area management 2.Establish catchment area committee 3.Implement activities concerning water allocation, conservation and control of water usage.	NRWA officials MoAIWD officials District councils Water users
2. Registration of Water Users Association		
Many water user associations have been established to monitor and manage water usage. However, these entities are currently not registered or regulated by any legal institution. Many farmer assoiations created WUAs under the Department of Irrigation, as well as Blantyre Water Board and Lilongwe Water Board, but there is no supervising entity to regulate and support WUAs at the operational level.	1.List and register all WUAs in Malawi 2.Facilitate WUAs to create and agree on constitutions 3.Sensitize to pay water license charges to NWRA	WUAs; District Councils; NRWA officials; Dept. of Irrigation

Source: Project Team

7.4 Capacity Development Program during the Study

The capacity development program was implemented during the study to facilitate understanding on the planning process of the master plan. The subject fields are summarized in the following table. The areas of the capacity development program are framed from the viewpoint of master plan development, relevant topics and skills that are necessary to draw a master plan.

The primary objective of the seminar for policy level is to discuss overview of methodology and the steps to formulate a master plan, with particular emphasis on policy implication. The topics include the agricultural sector, urban water supply, rural water supply and water resources management. The program is shown in **Table 7.4.1**.

Table 7.4.1 Policy Level Seminar Program during the Master Plan Study

Target Group	Program	Main Theme	Contents
Policy Making Level	Agriculture	Water management in Agricultural Sector	The objective of the seminar is to share a conceptual framework for policy formulation on water resources management for agricultural and irrigation usage using quantitative data on water availability, irrigation areas, cropping patterns and water saving irrigation among others.
	Urban water	Urban water supply planning	The objective of the seminar is to share a planning framework for urban water supply schemes for market centers and other urban areas. The topics include challenges identified during the study, parameters for planning and preliminary project proposals.
	Rural water	Rural water supply planning	The objective of the seminar is to share a planning framework for rural water supply schemes and market centers. The topics include challenges identified during the study, parameters for planning and preliminary project proposals.
	Water resources management	Water resources management policy implications	The objective of the seminar is to share a planning framework from the perspective of Integrated Water Resources Management (IWRM) approach. Topics for policy formulation and implementation include the water balance calculation, water demand, water availability, among others.

Source: Project Team

Table 7.4.2 Technical Level Training Program during the Master Plan Study

Program	Main Themes	Necessary Tool	Indices
Surface water Basic data arrangement	Field observation for flow capacity, groundwater level, water quality, etc.; Data collection and arrangement related to water resource development; Development or enhancement of database	- Total Station - Velocity Meter - Boat - Staff gauge - Laptop PC	- Records of OJT related field observation - Learning the method of field observation - Data collection and arrangement - Records of OJT related to the data collection and arrangement - Creation of data indices - Creation of database - Creation of the Manual for observation
Hydrology analysis	Rainfall and runoff analysis; Groundwater analysis; Analysis of climate change impacts	- GIS - MIKE SHE - Laptop PC	- Record of OJT related to hydrology analysis - Acquisition for field observation - Creation of the Manual for hydrology analysis.
Water Demand analysis	Analyzing demands of drinking/industrial and irrigation water Analysis of river maintenance flow	- Laptop PC - Software for calculation	- Record of OJT related to water demand analysis - Technical transfer of water demand analysis - Creation of the manual for water demand analysis
GIS Software	Learning how to setup GPS device Learning how to install Satellite image into GPS device Learning how to create Geo-tag photo	- GIS - GIS Manual - Laptop PC	- Understanding of the GPS basic theory - Understanding of the GPS device basic setup - Understanding of the GPS device advance setup - Practice using GPS and Camera - Record of GPS data - Download of GPS data to PC - Creation of Geo-tag (Photo with GPS coordinate)

Source: Project Team

7.4.1 Program Schedule and Contents

The program was held during the data collection activities in Phase I. Seminars on each topic were conducted during the Phase I period starting from August 2012 to March 2013. The planned program schedule and contents are summarized in **Table 7.4.3**.

Table 7.4.3 Schedule Planning of Capacity Development Program

No.	Date	Topic	Venue	Target
1	7 August 2012	GIS Introduction	Tikuwele House	Junior to Middle technical officials
2	November 2012	Hydrological data arrangement and analysis	Tikuwele House	Junior to Middle technical officials
3	November 2012	Discharge observation and cross sectional survey	Tikuwele House	Junior to Middle technical officials
4	February 2013	Groundwater analysis	Tikuwele House	Junior to Middle technical officials
5	February 2013	GIS Intermediate	Tikuwele House	Same participants as Program 1

Source: Project Team

7.4.2 Progress of Individual Programs

A workshop on GIS introduction was conducted on 7 August 2012. The outline and evaluation of the workshop are as summarized below. It was found through the interviews that GPS devices have been given to the Ministry through various projects in the past; nonetheless, the knowledge on usage of GPS and GIS is limited to a level of almost not countable among the junior to middle level government officers. The technology is very useful to record the information of location on a map to be used for data storage, monitoring and planning.

