Institut für Wasserwirtschaft, Hydrologie
und landwirtschaftlichen Wasserbau

Master Thesis

Water supply options for the growing megacity of Yangon - scenarios with the WEAP model

Water Resources and Environmental Management (WATENV)

Leibniz University Hannover

Zaw Win Aung

Matr.-Nr. 2919270

Examiner:

Dr.-Ing. Jörg Dietrich, Dr.-Ing. Sven van der Heijden

Advisors:

Dr.-Ing. Jörg Dietrich, Dr.-Ing. Sven van der Heijden

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Leibniz Universität Hannover

Prof. Dr.-Ing. U. Haberlandt (GL)
Dr.-Ing. J. Dietrich

Appelstr. 9A, 30167 Hannover
Tel: +49 (0)511 762 2237
Fax: +49 (0)511 762 3731
E-Mail: info@iww.uni-hannover.de
Web: www.iww.uni-hannover.de

Master Thesis for

Zaw Win Aung, Matr.-No. 2919270

"Water supply options for the growing megacity of Yangon - scenarios with the WEAP model"

Integrated water resources planning models can simulate the water balance and the impact of different water uses on the water balance. Different management schemes can be implemented and compared. WEAP (Water Evaluation And Planning System) is a model often used in developing countries, which is particularly strong in the development of IWRM schemes for a sustainable water use in the region or catchment.

In this study, a WEAP model for the water supply system of the city of Yangon, Myanmar, should be developed, which will be applied to analyze different options for future water supply under growing water demand.

The following points need to be addressed in the thesis:

1) Literature research: models of water availability and demand for large cities in rapidly developing urban regions, applications of the WEAP model in developing countries, esp. in monsoon regions
2) Overview of the Yangon water supply system and water uses
3) Development of a WEAP model for water supply of Yangon
4) Simulation of status quo and future scenarios including the following aspects:
    - Evaluation of WEAP for today's supply system and demand
    - Estimation of future demand under population growth and development
    - Different sources and techniques (e.g. used or brackish water) for extension of the current system in a sustainable manner
5) Evaluation of the scenarios
    - How could the future development influence water flows?
    - How will the reliability of the supply system develop?
    - Recommendation for long term planning of the system from the water availability point of view

The ArcGIS software is available for this thesis. The student needs to acquire a license of the WEAP model, which is free for students from developing countries.

The completed work should give a well sorted overview over the topic using diagrams and tables. One electronic and two hardcopy versions of the work have to be submitted. The student has to present the results in a talk of 20 minutes duration plus discussion.

Date of issue:

Date of start:

Date of end:

Advisors: Dr.-Ing. Jörg Dietrich, Dr.-Ing. Sven van der Heijden

Examiner 1: Dr.-Ing. Jörg Dietrich

Examiner 2: Dr.-Ing. Sven van der Heijden

Hannover, 01.04.2014

Declaration

I declare that I have written this Master's Thesis independently. No other that the given sources and resources were used. The quotations or the consulted materials have been identified as such.

[I declare that this research paper for the degree of Master of Water Resources and Environmental Management, Faculty of Civil Engineering at Leibniz University Hannover hereby submitted has not been submitted by me or anyone else for a degree at this or any other university. That it is my own work and that materials consulted have been properly acknowledged.]

City, Date: …………………………………… Signature: ……………………………………..

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Secondly, I would like to express my special thanks to Chief Engineer, Head of Department, Engineering Department (Water & Sanitation), Yangon City Development Committee, for allowing me to work on Master thesis related with water supply management of Yangon City. Additionally, I sincerely thank all engineers and employees from this department providing me all data and documents I needed and for coordinating throughout my research. Moreover, I also want to thank JICA expert and JICA master plan team for Water & Sanitation Department (YCDC) for providing the data I requested during my research.

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Abstract

Integrated Water Resources Management approach using software tools can provide effective results for water supply and demand analysis. This study used Water Evaluation And Planning System (WEAP) modelling software as a tool to develop a model for Yangon City Water Supply System (YCWSS) and this model was applied to analyse the situation of current system and the impacts of various external alternatives and management options mainly focusing on the water demand coverage of Yangon City. To develop this model, Hydrological and meteorological data and water supply-demand data were obtained from Department of Meteorology and Hydrology (Myanmar), Ministry of Agriculture and Irrigation, and Engineering Department (Water & Sanitation), Yangon City Development Committee. Moreover, Rainfall-runoff (simplified coefficient) method and Specify yearly demand and monthly variation method were used to simulate the water supply and demand. In this model, Reference Scenario was created to represent the current water supply system. For scenarios analysis, other scenarios were explored from the reference scenario, which are external driven scenarios for socioeconomic change and climate change, and management scenarios for both demand-side and supply-side. Three scenarios for socioeconomic change were built to analyse the effect of high population growth, low population growth, and higher living standards, and a climate change scenario using a global climate model data was constructed. Four scenarios for management strategies were developed to analyse the effect of management practise on both demand and supply sides such as water-pricing policy, sustainable water source, non-revenue water control, and alternative supply source. The results of Reference Scenario were verified using observed volume of reservoirs for supply sources and observed demand coverage of Yangon City for demand site, and these results showed that the future unmet demand of Yangon City under this scenario will be 202 MGD with demand coverage 33% in 2040. According to the results of other scenarios analysis, high population growth with higher living standards scenario will face the worst situation in Yangon City declining 11% demand coverage with the unmet demand amount 461 MGD in 2040. However, implementation of four management strategies in Yangon City under this worst situation can achieve 100% demand coverage starting from 2030. Even implementing three management strategies except extending alternative supply sources under Reference Scenario demonstrated that the demand coverage in Yangon City can get about 80% in 2040 and the unmet demand will be 50 MGD. According to these results, the two proposed projects in YCWSS with 240 MGD capacity and 180 MGD capacity should be revised concerning with capacities and project periods. As a result, this study can formulate the strategic development options for YCWSS to adapt under future alternatives, and this WEAP model can assist water managers and local authorities of Yangon City in decision making for the improvement of YCWSS.

Keywords: Socioeconomic change; Climate change; Modelling; Scenarios analysis; Management strategies; Yangon City Water Supply System

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Lists of Abbreviations

CBD	Central Business District
DMH	Department of Meteorology and Hydrology (Myanmar)
DSS	Decision Supply System
EDWS	Engineering Department (Water & Sanitation)
GCM	Global Climate Model
gpcd	imperial gallons per capita per day
IUR	Inner Urban Ring
IWRM	Integrated Water Resources Management
JICA	Japan International Cooperation Agency
MGD	Million Imperial Gallons per Day
MoAI	Ministry of Agriculture and Irrigation
NewSZ	New Suburbs Zone
NRW	Non-Revenue Water
NSZ	Northern Suburbs Zone
OldSZ	Older Suburbs Zone
ORZ	Outer Ring Zone
PIS	Performance Indicators
PS	Pumping Station
RCP	Representative Concentration Pathway
RWH	Rainwater Harvesting
SCBD	South of Central Business District
SEI	Stockholm Environmental Institute
SEZ	Special Economic Zone
TS	Township
WEAP	Water Evaluation And Planning
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant
YCDC	Yangon City Development Committee
YCWSS	Yangon City Water Supply System

Lists of Unit Conversions

Area

1 acre	=	4046.86 km^2 (square kilometre)	=	0.404686 ha (hectare)
1 sq-mi (square mile)	=	2.59 km^2 (square kilometre)		

Length

1 ft (foot)	=	0.3048 m (metre)
1 mi (mile)	=	1.61 km^2 (kilometre)

Volume

1 gal (imperial gallon)	=	0.004545 m^3 (cubic metre)	=	4.545 l (litre)
1 MG (million imperial gallon)	=	4545.45 m^3 (cubic metre)		
1 Acre-ft	=	0.27133 MG (million imperial gallon)		

Currency

1 € (Euro)	=	1300 K (Myanmar Kyat)

Pressure

1 MPa (Mega Pascal)	=	10 bar

1 Introduction

Water, a precious natural resource, is vital for physiological processes of all organisms. Moreover, water also has a social and economic value for human beings, and on the other hand, population growth and economic development put constant pressure on the ecosystems of water resources (Alcamo et al., 2007). There is a strong positive correlation between water demand and urbanization or population growth (Malmqvist & Rundle, 2002). Urban water system should provide safe water for different uses without harming the environment, and increasing demand for sustainable development will deeply affect on all urban infrastructures (Hellström et al., 2000). Therefore, sustainable management of water supply for various water uses in urbanized cities is extremely important to achieve the sustainable development of these cities. Comprehending the urban growth and clearly explaining options are two main requirements for effective decision-making about sustainable development of urban infrastructure (Grigg, 1997).

Cities emerge and grow accompanied with population growth because of human resources and labour force availability and their attraction to economic activities (Haughton & Hunter, 2004). For example, Yangon City, the biggest city of Myanmar and also commercial and financial capital of Myanmar, experienced higher population growth rate about 2.8% between a decade from 1993 to 2003, whereas the national population growth rate was less than 2% (Aung, 2013). Yangon City is undergoing accelerated urbanization and rapid development as the nation moves towards democracy. Yangon City, its population is 5.14 million at present and expected to reach above10 million in 2040 together with both urbanization and industrialization, is forecasted to become a megacity in the future (Yangon Region Government, YCDC & JICA, 2013).

As the other urbanized cities of the world, population of Yangon City is increasing alarmingly together with the city area, and this is exerting more pressure on it's existing old infrastructures including the water supply system. Currently, insufficient data and lack of the plan for the future are restricting the management of the water supply system of Yangon City and the decision making for future options for various urban issues.

1.1 Background

Myanmar, officially “the Republic of the Union of Myanmar,” is one of the Southeast Asia countries and surrounded by the Andaman Sea, the Bay of Bengal, Bangladesh, India, China, Laos, and Thailand. Its total area is 676,552 km^2, the world’s 40th largest country and the second largest country in Southeast Asia, and its population has increased from 28.9 million in 1973 to over 60 million in 2009 (Morley, 2013). Myanmar has abundant natural resources and sizeable workforce for domestic manufacturing and industries (Morley, 2013). In the report of the Immigration and Manpower Department (Ministry of Immigration and Population), the total population of the Union of Myanmar in 2012 is 63.5 million. Political reform has recently occurred in Myanmar, and a new constitution was approved in 2008 and then the first general election was held in November 2010. As a consequence, Present-day Myanmar is a place encountering rapid transformation in every sector and largely investing in infrastructure for economic development. According to International Monetary Fund (IMF, 2014), Myanmar’s Gross Domestic Product (GDP) using current prices grew from $7.45 billion in 1998 to $56.4 billion in 2013.

Figure 1.1: A map of Myanmar and Yangon Region

In the new constitution of the Republic of the Union of Myanmar (2008), Myanmar is divided into 21 administrative subdivisions; 1 Union Territory, 7 States, 7 Regions, 5 Self-administered Zones, 1 Self-administered Division. Among 7 regions, the Yangon region has the smallest land area, only 1.5% of the total country's area, however, it has the highest population in all subdivisions, 12% of the national population. The above Figure 1.1 shows the map of Myanmar and Yangon Region.

Yangon City, the former national capital of Myanmar, is the capital city of Yangon Region and the largest city of Myanmar. Yangon is not only the centre for transportation and commercial activities in Myanmar but also the centre for all opportunities in education and health services (Khaing, 2006). Yangon City has an area of 794.4 km^2 with 33 townships, and it is one of the largest spatial extent cities in South East Asia (Morley, 2013). Even though the national capital of Myanmar was moved to Naypyidaw, a new administrative city situated about 320 km north of Yangon City, in 2006, Yangon is still important for nation's economy, culture and social issues. Yangon City is the largest urban agglomeration area in Myanmar, and it contributes 22% of the national GDP (Aung, 2013). Nowadays, Yangon is undergoing major alterations in its economic, social and infrastructures accompanied with country's changes.

The following Table 1.1 shows the historical population trend of Yangon City against city's spatial extent, population density and population growth rate (Census of India, 1891; Census of India,1901; Census of India,1911; YCDC, 2014b). The population of Yangon City speedily elevated from about 3.1 million in 1993 to over 5.14 million in 2013 with a growth rate 2.56% (Yangon Region Government, YCDC & JICA, 2013). The future population growth rate of Yangon City is likely to be the same rate or may even increase due to political changes and national development plans, such as, Plan of Economic zone at Thilawa, Plan of the new international airport near Bago, and also due to the growth and attraction of the city itself (Aung, 2013). With the same population growth rate 2.56%, the population of the city will have more than 10 million in 2040 (Yangon Region Government, YCDC & JICA, 2013).

Yangon City Water Supply System has a long history. Although Yangon City water supply services initiated since 1842, service coverage is still only 30 % of the whole city and non-revenue water is 66 % of total daily supply water amount (JICA & YCDC, 2013). Approximately 90 % of the total supply water to Yangon City comes from surface water via drinking water reservoirs and the rest comes from tube wells, however, water treatment system is insufficient and needs to improve qualitatively and also quantitatively. Water charge is quite low comparing with other countries, about 0.068 € (88 MMK) per m^3 for domestic use and 0.085 € (110 MMK) per m^3 for commercial use, so that it cannot be secure to get financial sources for operation and maintenance of water supply system. On one side, there are many requirements for improvement in the operation and maintenance of existing water supply system, and on the other side, there will be necessary to analyse and prepare for the future challenging boosted water demand in association with alarming increased population.

Table 1.1: Population trend of Yangon City

(Source: Population data are obtained from Department of Population, Ministry of Immigration and Population. Data from 1881 to 1931 is derived from censuses of India, data from 1953 to 1983 come from national censuses, and data from 1993 to 2013 is estimated. Area data are acquired from Urban Planning Division, YCDC, and History of Yangon City retrieved from the official website of YCDC.)

Year	Population (million)	Population Growth Rate (%)	Area (km^2)	Population Density (person/km^2)	Remark
1800	0.0300	-	~ 2.0	-	-
1851	0.0400	0.1	No data	-	-
1861	0.0600	4.1	No data	-	-
1871	0.0987	5.2	No data	-	-
1881	0.1342	3.0	28.49	4710	Expansion in 1876
1891	0.1803	3.0	49.21	3664	Expansion in 1880s
1901	0.2349	3.2	49.21	4773	-
1911	0.2933	1.7	72.52	4044	Expansion in 1900s
1921	0.3419	1.5	79.77	4286	Expansion in 1910s
1931	0.4004	1.6	79.77	5019	-
1953	0.7370	2.8	123.3	5977	Expansion in 1930s & 1940s
1963	0.9400	2.5	164.2	5725	Expansion in late 1950s
1973	2.0152	7.9	221.4	9102	Expansion 1965 and 1973
1983	2.5130	2.2	346.0	7263	Expansion in 1983
1993	3.0978	2.1	603.5	5133	Expansion in 1991
2003	4.1000	2.8	794.4	5161	Expansion in 2003
2013	5.1400	2.3	794.4	6470	-

In order to solve the problems of existing and future water supply system of Yangon City, many processes are necessary to establish for the development of the water supply system of growing megacity Yangon. For example, formulation of the water management model and plan for the future scenario analysis, investigation of potential water resources, alternation of systems and technologies, maintenance of the old system, implementation of new water facilities etc. At present, Yangon City Development Committee (YCDC), a local administrative organization for Yangon City, has been formulating the project for the strategic urban development plan of **Greater Yangon** (Yangon City and 6 peripheral townships (Kyauktan, Thanlyin, Hlegu, Hmawbi, Htantabin, Twantay) with the coordination of Japan International Cooperation Agency (JICA) and other local and global organizations. A study on the improvement of water supply in Yangon City is also one of the topics included in this project. However, due to various reasons and restrictions, for instance, lack of systematic data and up-to-date water resources management knowledge, Yangon City is encountering problems to establish the improvement of water supply system, and it is limited in its ability to respond to these problems.

1.2 Study problem

Yangon City Water Supply System (YCWSS) is experiencing water supply facilities operation and management problems, and on the other hand, rapid urbanization and industrialization together with increasing population, are challenging the water supply system of Yangon City. Therefore, organizations, which are responsible for the water supply of Yangon City, require putting efforts to solve these problems as well as to find the new water resources for increasing water demand.

So, it is required to formulate the future development plans and management strategies for water supply system of Yangon City by using different possible future scenarios. It is also needed to compare and contrast these different scenarios, and then recommend the best effective and sustainable plan in order to contribute to economic development and improvement of the living environment of Yangon City. It is also necessary to forecast water demand and supply of the City in the future for operation and management of the city water supply system and new projects and plans. Using a water supply-demand modelling tool is the best approach to solve these problems.

1.3 Study objective

The main objective of this study is to develop Water Evaluation And Planning (WEAP) model for the water supply system of Yangon City, which will be used to analyse the different scenarios for the future water supply against with the growing water demand.

In order to reach this study objective, the tasks need to be done are:

- To describe the overview of the current situation of Yangon City water supply
- To analyse the status quo and future scenarios of water supply system
- To evaluate and make recommendations for these different future scenarios

1.4 Study methodology

In this thesis, firstly, publications from WEAP website and other research literature are collected and reviewed, focusing on the water supply demand models of large cities and about WEAP modelling especially for developing countries in monsoon regions.

Secondly, reports and documents of Engineering Department (Water & Sanitation), YCDC are studied and reviewed to extract the data, which are reliable as an official data and are applicable as an input data for the purpose of the study. Moreover, Water Supply Master Plan 2002 and 2014, formulated by YCDC and JICA, are also reviewed to get the data relating to the current water supply system analysed data, customer survey data, and feasibility study data of new water resources for future projects.

Thirdly, field research was done to collect the data of water supply and demand data in actual condition, for instance, visiting the water supply reservoirs of Yangon City to collect the water supply data and visiting the offices of different divisions of EDWS to collect the actual water supply-demand and water uses data.

Finally, WEAP model is applied to quantify and observe the positive and negative impacts of future scenarios, also to give recommendations for the future implemented projects. In the WEAP model, demand-side and supply-side management scenarios are explored, and then analysed their behaviours by simulation. WEAP model is used as an analysis instrument to understand the impacts of the water supply system of Yangon City at present and future. By discussing the results of the model, impacts of scenarios that can be taken in more considerations and options, which can be used as recommendations, are evaluated and highlighted.

To sum up, methods used in this study are literature review, official report and document review, field research and WEAP modelling.

1.5 Structure of the Thesis

The thesis is organized and presented with seven parts. They are as follows:

(1) Introduction

In this part, the background of the thesis, the study problem, the study objective, and the study methodology will be introduced.

(2) Literature Review

In this part, firstly, the idea of the water management models will be described by reviewing research literature. Then, the literature review of WEAP model will be presented. Finally, the application of WEAP model in different countries, especially in urban regions, will be highlighted by using WEAP model studies.

(3) Yangon City Water Supply System (YCWSS)

In this part, an overview of the study area, Yangon City, will be presented by expressing the current situations. After that, the study organization, Yangon City Development Committee and its department, Engineering Department (Water & Sanitation), will be described. At last, the past and present water supply system of Yangon City will be expressed by analysing the reports and documents from water-authorised organizations.

(4) Development of WEAP model for YCWSS

In this part, a WEAP model for water supply system of Yangon city will be developed and simulated not only to evaluate for Today's water supply system and water demand, but also to estimate Future demand.

(5) Creation of scenarios in WEAP

In this part, different scenarios for the future of Yangon City, such as, population growth, economic development, climate change, demand side management, and supply side management, will be created.

(6) Simulation and Evaluation of scenarios

In this part, the evaluation of the simulated results of the scenarios will be done by comparing and contrasting the future development impacts and examining the reliability of the water supply system.

(7) Discussions and Recommendations

In this part, future options for the water supply system of Yangon City will be discussed based on the results of WEAP model simulations. After that, recommendations for long-term planning of the water supply system of Yangon City will be presented.

2 Literature Review

Many regions are facing alarmingly challenges about water management as well as limited water resources allocation, environmental quality and sustainable water use policies are increasing concerned issues. Over the last decade, an integrated water development approach has emerged and replaced for the conventional supply-oriented simulation models, and which aimed to develop the context of demand-side, water quality and ecosystem preservation issues in water supply projects. To explore options for the future, the appropriate simulation models are required to see how the impact of future trends will occur and how we can adapt to these in the most sustainable way.

This part will describe about the background knowledge of the water management models and the modelling of water availability and demand for large cities by reviewing the literature. At first, water supply-demand management models will be discussed. After that, WEAP model will be introduced according to the publications from WEAP website. At last, the review of the application of the WEAP model in different countries and different water basins, focusing on urban water management issues, will be presented.

2.1 Water Resources Management Models

Water resources planning and management was generally an exercise-based on engineering considerations in the past. Nowadays, it increasingly occurs as a part of complex, multi-disciplinary analysis that brings together a wide range of individuals and organizations with different interests, technical skills, and options (Yates et al., 2005; Hamlat, Errih & Guidoum, 2013). Successful planning and management of water resources requires application of effective integrated water resources management (IWRM) models that can solve the encountering complex problems in these multi-disciplinary investigations (Loucks, 1995; Laín, 2008).

Water resource planning and management processes aided IWRM models have become more common, however generic tools that can be applied to different basin settings are frequently difficult to use because of the complex operating rules that govern individual water resource systems (Watkins and McKinney, 1995). IWRM models, which can incorporate and operate hydrology and management processes at the same time, are needed to help planners under different reality cases and management options (Yates et al., 2005). These IWRM models must be effective, useful, easy-to-use, and adaptive to planners' priorities.

Effective IWRM models must deal with the biophysical system, which create runoff generation and its movement, and the socioeconomic management system, which create water storage, allocation, and delivery (Yates et al., 2005). For the biophysical system, the hydrology model that simulates the physical processes must be used, and for the socio-economic system, planning model that relates the management system for the operation of water structures such as reservoirs and channels and the allocation of water must be considered (see in Figure 2.1) (Yates et al., 2005).

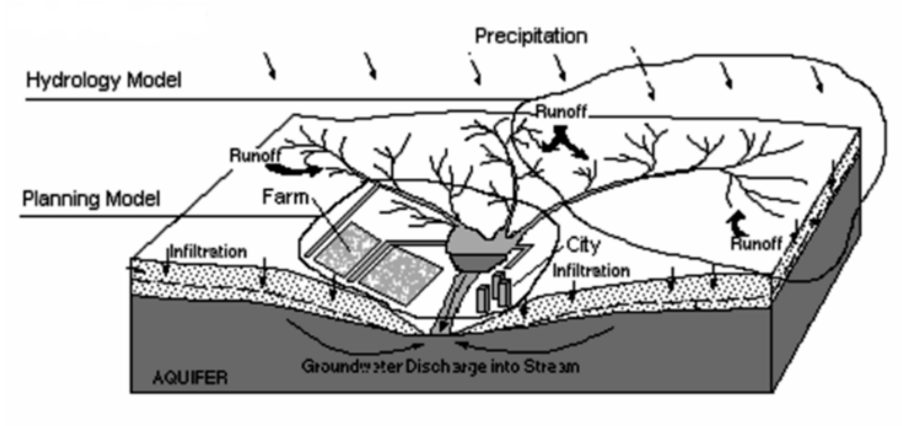


Figure 2.1: Implications of water resource infrastructure on the hydrologic cycle (Yates et al., 2005)

According to the literature, there are many hydrological and IWRM models for the water management, and the number of models must be in the order of thousands, however, no standard model is still emerging, for example **MODFLOW** is the de-fecto standard in groundwater modelling (Immerzeel & Droogers, 2008). These models have tried to focus on the understanding of water flows in a catchment regarding hydrologic processes and the available water allocation. Some existing model overviews will be described below in more detail. To select the appropriate models for solving specific problems, the classification of models depending on the spatial scale and physical detail of the model are important to know the determination of model behaviour as required data, required expertise, expected accuracy and user-friendliness (see in Figure 2.2) (Immerzeel & Droogers, 2008). **Podium**, **STREAM**, **SLURP**, and **WSBM** are IWRM models for national scale, **SWAT**, and **WEAP** are the basin and system analysis IWRM model, and **SWEAP**, **WaterMod** and **FutureView** are small-scale IWRM tools.

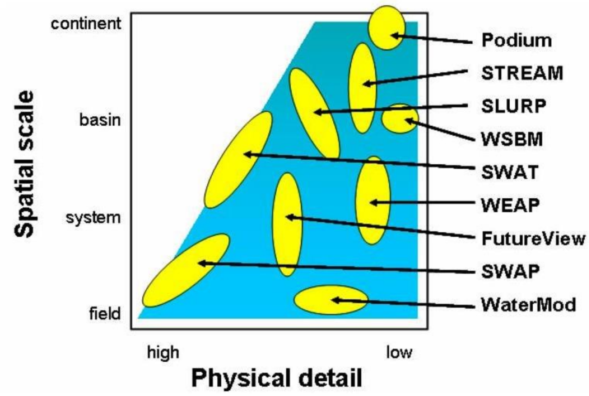


Figure 2.2: Spatial and physical detail of hydrological models (Immerzeel & Droogers, 2008)

SWAT (Soil and Water Assessment Tool) includes complex physical hydrology modules as rainfall-runoff, irrigated agriculture, and point and non-point catchment dynamics, but it is a relatively simple reservoir operations module (Srinivasan, 1998; Neitsch et al., 2002; Fontaine et al., 2002). This model is originating from United States Environmental Protection Agency's research program, and it might have the potential to be a de-facto standard in basin scale modelling (Immerzeel & Droogers, 2008).

RiverWare™ DSS is a hydrology and hydraulics operations model, and can be used to develop multi-objective simulations and optimizations of river and reservoir systems like river reaches, diversions, storage reservoirs, hydropower reservoirs, and water uses, but it needs to upstream flow acquired from a physical hydrologic model (Zagona et al., 2001).

US Geological Survey's **Modular Modelling System** gives a framework for integration with RiverWare by using such the Precipitation Runoff Modelling System to supply boundary flows (Leavesley et al., 1983). US Army Corp of Engineers' **HEC-ResSim** is a reservoir simulation model, and can show the operating rules and requirements, but it needs prescribed flows from other models (Klipsch, 2003).

MODSIM DSS is a generalized river basin model, and incorporate the complex physical, hydrological, and administrative basin management, but it requires boundary flows (Labadie et al., 1989). **MULINO DSS** (Multi-sectoral, Integrated and Operational Decision Support System) is a decision support system for sustainable use of water resources at the catchment scale focusing on multi-criteria decision aid, and it can link an external physical hydrology model by appropriate input-output procedures (Giupponi et al., 2004).

WaterWare is a sophisticated decision support system and includes dynamic simulation about physical hydrology (water quality, allocation, rainfall-runoff, groundwater) and water management (demand-supply, cost-benefit analysis, and multi-criteria analysis), but it requires a complicated user/hardware support (Jamieson & Fedra, 1996; Fedra & Jamieson, 1996).

RIBASIM (River Basin Model) is a comprehensive and flexible model for analysing the behaviour of river basins under various hydrological conditions to evaluate the operation and management measures in terms of water quantity and quality (Krogt, 2003; Loucks, 2006; Mugatsia, 2010). It provides a source analysis, giving insight into the water's origin at any location of the basin. It utilizes various hydrologic routing methods to execute the flow on a daily basis, and provides water distribution patterns, source analysis, and water quality and sedimentation analysis in reservoirs and river (Krogt, 2003; Loucks, 2006; Mugatsia, 2010), and is applied for river basin planning and management in different projects in countries around the world. However, this model requires good data based infrastructures to build the input data.

MIKE BASIN is a hydrologic modelling with ArcGIS to provide basin-scale solutions of water allocation, conjunctive use, reservoir operation and water quality issues by simulation and visualization in space and time (Loucks, 2006; Assata et al., 2008). It is a quasi-steady-state mass balance model for river flows routing, and assuming purely advective transport for the water quality analysis and using the linear reservoir equation for the groundwater analysis (Loucks, 2006; Assata et al., 2008). It requires to link with a separate hydrological model like NAM, or MIKE SHE of DHI to perform an integrated catchment management system, and the model data requirement has constraints, such as complete discharge time series, accurate spatial water abstraction data etc. (Loucks, 2006; Assata et al., 2008).

WBalMo (Water Balance Model) is an interactive simulation tool for river-basin management, and it simulates the natural processes of runoff and precipitation stochastically by balancing the respective time series with monthly water use demands and reservoir storage changes (Loucks, 2006; Mugatsia, 2010). It can identify management guidelines for river basins, design reservoirs and their operations, and perform scenario analysis and environmental-impact analysis for development projects, but it requires detailed data for design purposes (Loucks, 2006; Mugatsia, 2010).

WEAP (Water Evaluation And Planning) model tries to fill the gap between water resources management and physical hydrology, and integrates the management of demands and water facilities with physical hydrologic processes in a simple and perfect way (Yates et al., 2005). WEAP is effective, useful, easy-to-use, affordable, and readily available. It can also analyse multiple scenarios, including climate change scenarios and other changes, such as technical changes, social-economic changes, and policy changes. For example, land use changes, municipal and industrial demands changes, operating rules changes, etc. The main aim of WEAP is to solve the water planning and resource allocation problems and issues, but can also analyse the water quality, cost-benefit, and hydropower based on hydrological processes (Yates et al., 2005; SEI, 2011).

The best approach for IWRM models is to develop a straightforward and flexible tool to assist rather than to substitute the skilled water professionals, the users of the model (SEI, 2011). WEAP is a new generation of water planning and management software, and the powerful capability of today's personal computers can easily use it everywhere to access to the appropriate tools.

2.2 WEAP model

WEAP modelling software developed by the Stockholm Environmental Institute (SEI) is an object-oriented computer-modelling package and IWRM tool, designed for simulation of water supply system and demand analysis, and WEAP is a laboratory for analysing alternative water management and development strategies (SEI, 2011). WEAP approaches to simulate water systems by its policy orientation, and balances the demand side (water uses, equipment efficiencies, water reuse, prices, hydropower energy demand, and water allocation) and the supply side (streamflow, groundwater, reservoirs, and water transfers) (SEI, 2011). The basic principle of WEAP is a water balance accounting operation with monthly time step, and it can be applied in a single catchment to a complex trans-boundary river basin (SEI, 2011). WEAP can analyse a wide range of issues, such as water demand, water conservation, water quality, water rights, allocation priorities, groundwater, streamflow, reservoir operations, hydropower generation, energy demands, ecosystem requirements, and project cost-benefit (SEI, 2011).

In WEAP, the time horizon and spatial boundary of the study, components of the system, and configuration of the problem are needed to set up. WEAP represents the system with supply sources, demand sites, transmission links, wastewater treatment plants, ecosystem requirements, and pollution generation, and analyses with the customized data structure and level of detail to meet the requirements and restrictions (SEI, 2011). WEAP's objects and model-framework are graphically oriented to allow the spatial referencing of attributes, e.g. river and groundwater, demand sites, WWTPs, catchments and political boundaries, and river reach lengths etc. (SEI, 2011). WEAP model simulates as a set of scenarios and simulation time steps can be daily, weekly, monthly, and seasonally with a time horizon from a single year to more than 100 years (SEI, 2011).

The *Current Accounts* in WEAP represents the overview of actual water demand, water supply sources, supplies for the system, pollution loads, at the current year or a baseline year (SEI, 2011). *Scenarios* are alternative sets of future options based on different policies, different management strategies, different economic, demographic, hydrological and technological trends, over the time horizon of the study (SEI, 2011). Scenarios are evaluated based on demand coverage, costs and benefits, compatibility with targets, and sensitivity to key variables uncertainty (Yates et al., 2005).