(1) GIS Introduction Workshop

A GIS introduction course was conducted in August 2012. Other training sessions were planned to be held in the course of Phase I. Brief outlines of the planned training courses are as described below.

Program 1: GIS Introduction

Objective: The primary objective of the training is to give hands-on training to the staff of MoAIWD on the use of GPS to implement the activities relating to water recourses management. This course has strong emphasis on the application on actual field activities for the project.

Tools: GPS, GIS software, Google Earth

Target: Junior to middle level engineers

Duration: 1 day

The following are the specific objectives of the training:

- To learn how to create Geo-Tag pictures using GPS machine and digital camera;
- To learn how to create KML(Google Earth) using Geo-Tag pictures and GPS data (track log); and
- To learn how to apply satellite images, maps and shape files (JPEG) to the use of GPS (IMG).

1) Necessary Materials and Tools

- Laptop PC: Each participant should bring a Laptop PC with internet dongle.
- Handy GPS: Each participant should bring Handy GPS with USB connecting cable.
- Software: The Project Team will provide the following software:
- GPS Babel (Free Software) * for converting Garmin GPS data to common GPS data format
- Easy GPS (Free Software) *for adding Geo-Tag to pictures using common GPS data format
- Google Picasa (Free Software) *for sending GPS data to Google Earth
- Google Earth (Free Software) *for showing location of photographing site and track log on Google Earth

Table 7.4.4 GIS Workshop Program

No	Theme	Subjects	Venue	Schedule	Evaluation
1	GPS device set up	GPS basic theory GPS device setup about Unite and coordinate system	Seminar Room	09:00 - 12:00	- Knows the GPS basic theory - Knows the GPS device basic setup
2	Satellite image installation	GPS device setup about Satellite or Topographic Map data GPS data and Photographic data recording	Seminar Room	13:30 - 15:00	- Knows the GPS device advance setup - Can use GPS and Camera
3	Geo-tag data creation	Download of GPS data to PC Geo-tag	Seminar Room	15:30 - 17:00	- Can download GPS data to PC - Can create Geo-tag (Photo with GPS coordinate)

Source: Project Team

2) Evaluation

In order to measure how far the participants understood the seminar contents, the following ten questions were posed to participants and answers were given with rating indicators.

Table 7.4.5 Evaluation Questions

No.	Evaluation Questions	Before	After	Difference
Q1:	Do you know how to set up "GPS coordinate system" in your handy GPS?	1.8	4.7	2.9
Q2:	Do you know how to download or upload "GPS data"?	1.4	4.1	2.7
Q3:	Do you know how to change "GPS format (GPX format etc.)"?	1.2	4.1	2.9
Q4:	Do you know how to set up "Google Earth coordinate system"?	1.2	4.1	2.9
Q5:	Do you know how to download or upload "GPS data by Google Earth"?	1.1	3.8	2.7
Q6:	Do you know how to use "Google Earth Time scale"?	1.1	4.1	3.0
Q7:	Do you know the meaning of "Geo-tag"?	1.0	4.3	3.3
Q8:	Do you know how to create Geo-tag by "GPS" and "Digital Camera"?	1.0	3.9	2.9
Q9:	Do you know ho w to manage (delete or modify) Geo-tag by "Free software"?	1.0	4.3	3.3
Q10:	Do you know how to use "Geo-tag with GIS software (Free software)"?	1.0	1.0	0

Source: Project Team

Table 7.4.6 Evaluation Rating Indicators

Level	Rating Point	Before	After
Level 1	1	I don’t know anything.	I don’t understand anything
Level 2	2	I know some but I don’t have experience	I understand some but I need theory
Level 3	3	I have some experience but I can’t use my work.	I understand very well but I need practice
Level 4	4	I can use my work but I can’t teach	I can use my work but I can’t teach
Level 5	5	I can teach	I can teach

Source: Project Team

Interviews and assessment prior to the training revealed that, in general, the participants did not have any practical knowledge on the GIS system. Therefore, the program was prepared to start with a general explanation on the GPS and GIS systems, applications and possible practical usage of the technology. The participants were selected among the government staff at the headquarters of the Ministry who may be in charge of data compilation, processing and planning for projects and statistics presently or in the future. As **Table 7.4.6** shows, most participants had very little knowledge on the GIS technology at the onset of the training session. After the course and practical exercises, the assessment result improved by 2.7 points on average. Considering that most of the participants were of level 1 (I don’t know anything at the on-set of the session), an improvement of 2.7 points means they reached level 3 (I understand very well but I need practice). Since the course was an introductory course, the general objective that the participants acquired general introductory knowledge was met. The improvement rate of Q10 was 0. Due to time constraints, the subject ”Geo-tag” was not covered in the program. A follow-up program was planned in February 2013 to cover this subject as well as a more advanced curriculum of GIS usage exercise.

(2) Hydrological Observation and Monitoring (Discharge Measurement and Cross Section Survey)

Program 2: Hydrological data arrangement and analysis for Water Balance Analysis

Objective: To learn how to analyze the water balance by using MIKE-BASIN and MIKE-SHE which are commonly used in many countries. Rainfall analysis will also be included in the training.

Tools: Laptop with MIKE-BASIN and MIKE-SHE

Target: Junior to middle level engineers

Duration: 1 day

The primary objective of the training was to give hands-on training to the staff of MoAIWD on the use of propeller-type current meter and total station to implement the activities such as flow measurement relating to water resources management. This course had strong emphasis on the application to actual field activities. The following were the specific objectives of the training:

- To train on how to measure flow velocity using propeller current meter;
- To train on how to survey cross section using total station; and
- To train on how to calculate river flow using measuring results.

1) Equipment Used for the Course

- Laptop PC (Each participant should bring a Laptop PC)
- Survey materials:

  - Each participant should bring a field note and pens
  - Each participant may bring high rubber boots and work clothes for field activities (day two), if any.

- Observation equipment: The Project Team prepared the following equipment:

  - Propeller-type electric current meter (1 set)
  - Total Station (1 set)
  - Tripod stand (3 sets)
  - Prism & Pole (2 sets)
  - Measuring tape (1 set)

Table 7.4.7 Hydrological Observation and Monitoring Workshop Program

No	Theme	Subjects	Venue	Schedule	Evaluation
1-1	Move to Salima			10:00 - 12:00	-
1-2	Lunch			12:00 - 13:00	-
1-3	Preparation for field work	• Flow measurement basic theory • Training on operation of measuring equipment	Seminar Room	Halfday (afternoon) (13:30 - 16:30)	• Knows the flow measurement basic theory • Knows the method of operation of measuring equipment
2	Flow measurement in the field	• How to implement flow measurement.	Field Work (4B1: Linthipe R. at Salima Rail-bridge)	1 day (8:30 - 16:00)	• Can operate equipment and implement flow measurement including cross sectional survey in the field
3-1	Calculation of flow	• How to calculate flow using measurement data using PC • How to arrange the data	Seminar Room	Halfday (morning) (9:00 - 11:30)	• Knows the method of flow calculation • Can calculate flow using measurement data
3-2	Lunch			12:00 - 13:00	-
3-3	Move to Lilongwe			13:00 - 15:00	-

Source: Project Team

Place: Field in Salima and Meeting Room of Kambiri Lodge, Salima

Duration: Three days (One day in the field and Two days (2.5 days) in meeting room from 10 to 12 December 2012

2) Evaluation

Seven (7) participants attended the seminar as follows.

Table 7.4.8 Participants of Hydrological Observation and Monitoring Training

Name	Position (Dep./Sec.)
EMMANUEL CHIUNDIRA	Hydrologist
SUSAN KUMWENDA	Hydrologist
MJ. MBAMA	Assistant Hydrologist
P. KAUNDA	Assistant Hydrologist
SOLOMON KALIMA	Water Resources Engineer
CHIKONDI MBEMBA	Water Resources Engineer
HASTINGS MBALE	Water Resources Development Officer

Source: Project Team

In order to measure how far the participants understood the seminar contents, the following ten questions were posed and answers were given with rating indicators.

Table 7.4.9 Evaluation Questions

Nr.	Evaluation Questions	Before	After	Difference
Q1	Do you know meaning and objective of discharge measurement?	2.6	5.0	2.4
Q2	Do you know types of discharge measurement?	2.3	5.0	2.7
Q3	Do you know how to do discharge measurement using a current meter?	2.0	5.0	3.0
Q4	Do you know how to record use a propeller-type electric current meter?	1.4	5.0	3.6
Q5	Do you know how to record the measuring data to measurement sheet?	2.1	5.0	2.9
Q6	Do you know how to calculate discharge using measuring results?	2.3	5.0	2.7
Q7	Do you know how to do cross sectional survey?	2.1	4.9	2.7
Q8	Do you know how to use a Total Station?	1.3	4.9	3.6
Q9	Do you know how to make cross sectional profile using measuring results?	1.7	5.0	3.3
Q10	Do you know how to make a rating curve?	2.1	4.7	2.6