A number of methodological considerations, such as integrated and comprehensive planning framework, scenario analyses of the effects of different development options, demand-management capability, environmental assessment capability, ease-of-use, and urban water planning and management, designs WEAP model (SEI, 2011).

WEAP integrates demand and supply, water quantity and quality, and economic development objectives and environmental constraints, and evaluates specific water problems in a comprehensive framework (SEI, 2011). In WEAP, *Current Accounts* and *Reference scenario or business-as-usual scenario* need to create first, and then other alternative policy scenarios can be developed for comparison of their effects on the system against the *business-as-usual scenario* (SEI, 2011). The *business-as-usual scenario* represents the current situation of economic and demographic development, water supply and demand, policy, and other aspects without any alternatives. WEAP can also represent the effects of demand management on water systems, for example, the effects of water pricing policy or priorities for allocation water demand and sources, improved technologies (SEI, 2011). WEAP can provide the requirements for aquatic ecosystems such as concentration of river water quality, pollution pressure of different water uses on the overall system by tracking from subject to object (SEI, 2011). WEAP has a user-friendly interface with graphical drag-and-drop GIS-based inputs and outputs as maps, charts, and tables. The WEAP's intuitive graphical interface is simple but powerful to construct, view, and modify the system and its data, and WEAP handles loading data, calculating and reviewing results with an interactive screen structure, which catches errors, provides on-screen guidance and prompts the user (SEI, 2011). In WEAP, the data structures are expandable and adaptable to evolving needs of water analysts as better information become available, and planning changes, and users' own set of variables and equations can develop for further analysis of specific constraints and conditions (SEI, 2011).

WEAP is adaptable and flexible to all available data, i.e. daily, weekly, monthly, or annual time-steps, to describe the system's water supplies and demands, i.e. it can be applied in a range of spatial and temporal scales (SEI, 2011). At past, WEAP has been used to assess the reliability of water supply and the sustainability of surface water and groundwater supplies in future scenarios of the proposed management and project. At present, WEAP model can be used in the urban water management integrating storm water, wastewater, and water supply, by using updated features, such as *infiltration and inflow, infiltration basins & retention ponds, display of user-defined performance measures as results, tiered water pricing, combined sewer overflows* (SEI, 2011). WEAP can link to other models and software, such as **QUAL2K** (surface-water quality model), **MODFLOW** (groundwater flow model), **MODPATH** (a particle-tracking model for MODFLOW), **PEST** (parameter estimation tool), **GAMS** (general algebraic modelling system), **Excel**, and **Google Earth** (SEI, 2011; WEAP, 2014).

WEAP is based on the most basic idea, water supply depends on the amount of rainfalls on a catchment or a series of catchments, which is progressively decreased through natural hydrological processes, human demands, or increased through catchment enlargement (Yates et al., 2005). WEAP includes *a water balance model* for hydrologic processes within a catchment system and that can address the propagating and non-linear effects of different water uses, and also includes *a point-source pollutant loading descriptive model* that can simulate the impacts of wastewater on receiving waters (Yates et al., 2005).

The basic idea in the WEAP water management analysis is the development of different water demands such as municipal, industrial, irrigation, and ecosystem requirements, with user-defined priority (given as an integer from 1 to 99, highest to lowest priority), and each demand links to its available supply sources with user-defined preference (Yates et al., 2005). The supply-demand network is constructed and optimized routine that allocates available supplies to all demands. Demand analysis in WEAP is based on the evapotranspiration and the disaggregated end-use that determines water requirements at each demand node. Exploring by scenarios use demographic and water-use information, and WEAP computes all supply and demand sites by applying Linear Program (LP) allocation algorithm, which determines the final delivery to each demand node, based on the user-defined priorities (Yates et al., 2005).

Demand sectors can be disaggregated into different sub-sectors, end-uses, and water-using devices, but, agriculture and urban water demands are not included in the disaggregated demand analysis if the physical hydrology module is used. Demand data are based on the data availability, the analysis types, and unit preferences to meet specific purposes, and demand calculations are based on disaggregated social and economic measures of different activities (e.g., activity level, water use rates, etc.) (Yates et al., 2005). Activity levels are multiplied by the water use rates of each activity, and each can be projected into the future using WEAP's built-in spreadsheet like expression builder by applying simple exponential growth rates and interpolation functions for using sophisticated modelling techniques (Yates et al., 2005).

Reservoirs represent a special object in WEAP model to store water that is available either from the solution of the physical hydrology module or stream flows. Reservoir storage is divided into four zones from top to bottom as the flood control, conservation, buffer, and inactive (SEI, 2011). WEAP always keeps the flood control zone vacant to hold water temporarily, and the volume of the reservoir cannot exceed the top of the conservation zone. WEAP allows the water from the conservation zone to release freely for all requirements. WEAP restricts the water release from the buffer zone according to the buffer coefficient to conserve the reservoir shortages. Water in the inactive zone is the dead storage that is not available to use (SEI, 2011). Reservoir operation determines available water in the current time step for release to satisfy demand, flow requirements, hydropower generation, and flood control requirements, and carried over water until a later time-step (Yates et al., 2005). If the assigned priority of storing water in a reservoir is lower than demands or flow requirements, WEAP will release as much of the available storage as to satisfy demand and flow requirements (Yates et al., 2005).

WEAP calculates water and pollution-mass balances for every node and link in the system at every time step, however, each step is independent of the previous step, except about reservoir storage, aquifer storage, and soil moisture (Yates et al., 2005). Therefore, all of the water entering the system in a given period is stored in the soil, an aquifer, a reservoir, or leaves the system at the end of that period. WEAP computes point-load pollution into receiving water bodies and in-stream water quality, based on the concentrations and constituents, such as BOD, DO, and temperature (Yates et al., 2005). WEAP assumes all flows occur simultaneously and a demand site can take water from the river, consume some, and return the rest to the system directly or via WWTP in the same time step (Yates et al., 2005).

A standard iterative linear program is used to solve water allocation problems according to ranking of demand priorities, supply preferences, mass balances, and other constraints at each time steps (Berkelaar et al., 2004). The LP constraint set is written to supply an equal percentage of water to all same-priority demand sites and to choose the supply for a demand site by supply-preferences rank, because irrigations and municipalities will mostly depend on multiple water sources to meet their demands (Yates et al., 2005). The LP algorithm iterates all supply preference to optimize the demand coverage and operates depends on the user-defined constrains, such as maximum flow volume of transmission links, percent of demand, physical or contractual limits, besides supply preferences (Yates et al., 2005).

To sum up, WEAP is one of the useful IWRM tools, and capabilities to build complex, distributed physical hydrology and demand models of municipal, industrial, agricultural, and environmental demands at different spatial and temporal scales (Yates et al., 2005). WEAP incorporates a demand priority and a supply preference approach to describe water resource operating rules. Nowadays, WEAP has been used throughout the world to analyse the variety of water management issues in small scales to large ones.

2.3 Applications of WEAP model

WEAP model was created in 1988 as a flexible IWRM tool for the current water supply-demand system evaluation and future scenario exploration (WEAP, 2014). It has a long history of development and use in the water-planning field. The first major application of WEAP was in 1989 to study on the water development strategies and water supply-demand analysis for the Aral Sea region in 1989 with the sponsorship of SEI (Raskin et al., 1992). The version of WEAP at that time had several limitations, such as an allocation scheme, demand sites priorities, water allocations (Raskin et al., 1992). Because of these deficiencies, WEAP introduced major advances, including a modern Graphic User Interface and a robust solution algorithm to solve the water allocation problem. Moreover, WEAP integrated hydrologic sub-modules such as a conceptual rainfall-runoff model, an alluvial groundwater model, and a water quality model (Yates et al., 2005). WEAP software has been supported to water planners from global organization and institutions, especially, freely transferred to governmental and academic users from developing countries, and WEAP has been applied in many countries and river basins over two decades (WEAP, 2014).

Johnson, W. K. (1994) applied WEAP for accounting of Water Supply and Demand in the upper Chattahoochee River Basin of Georgia, to illustrate the capability of WEAP, to provide a document for WEAP users how the program is applied in a multiple-use river and reservoir. Purkey, Thomas, Fullerton, Moench & Axelrad (1998) used WEAP in the groundwater banking feasibility study in California by analysing hydrology, legal & institution, operation and economics. Strzepek et al. (1999) introduced new methods of linking IWRM models (WATBAL for water supply, CERES, SOYGRO, CROPWAT for crop and irrigation modelling, and WEAP for planning and water demand forecasting) with climate change scenarios for the study of future water availability in the U.S. Cornbelt's agriculture.

Water-demand management scenarios (saving water by individual users with three options 10%, 20%, and 30%) for diverse climate situations (dry years to normal years) at the Steelpoort Sub-basin of the Olifants River in South Africa was tested by using the WEAP model (Lévite, Sally, & Cour, 2003). Even though there are some limitations of the WEAP model like as a water year method, the user-friendly model and its interfaces make easy for discussions and dialogue on water management among decision makers and local stakeholders, and for the promotion of public awareness and understanding of key issues and concerns (Lévite, Sally, & Cour, 2003).

The application of WEAP models to major agricultural regions in Argentina, Brazil, China, Hungary, Romania, and the US, was analysed by simulating future scenarios about climate change, agricultural yield, population, technology, and economic growth (Rosenzweig et al., 2004). Climate change projection using global climate models (GCM) simulations indicates eventually larger changes in the 2050s and beyond, but the water for the agricultures is sufficient in most of the water-rich areas (Rosenzweig et al., 2004). Northeastern China shows the most stressed in water availability for agriculture and ecosystem services both in the current state and in the climate change projections (Rosenzweig et al., 2004).

The study about water evaluation and the planning system in Kitui-Kenya clearly demonstrated that WEAP is a powerful framework in the evaluating of current and future options of water resources, and evaluation can be performed within a few minutes by adding more accurate data to increase the accuracy of the analysis and validation of results (Van Loon & Droogers, 2006). To help decision makers and stakeholders, Integrated Decision Support System (DSS) for pollution control in the upper Litani Basin of Lebanon was developed by using WEAP, and this DSS was effectively used in projection of three future scenarios for the water quality conditions in the basin (Assaf & Saadeh, 2006).

As population growth, urbanization, and current policies and water management practices give stresses on water resources and urban infrastructure, urban water management tools are becoming essential for urban water planners to see the overview of their water system (O'Connor, Rodrigo, & Cannan, 2010). Urban water systems can be improved by reducing water demands, increasing water recycling and reuse, creating alternative water supply sources from storm water/rain water, providing water quality to end-use needs, and implementing multi-purpose, multi-benefit infrastructure to achieve environmental goals (O'Connor, Rodrigo, & Cannan, 2010).

WEAP was also applied as an urban water management tool in the study of water resources and city sustainable development of Heng Shui City in China (Ojekunle, 2006). This study pointed out that the availability and reliability of data are very important and must be analysed carefully with good judgment, and the adoption of water demand management gives opportunities during normal hydrological years but not in dry years. This study explored and evaluated the future scenarios concerning about high population growth, high technology, demand management, using the water year method, demand disaggregation, and supply preferences.

O'Connor, Rodrigo, & Cannan (2010) studied the total water management for urban water resources in the City of Los Angeles by using real data and WEAP model, to assist the planners and decision-makers in the development of management techniques to improve urban systems. This WEAP model simulated water supply reliability, total life cycle costs, water quality, and a number of other environmental indicators by using strategies such as increasing water conservation, expanding water recycling and reuse, grey water/storm water recharge, rainwater harvesting, integrating water supply (O'Connor, Rodrigo, & Cannan, 2010). This study could provide opportunities for achieving multi-benefits urban system goals that would not exist in single-purpose, traditional planning.

According to the WEAP literature provided in the official website, WEAP is applied effectively in multi-criteria in IWRM field all over the world, including water supply-demand management issue in urban regions to achieve multi-benefit goals.

3 Yangon City Water Supply System

The main objective of this part is to introduce the water supply system and water uses of Yangon City. Firstly, an overview of the study area, Yangon City, will be expressed concerning about the current physical situations. Secondly, a description of the studied organization, Engineering Department (Water & Sanitation) of YCDC, which is responsible for the water supply service of Yangon City, will be presented. Lastly, the history and the state of the art of the water supply system of Yangon City. To achieve the main objective of this study, which is to develop WEAP model of Yangon City Water Supply System (YCWSS), input data of different components of the system are needed to figure out by clearly comprehending the study area and system.

3.1 Overview of Study Area

This part will present physical situations of the study area about natural situation, such as location, area, geography, and climatology of study region, hydrological situation, and social-economic situation, such as population, urbanization, land use, and health of Yangon City.

3.1.1 Natural Situation

In this part, natural situation of Yangon City concerning about the location and area of Yangon city, including geography and climatology of this area, will be described.

3.1.1.1 *Location*

The study area is Yangon City in Yangon Region of Myanmar, which is located at the heart of the lower part of the country on the bank of Yangon River, which is connected by creek with Ayeyarwady delta (Spate & Trueblood, 1942). Yangon City lies at the confluence of Bago River and Yangon River about 40 km north of the Andaman Sea. The latitude of Yangon City falls in the latitude between 16º45' N and 17º N and the longitude between 96ºE and 96º15' E (Lwin & Khaing, 2012).

3.1.1.2 *Area*

Yangon Region is composed of 45 townships with an area about 10170 km^2, and among them, 33 townships are belonged to in Yangon City and are administrated by the Yangon City Development Committee (YCDC) and the rest 11 townships are under the administration of Yangon Regional Government. Figure 3.1 illustrates that the townships include in Yangon Region as well as in Yangon City. The city administrative area expanded several times in the past and has been gradually widening, integrating urbanizing townships in the peripheral area. At present, the city covers an area about 794.4 km^2. According to the urban development plan of the Greater Yangon, some parts of the six peripheral townships, namely, Kyauktan, Thanlyin, Hlegu, Hmawbi, Htantabin, and Twantay, might be incorporated with the Yangon City in the future and its total area will have approximately 1500 km^2. The 33 townships of Yangon City can be differentiated into seven zones: the Central Business District (CBD), the Inner Urban Ring (IUR), the outer Ring Zone (ORZ), the South of Central Business District (SCBD), the Northern Suburbs Zone (NSZ), the Older Suburbs Zone (OldSZ), the New Suburbs Zone (NewSZ). The figure showing these zones of the city will describe in the next section.

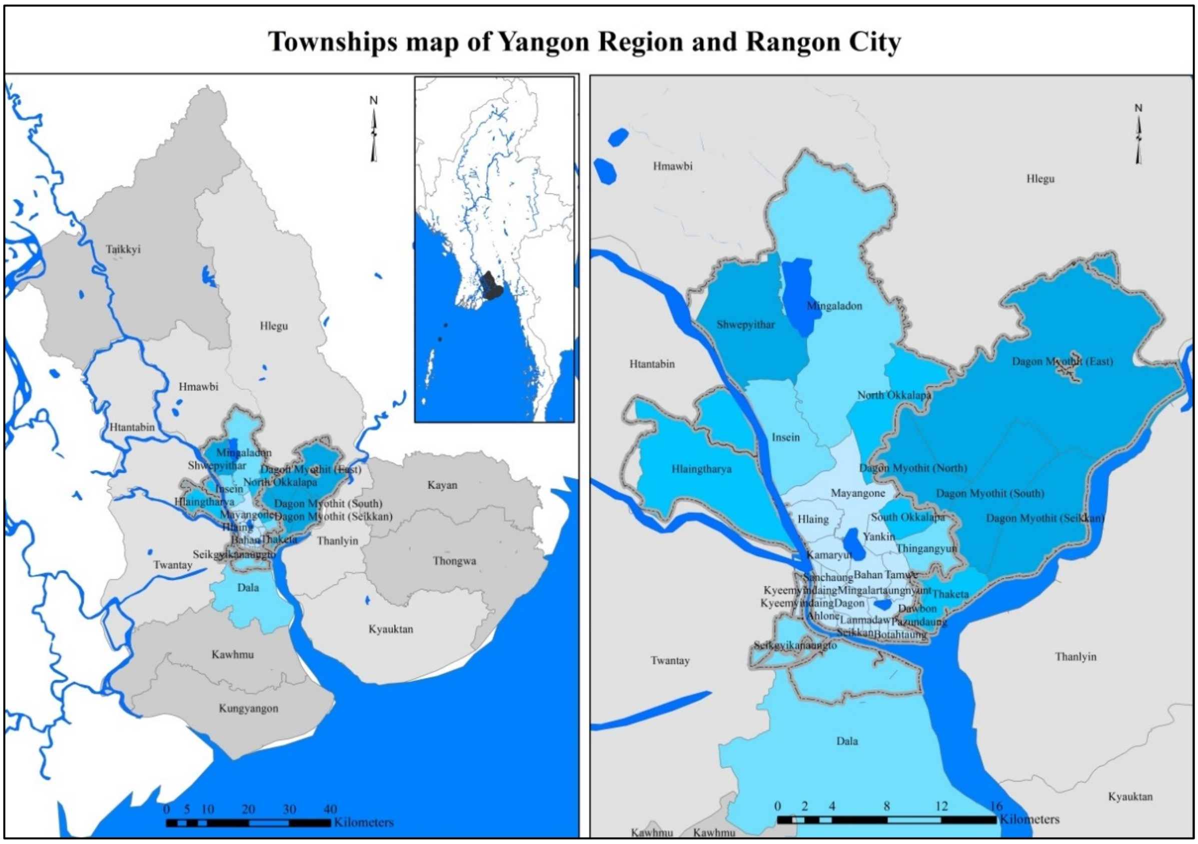


Figure 3.1: Townships map of Yangon Region and Yangon City

3.1.1.3 *Geography*

Yangon City is situated on a low ridge, which is a long spur running out from the southern part of Bago Range, surrounded by the delta alluviums (Spate & Trueblood, 1942). This Yangon ridge slopes gradually into flat plains towards east and west. The original settlement was located on the ridge, and the extended town was built on alluvium, however, subsequent expansions were taken place on both the ridge and the delta land. Therefore, topography of the city varies from a low ridge in the central and northern part to a flat plain in the peripheral parts. The average height of the low ridge is about 30 m, and that of the flat plain is between 3m to 6m above the mean sea level.

The geological structure of the central part of Yangon Region is Miocene consolidated sediments overlain by the Quaternary sands, silts and clay, and that of the outskirt of Yangon City is widely distributed with the Quaternary sediments, consisting of thick, high plastic, stiff clay underlain by sand and silt (Lwin & Khaing, 2012).

3.1.1.4 *Climatology*

Yangon Region is located in the tropical monsoon climate region, and it has three seasons, summer (March to May), rainy season (June to October), and cool season (November to February). In Yangon Region, there are three meteorological stations, namely, **Kaba-Aye**, **Mingalardon**, **Hmawbi**, which are managed by Department of Meteorology and Hydrology, Ministry of Transport. Long-term monthly averages for the climatic parameters, which can represent the climate of Yangon Region, are obtained by analysing the observed data from these three stations. CLIMWAT 2.0 of FAO is used to obtain the global data for the comparison with local data.

Temperature: In long-term analysis, the maximum mean daily temperature of Yangon Region is 37.5ºC (in April) and the minimum is 17.8ºC (in January). The difference between monthly maximum and minimum temperature is large (more than 10º) in the period from December to March and small (around 5º) in the period between June and September, which is the rainy season. The long-term monthly average of mean daily maximum and minimum temperature of Yangon Region is shown in Figure 3.2 by analysing the data for the period 1991 to 2013. The dotted lines represent the data that obtained from the software CLIMWAT 2.0.

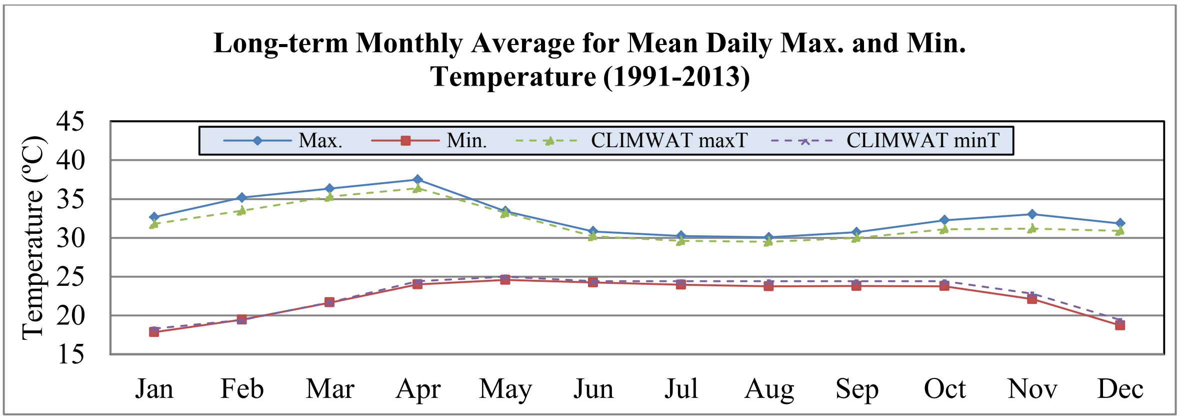


Figure 3.2: Long-term monthly averages for mean daily maximum and minimum temperature (1991-2013)

Relative Humidity: In long-term analysis, the mean daily relative humidity of Yangon Region is high (about 90%) in the rainy season from June to September at both morning and evening measurements. However, the relative humidity drops in other months until around 50% in the morning and around 70% in the evening. The lowest relative humidity in Yangon Region is about 48% in February 09:30 measurements. The difference between morning and evening relative humidity is large (about 20%) in the period between January to April, but there is no difference in the period between June to September. The long-term monthly average for the mean daily relative humidity of Yangon Region at 09:30 hr. and 16:30 hr. is illustrated in Figure 3.3 by analysing the data from 1991 to 2013.

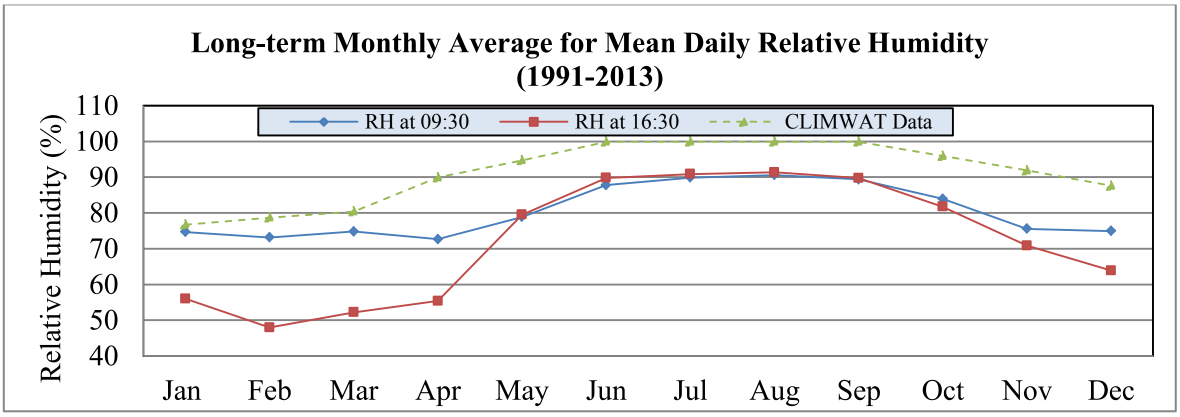


Figure 3.3: Long-term monthly average for daily relative humidity of Yangon Region (1991-2013)

Wind speed: Maximum mean daily wind speed of Yangon Region is 223.5 kilometres per hour (in May), and the minimum is 145.67 km/hr. (in February). Wind speed in Yangon Region is higher in the rainy season than the other period. Although cyclones come to the country at the beginning and ending of the rainy season, Yangon Region seldom experiences the effect of cyclone wind. Wind direction is generally the southwest (SW) during the summer and the rainy season, but it changes to the northeast (NE) direction in the cool season. The long-term monthly average for mean daily wind speed of Yangon Region is described in Figure 3.4 according to the data for the period 1991 to 2013.

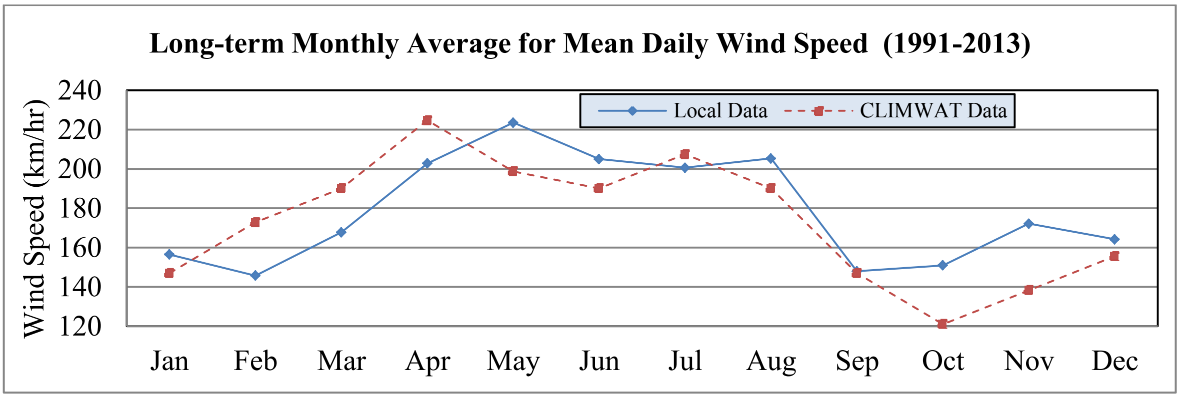


Figure 3.4: Long-term monthly average for mean daily wind speed of Yangon Region (1991-2013)

Sunshine hours: According to the long-term measurements, the maximum mean sunshine hour per day of Yangon Region is 9.2 hours in February, and the minimum is 2.2 hours in August. Generally, Yangon Region has more sunshine hours in the period between December and April, on the other hand, the period between June and August has fewer sunshine hours because of monsoon rainy weather. The long-term monthly average of mean sunshine hours per day of Yangon Region is expressed in Figure 3.5 by observing the data for the period 1991 to 2013.

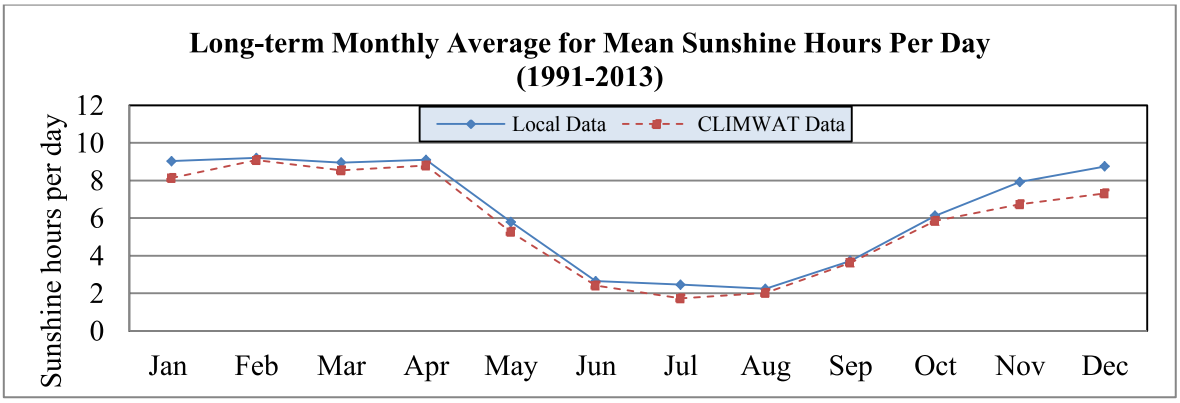


Figure 3.5: Long-term monthly average for mean sunshine hours per day of Yangon Region (1991-2013)

Evaporation: The long-term average for maximum monthly evaporation of Yangon Region is 179 mm in April, and the minimum is 71 mm in August. Evaporation in Yangon Region is high in the summer, especially in April and low in the rainy season. Figure 3.6 shows the long-term monthly average evaporation of Yangon Region for the period 1991 to 2013. The long-term average for annual evaporation is about 1330 mm.

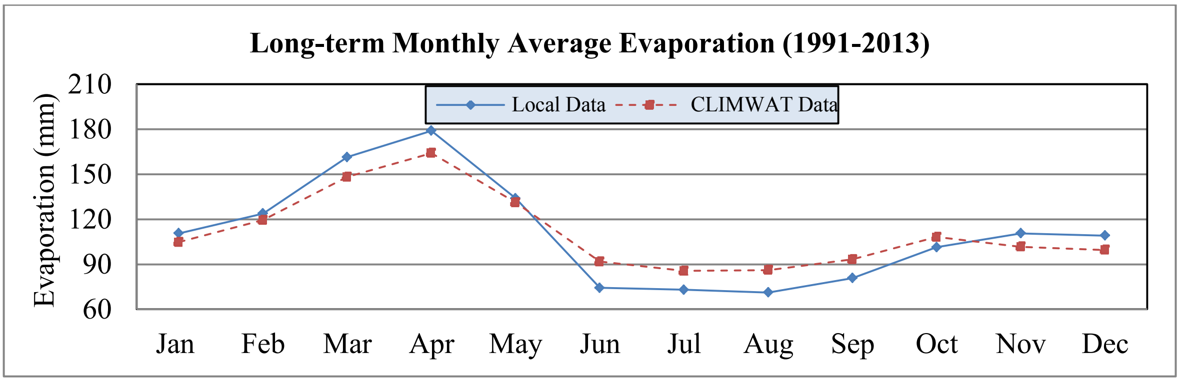


Figure 3.6: Long-term monthly average evaporation of Yangon Region (1991-2013)

Rainfall: Figure 3.7 illustrates the long-term average for monthly rainfall data, which are observed in different meteorological stations in Yangon Region such as Kaba-Aye, Mingalardon, and Hmawbi. The rainfall data of Kaba-Aye station is a little bit higher than the other two stations, Mingalardon and Hmawbi, but rainfall data of the latter two stations are nearly the same. Kaba-Aye station is located in the city and the other two stations are located near the water supply reservoirs of Yangon City. In Yangon Region, the average monthly rainfall is high until around 600 mm in the months of rainy seasons, however, that become nearly zero in the period from November to April. The long-term average for annual rainfall of Kaba-Aye, Mingalardon, and Hmawbi stations are 2884 mm, 2607 mm and 2562 mm respectively.

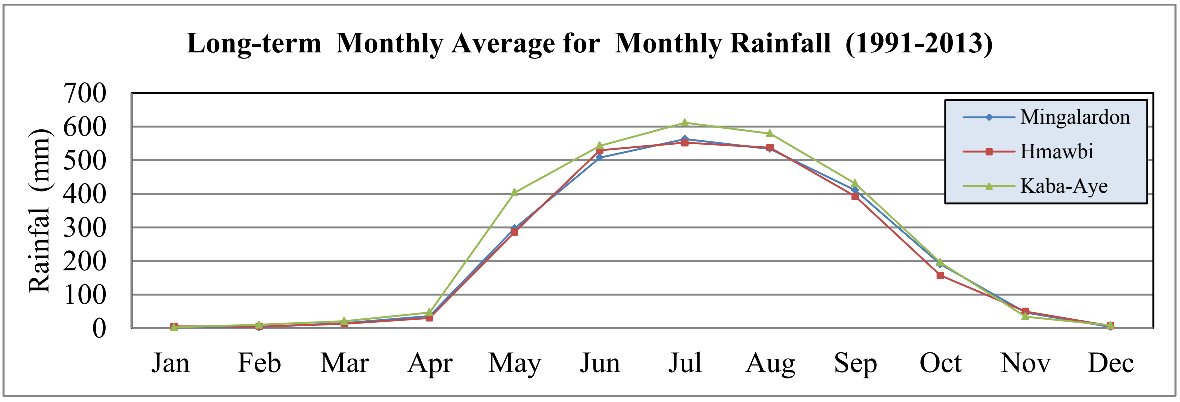


Figure 3.7: Long-term monthly average for monthly rainfall in Yangon Region (1991-2013)

3.1.2 Hydrological Situation

Yangon City is a place of abundant water resources and heavy rain. It lies at the confluence of Yangon River and Bago River and is surrounded by rivers. Its boundaries have been formed in a U-shaped by Hlaing River and Yangon River, which becomes by joining Pan Hlaing River and Hlaing River, to the west, Yangon River to the south, and Pazundaung Creek, which is known as Ngamoeyeik Creek at the upstream, to the east. After joining with the Bago River, which flows into the Yangon River from the northeast, Yangon River runs southward into the Gulf of Mottama of the Andaman Sea. The city lies northeast of the Ayerawady Delta, and Yangon River has been connected with the Ayerawady Delta by Twante Canal since colonial times (Seekins, 2014).