Source: Project Team

Table 7.4.10 Evaluation Rating Indicators

Level	Rating Point	Before	After
Level 1	1	I don’t know anything.	I don’t understand anything
Level 2	2	I know some but I don’t have experience	I understand some but I need theory.
Level 3	3	I have some experience but I can’t use my work.	I understand very well but I need practice
Level 4	4	I can use my work but I can’t teach	I can use my work but I can’t teach
Level 5	5	I can teach	I can teach

Source: Project Team

Participants generally had some knowledge and experience on flow measurement and cross sectional survey prior to the training. Before the training, most of the participants were not familiar with the mechanical equipment like the Total Station and Propeller-type Electric Current Meter. The course then gave an introductory overview of the technical equipment that are useful for flow measurement. The understanding rate on most evaluation questions was 50% before the training. After the training the understanding rate increased to almost 100% with three exceptions.

The course intended to offer training including field exercises to use propeller-type current meter and Total Station to conduct flow measurement. Further follow-ups are important to incorporate the skills acquired into water resources planning. These may include databank management, interpretation and usage of collected data for planning.

Source: Project Team

Figure 7.4.1 Measurement Exercise 1

Source: Project Team

Figure 7.4.2 Measurement Exercise 2

(3) Hydrology and Hydrological Data Management

Program 3: Discharge observation and cross sectional survey

Contents: Training on discharge measurement including cross sectional survey

Tools: Total station and current meter

Objective: To learn measurement and data compilation techniques of cross section, flow velocity and river discharge in order to utilize the data/result for water allocation and flood control planning

Target: Junior to middle level engineers

Duration: 1 day

Following the Hydrological Observation and Monitoring (Discharge Measurement and Cross Section Survey) conducted in December 2012, a data management course was offered to the same target participants as a follow-up course after two weeks in December 2012. The primary objective of the training was to give a better understanding of hydrological analysis and maintain quality preservation of hydrological data. The following were the specific contents of the training:

- To understand general hydrological theories
- To train on how to analyze hydrological data

1) Equipment Used for the Course

- Laptop PC: Each participant should bring a Laptop PC

Table 7.4.11 Hydrology and Hydrological Data Management

No	Day	Subjects	Venue	Schedule	Evaluation
1	20 Dec	• Common hydrology and hydrological analysis • Importance of data management	Conference Room, MoAIWD	13:30 – 16:30	• Knows common hydrological system • Knows methods of runoff simulation • Knows importance of hydrological data
2	21 Dec	• Practice on Runoff Model	Conference Room, MoAIWD	10:00 – 16:00	• Can make and operate simple runoff simulation model

Duration: Two days from 20 to 21 December 2012

Source: Project Team

2) Evaluation

Eight (8) participants attended the seminar as follows.

Table 7.4.12 Participants of Hydrological Observation and Monitoring Training

No	Name	Position (Dep./Sec.)
1	EMMANUEL CHIUNDIRA	Hydrologist
2	SUSAN KUMWENDA	Hydrologist
3	MJ. MBAMA	Assistant Hydrologist
4	P. KAUNDA	Assistant Hydrologist
5	SOLOMON KALIMA	Water Resources Engineer
6	CHIKONDI MBEMBA	Water Resources Engineer
7	HASTINGS MBALE	Water Resources Development Officer
8	LYSON MSEU	Water Resources Development Officer

Source: Project Team

In order to measure how far the participants understood the seminar contents, the following ten questions were posed to participants and answers were given with rating indicators.

Table 7.4.13 Evaluation Questions

Nr.	Evaluation Questions	Before	After	Difference
Q1	Do you know the concept of hydrological conditions (circulation)?	3.3	4.8	1.5
Q2	Do you know what kind of data you need for hydrological analysis?	3.0	5.0	2.0
Q3	Do you know how to estimate basin mean rainfall?	1.5	4.0	2.5
Q4	Do you know runoff analysis?	1.5	4.3	2.8
Q5	Do you know elements which affect a runoff process?	2.0	4.5	2.5
Q6	Do you know the procedures of runoff analysis?	1.8	4.3	2.5
Q7	Do you know the characteristics of runoff model?	2.3	4.3	2.0
Q8	Do you know how to do cross sectional survey?	3.5	4.5	1.0
Q9	Do you know the important points to establish runoff model?	1.8	3.8	2.0
Q10	Do you know the concept of tank model?	1.3	3.8	2.5
Q11	Do you recognize the importance of discharge data quality control?	2.5	4.3	1.8

Source: Project Team

Table 7.4.14 Evaluation Rating Indicators

Level	Rating Point	Before	After
Level 1	1	I don’t know anything.	I don’t understand anything
Level 2	2	I know some but I don’t have experience	I understand some but I need theory.
Level 3	3	I have some experience but I can’t use my work.	I understand very well but I need practice
Level 4	4	I can use my work but I can’t teach	I can use my work but I can’t teach
Level 5	5	I can teach	I can teach

Source: Project Team

Participants generally had some knowledge on hydrology and data management. This course focused more on the theoretical understanding of basic and medium advanced hydrology. Basic understanding of hydrology (Q1) and cross sectional survey for which training was conducted two weeks before (Q8) was relatively higher than other subject matters. Especially, conceptual runoff models (Q9) and tank models (Q10), and procedures of runoff analysis (Q6) are relatively advanced technical procedures that further exercises to fully understand them are needed. These technical analyses are important for hydrological analysis to use in the water resources planning.

(4) Data Management for Groundwater Resources

Program 4: Learning the process of hydrogeology and training on groundwater analysis with GIS

Tools: Laptop including GIS

Object: To learn the basic knowledge of hydrogeology, how to use borehole database on computer, and evaluation / simulation of current / future groundwater potential using GIS in order to handle rural water supply planning.

Target: Junior and middle level engineer

Duration: 1 day

Data management exercises were conducted after the previous hydrological seminars. This course particularly focused on data management of groundwater resources. The primary objective of the training was to discuss the appropriate data management for groundwater resource for the MoAIWD officials to better understand the groundwater resources data and incorporate the data set to the master plan of water resources in Malawi. The following are the specific contents of the training:

- To improve the knowledge on groundwater
- To understand the data arrangement of groundwater survey

1) Equipment Used for the Course

- Laptop PC: Each participant should bring Laptop PC
- Equipment for demonstration: The Project Team will prepare the following equipment
- - Potable water quality analyzer (1 set)
- - Plastic Beaker (1 set)

Table 7.4.15 Data Management for Groundwater Resources

No	Theme	Subjects	Venue	Schedule	Evaluation
1	Lecture on Basic Knowledge of Groundwater	• Water cycle • Groundwater Recharge • Groundwater Quality (Demonstration of analyzing water quality) • Physical Mechanism of Groundwater • Darcy's Law	Seminar Room	10:00 – 12:00	• Knows the basic theory of groundwater • Knows the relationship between groundwater and geology • Knows groundwater mechanism
2	Lecture on Data Management for Groundwater Resources	• Exploration for groundwater • Drilling borehole • Pumping test • (Practice on analyzing hydraulic parameters on PC) • Groundwater monitoring	Seminar Room	10:00 – 13:00	• Knows the methodology of groundwater survey • Knows appropriate borehole construction • Can make data arrangement on groundwater survey

Source: Project Team
Place: Meeting room on 2nd Floor of Tikwere House
Duration: Two days from 7 to 8 March 2013

2) Evaluation

Eleven (11) participants attended the seminar as follows.

Table 7.4.16 Participants of Data Management for Groundwater Resources Training

No	Name	Position (Dept. /Sec.)
1	M.G.M. Nkhata	Chief Hydrogeological Research Officer
2	K.H. Msonda	Principal Hydrogeological Research Officer
3	A. Joloza	Hydrogeological Research Officer
4	P. Chintengo	Principal Driller
5	T. Nyasulu	Senior Groundwater Development Officer
6	P. Chiwaula	Senior Drilling Officer
7	H. Sapulayi	Mechanical Engineer
8	C. Chivunga	Senior Technical Officer
9	B. Mphanje	Technical Assistant
10	R.M. Chikomphola	Technical Assistant
11	F. Mukwaudiyo	Technical Assistant

Source: Project Team

All officers and technicians need some training in different areas regarding groundwater. It is critical that the importance of groundwater analysis would be put on analysis and presentation of data in different forms including maps (practical GIS), manipulation of different information on different maps and diagram presentation. It is a wish of the Division that the capacity be strengthened to be able to produce maps, models using the local groundwater data. This would be useful in areas of groundwater exploration, groundwater risk assessment, scientific opinion paper presentation and writing among others.

Source: Project Team

Figure 7.4.3 Groundwater Assessment 1

Source: Project Team

Figure 7.4.4 Groundwater Assessment 2

7.4.3 Policy Guidance and Institutional Functions

The Ministry has implemented various interventions with regard to water resources management activities mainly through the National Water Development Program (NWDP) since 1997 which acted as a coordinating and implementation agency to plan and implement the projects followed by the NWDP-II program. The main reason for this ad-hoc arrangement was due to the lack of human resources capacity. The NWDP-II is due to end in 2015, yet the Ministry is still under stretched conditions in terms of human resources to undertake the role as NWDP Secretariat.

A capacity development program was implemented to enhance policy formulation capacity and the understanding of implementation activities of various institutions with regard to water resources management. The main focus of the training was to learn about the policy implementation strategies. The training was held in Japan. The periods and programs of training are outlined in the following paragraphs.