All rivers and creeks adjacent to Yangon City have tidal and saline water intrusion effects within and beyond the limits of the city (Nakagami et al., 2009). In these rivers and creeks, freshwater with sediment concentrations of 1gram per litre (g/l), or less, flows unidirectional, seaward direction during the rainy season, however, saline water intrusion to the landward direction occurs during the dry seasons and low river flow period and salinities reach maximum 20‰ and sediment concentrations rise to 6 g/l (Nelson, 2001).

In the central region, the low ridge, of Yangon City, ground water potential is low, and iron content is high in groundwater from this area and adjacent areas. On the other hand, groundwater potential is high in the rest flat plain region and very high along the rivers, however, salinity is high in ground water (JICA & YCDC, 2002).

3.1.3 Social-economic situation

3.1.3.1 *Population*

Currently, the total population in Yangon City is about 5.14 million and the city is growing with increasing population, reinforced by the continuous migration of rural people to the city and the creation of new satellite towns (Yangon Region Government, YCDC & JICA, 2013). Moreover, due to the current national changes and development plans, Yangon City is forecasted to become a mega city with 10 million populations in 2040 (Yangon Region Government, YCDC & JICA, 2013). Figure 3.8 is illustrating the past population data of Yangon City from 1800 to 2013 according to the data observed from the history of Yangon City, the censuses of India, the national censuses of Burma and the report of Department of Population, Ministry of Immigration and Population, Myanmar. In addition, this graph is also showing the predicted population data for the future starting from 2014 to 2040 by using the population growth rate 2.5 %.

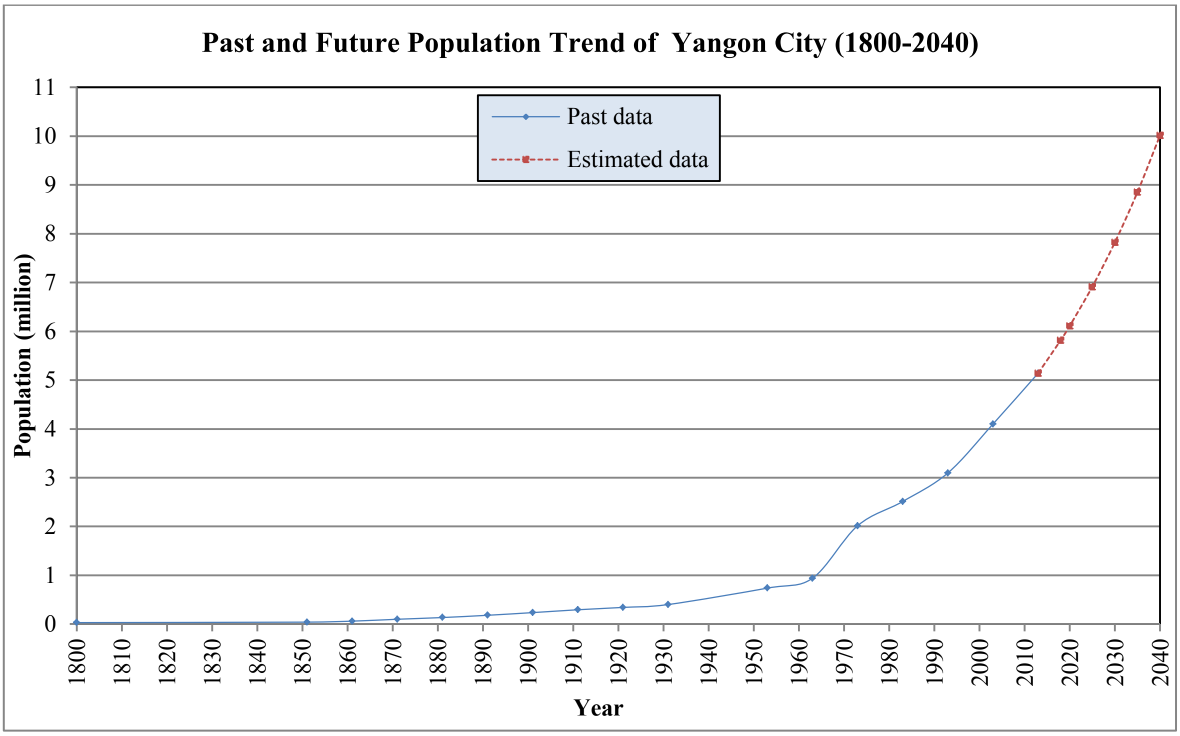


Figure 3.8: Historical population and an estimated population of Yangon City (1800-2040)

The following Table 3.1 lists the area, population, population density and population growth rate (1993-2013) of each township of Yangon City in 2013. The population density in the central business district (CBD) of Yangon City is the highest and that in the South of CBD is the lowest. However, the population in the CBD has stopped growing, whereas, that in new suburbs and the south of CBD have been growing with a high rate.

3.1.3.2 *Urbanization*

The origin of Yangon City started from the CBD area and after the second Anglo-Burmese War in 1852, the British transformed Yangon as the commercial and political hub city of British Burma. After the third Anglo-Burmese War, Yangon became the capital of all British Burma in 1885. Myanmar regained independence from British Colony in 1948, and consequently, Yangon became the capital of the Union of Myanmar. In 1950s, Urbanization of the city expanded northward, and urban area was becoming an area of the CBD, the Inner

Table 3.1: Area, Population, Population Growth, and Density in Townships of Yangon City (2013) (Source: Urban Planning Section, YCDC)

No.	Township	Area (km^2)	Population	Population Growth (%)	Population Density (pop/km^2)	Remark
1	Latha	0.803	34125	0.37	56498	Central Business District (CBD)
2	Lanmadaw	1.399	43137	0.47	32954	
3	Pabedan	0.725	37551	-1.79	60762	
4	Kyauktada	0.725	34797	-1.80	49639	
5	Botahtaung	2.486	49134	-0.53	18912	
6	Pazuntaung	1.010	53648	2.61	50326	
7	Ahlone	2.694	65510	3.19	19405	Inner Urban Ring
8	Kyeemyindaing	12.458	115841	2.18	26032	
9	Sanchaung	2.486	105208	2.25	43818	
10	Dagon	5.076	24492	-3.7	5012	
11	Bahan	8.832	100695	0.44	11900	
12	Tarmwe	4.429	191114	3.10	38384	
13	Minglartaungnyunt	5.076	155767	2.73	31557	
14	Seikkan	16.602	2241	3.81	1910	
15	Dawbon	3.807	87284	0.71	28093	
16	Kamaryut	6.216	87881	0.45	13598	Outer Ring Zone
17	Hlaing	13.623	151014	-0.81	15402	
18	Yankin	5.025	125909	1.25	26313	
19	Thingangyun	11.396	231621	-0.29	17678	
20	Mayangone	25.330	205403	0.89	7963	Northern Suburbs
21	Insein	35.017	311200	2.00	9927	
22	Mingalardon	112.846	288858	4.12	2261	
23	North Okkalapa	26.729	333484	4.46	12033	Older Suburbs Zone
24	South Okkalapa	10.179	191388	-1.07	23323	
25	Thaketa	12.769	253284	-0.76	18860	
26	Dala	10.101	181087	6.77	2790	South of CBD
27	Seikkyikhanaungto	5.879	38425	3.18	3180	
28	Shwepyithar	66.718	295993	4.25	5626	New Suburbs Zone
29	Hlaingtharyar	68.169	488768	7.15	6308	
30	Dagon Myothit (North)	60.269	221200	6.16	9162	
31	Dagon Myothit (South)	79.125	370403	7.75	9889	
32	Dagon Myothit (East)	91.039	145505	7.74	853	
33	Dagon Myothit (Seikkan)	85.392	120161	15.59	2862	
	Total	**794.431**	**5142128**	**2.56**	**6473**	

Urban Ring (IUR), the Outer Ring Zone (ORZ), and the Northern Suburbs Zone (NSZ). In 1959, new satellite townships, Thaketa, South, and North Okkalapa (Old Suburbs Zone) were developed. The following Figure 3.9 illustrates the urbanization pattern of Yangon City together with different zones of Yangon City.

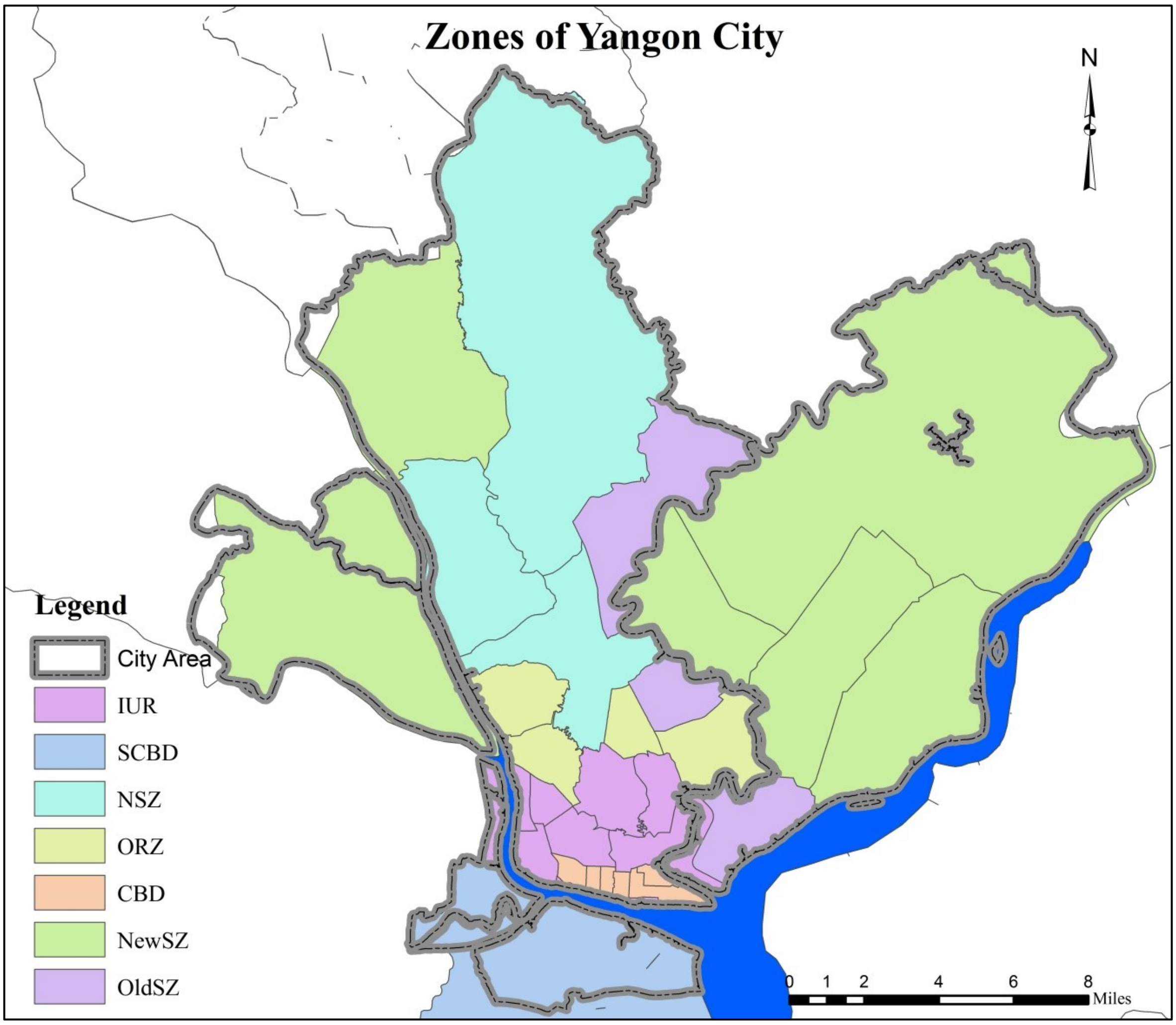


Figure 3.9: Urbanization trend of Yangon City with different zones

This old city area was situated along the central ridge region between the Hlaing River (Yangon River) and the Pazuntaung (Ngamoeyeik) Creek. In late 1980s, urbanization was extended towards east and west crossing the above river and creek as new satellite townships (New Suburbs Zone) created by YCDC. Urbanization has not yet started to the southward direction because of the poor transportation access to the urbanized area.

3.1.3.3 *Present Land Use*

In the urban development study for Yangon City, the land use map of Yangon City was developed based on the analysis of satellite images in 2012 (see in Figure 3.10) (JICA & YCDC, 2014). According to the land use pattern, most of the outside areas of Yangon City are still as cultivated land although Yangon City area is undergoing development. The catchment areas of the supply water reservoirs are dense forest, sparse forest and scattered trees zones.

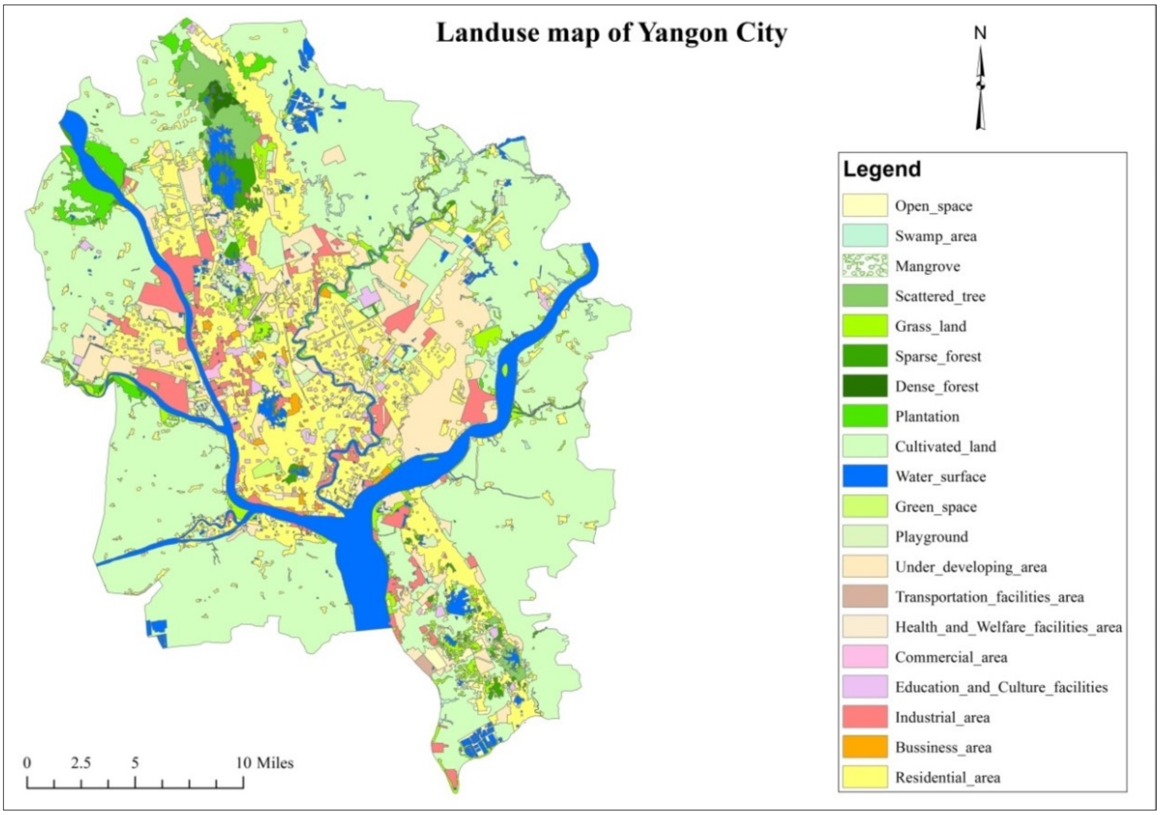


Figure 3.10: Land use map of Yangon City and its surroundings (2012)

3.1.3.4 *Industrialization*

Industrialization pattern of Yangon City and surrounding 6 townships are composed of 37% for processing and manufacturing sector, 25% for trade sector, 24% for service sector and only 8% for the total of agriculture, livestock, and fishery sectors in 2011 (JICA & YCDC, 2014). According to the data from Yangon regional office of Planning Department, Ministry of National Planning and Economic Development, Myanmar, the whole Yangon Region had 15089 factories/workshops in Yangon Region in 2010/11, and about 80% of this amount (11903 factories/workshops) is in the Yangon City area (JICA & YCDC, 2014). According to the number of factories, NewSZ is the most industrialized zone and IUR, OldSZ, and NSZ are industrialized zones. Department of Human Settlement and Housing Development (Ministry of Construction) and YCDC implemented 25 industrial zones in Yangon City.

3.1.3.5 *Health*

The life expectancy at birth of Myanmar is 66 for both sexes, whereas the regional average is 67, and the global average is 70 (WHO, 2012). Therefore, the life expectancy of Myanmar is a little bit lower than that of the world average but nearly the same with that of Southeast Asian countries. Under-5 mortality rate, Infant mortality rate (under 1), Crude death rate, and life expectancy were improved from 106 in 1990 to 52 in 2012, from 76 in 1990 to 41 in 2012, 10.1 in 1990 to 8.5 in 2012, 58.7 in 1990 to 65 in 2012, respectively (UNICEF, 2013).

However, Crude birth rate was decreased 26.8 in 1990 to 17.4 in 2012 together with decreasing fertility rate in Myanmar (UNICEF, 2013). Myanmar has a low fertility rate comparing with the other Southeast Asia countries and fertile rate has been declining significantly from 4.7 in 1983, 2.4 in 2001 to 2 in 2012 (UNICEF, 2013; Jones, 2007). The fertility rate is mainly lower in urban areas because of extreme delays in marriage and the high number of single and unmarried women in reproductive age. In Myanmar, the proportion of single women at age 30-34 increased 9.3% in 1970 to 25.9% in 2000 (Jones, 2007).

3.2 Study Organization Description

This section will describe Yangon City Development Committee (YCDC), the present city authority, and its department, Engineering Department (Water & Sanitation) which is responsible for the city's water supply facility.

3.2.1 Yangon City Development Committee (YCDC)

YCDC was initially established as a city municipal organization since Myanmar was under the British to carry out municipal works, and its name was changed in history as Rangoon City Municipal Corporation in 1922, as Rangoon City Municipal Committee in 1972, as Rangoon City Development Board in 1977, as Rangoon City Development Committee in 1985 (YCDC, 2014a).

According to the provisions of **Yangon City Development Law** (14 May 1990), YCDC bestowed wide powers and authority, for instance, YCDC was authorized to implement its own project by using its own funding resources. However, at present, YCDC needs to apply permissions of projects to the national government, and the funding sources of YCDC are incorporated into the national budget by the new policy. YCDC set up as a ministerial level and comprises with 20 departments and one committee office, to create a modern city with the features and characteristics of city while preserving its greenery and the intrinsic beauty for its citizens by the guidance of the national government. YCDC is directly responsible for the development and maintenance of Yangon City in all aspects.

According to **Yangon City Development Law,** YCDC must organize with minimum seven members to maximum 15 members; the Chairman, Vice-Chairman (Vice-Mayor), Secretary, Joint-Secretary, and the other are Committee Members. Mayor of Yangon City is responsible not only the Chairman of YCDC but also the minister of Development Affairs of Yangon Region. The current organizational chart of YCDC is showing in Figure 3.11.

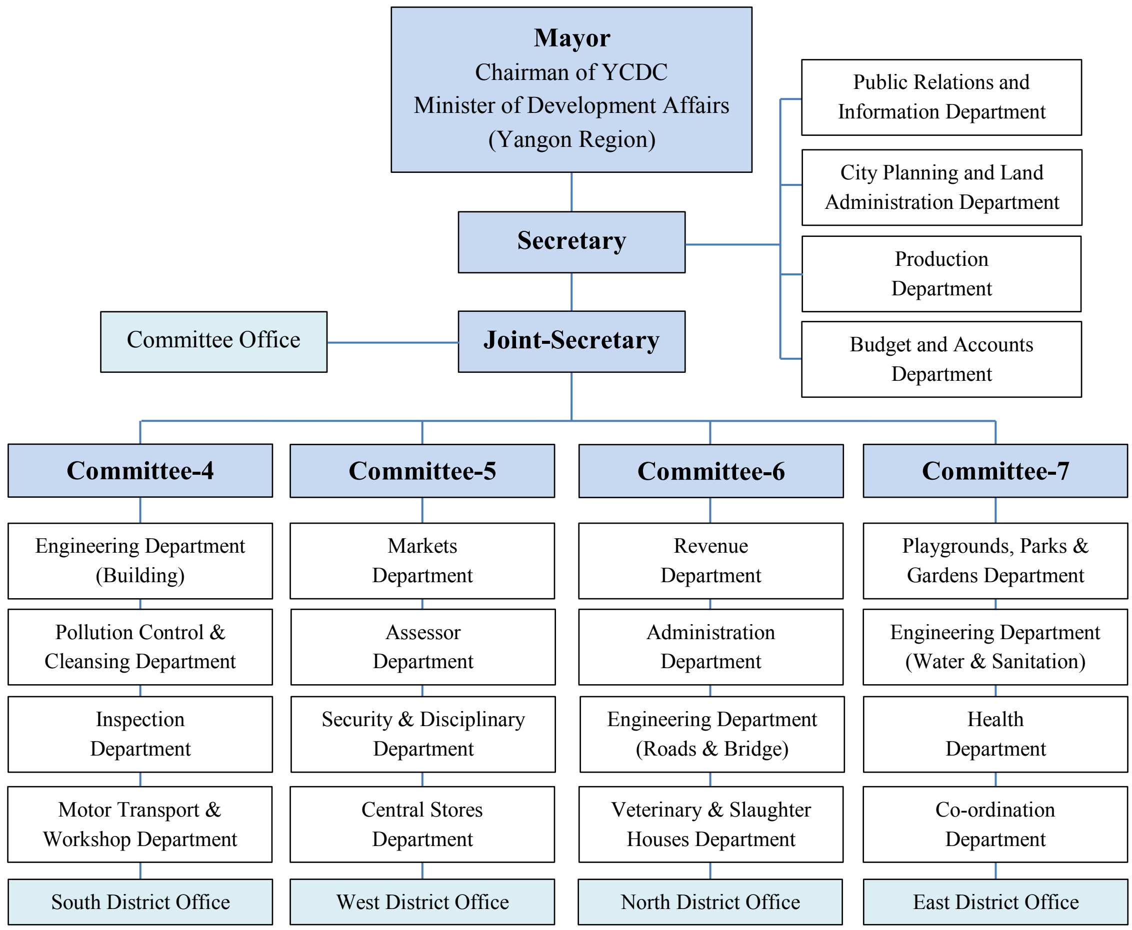


Figure 3.11: Organization chart of Yangon City Development Committee

3.2.2 Engineering Department (Water & Sanitation)

Engineering Department (Water & Sanitation) (**EDWS**) is one of the 20 departments under YCDC, which is responsible to supply of clean and potable water to the citizens of Yangon City and to serve sewerage and sanitation facilities of the city. The main objectives of EDWS are:

1. To distribute the adequate, safe and wholesome water for city dwellers
2. To collect the water tariff completely
3. To prevent water leakage and control the reduction of non-revenue water
4. To manage for systematic sewage disposal
5. To upgrade water distribution facilities and sewerage system

EDWS is organized with 6 divisions (**Reservoirs division, Water Supply division, Sanitation division, Revenue and administration division, Electrical and mechanical division, Pipe plant division**) and a supporting branch, which has 4 sections: Research section, Store section, Computer section, and Water quality monitoring section. The head of department is Chief Engineer (CE), who is supported by 2 Deputy Chief Engineers (DYCE) and 6 Assistance Chief Engineers (ACE), heads of each division. The total number of staff members in the whole department was 2171 in 2013. The below Figure 3.12 illustrates the organization chart of EDWS.

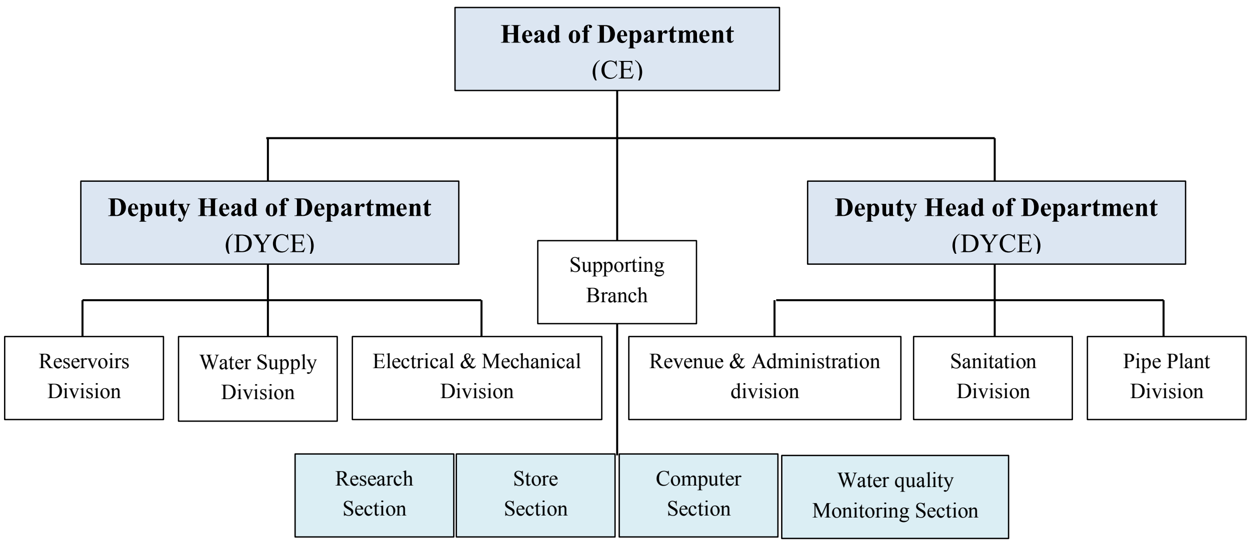


Figure 3.12: Organization chart of Engineering Department (Water & Sanitation)

3.3 History and Status quo of Water Supply System

This section will present two parts of Water supply system of Yangon City. The first part deals with the water supply system history in the past and the second part deals with the present water supply system.

3.3.1 Past Water Supply System

Yangon city water supply system has a long history of more than 150 years. In 1842, King Tharrawady gave instruction to construct 30 open wells in Yangon City to start the water supply facility of the city.

In 1879, the first water supply system with pipeline was initiated in Yangon City by using water from Kandawgyi Lake to Baotahtaung and Pazundaung townships via 10" diameter cast iron pipes.

In 1884, this water supply system was augmented by the construction of Inya Lake, water from which was diverted to Kandawgyi Lake by 30" diameter pipelines and distributed to the city through 27" diameter pipelines.

In 1894, the water supply system in Yangon City was developed with pumping station and service water tank by the construction of Phoesein pumping station and Shwedagon service water tank (1MG storage capacity). The water delivered from Kandawgyi Lake to Phoesein pumping station was pumped to the Shwedagon service tank via 27" diameter pipeline and distributed water to the western part of the city from that tank.

In 1904, **Hlawga Reservoir** (14 MGD supply capacity), situated about 17 miles (27km) north of Yangon City, was introduced in Yangon City water supply system, continuously, the water supply from Kandawgyi Lake and Inya Lake has ceased due to the deterioration of water quality from these lakes resulted by rapid urbanization. Water from Hlawga reservoir was pumped through 42" diameter CI pipeline to Yegu pumping station by booster pumping station of Hlawga reservoir. In 1906, the construction of Yegu pumping station was completed, and water was pumped to Shwedagon reservoir via 42" diameter, from which water was distributed to the whole city. Since that time, the use of Phoesein pumping station was terminated. In 1925, Kokkine service water tank (20 MG storage capacity) was constructed and added to the existing water supply system to expand the served area.

In 1941, the construction of **Gyobyu reservoir** (27 MGD supply capacity), situated about 40miles (64km) north of the city, was completed, and water was supplied with 56" diameter mild steel pipes through Yegu pumping station to Kokkine service water tank.

In 1989, **Phugyi reservoir** (54 MGD supply capacity), situated about 32 miles (51 km) of the city, was added to the water supply system by connecting with Hlawga reservoir through a 60" diameter pre-stressed concrete pipe. In 1992, 66" diameter pre-stressed concrete pipe laying project from Hlawga reservoir to Yegu pumping station was completed and water has been distributed to Yangon City. At that time, the daily water supply amount of the whole system was 85 MGD, including water amount (10MGD) from YCDC owned tube wells.

In 2000, **Yangon Pauk** ground water treatment project was implemented to supply 1MGD water amount to Dala Township, southern part of the city on the other bank of Yangon River.

In 2005, **Ngamoeyeik WTP** project (Phase 1 with 45 MGD supply capacity), using water source from **Ngamoeyeik reservoir**, which was constructed and managed by Ministry of Agriculture and Irrigation, was operated to supply water to the eastern part of the city, especially, new suburb townships of the city.

In 2009, **South Dagon** ground water treatment project (No.1 and No.2 with total 2 MGD supply capacity) and **Thaephyu** ground water treatment project (1MG supply capacity) was implemented at the eastern and western extended part of the city to supply water to the suburb regions which are far from the main water supply system.

The second phase of Ngamoeyeik WTP was accomplished in early 2014, and it started its function to reinforce the water supply system of the city with daily supply capacity 45 MG.

3.3.2 Present Water Supply System

3.3.2.1 *Water Supply Sources*

The current water supply amount of YCWSS is 205 MGD, including the amount of water generated from the second phase of Ngamoeyeik WTP, i.e. 45MGD. The total water supply amount was 160 MGD until the end of financial year 2013-2014.

Table 3.2 shows a list of current water sources of Yangon City together with their daily water supply capacity. About 90% of the water source of the system is surface water from reservoirs, and the rest is ground water from tube wells as the supplement of water supply system.