(1) Policy and Implementation Strategies: Training I

Period: 03 December to 15 December 2012

Objectives: The course was programmed to learn about the functions and policy implementation mechanisms of institutions, particularly:

- The Integrated Water Resources Management, Japanese practices
- Sustainable water resources management policy implementation
- Water utilization facilities coordinated management

Particular emphasis was placed on the roles and functions of the Ministries and other related government agencies that are managing the water resources both from policy guidance and implementation strategies, as well as supervision of the activities implementation.

Participants were selected by the Ministry to attend the course.

Table 7.4.17 Participants of Policy Guidance Training (1)

No	Name	Title	Dept./Section
1	Modesta Kanjaye	Director of Water Resources	Water Resources
2	Macpherson G. M. Nkhata	Chief Ground Research Officer	Groundwater
3	Laison M Mseu	Water Resources Development Officer	Surface Water

Source: Project Team

During the month of December 2012 the following training and seminars were conducted for the officers of the Ministry. The program schedules and contents are summarized in **Table 7.4.18**. The visits and lectures at concerned Ministry offices in Japan were realized through cooperation of the respective Ministries in Japan.

Table 7.4.18 Program of Policy Guidance Training

Date (2012)	Visit	Contents
05 Dec	Japan Water Agency	IWRM practices in Japan Functions of JWA
06 Dec	Ministry of Land, Infrastructure, Transport and Tourism	Water resources policy, the current water usage, future plan Policies on surface water, groundwater Water utilization facilities
07 Dec	JICA	Decision making process for water resources development and management
07 Dec	Osaka University	Conflict resolution for international watercourse
10 Dec	Kiso River Canal	Water utilization canal
11 Dec	Aki River Dam, Maruyama Dam, Hydropowe Plant	Strategies and coordination for water utilization dams, activity implementation
12 Dec	Asakawa Water Recycling Center	Sewage treatment process and strategies
13 Dec	Asagiri Water Treatment Plant	Water treatment for potable water and distribution planning

Source: Project Team

1) Evaluation

The program included lectures and presentations as well as discussions at various institutions and visits of facilities. At the end of the training, the participants presented the following lessons learnt:

- The conflict resolution of international watercourses is a matter of interest for Malawi and Tanzania boarders along Lake Malawi. It would be useful to learn the perspective of international laws and other countries' examples.

- The water resources management strategies in Japan that are planned with consideration to the biospheres at the downstreams are very practical and useful example for Malawi water resources.
- The multi-dam control and policies are very useful for water resources management in Malawi. The purpose of the dams is multi-faceted: water control, water utilization and recreation. Currently the scale of dams in Malawi is very small. From a strategic water resources management viewpoint, dams should be planned as multi-purpose for Malawi.
- Flooding has become an issue also in Malawi. A coping strategy is needed to be elaborated.

(2) Policy and Implementation Strategies: Training II

Period: 01 September to 26 September 2013

Objectives: The course was programmed for middle officers to learn about the functions and policy implementation mechanisms of institutions, particularly:

- The Integrated Water Resources Management, River Management
- Surface water, groundwater utilization and management
- Sustainable water resources management policy implementation
- Water utilization facilities coordinated management

Particular emphasis was placed on the roles and functions of the Ministries and other related government agencies that are managing the water resources both from policy guidance and implementation strategies, as well as supervision of the activities' implementation.

Participants were selected by the Ministry to attend the course.

Table 7.4.19 Participants of Policy Guidance Training (2)

No	Name	Title	Dept./Section
1	Peter Banda	Director of Water Resources	Water Resources Board
2	Kalima Solomon	Chief Ground Research Officer	Surface Water Section
3	Kaunda Piyasi	Water Resources Development Officer	Water Resources Management

Source: Project Team

The following training and seminars were conducted for the officers of the Ministry. The program schedules and contents are summarized in **Table 3.1.4**.