Table 3.2: Current water sources of Yangon City Water Supply System

Water Sources	Daily Capacity	Water Source	Start-up Year
Hlawga Reservoir	14 MGD	Surface water	1904
Gyobyu Reservoir	27 MGD	Surface water	1940
Phugyi Reservoir	54 MGD	Surface water	1992
Ngamoeyeik WTP (Phase 1)	45 MGD	Surface water	2005
Ngamoeyeik WTP (Phase 2)	45 MGD	Surface water	2014
Yangon Pauk	1 MGD	Ground water	2000
South Dagon	2 MGD	Ground Water	2009
Thaephyu	1 MGD	Ground Water	2009
YCDC tube wells	16 MGD	Ground water	-
Total	**205 MGD**	**90% Surface Water + 10% Ground Water**	

Table 3.3: Reservoirs of Yangon City Water Supply System

Items	Hlawga Reservoir	Gyobyu Reservoir	Phugyi Reservoir	Ngamoeyeik Reservoir
Constructed years	1900-1904	1937-1940	1973-1984	1992-1995
Location (from city)	17 mi North	40 mi North	32 mi North	38 mi North
Catchment area (sq-mi)	10.5	12.9	27.27	160
Water surface area (sq-mi)	4.4	2.8	6.8	17.19
Total capacity (MG)	12000	16600	23000	52000
Effective capacity	10000	8240	20000	48840
Maximum Water Level	62	215	120.86	117
Top of spillway (ft)	62	215	115.5	107
1st intake level (ft)	57.2	201	90	90
2nd intake level (ft)	49.2	180	74	72
3rd intake level (ft)	42.2	138	-	-
Water supply capacity (MGD)	14	27	54	45 + 45
Start-up year	1904	1940	1992	2005 (Phase-1) 2014 (Phase-2)

Table 3.3 lists the physical and operational data of reservoirs used in YCWSS. YCDC owns three water supply reservoirs, namely, Hlawga, Gyobyu, and Phugyi, and operates and manages these reservoirs only for city water supply purpose. Ministry of Agriculture and Irrigation (MoAI) has constructed and managed Ngamoeyeik reservoir for multi-purposes, such as water supply for agriculture, saltwater intrusion prevention, flood control etc., and one of these purposes is to supply 90 MGD raw water for Yangon City. YCDC constructed Ngamoeyeik WTP for the treatment of raw water obtained from Ngamoeyeik reservoir. First phase of WTP has been operated in 2005 and second phase in 2014 (March), and each phase has capacity of 45 MGD.

YCDC has three main ground water supply projects in NewSZ and SCBD, which are far from the main water supply network. Moreover, YCDC is using ground water source from tube wells and directly injected into the distribution pipeline network to reinforce the surface water from reservoirs. At present, there are 645 YCDC-owned tube wells with total maximum yield amount of 20 MGD, however actual yield amount is less that maximum amount is depending on the operation hours of the tube wells. Most of the tube wells are concentrated in the CBD area. Moreover, about 3 million populations in Yangon City, who cannot get YCWSS services, are using private tube wells as a water source. The total withdrawal amount from both YCDC and private tube wells is estimated about 79MGD. If additional groundwater would be used in future to meet the increasing water demand, this extraction amount can exceed the total groundwater potential, i.e. 83 MGD (estimated).

Water Supply Facilities

There are six WTPs in the existing YCWSS. Two treatment plants are for the surface water treatment and treated by flocculation, sedimentation, and filtration processes. The other four are ground water treatment plants by cascade aeration and filtration processes. In YCWSS, there are six main pumping stations to transport water and to supply water with pressure, however, most of the pumping stations require proper equipment for operation, such as pressure gauges, flow meters etc. YCWSS has two service water tanks to regulate the water supply.

Water Supply Pipelines

In YCWSS, some transmission pipelines are more than 100 year old and choked by scaling. Also, the distribution network have been expanded year by year due to population growth in the city and development activities, thus, new and old pipe are mixed. The total length of transmission and distribution pipes in YCWSS is about 1455 km and the detail data of aged pipes are listed in Table 3.4.

Table 3.4: Aged transmission main pipes in YCWSS

Start-up year	Pipe material	Diameter	Length	Age
1904	Cast iron	1060 mm	22.85 km	109
1914	Mild steel	1060 mm	8.05 km	99
1940	Mild Steel	1400 mm	69.2 km	73
1989	Pre-stressed concrete	1520 mm	25.75 km	24
1992	Pre-stressed concrete	1650 mm	16.74 km	21

The following Figure 3.13 illustrates the current water supply system of Yangon City together with water supply service facilities, such as reservoirs, treatment plant, pumping stations, main transmission pipeline, etc.

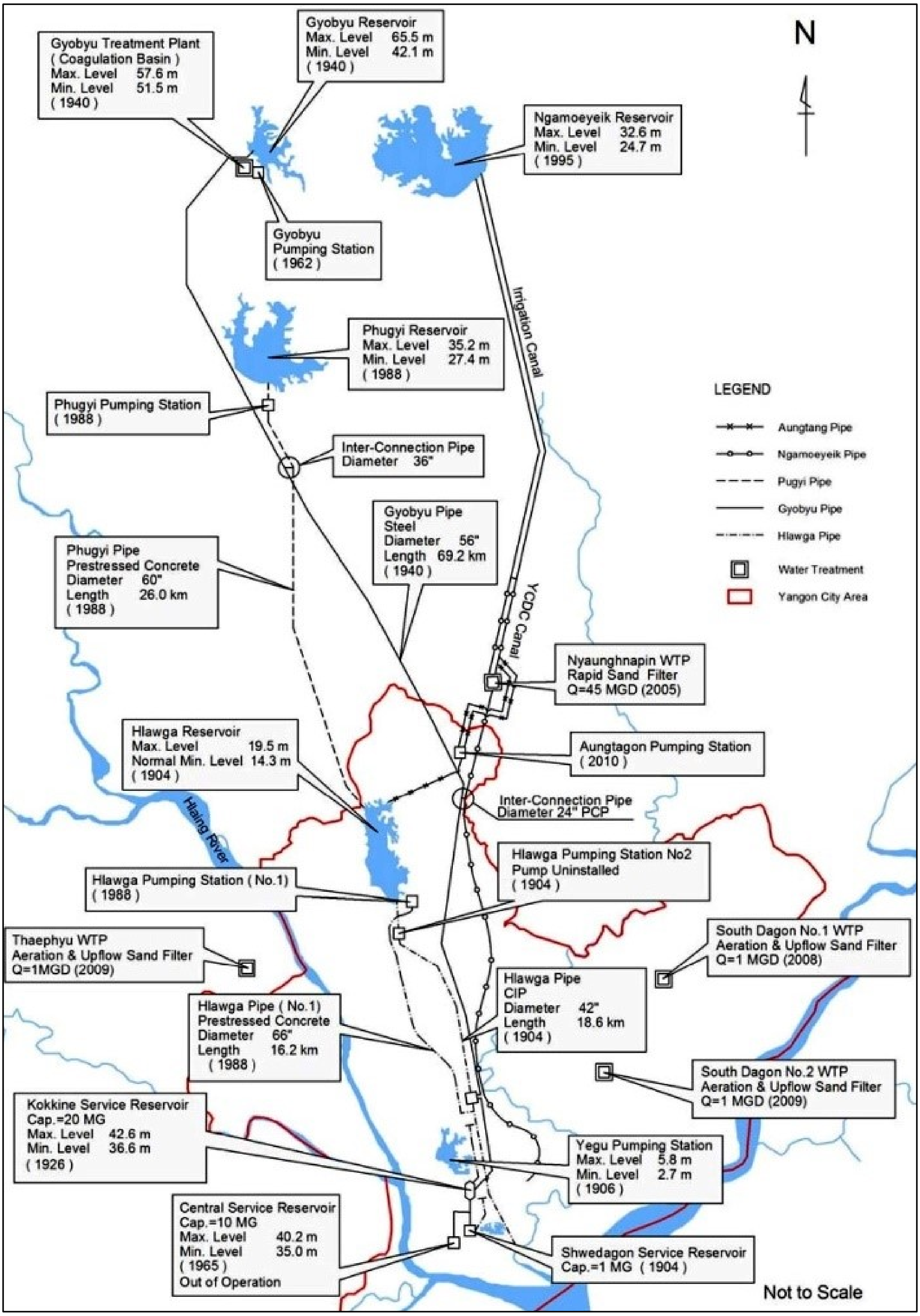


Figure 3.13: Current Water Supply System of Yangon City in 2013 (JICA & YCDC, 2014)

3.3.2.2 *Demand sites*

The main objective of the whole system is to supply the adequate safe water for the city, so the main and only one demand site in this system is Yangon City, with population 5.14 million in 2013. According to the data of EDWS, the daily water consumption amount for a person in Yangon City is about 30 imperial gallons.

In 2013, the total daily water demand was 154.2 MGD by using the consumption rate 30gpcd (gallons per capita day).

Demand coverage

The water demand coverage of the YCWSS is about **30 %** and people with no water supply service obtain water from other water sources like wells, tube wells, ponds, and rain (Yangon Region Government, YCDC & JICA, 2013; Khaing, 2006). Generally, Yangon City Water Supply System can supply water only one-third of city dwellers.

There were 825620 households in Yangon City, however, the number of water connections, households connected with city water supply system, was only 269268 at the end of 2013. Based on the number connection, the water demand coverage of Yangon City was about 32 %.

In 2013, the actual daily water supply amount in Yangon City was 54.52 MGD that was calculated by using the actual income from 2013-December water meter bills. The total daily water demand was 154.2 MGD calculated by using water consumption rate 30 gpcd for 5.14 million populations in 2013. Therefore, the water demand coverage of Yangon city in December 2013 was about 35% according to the income based calculation. The following Table 3.5 shows the calculations of demand coverage of the system in Yangon City based on connections and volume derived from actual income. In 2013, the average water supply volume was about 50 MGD and the demand coverage is about 32.4 % for the whole year.

Table 3.5: Demand coverage of the YCWSS in 2013

Demand site	Yangon City	
Daily Demand	154.2 MGD	5.14 million population with 30 gpcd consumption
Demand Coverage (connection based)	32.6 %	The ratio of the number of actual supply connection, i.e. **269268**, and the number of households, i.e. **825620**
Demand Coverage (income based)	35%	The ratio of the actual supply volume derived from actual income, i.e. **54.52 MGD**, and the total demand by using 30 gpcd, i.e. **154.2 MGD**

Water Uses

In YCWSS, there were 269,268 connections in December 2013, and out of these connections, 90% is domestic connections, 8% is commercial connections, 1% is departmental connections and the rest 1% is free of charge connections for religious buildings, such as pagodas, temples, monasteries, churches, mosques etc. 78% of total connection are metered and the others are unmetered. The detail number of connections of different water use types will show in the following Table 3.6.

Table 3.6: Number of connection based on category of water uses in December 2013

Category	Domestic	Commerce	Department	FOC	Total
Metered	189154	20611	1425	-	211190
Unmetered	53987	735	808	2548	58078
Total	243141	21346	2233	2548	269268

Water supply amount estimated from the water use amounts based on the water bill income of YCDC in December 2013 was 54.52 MGD, in which 58 % is for domestic use, 21 % is for departmental use, 15% is for commercial use, and the rest is for free-of-charge connections. The detail data is listed in the below Table 3.7.

Table 3.7: Water consumption amount of different water uses in December 2013

Category	Domestic	Commerce	Department	FOC	Total
Monthly consumption (m^3)	4,325,129	1,131,127	1,595,904	382200	7,434,360
Daily consumption (m^3)	144171	37704	53197	12740	247812
Daily consumption (MGD)	31.72	8.29	11.70	2.80	54.52

FOC connections are estimated with 5 units per day consumption rate.

3.3.2.3 *Water Supply Service Condition*

Services Hours

In YCWSS, service hours vary widely between 6 hours and 24 hours per day depending on areas. Areas located near to water source and main pipes, low areas, etc., can get water continuously, however, hydraulically unfavourable areas i.e. areas located far away from water source and main pipes, hilly areas, can get water only when there is surplus water or in night time. Average supply duration is estimated as 9.1 hours per day.

Water pressure

Water pressure of YCWSS also has the same situation as service hours' case and varies widely from < 0.3 bar to >1.5 bars, and average pressure is about 0.75 bars. Hydraulically favourable areas get high pressure, while hydraulically unfavourable areas get low pressure.

Non-Revenue Water Rate

Previously revenue water quantity was estimated as 54.52 MGD while supplied quantity was estimated as 160 MGD. Non-revenue water is calculated as 105.48 MGD or 66 % and the detailed water balancing analysis for non-revenue water amount is shown in Table 3.8. Non-revenue water amount in YCWSS is high because of leakage in old pipes, free water supply to religious buildings, water meters malfunction and illegal connections.

Table 3.8: Non-revenue water analysis of YCWSS

<table>
<tr><td rowspan="4">Total water supply volume 160 MGD (100%)</td><td rowspan="2">Authorized water consumption</td><td>Billed authorized consumption</td><td>54.52 MGD (34%) Revenue water</td></tr>
<tr><td>Unbilled authorized consumption</td><td rowspan="3">105.48 MGD (66%) Non-revenue water</td></tr>
<tr><td rowspan="2">Water losses</td><td>Commercial losses
Unauthorized consumption
Meter inaccuracies
Data handling errors</td></tr>
<tr><td>Physical losses (50% estimated)
Leakage in water facilities
Leakage in pipelines
Leakage in meters & connections</td></tr>
</table>

Water billing system

In YCWSS, metered connections are charged by fixed rate per unit billing system in every month, and unmetered connections are charged by flat rate billing system in every quarter of the year, i.e. every three months. Even though customers can be categorized in to four types: domestic, commerce, department, and FOC, there are only two charged rates, i.e. 0.085 € (110 MMK) per m^3 for commercial connections and 0.068 € (88 MMK) per m^3 for other connections except FOC connections. Flat rate billing system is charged depending on the estimated monthly water consumption.

3.3.2.4 *Problems in YCWSS*

Various problems, relating with technology, organization, institution, and finance & management that are encountering in YCWSS are listed in the following Table 3.9.

Table 3.9: Major problems facing in YCWSS

Technical problems	**(1) Low demand coverage** **(2) High non-revenue water amount** **(3)** Poor water quality **(4)** Ageing water facilities and main pipelines **(5)** Inappropriate layout of facilities **(6)** Insufficient O&M of facilities
Organizational problems	**(1) Lack of planning section** **(2) Lack of monitoring section** **(3)** Lack of O&M and management according to PIs **(4)** Poor awareness of customer services **(5)** Poor water quality testing system **(6)** Poor human resources development in the organization
Institutional problems	**(1)** Standards for installation of service connections **(2)** Standards for water meter **(3)** Standards for installation of individual storage tank **(4)** Standards for installation of individual pumping facilities **(5)** Inspection of installation works for service pipe
Financial Management problems	**(1) Cheap water price** **(2) Water pricing system** **(3)** Need for introducing corporate accounting system **(4)** Budget with little freedom **(5)** Computerization in limited services

3.3.2.5 *Consumer Survey*

In the Project for the Strategic Urban Development Plan of the Greater Yangon (2012), the household survey was carried out in every township with the total 10,000 households sample, i.e. 1 % of each township's households (JICA & YCDC, 2014). The questionnaires related to water are regarding about water source, access to water and consumption, evaluation of existing service level and water-borne diseases (see details in Appendix A). The following results were obtained from this survey.

Major Water Source

The water source for various purposes except drinking purpose is private tube well (37%), followed by YCWSS piped water (34 %) and neighbour's well (9 %). This 34 % of YCWSS piped water is equivalent to the coverage of water supply system.

The main sources of drinking water are bottled water (45 %), private tube well (17 %), and YCWSS piped water (12 %).

Desirable Water Amount

About 74 % of the respondents answered that they satisfied with the current consumption amount i.e. 30 gpcd, and 11% wanted to consume two times of the current consumption.

Expenditure for Water

The average expenditure of a household for drinking water is about 4.3 € (5600 MMK) per month and 3.4 € (4400 MMK) for other use. Some respondents answered high expenditure, so that the mean is higher than the median. The median shows 1 € (1300 MMK) for drinking water and 0.55 € (700 MMK) for other use, so it is estimated that the general public spends 1.55 € (2000 MMK) per month for water supply.

Willingness to Pay for Water Supply Services

The question on their willingness to pay for drinkable water supply 24-hour services was asked of all respondents. For untreated water supply, 54 % answered less than 0.8 € (1000 MMK) per month, and for a drinkable water supply, 44 % answered less than 0.8 € per month. The average willingness to pay the amount was 1.88 € (2400 MMK) per household per month and the monthly average water-consumption per household was also estimated 13.9 m^3. Therefore, the average willingness to pay per cubic meters was estimated as 0.135 € (175 MMK). If this amount is compared to the current tariff rate for domestic use, which is 0.068 € (88 MMK), the current tariff rate is almost half time lower than the willingness to pay the amount.

Focusing on the relationship between willingness to pay and monthly household income, the willingness to pay the amount per month is equivalent to 1.4% of the monthly median household income, i.e. 135 € (177500 MMK). Therefore, it is less than 4% of the income that is considered as a typical benchmark parameter.

As a result, the current tariff rate level and a willingness to pay rate are relatively low. If it is assumed that the affordability to pay is 4% of monthly average household income, the affordability to pay for water supply services is 0.385 € (500 MMK) per m^3.

Waterborne Diseases

1.4 % of the respondents' household members suffered from the diarrhoea, and other diseases such as dysentery, Cholera and typhoid are low (0.1 ~ 0.6 %). The percent for one-time infection in a year is 50.6 %, and 2-5 times is 45.6 %.

Satisfaction of YCWSS Service

According to the Household Survey, the degree of satisfaction on YCWSS is lower than that on other sources. This means that YCWSS cannot supply an adequate amount of safe drinking water to the customers continuously due to the limited amount of water source and inadequate capacity of water supply facilities.

3.3.2.6 *Service level target for future*

In the project for the improvement of YCWSS, the service level targets for the performance indicators (PIs) are set for the future (in Table 3.10).

Table 3.10: Service level target of YCWSS (JICA & YCDC, 2014)

PIs	Target Year						
	2013	**2018**	**2020**	**2025**	**2030**	**2035**	**2040**
Non-revenue water (%)	66	51	46	**35**	26	20	**15**
Leakage rate (%)	50	37	33	**25**	18	13	**10**
Demand coverage (%)	35	45	50	**60**	65	70	**80**
Served population (million)	1.8	2.6	3.0	**4.1**	5.1	6.2	**8.0**
Water consumption (gpcd)	30	30	30	**35**	35	35	**40**
Supply Pressure (bar)	0.75			**> 1.5**			
Supply duration (hour)	8hrs.			**24hrs.**			
Water quality	Non-drinkable	**Drinkable**					

To achieve these targets and to meet the increased water demand, the future management plan for water supply sources of YCWSS is implemented. According to this plan, groundwater abstraction in Yangon City need to be gradually reduced, and not utilized after 2025 to prevent groundwater table lowering, saline water intrusion, and land subsidence occurring. In addition, alternative water sources, such as river water sources, are deciding to implement for future demand. The proposed future development projects are listed in the below Table 3.11. According to the feasibility study for these projects, the data of potential rivers, which are estimated by using the data of MoAI reports (see in Appendices), are about 9984 MGD in Kokkowa River and 23424 MGD in Toe River and that potential water source amount is much higher than the withdrawal amount of the respective projects which is 240 MGD in Kokkowa River project and 180 MGD in Toe River project.

Table 3.11: Proposed future development projects of YCWSS (JICA & YCDC, 2014)

Project	Start-up year & Water supply capacity					
	2018	**2020**	**2025**	**2030**	**2035**	**2040**
Lagunpyin Reservoir (40 MGD)	40MGD	-	-	-	-	-
Kokkowa River (240 MGD)	-	15MGD	45MGD	60MGD	120MGD	-
Toe River (180 MGD)	-	-	15MGD	15MGD	30MGD	120MGD
Total	**40MGD**	**15MGD**	**60MGD**	**75MGD**	**150MGD**	**120MGD**

Moreover, other management plans for the improvement of YCWSS will be established not only to increase the water supply but also to control the water demand. For example, non-revenue water control management plan, water billing system management plan, human resources development plan, etc.

4 Development of WEAP model for YCWSS

This part will describe the development of WEAP model for YCWSS. In order that the water supply in the future is sustainable and adequate in quality and quantity to meet the booming demand, WEAP model will be developed and applied to evaluate the existing YCWSS and expected future scenarios for YCWSS by taking into account the different factors and policies that may affect demand and supply sources.

WEAP is a practical tool for water resources planning which incorporates not only water supply-side and water demand-side issues, but also water quality and ecosystem preservation issues, by its integrated approach to simulate water systems and by its policy orientation (SEI, 2011). This model will simulate water supply system operation of the city on a user-defined time step; compute the water mass balance for all nodes and lines of WEAP, components of the water system and links of these components, for the simulation period; evaluate and forecast water development and management scenarios for the future (SEI, 2011; Hamlat et al., 2013). The results coming out from WEAP software can assist planners and water supply authorities in developing recommendation for future water supply and demand management. In this study, WEAP model is selected to use as a database tool, a forecasting tool, and a policy analysis tool to analyse about YCWSS to forecast for the future options.

Application of the WEAP model generally includes the following steps (SEI, 2011).

- **Setting up the *Study Definition*,** which includes the spatial boundary, the time frame, the system components, and the configuration of the problem
- **Entering data in the *Current Accounts***, which provides an overview of the actual situation of the system (water demand, supply resources, pollution loads), and can also be viewed as a calibration step in the development of an application
- **Creating *Key assumptions*** in the *Current Accounts,* if necessary, which represent policies, costs and factors that affect demand, pollution, supply, and hydrology
- **Building S*cenarios*** on the *Current Accounts*, which can be explored the impacts of alternatives on the future water supply and demand
- **Evaluating *Scenarios*,** regarding with water demand coverage, costs, compatibility with environmental targets, sensitivity to uncertainty

The conceptual framework of WEAP model that required various parameters and variables to carry out its simulation are illustrated in the following Figure 4.1.

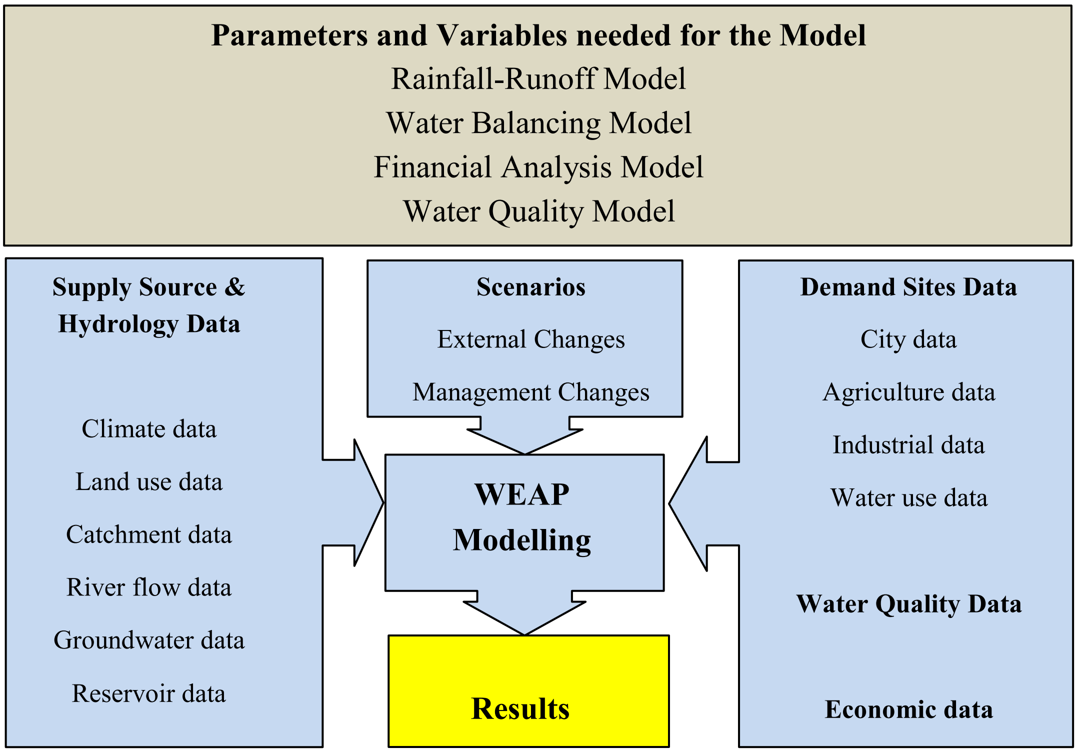


Figure 4.1: Conceptual Modelling Framework of WEAP

In designing the schematic representation of the YCWSS, both demand and supply sources are described not only as much as possible to represent the reality but also as simple as possible to comprehend the system easily. Therefore, unnecessary components, such as service water tanks and pumping stations, etc., are not shown in the schematic because these components are not affected on the WEAP model simulation and the scenario analysis for the whole city. However, to analyse the water supply and demand for the zones of the city with WEAP model, these components will be needed to consider, for example, the operation of service water tanks and pumping stations for different zones. Referring the Figure 4.2, the model schematic of YCWSS, this WEAP model consists of the following WEAP objects: 5 Catchments and 5 Runoff/infiltration links, 5 Reservoirs, 4 Groundwater Source, 6 Rivers and 1 Diversion, 13 Transmission Links, 3 Demand Sites, 1 Waste Water Treatment Plant, and 5 Return Flows. The systematic procedure for the development of the model and the entry data analysis of YCWSS will be expressed in the following sections, and then the detail data sets required for the model inputs will be attached in the appendix C.

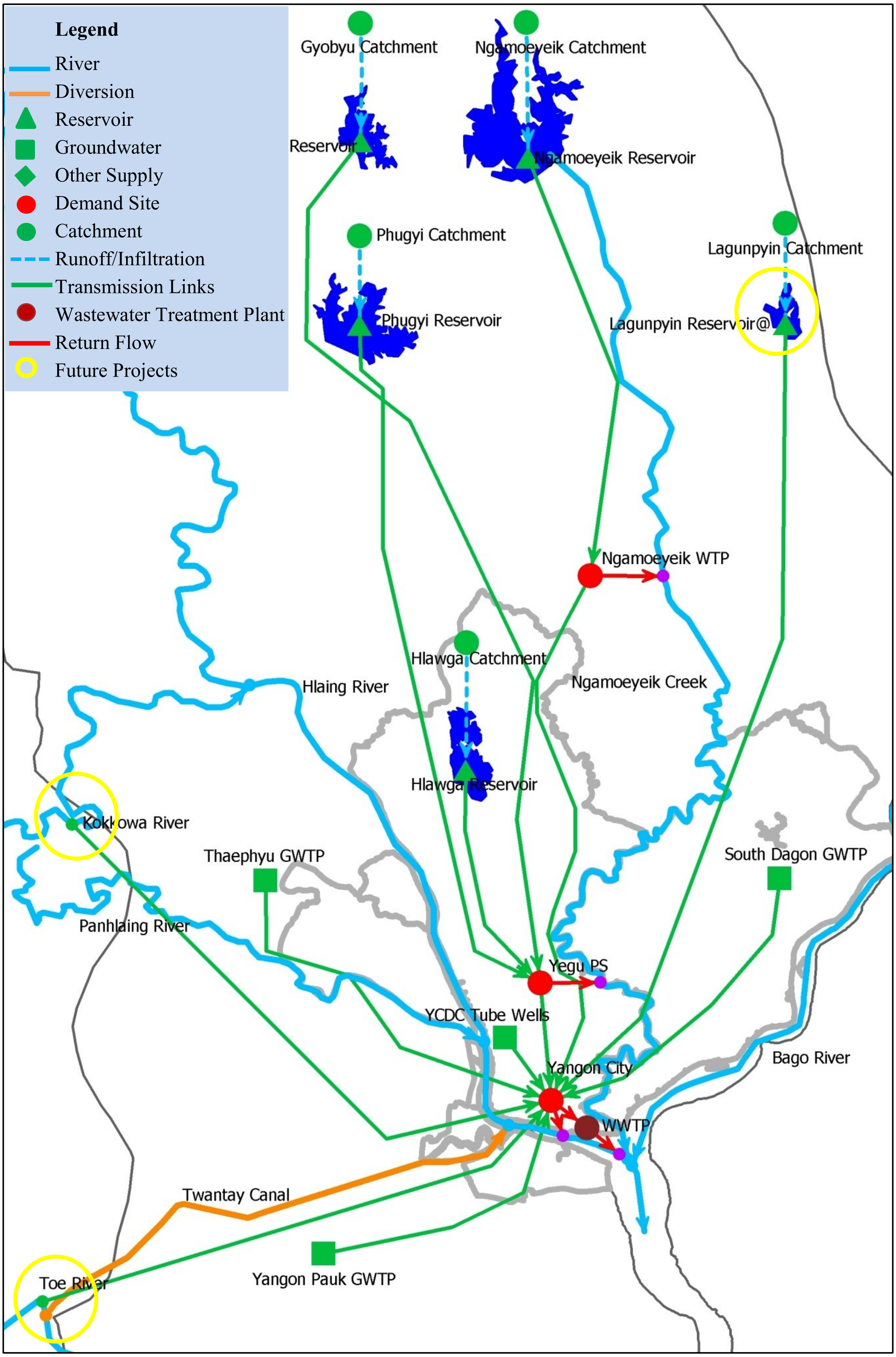


Figure 4.2: Simplified schematic for WEAP model of YCWSS

4.1 Study Definition

In developing a WEAP model, the study boundary, the study period, and the components of the study system are necessary to define as a self-contained set of data and assumptions. The study area can be defined as a specific water supply system, such as a river basin or a groundwater aquifer, or political or geographic boundaries (SEI, 2011).

The spatial boundary of the study area for YCWSS is initially created in WEAP by using the built-in GIS-based layers (Ocean, Country, States, Cities, and Major Rivers), and also by adding external raster layers (**Geo TIFF** or **ArcView GRID** files) and vector layers (**ESRI Shape files**) to orient and construct the system easily and to comprehend the system situation clearly. In this model, a raster layer is added as a background map, and other vector layers, such as Myanmar administrative areas, Myanmar water lines, Myanmar water areas, City area, Land use, Hydro features, Elevations, Reservoirs, are added to assist the model development and the results presentation. These added vector and raster layers are needed to adapt the geographic coordinate system with WEAP, which is WGS84, un-projected and directly based on latitude and longitude (SEI, 2011).

After creating the study area, the study period for the model is needed to define. For this model, the *Current Accounts Year* is set as **2013** and the *Last Year of Scenarios* is set as **2040**. The *Time Steps per year* is used as **12** based on a calendar month by starting in **January** and adding leap days. The *Current Accounts Year* is chosen to work as the base year of the model, and all system information, such as demand and supply data, on this year is input into the *Current Accounts.* Scenarios are built based on the data set of the *Current Accounts* and are explored for the possible changes to the system in the future until the last year of scenarios. A more detailed discussion of scenarios will be presented in Section 5.

The units of parameters, the water quality constituent parameters, and the basic parameters of the model can be predefined in WEAP. In this YCWSS model, most of the units are used in the British System, which is the local unit system in Myanmar (e.g. Imperial gallons for water volume, feet for length, squared miles for area), and the required unit conversions from the local system to the global system, SI system, are listed at the first part of this thesis. In this study, the water quality modelling will not carry out due to the insufficient data. In this model, different demand site components can have different monthly variation, and different supply site components can have different climate data.

In WEAP, the system components, such *as Catchments, Rivers, Reservoir, Groundwater, Demand Site, Catchment, Runoff/infiltration, Transmission Link* etc., can be defined by using its drag and drop graphical interface to describe and visualize the configuration of the water supply and demand system and its physical features. As it has been mentioned as before, the model for YCWSS is described as simple as possible to easily understand the system, by using current water supply sources (surface water from reservoirs and ground water from tube wells), future supply projects (river water from rivers), transmission pipelines from the supply source to demand sites. Yangon City is represented as only one demand site with aggregate method because this study is aimed to represent the supply-demand situation of the city level, and the acquired data is not sufficient to disaggregate the Yangon City. However, there are three demand sites in this model; one is Yangon City, and the other two are Ngamoeyeik WTP and Yegu pumping station to represent the some losses in these facilities. Nevertheless, the water from these facilities is transmitted to the Yangon City demand site in the end. In WEAP, nodes represent physical components of the system, and lines, which represent the transmission components of the system, link these nodes. Each node that represents the supply components may have a start-up year, and before this year, it cannot be active. Therefore, this feature can use to represent the component that will be implemented after the *Current Accounts* as future projects.