Table 7.4.20 Program of Policy Guidance Training

Date (2013)	Visit	Contents
05 Sep	Ministry of Land, Infrastructure, Transport and Tourism	Water resources policy, the current water usage, future plan Policies on surface water, groundwater Water utilization facilities
06 Sep	Ministry of Agriculture, Forestry and Fisheries	Agricultural policy The roles and functions of the Ministry of Agriculture, Forestry and Fisheries
06 Sep	Osaka University	International Watercourse dispute in case of Malawi, from the perspective of international law
09 Sep	Tone river dam, Fujiwara dam, Naramta dam	Dam management, policies and operation
11 Sep	Ministry of Agriculture, Forestry and Fisheries	Water resources management in the agricultural sector
11 Sep	Ochiai water recycling center	Sewage treatment process and strategies
12 Sep	Water resources for hydropower plant	Relation between water resources and hydropower
12 Sep	Shin-misato water treatment plant	Water treatment plant operation and planning strategies
13 Sep	Yokohama City	Groundwater monitoring operation and policies
17 Sep	Lake Biwa	Lake Biwa development policies
17 Sep	International Lake Environment Committee	Monitoring of lakes around the world Scientific approach for policy recommendation
18 Sep	Seta weir, Amagase dam	River water management
19 Sep	Land Improvement	Land improvement policies, practices, institutional structure
20 Sep	Toyogawa canal	Water supply policy for the canal, facility operation, institutional structure, organizational management
23 Sep	Water Balance Model	Concept of water balance model

Source: Project Team

1) Evaluation

Lectures and presentations were given at institutions and water utilization facilities. Participants actively participated in the discussions and question and answer sessions. The main narratives of lessons learnt from the course are summarized below.

- The institutional structure matters to implement effective water resources management interventions. The overlap of roles and responsibilities among the ministries in Malawi is causing conflicts of interest in the water sector management.
- The things have to be done as they are planned and initiated. Implementation is a very important factor to put things forward.
- Very limited resources are utilized with elaborate planning and operation in Japan. In Malawi, resources are not efficiently used. There are needs to improve planning and implementation.

7.4.4 Technical Seminars in October and November 2013

During the consultants visit in October and November 2013, the following trainings and seminars were conducted for the officers of the Ministry. Groundwater analysis and hydropower and water resources seminars were also planned for the month of April 2013. The planned program schedule and contents are summarized in **Table 7.4.3.** In the course of preparation of the Master Plan, interactions and discussions were held between the key government officials of the Ministry and the Project Team to improve the quality of outputs.

Table 7.4.21 Schedule of Capacity Development Program

No.	Date	Topic	Venue	Target
1	25 October 2013	GIS Data management	Tikuwele House	Junior to Middle technical officers
2	28 October 2013	Hydrological data arrangement and analysis	Tikuwele House	Junior to Middle technical officers
3	November 2012	Demonstration of Rainfall Runoff model	Tikuwele House	Hydrologist and assistant hydrological officer

Source: Project Team

(1) GIS Data Management Training

The GIS Data Management course was conducted in October 2012. Brief outlines of the planned training courses are as described below.

Program 5: GIS Intermediate

Objective: The primary objective of the training is to give techniques of ArcGIS 10 Desktop software which is convenient for the analysis of water resources data to the staff of MoAIWD. This course has strong emphasis on the water resources data management in MoAIWD for the future. It is a follow-up of the intermediate course following Program 1 on GIS software with practical exercise. (The program is a follow-up course of Program 1. The same participants were targeted for the course.)

Tools: GIS software (ArcGIS 10 Desktop)

Target: Junior to middle level engineers

Duration: 1 day

The following are the specific objectives of the training:

- To learn techniques of ArcGIS 10 Desktop software for the analysis of water resources data.
- To learn how to manage and provide the Geo-spatial data.

Participants were selected by the Ministry to attend the course.

Table 7.4.22 Participants of GIS Data Management Training (2012)

No	Name	Title	Dept./Section
1	Japhet Khoza	Technical Officer	Hydrology
2	Humphrey Sapulayi	Mechanical Engineer	Groundwater
3	Piyasi Kaunda	Senior Assistant Hydrogeologist	Hydrology
4	Bzian Mphanje	GINDA	Groundwater
5	Joeph M. Mbama	Senior Assistant Hydrogeologist	Hydrology
6	Collings Chumga	Senior Assistant Hydrogeologist	Groundwater
7	Limbani Kaluwa	Irrigation Engineer	Lilongwe Irrigation Service

Source: Project Team

1) Necessary Materials and Tools

- Desktop PC installed with ArcGIS 10
- GIS data for training (Water Quality Observatory, District boundary, WRA, Road, River)
- Arc GIS Desktop 10.0 Users guide created by the Project Team (as reference)

Table 7.4.23 GIS Data Management Program

No	Theme	Subjects	Venue	Schedule	Evaluation
1	Instruction on data processing with ArcGIS	• Coordinate Reference System • ArcMap configuration • Format • Importing Data	Conference Room	25 Oct 2012 (9:30 - 10:00 am)	☐ Knows the Malawian Coordinate Reference System (CRS) ☐ Knows the name and function of the ArcMap configuration ☐ Knows the format to use in ArcMap ☐ Knows how to import GIS data into ArcGIS
2	Practices of ArcGIS manipulation	• Data Processing • Data Analysis • Data Output	Conference Room	25h Oct 2012 (10:05 - 12:00 am)	☐ Available to process data by themselves ☐ Available to analyze data by themselves ☐ Available to print out results by themselves

Source: Project Team

2) Evaluation

In order to measure how far the participants understood the training contents, six questions were posed to participants and answers were given with rating indicators. The GIS training course enhanced the participants' skills shown in the summary of the questionnaire after the training (**Table 7.4.24**)**.** Before the training, the participants almost had no experience to process water resources data and geo-spatial information data on the GIS software. However, they learned the concern to manage the location and the water resources data together by gaining knowledge such as coordinate reference system, map accuracy and software operation.