After the schematic of the system has been implemented, the required data for each component of the system must be inserted in the *Current Accounts* to stand for the actual situation of the system in current condition.

4.2 Data Entry in the *Current Accounts*

In WEAP, the data can enter either putting numerals directly or using WEAP data entry wizards, such as **Expression Builder** or **Time-Series Wizard** or **ReadFromFile Wizard** or **Lookup Function Wizard** (SEI, 2011). The data for **demand sites and catchments, supply and resources, hydrology, water quality, key assumptions** and **other assumptions** are needed to input under the *Current accounts* to represent the current state of the water supply-demand system. In scenarios analysis, the alternatives data are necessary to modify under the respective scenarios to analyse the impacts of these alternatives in the future water supply-demand.

The data entry for the *Current Accounts* (2013) of YCWSS model will be explained precisely in the following sub-sections and that for the *Scenarios* (2014-2040) will be described in the next section - **Creation of Scenarios in YCWSS-WEAP model**.

4.2.1 Demand Sites and Catchments

The demand sites in WEAP determines the total water amount that required to supply from the sources and the catchments in WEAP carries out rainfall-runoff analysis in a specific area and transmits runoff water to the other water facilities such as reservoirs, rivers, and infiltrated water to groundwater aquifers by balancing water inputs and outputs (SEI, 2011).

4.2.1.1 *Demand sites*

Demand site can be defined as a set of water users sharing a physical distribution system or an important withdrawal supply source in a defined region (SEI, 2011). Demand sites can be lumped together into aggregate demand sites or demand sites for different water uses can be disaggregated into individual demand sites, and this aggregation level is generally determined by the level of detail for water use data available and the level of detail desired for analysis (SEI, 2011). In this study, the demand data cannot be available for individual sites of Yangon City, that means the detail data for differ water uses (industrial or domestic etc.) and different zones of Yangon City, but can be available for the whole city, moreover, the level aimed to analyse for this master thesis is the whole city level.

Defining demand sites can be used not only for the actual water uses, such as city and agriculture, but also for the other physical infrastructure, such as pumping stations, withdrawal facilities, water treatment plants and well fields (SEI, 2011). Demand sites in WEAP can be defined according to the following groupings, as major cities or counties, individual user that manages a water withdrawal point, irrigation sites, demands which return to a wastewater treatment plant, water utilities (SEI, 2011). In this YCWSS model, Ngamoeyeik water treatment plant, and Yegu pumping station also take into consideration as demand sites together with the Yangon City, a major demand site for this study. For determining the water demand for these demand sites, **annual demand with monthly variation method** is used in this model. Therefore, the input requirements for demand sites under this method are **water use data**, such as annual activity level, annual water use rate, monthly variation, consumption, **loss and reuse data**, **demand management data**, and **demand priority**.

Water demand is calculated by multiplying the **activity level**, a measure of social and economic activity such as population or households for city and hectares for agriculture area, with the **water use rate** (SEI, 2011). The water use data of all demand sites in YCWSS model are listed in Table 4.1. **Monthly variation** for water consumption of Yegu PS and Ngamoeyeik WTP is used based on the proportions of the number of days in a month, however the actual monthly variation of the consumption for Yangon City is calculated by deriving from the actual monthly income of water meter bill of EDWS for the period of 2007 to 2013. This calculation for monthly variation cannot derive directly from monthly income because of different connection number in different months and the water unit-price changes in the study period, thus, unit consumption variation in a connection is used in this study. Firstly, the total actual monthly income is converted into the monthly water charge amount per connection by using total connection number in the respective month. Then, that monthly water charge amount per connection is converted again into the monthly consumption unit per connection by using the water price per unit. At last, the monthly variation percent is calculated by finding the proportion of monthly consumption unit in total annual consumption unit. **Consumptions** for the demand sites are a fraction of their inflows, which represent the water losses to evaporation or treatment or unaccounted amount for, and these amounts are lost from the system (SEI, 2011). According to the data from the water balance research in Germany, the actual consumption amount of urban areas is only 16% of the total inflow and the rest 84% is the return flow to the environment. So, in this study, the consumption of the Yangon City is used as 16%, whereas that for Yegu PS is used as 8% and for Ngamoeyeik WTP is 16% depending on their structure types, Yegu PS is a closed-type system and Ngamoeyeik WTP is an open-type system.

Loss Rate is the distribution losses in a demand site and otherwise unaccounted for demands, such as physical leakage in municipal systems, unmetered water use in public parks and buildings, illegal connections, water used for line flushing, water use for firefighting etc., but it should not include **transmission losses** and should not be confused with **Consumption** (SEI, 2011). **Consumption** is lost from the system and can reduce the return flow, whereas **Loss Rate** is not lost from the system but can increase the supply requirements (SEI, 2011). **Reuse Rate** is water recycling or reuse to refer the processes in which water is used more than one application before discharge, and it reduces the supply requirement (SEI, 2011). In this YCWSS model, all losses from the whole system, i.e. NRW amount 66%, will represent with transmission losses in transmission links because of the lack of data for different losses. According to this assumption, there will be input as no loss rate and reuse rate in all demand sites of YCWSS.

DSM savings (Demand site management savings) represent the percent of reduction from the total monthly demand due to the various demand-side management strategies, for example, using water saving technology, using the block-rate water pricing (SEI, 2011). In this study, this function will use in scenarios analysis.

Priority is the demand site's priority for supply, relative to all other demands in the system and represent with integers, 1 is highest priority and 99 is lowest, and this user-defined demand priority system determines the order of allocations to demand sites (SEI, 2011). The main objective of this system is to supply adequate water to Yangon City. Thus, the priorities of all demand sites are used as 1.

Table 4.1: Demand sites data of YCWSS-WEAP model

Demand Sites	Yangon City	Yegu PS	Ngamoeyeik WTP
Annual Activity Level	5142128 cap	1 unit	1 unit
(Water Use Rate)	(30gpcd)	(95 MGD)	(45 MGD)
Annual Water Use Rate	10950 g/person	34675 MG	16425 MG
Monthly Variation (%)	Actual water use monthly variation (2007-2013)	Proportion of number of days in the month	
Consumption (%)	16%	8%	16%
Loss Rate	Assumed no loss		
Reuse Rate	No reuse		
DSM savings	No demand site management plan		
Priority	First priority (taken as 1)		

4.2.1.2 *Catchments*

Catchment is a user-defined area for hydrological processes such as precipitation, evapotranspiration, runoff, irrigation, and yields on agricultural and non-agricultural land (SEI, 2011). For a catchment, one of four methods, **Irrigation Demands Only** (Simplified Coefficient Method), **Rainfall-Runoff** (Simplified Coefficient Method), **Soil Moisture Method**, and **MABIA Method** (FAO 56, dual K_c, Daily), needs to choose to simulate catchment processes such as evapotranspiration, runoff, infiltration and irrigation demands, depending on the data availability and the required level to represent the catchment processes (SEI, 2011).

In this YCWSS model, there are five catchments, such as Gyobyu, Phugyi, Hlawga, Ngamoeyeik and Lagunpyin (Start-up year 2015), for the respective reservoirs, and **Rainfall Runoff (simplified coefficient method)** is used for the determining the runoff from these catchments to the reservoirs. This method determines the evapotranspiration using crop coefficients and the remainder of rainfall not consumed by evapotranspiration is simulated as run-off to a reservoir, or into a river, or infiltration into groundwater via runoff/infiltration links (SEI, 2011). Therefore, the input requirements for catchment under this method are **land use**

data, such as catchment area, crop coefficient (K_c), effective precipitation, **climate data**, such as precipitation and evapotranspiration, **reuse data**, and **yield data**.

Around this study region, there are seven meteorological stations, which are administrated by Department of Meteorology and Hydrology **DMH** (Myanmar): namely, Hmawbi, Mingalardon, Kaba-aye, Bago, Tharrawaddy, Maubin, and Henzada stations, and the location data of these stations are listed in the following Table 4.2. The local climate data from these stations are used to simulate the catchments of YCWSS in this model. According to the following Figure 4.3, there are only three stations in Yangon Region and the actual local meteorological data of these stations from DMH will use in this study to represent the climate of its surrounding. Hmawbi station is used for Gyobyu, Phugyi, Ngamoeyeik, and Lagunpyin reservoirs, and Mingalardon station is used for Hlawga Reservoir, and Kaba-aye station will be used to represent the climate of Yangon City.

Relating with the **land use** data of the catchment, the area of each catchment, the crop coefficient for each land class type, the effective precipitation in each catchment are necessary to input to represent the behaviour of hydrological processes in separate catchments. According to the land use map of Yangon Region 2012 (already described in Figure 3.10), these catchment areas are preservative zones by YCDC and covered with dense forest, sparse forest and scattered trees. In guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56, the crop coefficient **K_c** for tropical trees, for example rubber trees with maximum height 10m, is expressed as 1 (Allen, Pereira, Raes & Smith, 1998), so **K_c** values for all catchments in this study will be taken as 1.

Table 4.2: Location data of meteorological stations around Yangon Region

(Source: CLIMWAT 2.0, WMH, WMO)

Station name	WMO code	Longitude (ºE)	Latitude (ºN)	Altitude (m)
Mingalardon	48;096	96.13	16.9	29
Kaba-aye	48;097	96.16	16.86	16
Hmawbi	-	96.06	17.16	28
Henzada	-	95.41	17.66	26
Tharrawaddy	48;088	95.8	17.63	15
Bago	48;093	96.5	17.33	15

Effective precipitation in here is the percentage of rainfall available for evapotranspiration, and the remainder is for runoff (SEI, 2011). In this study, these effective precipitation values of each station for the period of 1991 to 2013 is computed from the respective station meteorological data, comparing the monthly precipitation data and the monthly reference evapotranspiration (ETo) data with FAO Penman-Monteith method.. Estimation of monthly ETo for the stations requires stations location, maximum temperature, minimum temperature, humidity, wind speed and sunshine hours data, and **CROPWAT 8.0 tool** is applied for this calculation.

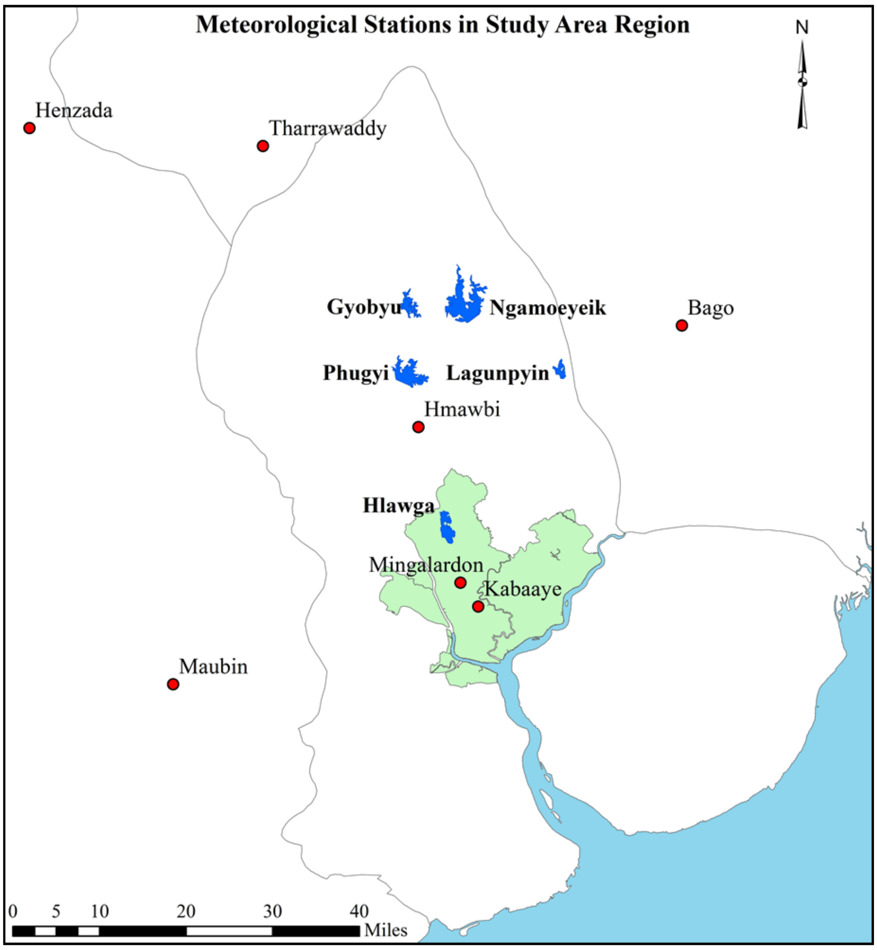


Figure 4.3: Meteorological stations of DMH around Yangon City

For **climate data**, actual **measured precipitation** data and **calculated reference evapotranspiration** data from 1991 to 2013 are inputs for every catchment. There is no **reuse water** and no **yield** data for agriculture from all catchments because these catchments are using only for water supply of Yangon City, except Ngamoeyeik reservoir, which is operated under the control of MoAI. Even though this reservoir is using for multi-purposes, it also assumed as using only for water supply in this study due to the difficulty to get the data for other fields, like as monthly agriculture water supply data. The data input for the catchments is summarised in the following Table 4.3.

Table 4.3: Catchments data of YCWSS-WEAP model

Catchment	Gyobyu	Phugyi	Hlawga	Ngamoeyeik
Area (sq-mi)	12.9	27.27	10.5	160
K_c	1	1	1	1
Effective Precipitation	Calculated monthly effective precipitation percentage (1991-2013)			
Precipitation	Local station monthly data (1991-2013)			
Evapotranspiration	Calculated monthly data using CROPWAT 8.0 from local station monthly climate (maximum temperature, minimum temperature, humidity, wind speed, sunshine hours) data (1991-2013)			
Reuse Rate	No reuse			
Yield	No yield			

4.2.2 Supply and Resources

Supply and resources section in WEAP determines the total water amounts, the available amounts, and the allocation of supply sources, and then simulates monthly river flows, surface water/groundwater interactions, instream flow requirements, hydropower generation, reservoirs storage, and groundwater storage based on the definitions of the system demand sites and catchments, and its hydrology (SEI, 2011). Supply and Resources in WEAP include different objects such as sources and links. Sources are **Local Reservoirs,** which are reservoirs not on the river, **Rivers and Diversions, Groundwater, Other Supplies,** which are alternative water sources as desalination. Links are **Transmission Links,** which link supply sources to demand sites and subject to losses, physical capacity, and other constraints, **Runoff and Infiltration links,** which link catchments to respective runoff flow destination, **Return Flows,** which route the wastewater from demand sites to wastewater treatment plants or rivers or groundwater nodes or other supply sources (SEI, 2011).

4.2.2.1 *Local reservoirs*

Local reservoirs in WEAP are managed independently on river streamflow and are needed to enter monthly **Inflows** from other water sources using different four input methods of WEAP. Besides, the other **Physical data** for local reservoirs, such as **Storage Capacity**, **Initial Storage**, **Volume Elevation Curve**, **Maximum Hydraulic Outflow**, **Net Evapora-**

tion, Loss to Groundwater, and **Observed volume**, are necessary to input for the simulation of reservoir operation in WEAP model.

Storage Capacity represents the total capacity of reservoirs and **Initial Storage** is the actual amount of water in reservoirs at the starting point of model simulation that means the initially stored water in the reservoirs at the beginning of the first month of the *Current Accounts* year. WEAP will balance the monthly inflows and outflows to compute the monthly storage volume of the reservoirs (SEI, 2011). **Volume Elevation Curve** can define the conversion between volume and elevation to compute the evaporation amount and/or energy production amount from hydropower (SEI, 2011). **Maximum Hydraulic Outflow** needs to define due to the hydraulic constraints in the reservoirs, and if there is no that constraint, WEAP will control the reservoir storage not to exceed the top of conservation zone (SEI, 2011). **Net Evaporation** is the difference between evaporation and precipitation on the reservoir surface, a positive value represents a net loss from the reservoir, and negative value represents the gain to the reservoir (SEI, 2011). **Loss to Groundwater** stands for the seepage losses from the reservoirs to groundwater, particularly in lakes and unlined reservoirs, and this function can be applied to model infiltration ponds and retention basins (SEI, 2011). Actual **Observed volume** data of the reservoir can be used to compare with the calculated reservoir storage data to assist in calibration of the model.

The physical data input for the four local reservoirs, Gyobyu, Phugyi, Hlawga, and Ngamoeyeik, of this YCWSS model are summarised in the following Table 4.4 and Volume Elevation Curves of the reservoirs are illustrated in the Figure 4.4. The monthly-observed volume data of the reservoirs for the period 2005-2013 are interpolated by using the daily water level data of the reservoirs and their volume elevation curves.

Table 4.4: Physical data of local reservoirs in YCWSS-WEAP model

Reservoir	Gyobyu	Phugyi	Hlawga	Ngamoeyeik
Inflow	Received simulated runoff from respective catchment			
Storage Capacity (MG)	16600	23000	12000	52000
Initial Storage	14946.24	18141.31	5539.24	45450.32
Maximum Hydraulic Outflow	Assumed as No hydraulic constraint			
Net Evaporation	Calculated monthly data using local station monthly evaporation and precipitation data (1991-2013)			
Loss to Ground water	Assumed no loss to groundwater			
Observed volume	Calculated observed volume of the reservoirs converted from daily reservoir level using Volume Elevation Curve by interpolation (2005-2013)			

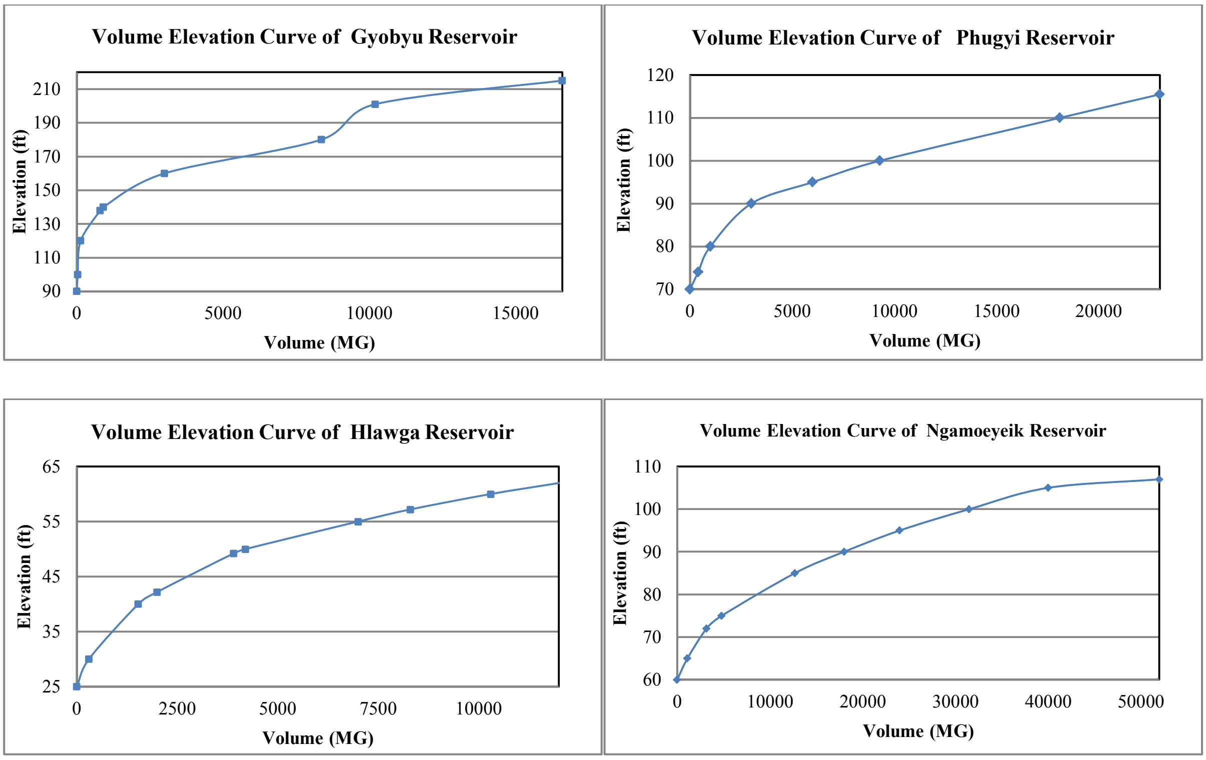


Figure 4.4: Volume Elevation Curves of Reservoirs in YCWSS

For the simulation of reservoir operation, reservoir storage is needed to divide into four zones from top to bottom as Figure 4.5, namely, Flood Control Zone, Conservation Zone and Buffer Zone and Inactive Zone. The conservation and buffer zones are the active water storage parts and the inactive zone is the dead storage part of the reservoirs, and WEAP will control the volume of water in the reservoir not to exceed the top of conservation in order to keep vacant the flood control zone (SEI, 2011). WEAP will allow the water from the conservation zone of the reservoir to release freely for demand sites, and if the storage level drops into the buffer zone, WEAP restrict the releases using the buffer coefficient, a fraction of the water in the buffer zone that is available for each monthly release, to conserve the reservoirs' dwindling situation (SEI, 2011). For the **Operation data** of the reservoirs, the volumes corresponding to **Top of Conservation**, **Top of buffer**, **Top of Inactive**, and **Buffer Coefficient** are required to enter as input data. The volume of Top of Conservation can represents the maximum volume of water in reservoir by leaving space for flood control, and in the case of reservoir without flood control function, it can be the same with the total storage capacity. The volume of Top of Buffer can represent the reservoir release restricted zone, and if water amount is less than this level, the release will be constrained depending on the buffer coefficient. The volume of Top of Inactive is not available for water allocation.

Moreover, some specific data are needed to enter depending on the different study fields in WEAP model, such as **Hydropower** generation data for the analysis of the hydro-power-generating reservoir, **Water quality** data for the quality analysis, Cost data for the costs-benefits analysis. **Priority** values are required to define for the determination of reservoir filling operation by using integers as 1 for the highest priority and 99 for lowest priority.

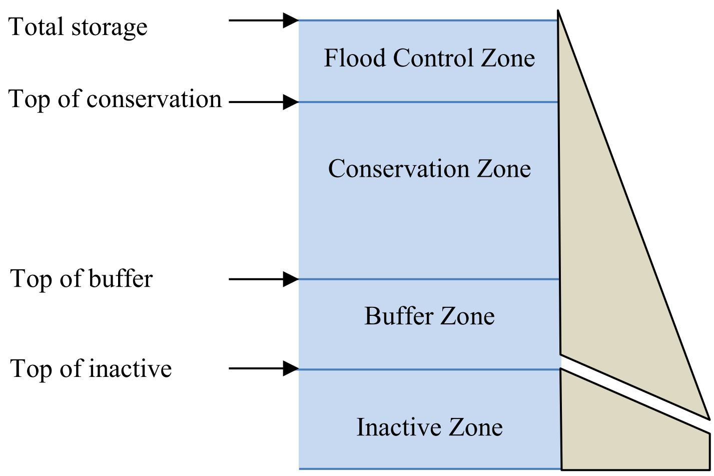


Figure 4.5: Zones of reservoirs in WEAP model (SEI, 2011)

The zones of the reservoirs from YCWSS are defined depending on their real operation's behaviour. As these reservoirs cannot carry out the flood control function, the volume at the top of conservation level is taken as the total storage capacity of the reservoirs. All of the reservoirs have at least two intake points. Thus, the first intake level is assumed as the top of buffer zone level to ensure the water supply service throughout the year. That means WEAP will control water releases if the water level is lower than the first intake level by using the buffer coefficient. In this study, the buffer coefficient is used as 0.33 that means one-third of the water below the first intake level will release each month, and the reason is to reserve the reservoir storage for the dry period, three months of summer. The input operation data of the reservoirs are listed in the following Table 4.5. The level for the inactive zone is used as the lowest intake level of the reservoir, however the top of inactive level for Gyobyu reservoir is used the second intake level instead of final intake level because of its water quality problem, i.e. the lower the water table in Gyobyu reservoir, the higher the turbidity significantly.

Priority values for all reservoirs are used as 99 in this YCWSS model so that all reservoirs will fill water after all other demands have been satisfied.

Table 4.5: Operation data of reservoirs in YCWSS model

Reservoir	Gyobyu	Phugyi	Hlawga	Ngamoeyeik
Top of Conservation	16600	23000	12000	52000
Top of Buffer	10200	3000	3900	18000
Top of Inactive	8360	400	2000	3160
Buffer Coefficient	0.33	0.33	0.33	0.33
Priority	99	99	99	99

4.2.2.2 *Groundwater*

Surface waters and groundwater are hydraulically connected, for example, stream can lose water as groundwater recharge or can gain water from the aquifer depending on the level of groundwater in the aquifer (SEI, 2011). Groundwater can get natural recharge not only from precipitation, but also from other sources, for instance, irrigation, in which a part of irrigated water may recharge the aquifer instead of taking up by the crop. Groundwater-surface water interactions can be simulated in WEAP by specify directly about groundwater- surface water flows or linking with groundwater- surface water flows model like as MODFLOW (SEI, 2011).

Groundwater nodes in WEAP can receive water inflows from natural recharge, infiltration of catchments, return flow of demand sites and wastewater treatment plant, leakage of transmission links and return flows, and river interactions (SEI, 2011). Groundwater nodes are needed to input the data for **Storage Capacity**, **Initial Storage**, **Maximum withdrawal**, **Natural Recharge**. **Storage Capacity** represents the maximum theoretically capacity of the aquifer, while **Initial Storage** represents the amount of water stored in the aquifer at the initial point of the model simulation, the first month of the *Current Accounts* Year. WEAP will balance the mass of monthly inflows and outflows in monthly basis to track the monthly groundwater storage, and WEAP will not allow the storage volume to exceed the storage capacity and not allow the storage volume to be negative unless WEAP is linking to MODFLOW (SEI, 2011). **Maximum Withdrawal** represents the monthly maximum withdrawal of all connected demand sites or the monthly maximum pumping capacity of the connected wells from this aquifer, and **Natural Recharge** represents the monthly inflow to the groundwater source without including the return flows from demand sites and surface water inflows from other sources (SEI, 2011).

In YCWSS, there are 645 YCDC-owned tube wells, including tube wells of three main GWTPs, withdrawing 20 MGD as a supplement source to reinforce the water pipeline network and to supply water in suburban areas that are far from the main water supply network of YCWSS. To study the groundwater system of Yangon City, there is no proper document and reliable paper to get the data about it. Therefore, some reasonable data are assumed to simulate the groundwater system. **Storage Capacity** for the aquifers is left blank by assuming unlimited storage capacity, and **Initial Storage** of the aquifers are estimated by using FAO groundwater potential data for lower Ayeyarwady delta region and the corresponding township areas where groundwater projects are located to represent the storage amount of the aquifers at the beginning of simulation. Lower Ayeyarwady river basin, from the confluence with Chindwin to its mouth, has about 95600 km^2 of the catchment area and 153.249 km^3 of groundwater potential (Ti & Facon, 2004). Monthly actual maximum withdrawal data only from YCDC owned tube wells are used to represent **Maximum Withdrawal** data, and **Natural Recharge** data is calculated using estimated effective natural recharge rate 100 mm/year and estimated effective area to recharge, i.e. 50 % of total area (JICA & YCDC, 2002; Döll & Fiedler, 2007; Taylor, 2013). The data used in groundwater simulation of YCWSS are listed in the following Table 4.6.

Table 4.6: Data of groundwater sources of YCWSS

Groundwater Source	South Dagon GWTP	Thaephyu GWTP	Yangon Pauk GWTP	YCDC Tube Wells
Storage Capacity	unlimited	unlimited	unlimited	unlimited
Initial storage	59888 MG	23977 MG	24841 MG	82694 MG
(Total Area)	170.16 km^2	68.13 km^2	70.58 km^2	234.96 km^2
Monthly Maximum Withdrawal	60.84 MG	30.42 MG	30.42 MG	486.67 MG
Monthly Natural Recharge	155.98 MG	55.77 MG	58.82 MG	215.38 MG

4.2.2.3 *Rivers*

Rivers and **diversions** in WEAP represent river nodes (river reservoirs nodes, Run-of-river hydropower nodes, flow requirement nodes, withdrawal nodes, diversion nodes, tributary nodes, return flow nodes, streamflow gauges) connected by river reaches, and other rivers may flow in or out of a river (SEI, 2011). Head flow data of the river and the maximum inflow of the diversions are necessary to insert for the simulation of the rivers and diversions system.

Even though Yangon City are surrounded by 6 rivers and 1 diversion, such as Yangon River, Bago River, Hlaing River, Kokkowa River, Panhlaing River, Toe River, Ngamoeyeik creek and Twantay Canal, there is no water supply from river source in YCWSS till now. In the future plan of YCDC and JICA, these rivers are potential water sources for the expansion of YCWSS and two river water supply projects, Kokkowa river project and Toe river project, are proposed to establish for future increased water demand. However, these projects are not active in Current Accounts, so about the data of rivers and projects will be discussed in the respective future scenarios.

4.2.2.4 *Transmission links*

Transmission links represent water transmission from reservoir, rivers, groundwater, and other water supplies to satisfy the required demand at demand sites as well as the transmission of wastewater outflows from demand sites and WWTPs to other demand sites for reuse, and **Supply preference** for each transmission link need to define for the water allocation (SEI, 2011). **WEAP** allocates water according to the demand priority if one supply source has more than one demand site and according to the supply preferences if a demand site has connections with more than one supply source (SEI, 2011).

Linking Rules in WEAP specify the mix of supply from multiple sources to analyst the observed allocation patterns in the Current Accounts and future scenarios of the model by defining **Maximum Flow (Volume)** to restrict the supply from a source, **Maximum Flow (Percent of Demand)** to restrict the flow using percent of the total requirement of demand site (SEI, 2011). **Loss from System,** as a percent of flow passing through links, represents the evaporation and leakage losses that will disappear from the system and **Loss to Groundwater** refers to the leakage losses that flow into a groundwater node.

In this YCWSS model, there are 13 transmission links, which are connecting the supply source to only one demand site, Yangon City, via Yegu Ps and Ngamoeyeik WTP. The maximum capacities of the sources are used as maximum flows of the transmission links in this model, and there is no constraint in every link and the supply preferences for all nodes is taken as 1 referring as first priority. Losses from the system in transmission links of surface water sources are used as 66% to represent NRW amount of Yangon City, however, that of groundwater sources are takes as 33% (half of NRW) because groundwater transmission pipeline system are shorter and leakage from this system is also smaller comparing with surface water system. Losses from system of the link from Ngamoeyeik reservoir to Ngamoeyeik WTP is assumed as 10% to represent the open channel transmission links and evaporation losses from it. Losses to Groundwater of all links are assumed as zero. The detail input data are summarised in the following Table 4.7.

Table 4.7: Data of Transmission links in YCWSS

Transmission Links From	To	Maximum Flow (Volume)	Maximum Flow (% of demand)	Supply Preference	Loss from System	Loss to Groundwater
Phugyi R	Yegu PS	54 MGD	No constraint	1	66	0
Hlawga R	Yegu PS	14 MGD	No constraint	1	66	0
Gyobyu R	Yegu PS	27 MGD	No constraint	1	66	0
Ngamoeyeik R	WTP	45 MGD	No constraint	1	10	0
Yegu PS	**Yangon City**	**95 MGD**	**No constraint**	**1**	**-**	**0**
Ngamoeyeik WTP	**Yangon City**	**45 MGD**	**No constraint**	**1**	**66-10**	**0**
South Dagon GWTP	**Yangon City**	**2 MGD**	**No constraint**	**1**	**33**	**0**
Thaephyu GWTP	**Yangon City**	**1 MGD**	**No constraint**	**1**	**33**	**0**
YCDC Tube Wells	**Yangon City**	**16 MGD**	**No constraint**	**1**	**33**	
Yangon Pauk GWTP	**Yangon City**	**1 MGD**	**No constraint**	**1**	**33**	**0**
Lagunpyin R	Yangon City	Not active in Current Accounts				
Kokkowa River	Yangon City	Not active in Current Accounts				
Toe River	Yangon City	Not Active in Current Accounts				

4.2.2.5 *Runoff and infiltration*

Runoff/infiltration links represent the runoff and infiltration from catchments to reservoirs, rivers, and groundwater nodes and Runoff Fraction values for branches are needed to define. In this model, five runoff links from five catchments are connected with their corresponding reservoirs and runoff fraction values for all links are taken as 100%.

4.2.2.6 *Return flow*

Return flow links represent the flow of water, which is not consumed at a demand site, to WWTPs, river or groundwater node, and other demand sites by defining as a percentage of outflows for **Return Flow Routing**, **Loss from System**, **and Loss to Groundwater**, and **Gain from Groundwater**. About 90 % of water coming out from Yangon City is directly re-entered to the environment and only 10% can be treated in WWTP, and after that, discharged into Yangon River. To represent this situation of YCWSS, the listed input data in Table 4.8 are used in this model.

Table 4.8: Data of Return Flows in YCWSS

Return Flow From	To	Return Flow Routing (%)	Loss from System (%)	Loss to Groundwater (%)	Gain from Groundwater (%)
Yangon City	WWTP	10%	0	0	0
Yangon City	Yangon River	90%	0	0	0
WWTP	Yangon River	100%	0	0	0

4.2.3 Others

4.2.3.1 *Waste water treatment plant*

Wastewater treatment plants in WEAP receive wastewater from demand sites, and treat it to remove pollutants, and then return treated water to other demand sites, river or other supply sources, and they are mainly used in water quality analysis. In YCWSS, there is only one WWTP with 1 MGD treatment capacity and the consumption of water in this WWTP is assumed as 16% of the inflow for this model simulation.

4.2.3.2 *Key Assumption and Other Assumptions*

In WEAP, **Key Assumptions** and **Other Assumptions** are used to create user-defined variables for all major modeling assumptions, particularly those will vary from scenario to scenario, to view and edit them conveniently (SEI, 2011). Key Assumptions are useful for applying the same expression in multiple places in the model or highlighting the major modelling assumption, and less important intermediate variables are defined as Other Assumptions (SEI, 2011). In this model, the annual population growth rate is defined as a key assumption to change easily in different scenarios and to use easily in multiple places.

After the WEAP model of YCWSS had been developed, the reference scenario to represent the current situation of the system and other alternative scenarios to represent the changes of system, such as socio-economic changes, climate changes, management changes in both demand and supply sides, would be created for the simulation of future options in YCWSS.

5 Creation of Scenarios in YCWSS-WEAP model

To implement the sustainable link between increasing water scarcity and growing water demand is becoming a challenge for the future in water management field. To explore the future option for water resources planning and management in the most sustainable way, IWRM models that can see the impacts of future trends are required. These models simulates to understand the processes and to analyse the future scenarios. In the model development, the real processes must be clearly comprehended to mimic these in the model, however the most relevant processes should be concentrated to simplify the model. Times-scale and spatial resolution are the main components in sustainable water resources management. The most important aspect of applying models is to explore indirect impact external driven scenarios, such as population growth and climate change, and direct impact management scenarios by water managers and policy makers, such as changes in reservoir operations, water allocation and agricultural/irrigation practices (See in Figure 5.1) (Immerzeel & Droogers, 2008).

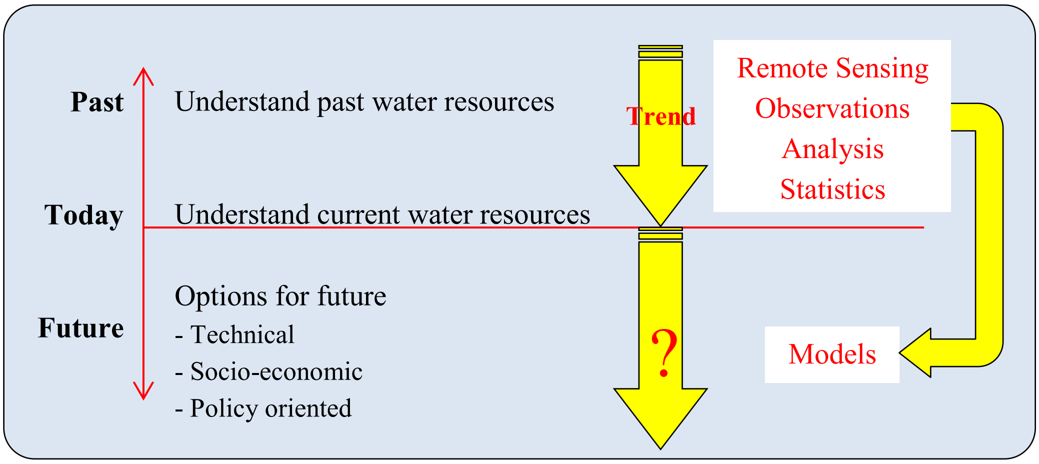


Figure 5.1: The basic concept of scenario analysis in IWRM model (Immerzeel & Droogers, 2008)

Scenario analysis can answer the 'what if' questions in a water supply system, by comparing the reference or business-as-usual scenario, which are developed by using the actual data for the understanding of current trend, and other scenarios, which are built on this reference scenario with changes on both demand and supply sides (SEI, 2011). This section will describe different scenarios based on the feasible changes in YCWSS to advance in WEAP model for city water supply options extending the current situation of the Current Accounts Year (2013) to the future until the Last Year of Scenarios (2040) with monthly time steps. The scenario analysis in WEAP will give out the results for flexible representation of the consequences of alternative development patterns and supply dynamics.

In this study, different scenarios relating with the external changes and different management alternatives will be created for the analysis of future water supply options in YCWSS. At first, reference scenario will be built to represent the current situation of the system. Then, the other scenarios, which represent the possible changes in the system supply sources and demand sites, will be constructed to study the impacts of these changes by comparing with the reference scenario.

5.1 Reference Scenario

Reference scenario, also known as a **default scenario** or **business-as-usual scenario**, is established from the Current Accounts, which represents the basic definition of the current system including the specification of supply and demand data for the first year of the study on a monthly basis, to stimulate likely evolution of the system without intervention (SEI, 2011). Reference scenario carries forward the current data into the entire time horizon in which no major changes are imposed and serves as a point of comparison for the other scenarios in which changes are made in the system data.

In this study, **Reference Scenario** will be applied to analyse the situation of YCWSS without any development in of the system except the population growth with normal growth rate 2.5%, Second phase of Ngamoeyeik WTP, and Lagunpyin reservoir water supply project, which is ongoing project started in 2013 and will finish in 2015. Design supply capacity of Lagunpyin reservoir is 40 MGD, and it will be initiated its operation in 2015. To set up this Reference Scenario (2014-2040), the additional data for population growth, new water sources are needed to add in it. Concerning about the population growth, the normal growth rate 2.5% is used to project the population until the end of study period. The second phase of Ngamoeyeik WTP was initiated in 2014, and the water supply capacity was increased from 45 MGD to 90 MGD. So, to represent these changes in the model, the maximum flow volume in the transmission link from Ngamoeyeik Reservoir to Ngamoeyeik WTP and that from Ngamoeyeik WTP to Yangon City are raised from 45 MGD to 90 MGD. Then, ongoing project using water source from Lagunpyin Reservoir and its water source, Lagunpyin Catchment, and its transmission links with source and demand site are added in this scenario by using the data, which are described in Table 5.1, and the climate data for this catchment and reservoir is used the data of the nearest meteorological station, Hmawbi station.

Table 5.1: Data of Lagunpyin Catchment and Lagunpyin reservoir in YCWSS

Lagunpyin Catchment	
Start-up Year	2015
Area	42 sq-mi
K_c	1
Effective Precipitation	Calculated monthly effective precipitation percentage (1991-2013)
Precipitation	Hmawbi station monthly data (1991-2013)
Evapotranspiration	Calculated monthly data using CROPWAT 8.0 using local station monthly climate (maximum temperature, minimum temperature, humidity, wind speed, sunshine hours) data (1991-2013)
Reuse Rate	No reuse
Yield	No yield
Advance	Rainfall-Runoff (simplified coefficient method)
Runoff link from Lagunpyin Catchment to Lagunpyin Reservoir with 100% runoff fraction	
Lagunpyin Reservoir	
Start-up year	2015
Inflow	Runoff from Lagunpyin Catchment
Storage Capacity	40373.61 MG
Initial Storage	40373.61 (assumed)
Volume Elevation Curve	Used design data
Maximum Hydraulic Outflow	No hydraulic constraint
Net Evaporation	Calculated monthly data using Hmawbi station monthly evaporation and precipitation data (1991-2013)
Loss to Ground water	Assumed no loss to groundwater
Observed volume	No data
Top of Conservation	Storage Capacity
Top of Buffer	Top of Inactive
Top of Inactive	1424.47 MG
Buffer Coefficient	1
Hydropower	No hydropower generation
Cost	No cost analysis
Priority (reservoir filling)	99
Transmission Links from Lagunpyin Reservoir to Yangon City	
Start-up year	2015
Maximum Flow (Volume)	40 MG
Maximum Flow (% of demand)	No constraint
Supply Preference	1
Loss from System	0
Loss to Groundwater	Assumed no loss

5.2 Other Scenarios

Besides the reference scenario, other scenarios are developed to understand the impacts of external changes in YCWSS and the effects of management practises in both demand and supply sides in this system. The following future scenarios will be developed and analysed in this study.

- **External driven scenarios**

Socioeconomic change scenarios

***High Population Growth (HPG) scenario*:** It analyses the situation with high population growth rate 3.5%.

***Low Population Growth (LPG) scenario*:** It analyses the situation with low population growth rate 1.5%.

***Higher Living Standards (HSL) scenario*:** It analyses the situation of increase in water consumption rate from the present rate 30 gpcd to 40 gpcd in 2040 because of higher living standards.

Climate change scenario

***Climate Change (CC) scenario*:** It analyses the situation of water supply system under climate change data.

- **Management scenarios**

Demand-side management (DSM) scenarios

***DSM-Water-Pricing Policy (WPP) scenario*:** It analyses the situation with changing water-pricing policy.

***DSM-Sustainable Water Source (SWS) scenario*:** It analyses the situation with introducing new sustainable water sources in demand-side such as rainwater harvesting.

Supply-side management (SSM) scenarios

***SSM-NRW Control (NRWC) scenario*:** It analyses the situation with NRW control management plan.

***SSM-Alternative Supply Source (ASS) scenario*:** It analyses the situation with the development of the system start-using alternative water source, river water source, and stop-using groundwater source in 2025.

Based on these future scenarios, the best management option for future water supply of Yangon City in the worst condition will be figured out by integrating these different scenarios, as the following Figure 5.2, in the scenario analysis of YCWSS-WEAP model.

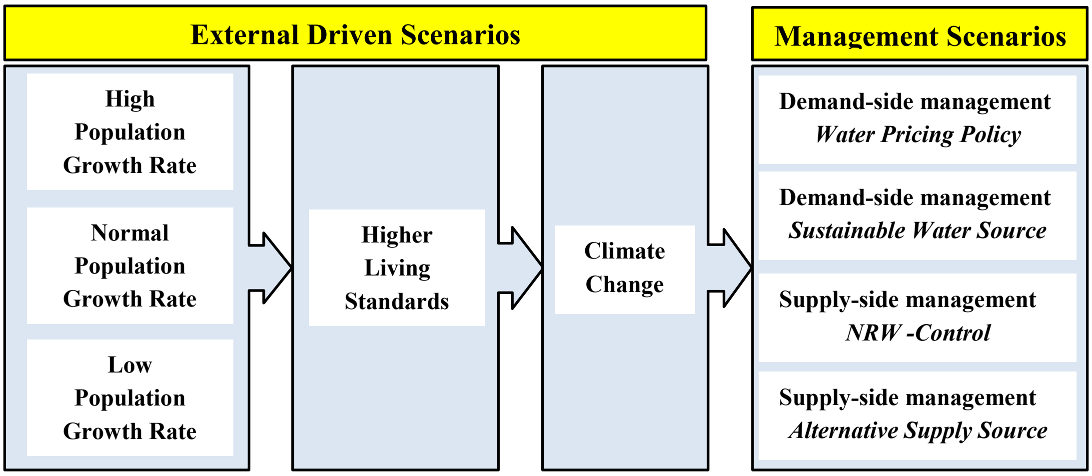


Figure 5.2: Different options for future water supply in Yangon City

5.2.1 External driven scenarios

5.2.1.1 *Socioeconomic Change Scenarios*

Yangon City is the largest urbanization area in the country because of being the former capital of the country. According to the report of Urban Planning Department of YCDC, the percentage of urban population in Yangon Region in 2012 is 76%, whereas the urban population percentage in the country is only 30% (Aung, 2013). Moreover, Yangon region contributes around 22% to the total national GDP as well as the region has the highest per capita GDP in the Union of Myanmar (Aung, 2013). According to the data from Urban and Regional Planning Division of Ministry of construction, Special Economic Zone, National Government Project, is start implementing in Yangon Region, and its first phase will start operate in 2015 with labour force around 50,000 and it will be developed gradually to the final state with the labour force about 200,000 in 2035. This means that migration of people from rural areas will be increased because of increasing job opportunities together with urbanization and industrialization.

Nowadays, Yangon City is encountering the socioeconomic changes, however, there is no reliable data about population because there was no national census data in Myanmar since 1981 until the end of 2013. In April 2014, Myanmar Government was taken the national socioeconomic data all over the country in order to use the national level development project by using these data. To draw the city's master plan and urban development projects, Urban Planning Department of YCDC is forecasted that the city's population will become 10 million in 2040, by using the past population growth rate in the period 1993-2013 that is 2.5 %. In addition, another high population growth scenario is also predicted by using 3.5 % because of national development projects in the city region, urbanization, and industrialization, and migration of rural people. On the other hand, the global forecasted data for the population and population growth rate of Yangon City is lower than the local data, and the fertile rate is declining especially in urban region together with increasing number of single and unmarried person. Therefore, the scenario with low population growth rate also should be considered to forecast the future population of Yangon City. The forecasted data using different population growth rate are illustrated in the following Figure 5.3.

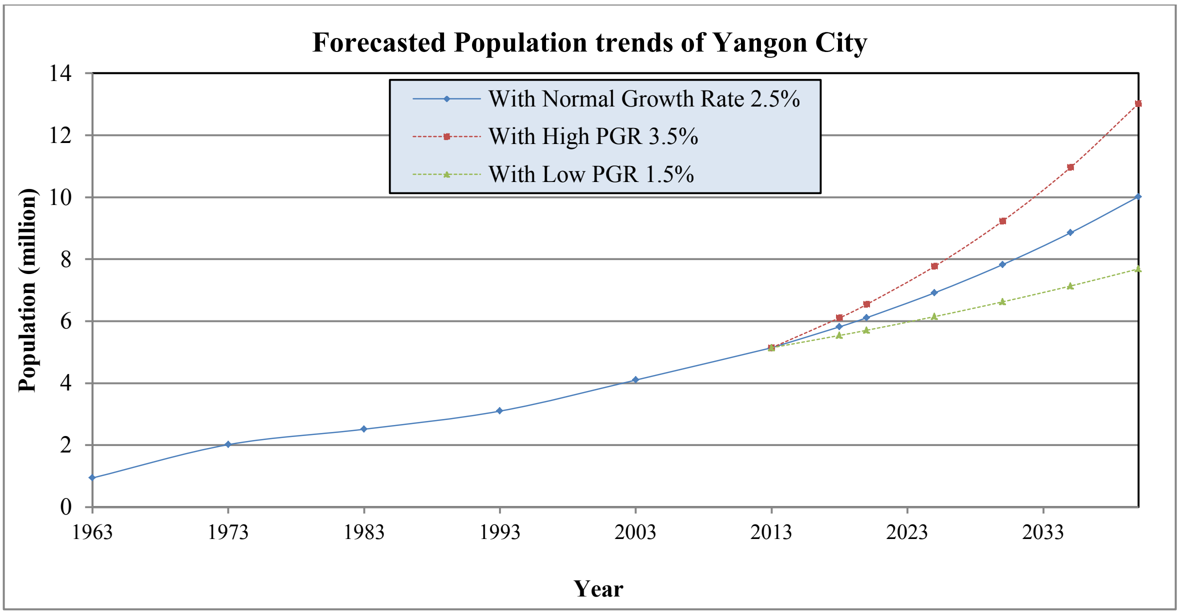


Figure 5.3: Forecasted data for future population growth rate

Since population growth is the main threatening reason for the water crisis, water planner wants to see how different population growth will affect on water sustainability (Ke, 2009; Ke & Qin, 2011 May). In this study, the scenarios related with population change will simulate using high population growth rate 3.5 % and low population growth rate 1.5 % and then the results of these scenarios will be analysed by comparing with the reference scenario, which is using normal population growth rate 2.5 %, to know the impact of this changes. The following two scenarios, only difference between these scenarios and the Reference Scenarios is the population growth rate, will be developed to explore the sensitivity to population.

High Population Growth (HPG) Scenario: This scenario looks at the impact of increasing population growth rate for Yangon City from normal population growth rate 2.5 % to 3.5 because of urbanization, industrialization, and migration of people from rural areas. Under this scenario, the *Annual Population Growth Rate* in *Key Assumption* is input as 3.5 % and the *Annual Activity Level* of Yangon City is calculated using this input data.

Low Population Growth (LPG) Scenario: This scenario looks at the impact of decreasing the population growth rate for Yangon City from normal population growth rate 2.5 to 1.5 because of the declination of the fertile rate. For WEAP analysis under this scenario, the *Annual Population Growth Rate* in *Key Assumption* is changed as 1.5 %, and the *Annual Activity Level* of Yangon City is projected applying this low rate.

Parallel with urbanization and economic development in Yangon City, water consumption rate will increase in order to achieve the higher living standards. Water consumption rate is becoming significantly increased due to rapid economic development, urbanization, migration, lifestyle changes and other social transitions in Asia Countries (Hubacek et al., 2009). According to the results of JICA research, the more urbanized city has the better water supply service and the water consumption rate for each person in that city is higher than the other cities (JICA & YCDC, 2014). The performance indicators (PIs), which can determine the service level of the city water supply system, of Southeast Asia cities are listed in Table 5.2, and the most urbanized city, Singapore, has the better water supply service with 100% coverage, 4% NRW, and 58 gpcd consumption rate.

Table 5.2: Performance Indicators of water supply service in cities of Southeast Asia countries (JICA & YCDC, 2014)

Country	Indonesia	Thailand	Vietnam	Singapore	Philippine	Cambodia	Malaysia	Lao PDR
City	Jog Jakata	Bangkok	Ho-Chi-Minh	Singapore	Davao	Phonon Penh	Kuala Lumpur	Vientiane
Population (million)	8.7	7.958	5.976	4.737	4.468	1.519	1.493	0.799
Water Coverage (%)	62	93	84	100	59	80	100	50
Water Use Rate (gpcd)	25	37	32	58	36	38	83	65
NRW (%)	50	29	41	4	25	6	35	28
Water Price (€ per m^3)	0.53	0.34	0.2	0.71	0.26	0.21	0.34	0.09
Statistical Year	2007	2009	2009	2008	2009	2007	2007	2007

For the improvement of water supply service in Yangon City as other Asian cities, YCDC put a plan to serve higher water consumption amount year-by-year becoming higher living standard with economic development in the future. In this study, the situation related with increased water consumption rate will analyse using the future target value of YCDC-JICA Master Plan, that is to improve the water supply for increased consumption rate from the present value 30 gpcd to 35 gpcd in 2025 and 40 gpcd in 2040.

Higher Living Standard (HSL) Scenario**:** This scenario looks at the impact of increasing water consumption rate corresponding to the higher living standard because of the economic development of Yangon City. For this scenario, the *Water Use Rate* for Yangon City is changed by using the smooth inclination form 10950 imperial gallons per person, i.e. 30 gpcd is multiplied by 365 days, in 2013 to 12775 imperial gallons per person in 2025 and 14600 imperial gallons per person in 2040 by using 30 gpcd and 40 gpcd rates.

5.2.1.2 *Climate change Scenario*

Climate change is important for the water supply system because it can change the existing water management situations and increase the requirement for new management options (Mounir et al., 2011). Climate change is important to water planners and decision makers but climate change can make confound water resources planning because of its uncertain effects and difficult prediction (Conway et al., 2009; Mounir et al, 2011). For the analysis of climate change effect in YCWSS, Climate Change (CC) scenario is constructed by using the climate data acquired from climate change model.

Climate Change (CC) Scenario: This scenario looks at the impact of climate change in Yangon City using the downloaded Global Climate Model data set of the Coupled Model Intercomparison Project, Phase 5 (GCM: CMIP5 full set) from KNMI (Koninklijk Netherlands Meteorological Institute) Climate Explorer website. GCM: CMIP5 (full set) includes multiple realisations of each model, downweighed to be the same weight for each model and there are four representative concentration pathways (RCPs), such as RCP2.6, RCP4.5, RCP6.0, and RCP8.5. In this study for YCWSS, RCP6.0, a stabilization scenario in which greenhouse gas emissions rise quickly up to 2060 and then decrease, is used to get the climate data set of Hmawbi weather station located at 17.16 ºN and 96.06 ºE in Yangon Region for the period 2014-2040. Under this scenario, the future climate data (2014-2040) of the catchments, such as precipitation and evapotranspiration, are applied by GCM model data, instead of cycling the historical data as in the reference scenario.

5.2.2 Management Scenarios

As urban water, utilities are facing increasingly water scarcity problems due to population growth, climate change and environmental issues, city water planners are trying to find management strategies not only to advance the water supply but also to reduce the water demand (Baerenklau, Schwabe & Dinar, 2013). To solve the encountering problems of YCWSS, and the indirect effects of external changes, local authorities and water managers of Yangon City also need to find out the strategies for both demand and supply sides management options. In this study, two demand-side scenarios and two supply side scenarios will be generated and analysed to help the decision makers for alternative policy, management options, and future development plans.

5.2.2.1 *Demand-side Management (DSM) Scenarios*

Water-pricing policies, water-saving technologies, and public awareness are some important management strategies to control the demand-side. In general, water authorities practise two kinds of water-pricing system, flat-rate system and block-rate system or also known as tiered water-pricing system. Tiered water-pricing system charge with a higher price per unit water for higher consumption rates, thus it encourages users to reduce their water consumption. Using tiered water-pricing system in residential areas can reduce at least 18 percent of the total water demand, although the reduction is achieved gradually (Baerenklau, Schwabe & Dinar, 2013). In addition, the amount of water consumption can drop 5 % when the water price is increasing about 10%, and that can drop 10 % when the water price is increasing about 40 % (Guo et al., 2006). Increasing water price can save the domestic water demand, and the water demand saving amount abstained by increasing water price in tiered water-pricing system is more effective than that in flat-rate system (Baerenklau, Schwabe & Dinar, 2013). The benefits generated by this pricing strategies such as water price change and water-pricing system change could be simulated in WEAP model estimating the demand reduction amount, such as annual activity level, annual water use rate, and DSM saving percent etc. With the aggregated approach for DSM, the estimated reduction fraction of total demand for a demand site due to DSM programs must enter under DSM Savings (SEI, 2011). In YCWSS, flat rate is practising for water-pricing system with unit water-price about 0.07 €/m^3 that is much lower than other Asian countries (see in Table 5.2). Therefore, YCDC is drawing a plan about the water pricing policy by increasing the unit price and changing to the tiered system. To study for the effects of this plan in YCWSS, the first DSM scenario by water-pricing policy is constructed using assumed water saving amount with 20%.

Moreover, sustainable water sources, such as rainwater, seawater and recycle-water, and water-saving technologies should be introduced to the city dwellers to improve the public awareness and to reduce the water demand from the urban area. However, desalination and recycling technologies are not suited with the developing countries because of high cost and energy requirements, and rainwater harvesting (RWH) is a potential technology for Yangon City. Using RWH in urban areas could solve not only the current water shortage problems but also the urban stream degradation and flooding problems (Fletcher et al., 2008). The quantity of harvested rainwater amount of RWH in urban areas can be simply calculated by multiplying RW harvested area with rainfall by using system efficiency 80% (UNEP, 2009). In Yangon City, even though it is impossible to implement the RWH technique in existing buildings, new constructions are possible to install the RWH facilities. Therefore, local authorities should encourage practising this technique in new buildings not only for demand control but also for city flood control option. In this study, the second DSM scenario using sustainable water source in demand side is built assuming one squared metre RW harvested area and one cubic metre RW harvested storage amount for each increased person after the Current Accounts year, and using system efficiency 80 %.

1st DSM - Water-Pricing Policy (WPP) Scenario: This scenario will point out the benefits of water pricing policy by analysing a situation with DSM program that is changing from fixed water-pricing policy to tiered water-pricing policy together with the increasing the water price from current price amount to an affordability to pay amount from customer survey's result. Under this scenario, the *DSM saving* amount is assumed that 20 % could reduce in the total monthly demand due to this change of water-pricing policy.

2nd DSM - Sustainable Water Source (SWS) Scenario: This scenario will show the effects of introducing sustainable water source in demand sites, in here Rainwater Harvesting (RWH) in Yangon city. In YCWSS model, firstly, RWH supply is created and connected to the Yangon City with transmission links via RWH reservoirs. This virtual RWH supply source and RWH reservoir represent the RWH facilities of the newly constructed buildings in Yangon City after 2013. Precipitation data of Yangon City, harvested area, calculated by multiplying 1 m^2 per capita rate with increased population in Yangon City after 2013 and 80 % efficiency rate, are used for the data of RWH supply source. After that, this water supply source is linked with RWH reservoir that represents the RW storage tanks in these building by assuming 1 m^3 volume amount for each person, and then this reservoir is linked with Yangon City using supply preference as 2 representing second priority source for Yangon City.

5.2.2.2 *Supply-side Management (SSM) scenarios*

Extension of the system using the reliable water resources is one of the major solutions to improve the water supply service, but controlling the physical water losses and commercial losses in the system also can increase the water supply amount without disturbing the environment and with less investment. Comparing with the other Asian countries, NRW amount in Yangon City, i.e. 66%, is much higher, and EDWS should be responsible to reduce that amount by laying a project and target plan to improve the quality and quantity of supply water. Future target for NRW control in YCDC-JICA master plan is to reduce NRW amount from 66% current amount to 15% in 2040 by using different improvement plans for the different non-revenue water sources. In this study, the first SSM scenario will construct concerning about the NRW control project using these future target values for NRW that are mentioned in YCDC-JICA master plan.

Additionally, alternative water sources should develop to cover the water supply amount for future water demand. The total water demand amount of Yangon City in 2040 will be 400 MGD using 40 gpcd rate for 10 million people without including any losses from the whole system. On the other hand, the total water supply amount in Yangon City is only 225 MGD including Ngamoeyeik WTP 2nd Phase (45 MGD capacity) and Lagunpyin Reservoir (40 MGD capacity) without including groundwater source. Therefore, EDWS proposed two new water supply projects by using river water source from Kokkowa River and Toe River (see in Table 3.11) and to stop using groundwater source in YCWSS in 2025 because of groundwater table lowering, saline water intrusion, and land subsidence problems. The development of the potential water source is necessary to meet the future water demand of Yangon City, and Kokkowa River, which has minimum river discharge about 1045 m^3/s, and Toe River, which has about 2448 m^3/s, are considered as potential water sources for Yangon City according to the feasibility survey for these rivers. The survey data for this river by JICA and MoAI are listed in the Table 5.3, and JICA study team calculated and estimated these data using the flow rates and cross sections of the rivers that are measured by MoAI. These MoAI report for river flow survey will be described in appendix B. As these river flows are much greater than the required water demand of YCWSS in 2040, YCDC and JICA decided to use these water as source and at present detail survey for the project are still processing. In draft plan, YCWSS will use 240 MGD amount from Kokkowa River and 180 MGD from Toe River by implementing phase by phase. These projects will construct as the second SSM scenario by using alternative water sources to see the role of these projects in future water supply.

Table 5.3: Survey data for river water source (JICA & YCDC, 2014)

River (capacity)	Minimum River Discharge	Irrigation Use	Maintenance Use	Potential Water Source	Project Target
Kokkowa (240 MGD)	1045 m^3/s	12 m^3/s	525 m^3/s	520 m^3/s (9984MGD)	15 MGD (2020) + 45 MGD (2025) + 60 MGD (2030) + 120 MGD (2040)
Toe (180 MGD)	2448 m^3/s	0 m^3/s	1228 m^3/s	1220 m^3/s (23424MGD)	15 MGD (2025) + 15 MGD (2030) + 30 MGD (2035) + 120 MGD (2040)

1st SSM - NRW Control (NRWC) scenario : This scenario will analyse a situation with establishment of NRW control management plan in YCWSS to decrease the NRW amount from 66% to 35% in 2025 and 15% in 2040 (same amount as future target of YCDC-JICA Master Plan). In YCWSS-WEAP model, these data is input reducing the losses of transmission links, as 66% NRW amount was used as transmission losses in the *Current Accounts*.

2nd SSM - Alternative Supply Source (ASS) scenario: This scenario will inspect the situation with development of the system using alternative source, river water from Toe River and Kokkowa River, including stop-using groundwater source in 2025. Two new river water source project will be added supposing minimum river flows (maintenance flow and irrigation flow are already deducted) as river flow for the whole year due to the lack of time series data, however this assumption can use safely because these minimum flows are much higher than the withdraw amounts by these projects. The supply preference values of the transmission links from these new sources to the city are taken as 2 whereas those values for the current sources were used as 1. This means that Yangon City will prefer the old water sources to check the role of the new water sources in YCWSS, and Yangon City will not use water from new sources if there is no unmet demand in the system.

To be concluded, four external driven scenarios (such as HPG, LPG, HLS, and CC) and four management scenarios (such as WPP, SWS, NRWC, and ASS) are generated in this YCWSS-WEAP model to comprehend the impacts of these effects in future water supply-demand system of Yangon City by comparing with the reference scenario and to assist the planners to choose the best management option for the future YCWSS.

6 Simulation and Evaluation of Scenarios

This part will present initially about the current situation of YCWSS by evaluating the simulated results of the Reference Scenario to understand the current situation of YCWSS, and these Reference Scenario results will also be used to verify this YCWSS-WEAP model is fit to represent the actual situation of YCWSS. After that, the positive and negative impacts of the different scenarios will be evaluated by comparing and contrasting the results of the Reference Scenario and the other eight scenarios, which represent possible alternatives of YCWSS in the future and the reliability of YCWSS in different scenarios, will be also pointed out in those cases.

Water flows through the system in WEAP is guided by the principle of mass balance like other simulation models. After entering the data for study area, WEAP can run its monthly simulation and report the results of projections for all aspects of the system, concerning about demand sites, supply sources, water quality, and financial data (SEI, 2011). One of the strengths of WEAP model is that results can be presented in graphs, tables, or maps. In addition, the results can be exported directly to Microsoft Excel for further data analysis, and there are multiple options to aggregate the results in time, space or different components to compare different scenarios easily (Van Loon & Droogers, 2006). The most important data for the future management of YCWSS will be presented in this section, mainly focusing on the results for demand coverage and unmet demand of Yangon City in the Reference Scenario (the Current Accounts) and the impacts of other alternative scenarios on demand coverage.