Table 7.4.24 Evaluation Questions

No.	Evaluation Questions	Before	After	Difference
Q1	Do you know basic structure of the ArcGIS software?	1.3	3.0	+1.7
Q2	Do you know how to import the file data file onto the arcGIS?	1.5	3.0	+1.5
Q3	Do you know how to plot the information on a map?	1.5	3.3	+1.8
Q4	Do you know how to process data?	1.5	3.3	+1.8
Q5	Do you know how to do basic data analysis?	1.0	3.0	+2.0
Q6	Do you know how to produce data presentation material?	1.0	2.8	+1.8

Source: Project Team

Table 7.4.25 Evaluation Rating Indicators

Level	Rating Point	Before	After
Level 1	1	I don't know anything.	I don't understand anything
Level 2	2	I know some but I don't have experience	I understand some but I need theory
Level 3	3	I have some experience but I can't use my work.	I understand very well but I need practice
Level 4	4	I can use my work but I can't teach	I can use my work but I can't teach
Level 5	5	I can teach	I can teach

Source: Project Team

Source: Project Team

Figure 7.4.5 GIS Data Management Training (1/2)

Source: Project Team

Figure 7.4.6 GIS Data Management Training (2/2)

(2) Rainfall Runoff and Water Utilization Modeling

A hydrological modeling course was conducted in October 2013. Brief outlines of the planned training courses are as described below.

Program 2: Rainfall Runoff and Water Utilization Modeling

Objective: The objective of the training is to impart knowledge on the rainfall runoff model and the water utilization model to grasp the amount of water resources and water balance in Malawi. The following are the specific contents of the training:

Tools: MIKE BASIN

Target: Hydrologist and Assistant Hydrological Officer

Duration: half-day

The following are the specific objectives of the training:

- To learn how to represent hydrological processes by modeling and calibration of model.
- To learn how to estimate water balance.

1) Necessary Materials and Tools

- Laptop PC installed with MIKE BASIN
- GIS data of river stream and river basin, river flow data and water demand data for training
- Description of Water Utilization Modeling created by the Project Team (as reference)

Table 7.4.26 Participants of Rainfall Runoff and Water Utilization Modeling Program

No.	Name	Title	Dept./Section
1	Susan Kamuwenda	Hydrogeologist	Surface water
2	Gertrude Makuti	Civil Engineer	Sanitation and Hygiene
3	Joseph M’bama	Senior Assistant Hydrological Officer	Surface Water

Source: Project Team

Table 7.4.27 Rainfall Runoff and Water Utilization Modeling Program

No.	Theme	Subjects	Venue	Schedule	Evaluation
1	Instruction of rainfall runoff model	• Basic knowledge of rainfall runoff model • Calibration of the model	Library	28 Oct 2012 (10:00 - 10:30)	☐ Knows how to represent hydrological processes by model ☐ Knows how to calibrate model
2	Instruction of water utilization model	• Basic knowledge of water utilization model	Library	28 Oct 2012 (10:30 - 11:00)	☐ Knows how to estimate water balance
3	Demonstration of water utilization model	• Demonstration of water utilization Model	Library	28 Oct 2012 (11:00 - 12:00)	☐ Knows how to operate water utilization model

Source: Project Team

2) Evaluation

The rainfall runoff and water utilization modeling training course enhanced the participants' skills shown in the summary of the questionnaire after the training (**Table 7.4.28**). Before the training, the participants had little knowledge about hydrological modeling. After the training, they learned the outline of modeling and operation of the water utilization model.

Table 7.4.28 Evaluation Questions

No.	Evaluation Questions	Before	After	Difference
Q1	Do you know what the MIKE series software can do?	1.3	3.0	+1.7
Q2	Do you know how to represent hydrological processes by model?	1.3	2.7	+1.3
Q3	Do you know how to calibrate model?	1.3	2.7	+1.3
Q4	Do you know how to estimate water balance?	1.0	3.3	+2.3
Q5	Do you know how to operate water utilization model?	1.0	2.7	+1.7

Source: Project Team

Source: Project Team

Figure 7.4.7 Rainfall Runoff Modeling

Source: Project Team

Figure 7.4.8 Water Utilization Modeling