6.1 Evaluation of the Current YCWSS in Reference Scenario

The present situation of YCWSS can be evaluated according to the result of the Current Accounts, Reference Scenario. Before simulation of the scenarios, it is necessary to do the calibration and validation in WEAP, but WEAP has no automatic calibration operation and the changes implemented were tested manually by comparing the simulated and observed time series (SEI, 2011). In WEAP models, flows data are mostly used for calibration of the models. On the other hand, Water supply-demand models are complicated because they are required not only to simulate human behaviour for changes in demand but also to simulate physical processes of the water sources and facilities. This means that model calibration and validation is extremely difficult and has often been neglected in the past (McCartney & Arranz, 2007). In this YCWSS model, the calibration and validation of the model could not do properly because of the insufficient data and the method used for rainfall-runoff (simplified coefficient) method simulation. Nevertheless, the model performance was checked by using observed volume data of reservoirs of YCWSS from 2005 to 2013, and water coverage data of Yangon City in 2013. The Figure 6.1 shows that the graphs of the simulated data and the observed data for the reservoirs of YCWSS for the period from 2005 to 2013.

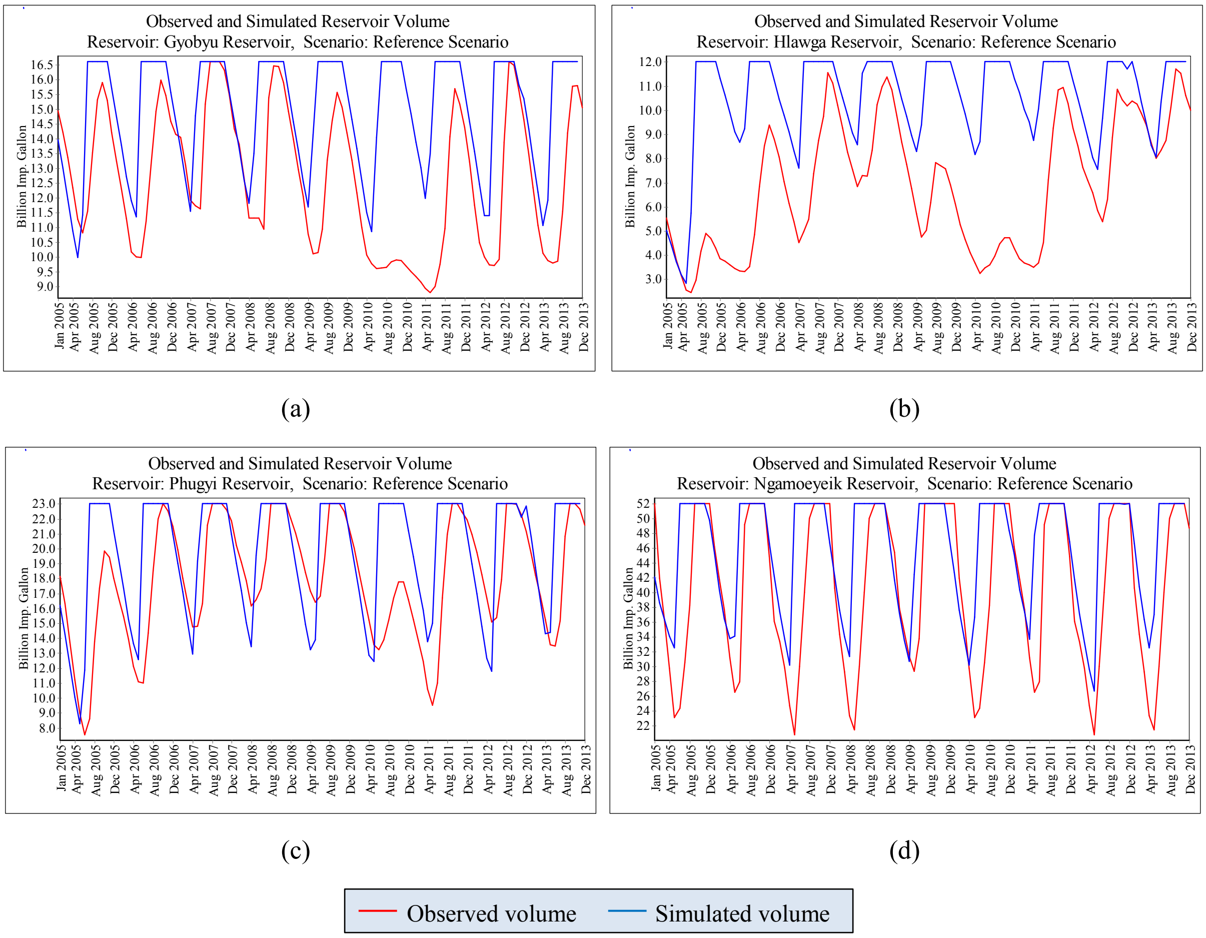
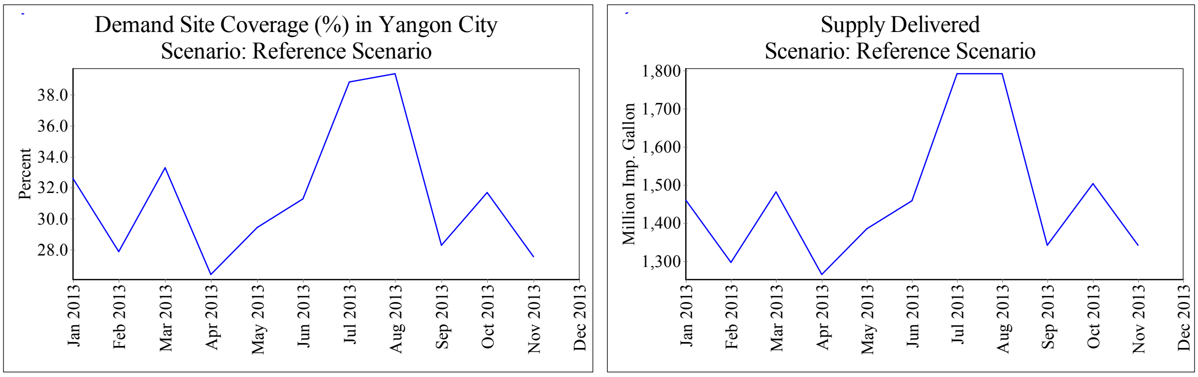


Figure 6.1: Observed volumes and simulated volumes of (a) Gyobyu Reservoir (b) Hlawga Reservoir (c) Phugyi Reservoir (d) Ngamoeyeik Reservoir (2005-2013)

According to these graphs, the trends of the curves are the same for the whole time series but the simulated volume curves are higher and earlier than the observed data. This YCWSS model is simulated by using the rainfall-runoff (simplified coefficient) method with land use data (area of the catchment, crop coefficient (K_c), effective precipitation) and climate data (precipitation, reference evapotranspiration data), and only K_c value can be used to calibrate the model. However, according to the sensitivity analysis results, that K_c value is not a sensitive parameter to calibrate this model. Mugatsia (2010) also pointed out that soil moisture method with more detailed data should be used to model the hydrology of the catchment with the aim of reducing the high peak hydrographs. It is obvious that there is some weakness in this simplified coefficient method, which is a lack of consideration about interflow and base flow processes and time of runoff concentration from the catchment to the reservoirs. Hence, the simulated water volumes in reservoirs are higher than the actual observed volumes, especially in the drought years as 2005 and 2010, and the simulated runoff are a bit earlier than the observed data. In hydrology studies used for management purposes, total volume errors below 10% are very good, between 10% and 20% is good, and between 20% and 30% is fair (Ingol-Blanco & McKinney, 2009). In this study, the differences between 9-year observed volume and model simulated volume in Gyobyu, Hlawga, Phugyi and Ngamoeyeik reservoirs are -18%, -53 %, -9%, and -12% respectively, and the coefficient of determination (R^2) for these reservoirs are 0.17, 0.18, 0.31 and 0.35. This means that the model is over-predicted and good to use for study according to the results of total volume errors, and according to the results of R^2, this model has high error variance.

Besides these supply-side results, the demand-side results also can be applied in the model performance analysis. The result data for demand coverage amount and supply delivered amount in Yangon City are shown in the Figure 6.2, the average demand coverage in Yangon City is about 31.16 % in 2013, and the average daily supply delivered amount in Yangon City is about 47.94 MGD in 2013. These data are nearly the same (less than 5% deviation) with the observed data, calculated depending on the actual data of EDWS (YCDC) in 2013, which is about 32.4 % for demand coverage and 50 MGD for daily supply amount in Yangon City.

In WEAP, the water supply amount in transmission links from reservoirs to demand site is controlled by using buffer coefficient only if the reservoir volume is lower than the buffer zone. In this study, reservoirs of YCWSS are rarely encountered about that problem in the past (2005-2013) not only in the simulated result but also in the actual observed data, apart from some cases that Gyobyu and Hlawga reservoirs faced that problem in drought years, 2005 and 2010 (see in Figure 6.1). Therefore, the observed and simulated water supply amount in the transmission links is the same in this YCWSS model, and the weak point of using rainfall-runoff (simplified coefficient) method for catchment simulation cannot disturb the water supply system of Yangon City as long as the reservoirs level are lower than their buffer zone. Therefore, this YCWSS model can be acceptable to use in the study for management purposes to analyse the future scenarios of water supply coverage in Yangon City.



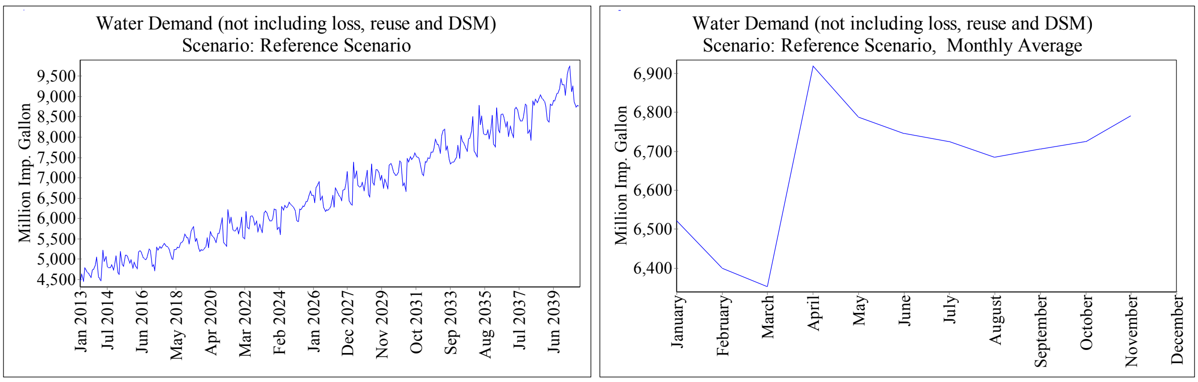
(a) (b)

Figure 6.2: (a) Demand coverage (b) Supply delivered amount in Yangon City (2013)

6.1.1 Estimation of Future Demand in YCWSS

According to the simulation results of Reference Scenario for water demand in Yangon City, which are shown in Figure 6.3, the future water demand in Yangon City is expected an increase from 4774 MG per month (154 MGD) in 2013 to 9300 MG per month (300 MGD) in 2040. According to the monthly average water-demand results, water demand in Yangon City is forecasted that it will be high in the summer, especially in April, and relatively low in other two seasons, the rainy season, and the cool season.

In this study, monthly water-consumption variation data was derived from the water-meter bill income of EDWS and the problem is that the monthly water consumption amount cannot get actual amount in March, which is the last month of the budget year. Staffs of EDWS collect the water meter readings in third week of the month in March and in last week of the month in the other months, thus, the water demand in March is the lowest comparing with the other months. Moreover, Yangon City get high rainfall in the rainy season but the water demand for this season is not much lower than other seasons, and it can be pointed out that people in Yangon City mainly consume the piped water without using rainwater.

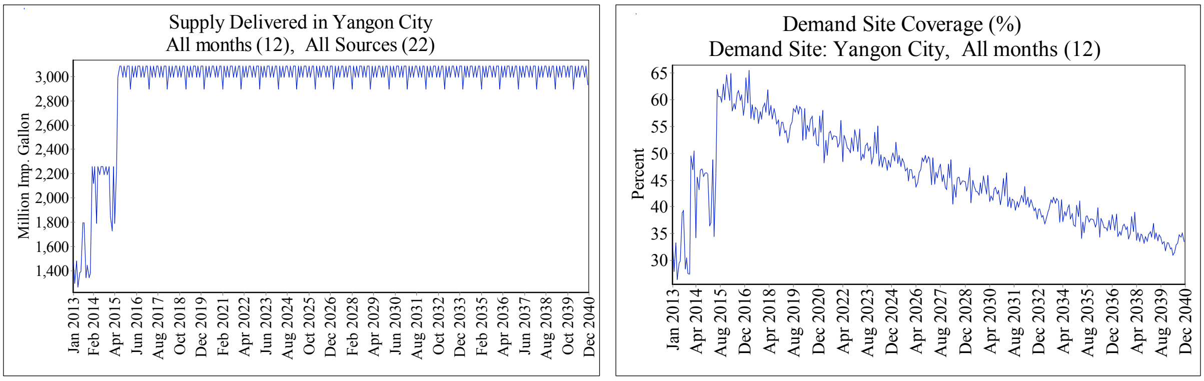


(a) (b)

Figure 6.3: Future demand of Yangon City in Reference scenario (a) 2013-2040 (b) monthly average

6.1.2 Prediction for Extension of YCWSS

The total water supply capacity of Current YCWSS was 160 MGD in 2013, and it will increase to 195 MGD in 2014 because of the second phase of Ngamoeyeik WTP, and 235 MGD in 2015 because of the ongoing project, Lagunpyin Reservoir. Therefore, the total water supply capacity of the whole system will be 235 MGD after 2015, and this situation is used as input data in this Reference Scenario, Current Accounts. In Reference Scenario, the result for the supply delivered amount in Yangon City is showing in Figure 6.4 (a) that there is an increase of from 1448 MG per month (47.62 MGD) in 2013 to 2190 MG per month (72 MGD) in 2014 and 304.76 MG per month (100 MGD) starting from June 2015 until the end of study period. According to the Figure 6.4 (b), the demand site coverage of Yangon City was increased significantly in 2014 and 2015 because of the continuing projects of YCDC, from approximately 31 % in 2013 to 45 % in 2014 and 53 % in 2015. Although the demand site coverage in Yangon City will be increased to 65.47 % in March 2017, it will be decreased gradually until 33 % in 2040 because of the steadily increased population.



(a) (b)

Figure 6.4: Reference Scenario results of (a) Supply delivered and (b) Demand site coverage in Yangon City (2013-2040)

The following Figure 6.5 illustrates that the unmet demand of Yangon City for the whole study period from 2013 to 2040. The average unmet demand in 2013 was about 3243 MG per month (106.6 MGD), and the unmet demand will decrease steeply to 2333 MG per month (76.55 MGD) in 2015, and afterwards it will increase steadily year by year and it will become about 6134 MG per month (202 MGD) in 2040. Generally, the unmet demand is the highest in April and the lowest in March, and the lowest unmet demand will face in June 2015, which is 1833 MG per month (61.1 MGD), and the highest will meet in April 2040, which is 6688 MG per month (223 MGD). According to these results, local authorities and water managers of YCWSS should draw a plan to extend the current system for the unmet demand problem of Yangon City. At present, YCDC and JICA are coordinating the implementation of water supply system development plan for Yangon City, and two river water supply projects with a total capacity 240MGD are included in this plan. Since the results of WEAP simulation are highlighted that 223 MGD for the future unmet demand for Yangon City, it is obvious that these two projects of YCDC are necessary to implement in YCWSS.

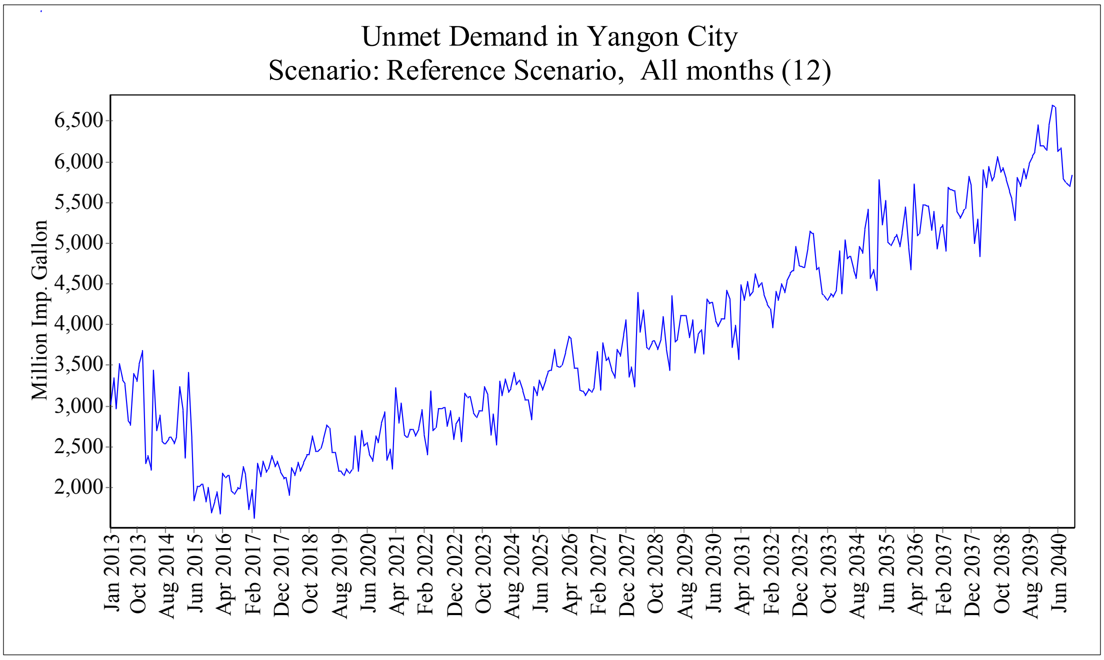


Figure 6.5: Unmet demand of Yangon City in Reference Scenario (2013-2040)

In this Reference Scenario, the situations of supply sources in YCWSS, which are surface water sources and ground water sources, can be evaluated by using the simulated results of WEAP. The below Figure 6.6 describes that the graphs of the runoff flows from the five catchments to their corresponding reservoirs of YCWSS for the study time horizon (2013-2040). In these graphs, runoff from the catchment will decline remarkably in some dry years like as 2020 and 2034. However, according to the simulated results of the reservoir storage volumes and zones of reservoirs, WEAP is forecasted that storage volumes of all reservoirs in YCWSS cannot be lower than the buffer zone until 2040, even though storage volumes of Gyobyu reservoir will approach to the buffer zone in some years. The Figure 6.7 lists the graphs for five reservoirs of YCWSS for the whole study projection starting from 2013 to the end of this study, 2040. Therefore, it is noticeable that all reservoirs of YCWSS are reliable for their operation until 2040 to supply their design water capacity to Yangon City via transmission links.

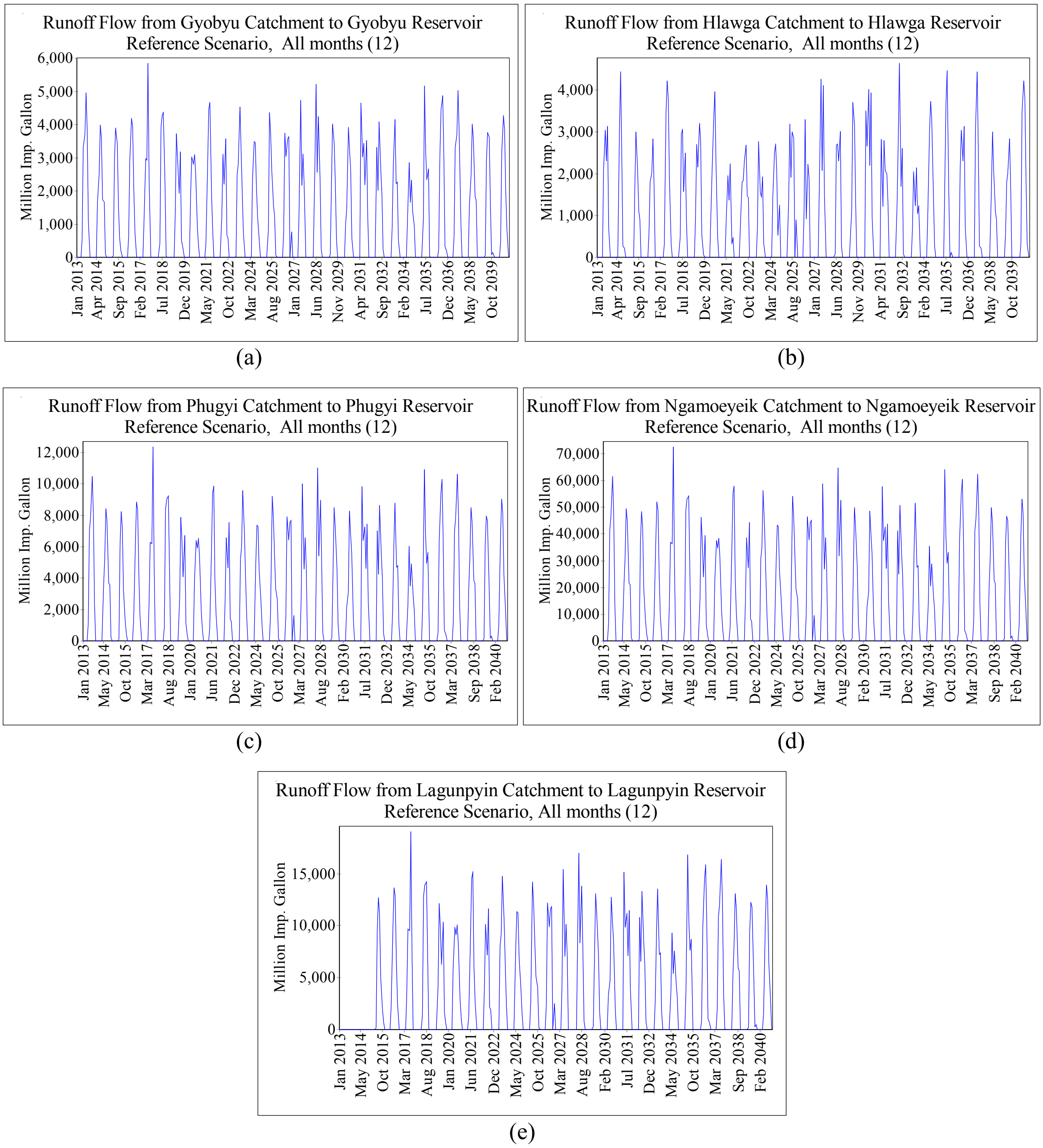
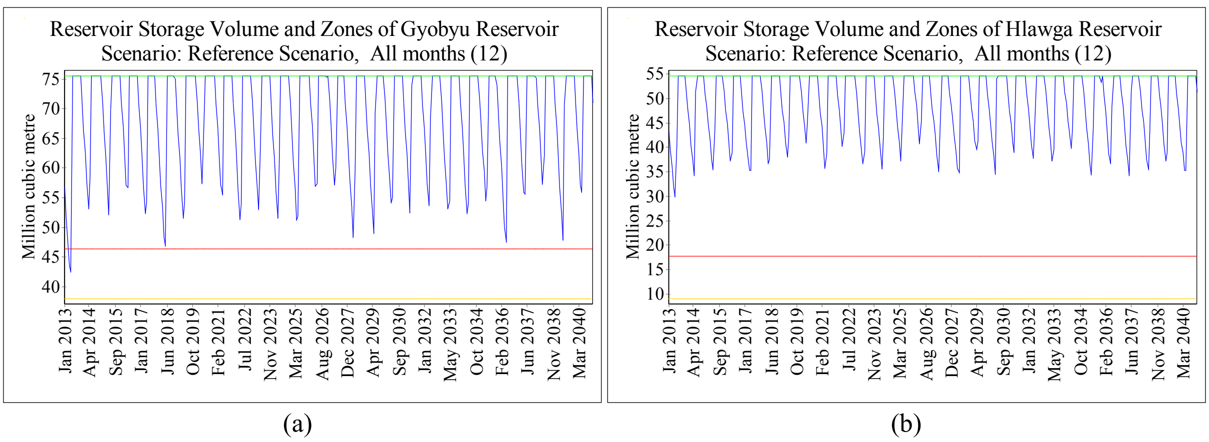
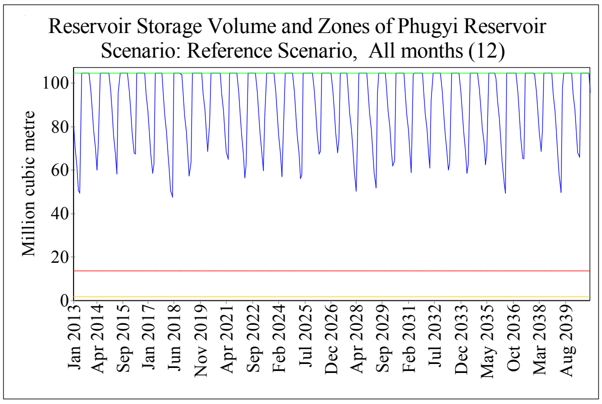
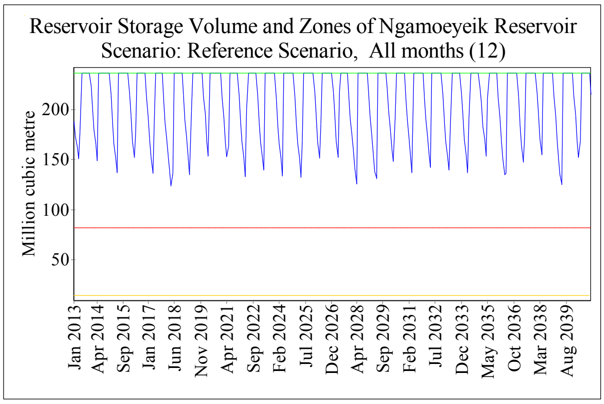


Figure 6.6: Runoff flow from (a) Gyobyu (b) Hlawga (c) Phugyi (d) Ngamoeyeik (e) Lagunpyin catchments to respective reservoirs of YCWSS (2013-2040)

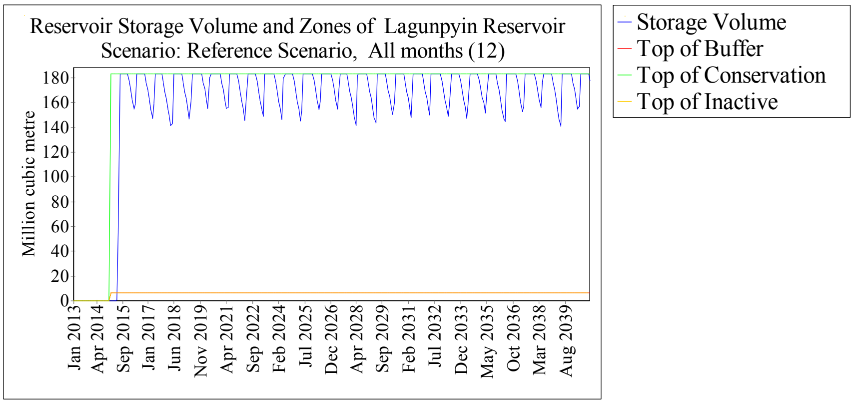




(c)



(d)



(e)

Figure 6.7: Simulated reservoir storage volumes and zones of (a) Gyobyu (b) Hlawga (c) Phugyi (d) Ngamoeyeik (e) Lagunpyin reservoirs of YCWSS (2013-2040)

The following Figure 6.8 represents the simulated results for future situations of groundwater sources in YCWSS, and in these results, the main groundwater source for YCDC tube wells is declining enormously due to the serious over-exploitation of groundwater, but groundwater analysis for YCWSS needs to revise by using the more reliable data. In YCDC-JICA study, it is pointed out that groundwater withdrawal amount is higher that groundwater potential in Yangon City and it encourage to stop using groundwater in Yangon City.

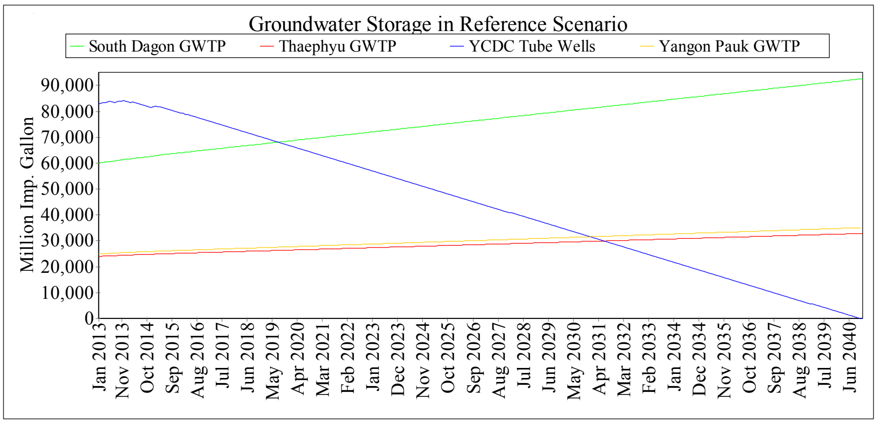


Figure 6.8: Groundwater storage changes in different groundwater sources of YCWSS (2013-2040)

Therefore, the current situation of YCWSS can be predicted that there will be a huge shortage in demand coverage and the unmet demand of Yangon City will be over 200 MGD in the late 2030s. The current YCWSS mainly depends on the surface water from reservoirs, which are seemed to be secure for the future whereas using groundwater source in Yangon City will have problem in future because of its limited amount and other environmental impacts. Moreover, external alternatives in the future, like as population growth and economic development of the city, and climate change, can have an effect on the situation of YCWSS, and these impacts will be discussed in the next section by simulating the different external driven scenario for YCWSS.

6.2 Impacts of External driven scenarios

The following Figure 6.9 and Figure 6.10 show the demand coverage and the unmet demand of Yangon City under four different external alternative scenarios, such as CC, HPG, LPG and HLS scenarios, comparing with the Reference Scenario for the simulation period 2013 - 2040. In general, there will be significant negative impacts on water demand coverage of Yangon City under HPG and HLS scenarios and large positive influence under LPG scenario, whereas there is no effect under the CC scenario (see in Figure 6.9). Likewise, the unmet demand amount in HPG and HLS will become higher gradually than that in Reference Scenario, but that in LPG Scenario is noticeable lower (see in Figure 6.10). However, there is no difference between the results of CC Scenario and Reference Scenario. The detail discussion for the result data of these scenarios can be described in the following sub-sections.

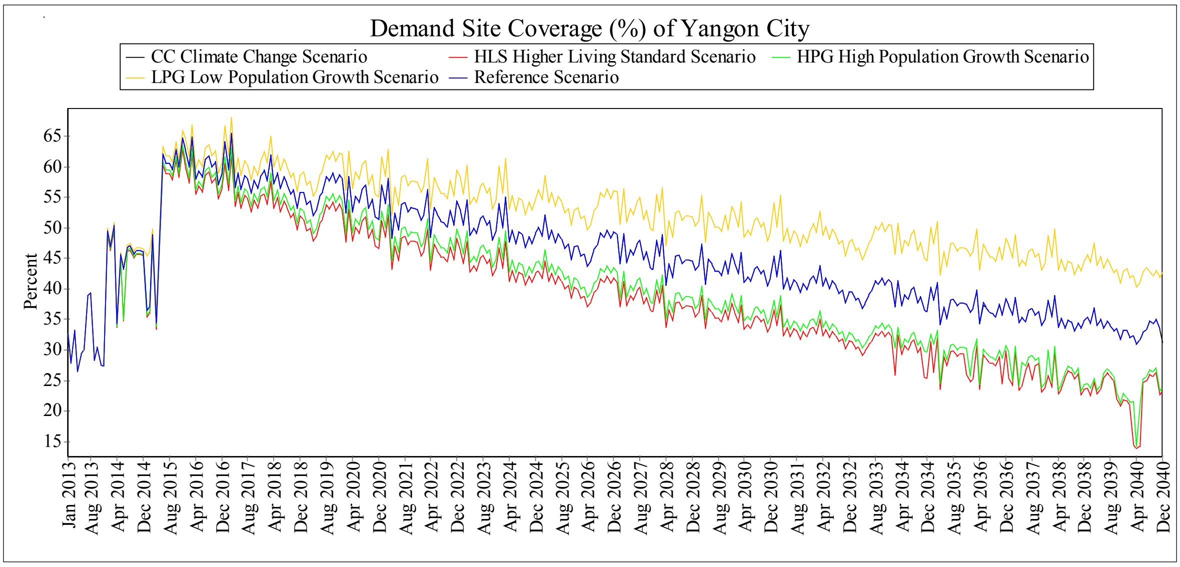


Figure 6.9: Demand site coverage of Yangon under different external driven scenarios (2013-2040)

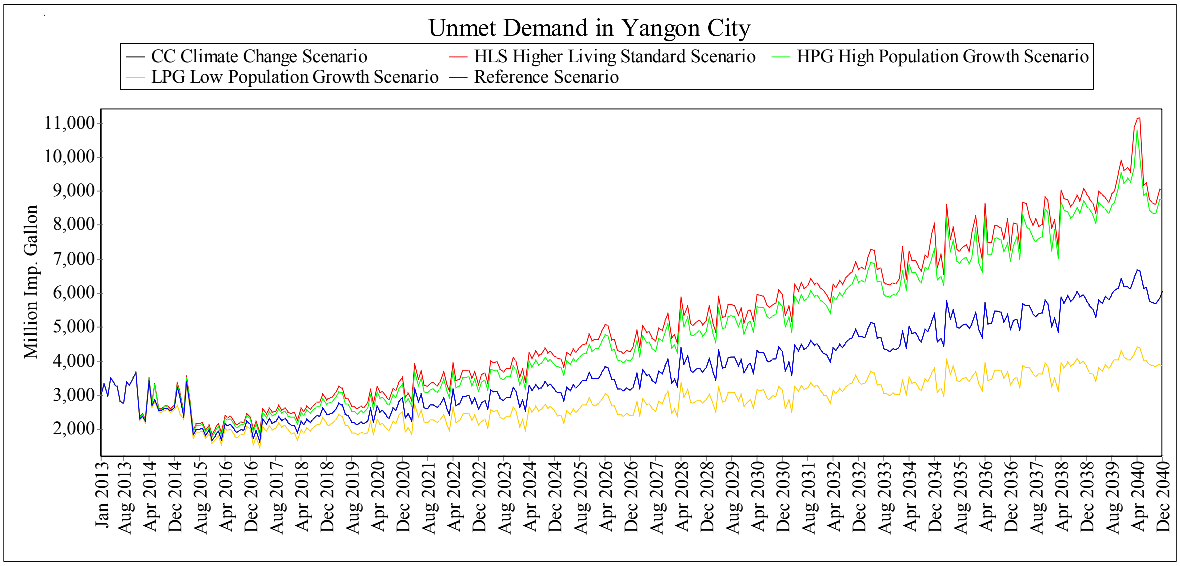


Figure 6.10: Unmet demand of Yangon City under different external driven scenarios (2013-2040)

6.2.1 High Population Growth - HPG Scenario

In this HPG Scenario, the population growth rate was used as 3.5 % instead of the normal growth 2.5 % as in the Reference Scenario, and the simulation results for demand site coverage of Yangon City show that both scenarios have similar fluctuation but the results of HPG Scenario is much lower than that of Reference Scenario (see in Figure 6.9). The lowest demand coverage amount in HPG scenario will be only 14 % in April 2040 whereas that in Reference Scenario will be about 31 % in April 2040. As a result of this low demand coverage problem, the unmet demand of Yangon City in this scenario will reach 10796 MG per month (360 MGD) in April 2040 as the maximum amount under this scenario (see in Figure 6.10).

Thus, YCWSS can encounter a huge water shortage problem if the population growth in Yangon City was increased due to the urbanization and industrialization of the urban region together with the migration of people from rural regions.

6.2.2 Low Population Growth - LPG Scenario

The population growth rate in this LPG Scenario was estimated as 1.5 %, and the demand coverage results of Yangon City in WEAP simulation provide that the results of LPG Scenario is substantially lower than that of Reference Scenario according to the Figure 6.9. In LPG scenario, even the demand coverage amount will be 40.3 % in April 2040, but that in Reference Scenario will be about 31 % in that month. Similarly, the unmet demand of Yangon City in this scenario will be 4436 MG per month (148 MGD) in April 2040 as the maximum unmet demand for the whole scenario while Reference Scenario will be unmet about 223 MGD (see in Figure 6.10).

As a result, YCWSS can improve its water supply capacity if the population growth rate in Yangon City was altered slower like as other urbanized mega cities.

6.2.3 Higher Living Standards - HLS Scenario

In this HLS Scenario, it was assumed that the water consumption rate would become rise together with the economic growth of the city because of higher living standards. In Asian countries, the higher the living standards and the economic growth, the higher the water consumption because of oriental living style, for example, wet sanitation. Future service target of YCDC for water consumption rate, 30 gpcd in 2013 to 40 gpcd in 2040, was used to analyse the impact of this changes. The simulation results for demand site coverage of Yangon City are the lowest in this scenario, which is 13.86 % in April 2040, comparing with all other scenarios (see in Figure 6.9). The unmet demand of Yangon City in this scenario will gain the highest peak, which is 11157 MG per month (372 MGD) in April 2040 (see in Figure 6.10).

Therefore, YCWSS can face a large water deficit problem if the higher living standards in Yangon City were occurred due to the change of economic development pattern in Yangon City.

6.2.4 Climate Change Scenario - CC Scenario

In this CC Scenario, GCM: CMIP5 full set climate data with RCP6.0 scenario was used to study the impacts of climate change in Yangon City, and the simulated results for both demand site coverage and unmet demand of Yangon City under this scenario have exactly the same trends as Reference Scenario (see in Figure 6.9 and Figure 6.10).

Hence, these results demonstrated that there is no impact of climate change on this YCWSS model using this RCP6.0 scenario climate change model data, and these results also highlighted that the climate data that used in Reference Scenario, that was cycled the historical climate data (1991-2013), are reliable to study the future of water supply-demand system. The other climate change data for different scenarios from different climate change models should use for further study about the climate change impact on this YCWSS.

6.3 Advantages of Management Scenarios

Regarding to solve the negative impacts of external alternatives in YCWSS, four scenarios for management options, two DSM scenarios and 2 SSM scenarios, to practise in the system will be explored to figure out their advantages on water supply coverage and unmet demand of Yangon City. Comparing the results of these scenarios in demand site coverage and unmet demand of Yangon City are illustrated in Figure 6.11 and Figure 6.12. These graphs show that all management options have significant positive impacts on the improvement of YCWSS, and 100% demand coverage can achieve under SSM-ASS Scenario starting from 2035. However, SSM-NRWC option is the best effective management option from economical and environmental points of view because Yangon can get maximum coverage 81% by implementing NRW control management plan without using big investment. Due to the SSM-NRWC option, demand coverage in Yangon City will improve about 20 % of the Reference Scenario result for the whole study period, and the average unmet demand of Yangon City under this scenario can reduce about 41 % of the Reference scenario. Similarly, demand coverage of Yangon City under DSM-WPP Scenario can improve 10 % of that under Reference Scenario, and the unmet demand will fall about 35 % of that under Reference Scenario. Under DSM-SWS option, the sustainable water source, rainwater was used to study the alternative technology in water supply system, and the remarkable effect on water demand coverage in the rainy season, and in the mid of rainy season, that value is more than 10 % of the data under Reference Scenario. The improvement of water supply service in each scenario will be discussed in their respective sub-section.

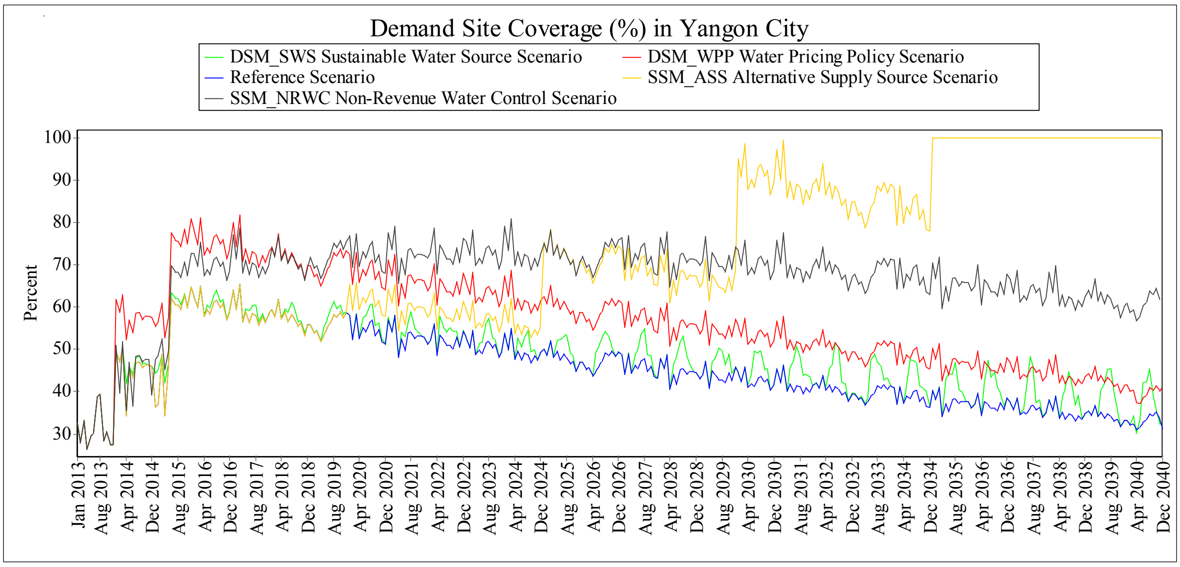


Figure 6.11: Demand Coverage of Yangon City under management scenarios (2013-2040)

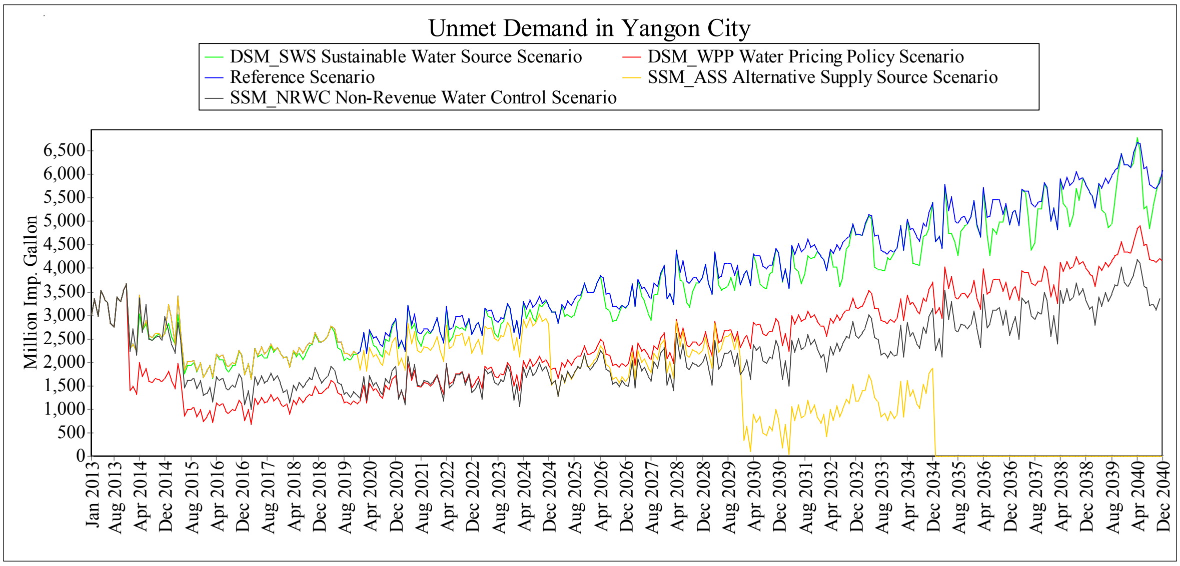


Figure 6.12: Unmet demand of Yangon City under management scenarios (2013-2040)

6.3.1 1st DSM - Water Pricing Policy (WPP) Scenario

In this DSM-WPP Scenario, the DSM saving was used as 20 % because of the changes of water pricing policy that is altering the water pricing system from fixed water-pricing to tiered water-pricing and increasing the water price to reduce the water demand of Yangon City. The Figure 6.11 provides the information for demand site coverage of Yangon City that is relatively higher than the default scenario with the average difference is about 11 % and both scenarios have the same trend from the beginning to the end of the study period. The high water coverage in this scenarios will be 81.8 % in March 2017 whereas 65.5 % in the default scenario. Although the difference between these two scenarios will be becoming smaller year after year, the diffidence amount still remains 10 % at the end of the study, December 2040. The maximum unmet demand in DSM - WPP Scenario is 4898 MG per month (158 MGD) in May 2040, and the same time 6679 MG per month (215 MGD) in Reference Scenario (see in Figure 6.12).

On one hand, it is obvious that water pricing policy change can provide an advantage for the improvement of the water supply service, and on the other hand, this change can increase the income of water authorities.

6.3.2 2nd DSM - Sustainable Water Source (SWS) Scenario

For this DSM-SWS option, RWH was used to initiate in the demand side of YCWSS by assuming only 1 m^2 harvested area and 1 m^3 storage capacity for each citizen who is increased after 2013. According to the Figure 6.11, the demand site coverage of Yangon City under this option will becoming significant in 2030s because the results in the rainy season under this scenario can be about 10 % more than that under Reference Scenario in those years. For instance, the demand coverage in this scenario will be 48.27 % in July 2037 and 45.33 % in August 40 while these in Reference Scenario will be 36.4 % and 34.78 % respectively. Meanwhile, the unmet demand under this DSM-SWS Scenario will descend to 4387 MG per month (141.5 MGD) in July 2037 and 4852 MG per month (156 MGD) in Aug 2040, but Reference Scenario will have 5394 MG per month (174 MGD) and 5788 MG per month (187 MGD) (see in Figure 6.12).

According to these results, RWH can help to improve the water supply system effectively into a certain level and YCDC should encourage installing this facilities in the demand sites to reduce the water demand from the network.

6.3.3 1st SSM – NRW Control (NRWC) Scenario

For this SSM-NRWC option, EDWS will carry out to reduce the water losses in the system by implementing different strategies, such as leakage control plan, pipeline rehabilitation plan, connection control plan, and water-meter reinstallation plan etc., to reach the future target for NRW that is to reach 15 % in 2040. For this scenario, future target data of YCDC-JICA master plan were used to study the effect of NRWC program. According to the results, this scenario can raise the water supply service enormously, for example, the demand site coverage in this scenario will have 61.5 %, and in Reference Scenario will have 31 % at the end of simulation period, December 2040 (see in Figure 6.11). In December 2040, the unmet demand in this scenario will be 3399 MG per month (109 MGD), whilst 6094 MG per month (196.5 MGD) in Reference Scenario (see in Figure 6.12).

Simulation for this SSM-NRWC showed that the water supply service in YCWSS could improve doubled by controlling NRW with low investment and energy. Moreover, NRW controlling not only can improve the quantity of the supply water but also can upgrade the supply water quality without disturbing environment. Therefore, NRWC option is the best strategy for the improvement of YCWSS.

6.3.4 2nd SSM - Alternative Supply Source (ASS) Scenario

In YCDC-JICA Master Plan, it is mentioned that the alterations of water supply sources in YCWSS to introduce river water sources and to cease the groundwater source. Two new river water supply projects will implement for future increased demand of Yangon City.

According to the results for this scenario from Figure 6.11 and Figure 6.12, the demand site coverage of Yangon City will achieve 100 % after January 2035, and there will not be unmet demand after 2034, even though the unmet demand in December 2034 can occur 1867 MG per month (60 MGD).

It is evidence that these new water supply projects for YCWSS are essential to attain 100 % reliable water supply service in the future.

6.4 Strategic Development Options for Future YCWSS

Since the main objective of YCWSS is to distribute the adequate water for city dwellers, water managers and decision maker of YCDC should formulate the development for YCWSS in order to contribute to socioeconomic development of Yangon City. Therefore, YCWSS should be developed not only for the business-as-usual case, but also for the worst cases by using the best management strategies. WEAP is the best tool to analyse the impacts of different management options under different situations. Moreover, WEAP can operate easily to integrate these different options and different situations to find out the worst situation and the best solution for the system. The following Figure 6.13 and Figure 6.14 illustrate the demand coverage percent and unmet demand in Yangon City that will encounter in April 2040 under different scenario. According to these figures, HPG and HLS scenarios can affect the highest negative impact on the system, and SSM-AAS option is the best option to gain 100 % system reliability. Besides, SSM-NRWC option can achieve significant positive effect on the system, which is double of Reference Scenario, and DSM-WPP option also can give moderate advantage to the system.

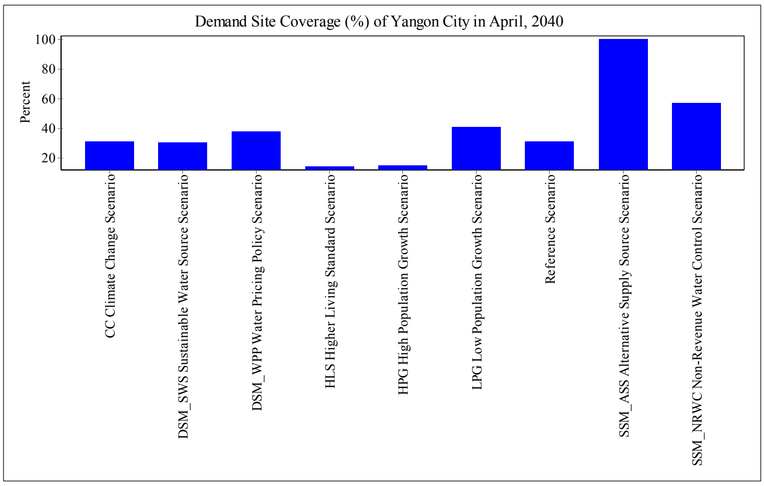


Figure 6.13: Comparison of water coverage in Yangon City under different scenarios (April, 2040)

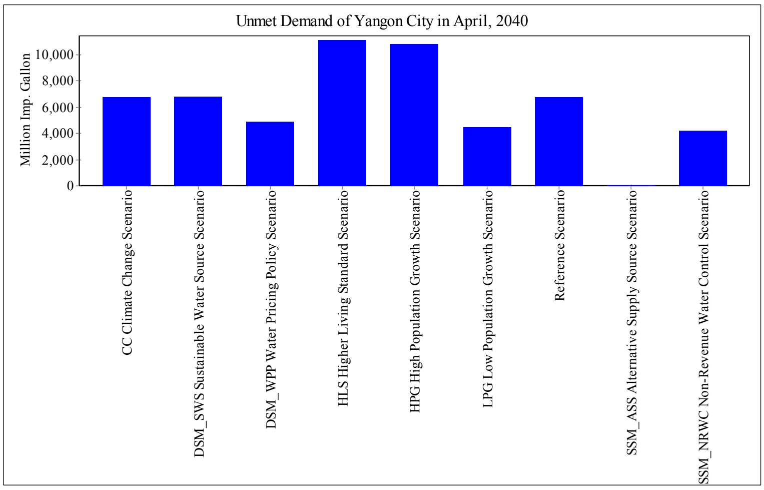


Figure 6.14: Comparison of Unmet demand in Yangon City under different scenarios (April, 2040)

According to the study of integrated external driven scenarios in WEAP, HPG with HLS Scenario is the worst situation for YCWSS in future. The results for this scenario concerning about the demand site coverage and unmet demand in Yangon City are described in the following Figure 6.15, comparing with the results of Reference Scenario. Under this scenario, the demand site coverage will go down around 10 % in 2040, and the unmet demand in Yangon City will climb up to the highest peak with 14992 MG per month (500 MGD) in April 2040 and 15055 MG per month (485 MGD) in May 2040.

Therefore, this HPG with HLS Scenario should use to formulate the best-integrated options for YCWSS.

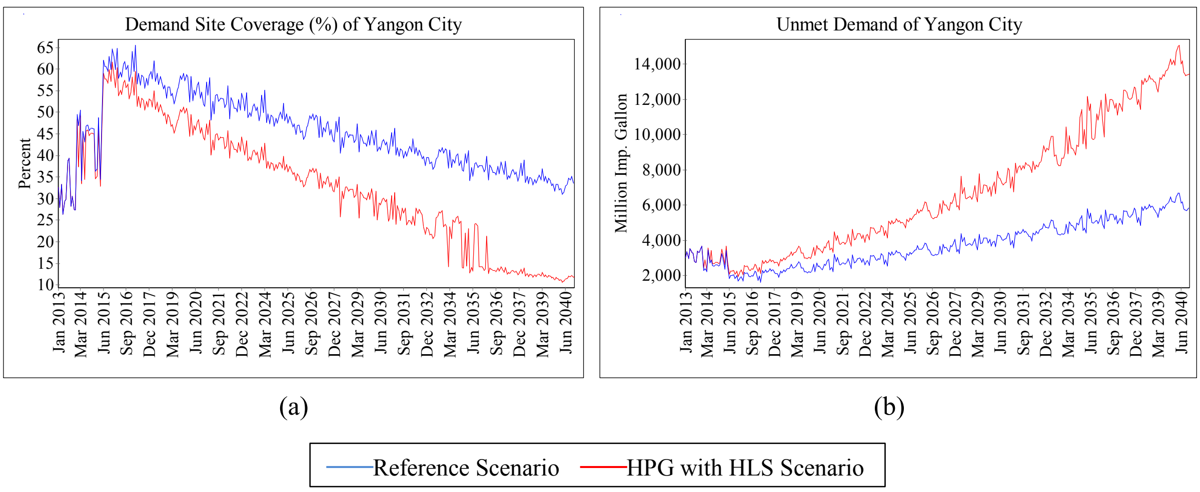


Figure 6.15: (a) Demand Site Coverage and (b) Unmet Demand of Yangon City under Reference Scenario and HPG with HLS Scenario (2013-2040)

In the meantime, according to the results of integrated management scenarios analysis in WEAP, the demand site coverage in Yangon City under implementing all management strategies scenario, i.e. SSM-ASS, DSM-SWS, DSM-WPP, SSM-NRWC Scenario, can achieve 100 % starting from January 2020 (see in Figure 6.16). The demand site reliability data for all possible integrated management scenarios are shown in Figure 6.17, and the demand site reliability in WEAP means the percent of monthly timesteps in which a demand site's demand was fully satisfied. By practising these four management options, the demand site reliability can get 73.21 %.

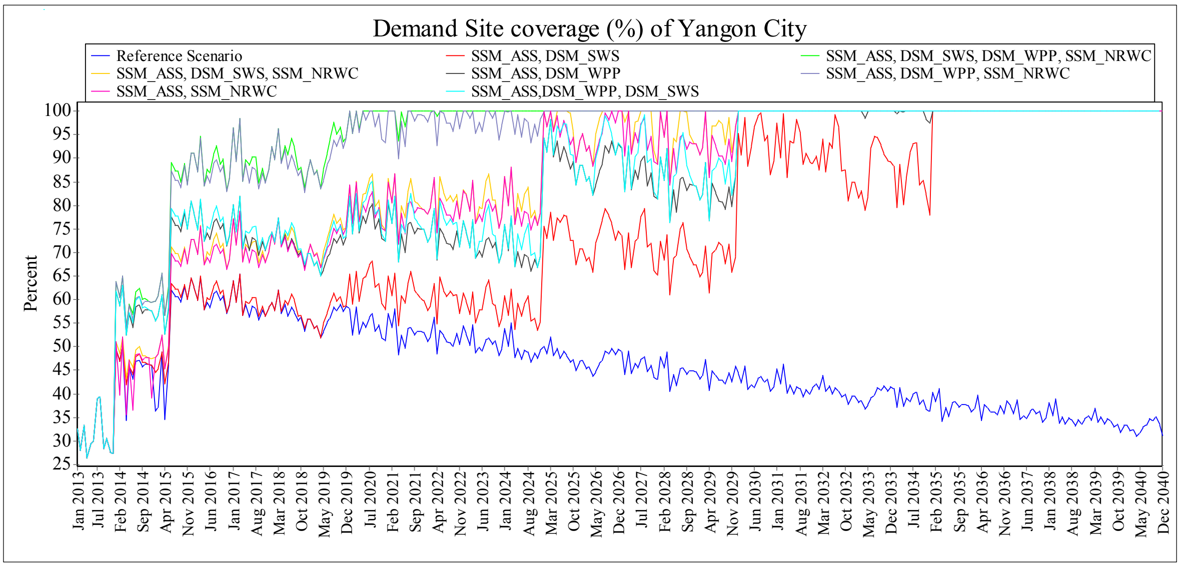


Figure 6.16: Demand site coverage results in Yangon City under possible management scenarios (2013-2040)

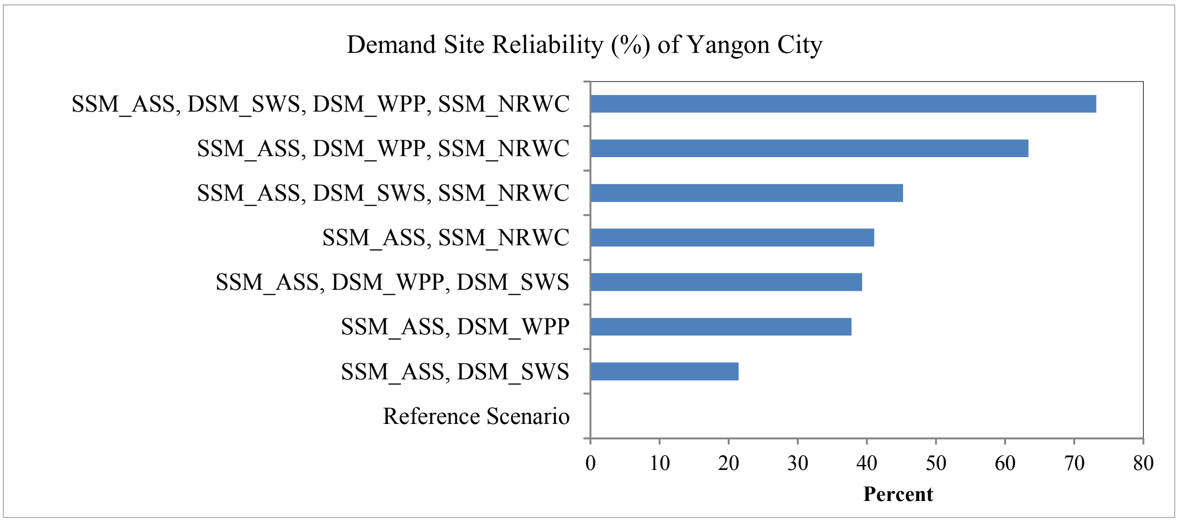


Figure 6.17: Demand site reliability of Yangon City under different integrated management scenarios

The following Figure 6.18 verifies that implementing four management strategies, water pricing policy, rainwater harvesting, non-revenue water control, and implementing new river water projects, can help YCWSS to be robust in the worst situation, high population growth rate with higher living standards. The demand site, Yangon city, will reach fully satisfied stage starting from January 2030 by developing all strategies under HPG with HLS condition and the demand site reliability for this HPG, HLS with 4 management strategies Scenario can get 30.36 %.

Therefore, these management strategies should be implemented in YCWSS to face the negative impacts of external alternatives successfully and to develop the future water supply under growing water demand.

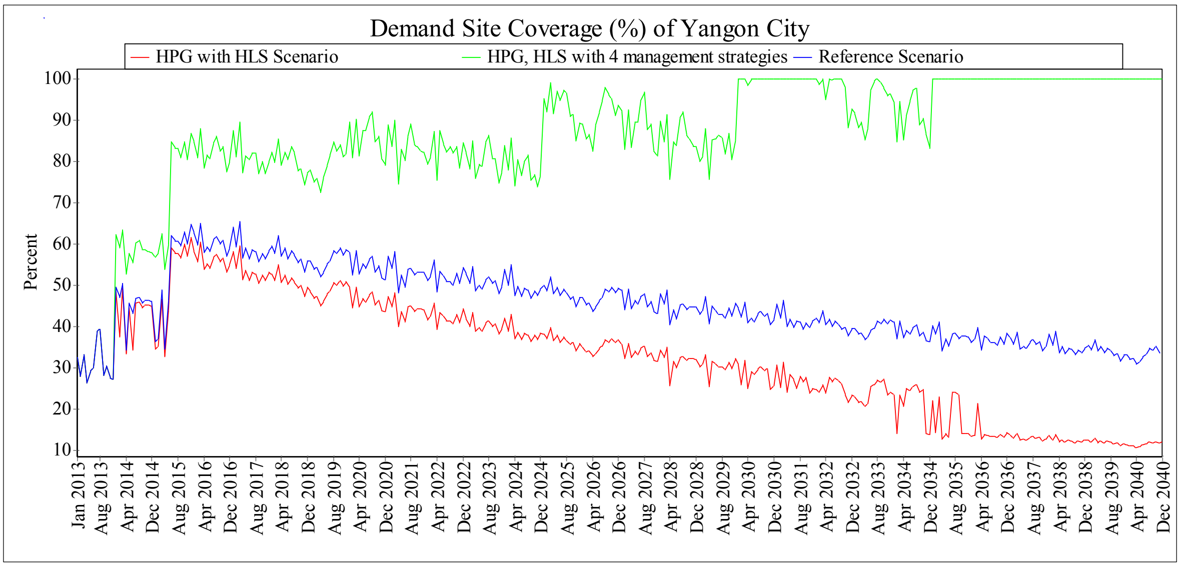


Figure 6.18: Demand site coverage of Yangon City under HPG, HLS scenario with four management strategies (2013-2040)

Moreover, the results of integrated scenarios analysis in WEAP can point out that implementing only three management strategies, water pricing policy, rainwater harvesting, and NRW control, under Reference Scenario can achieve 100 % in some months and the average demand coverage for the whole study period (2014-2040) is 87.76 %, see in Figure 6.19 (a). The unmet demand in Yangon City under this scenario is described in the following Figure 6.19 (b), comparing with the results of Reference Scenario. According to these simulated results, the unmet demand under this scenario will go down under 1000 MG per month (33 MGD) starting from June 2015 until January 2033, after that that amount will increase gradually over 1000 MG per month. Nevertheless, the maximum unmet demand under this scenario will be 2361 MG per month (78.7 MGD) in April 2040, which is much more lower than the capacity of two new water supply projects of YCDC, Kokkowa River Project with total capacity 240 MGD and Toe River Project Project with total capacity 180 MGD. As a result of this finding, water planner and decision makers of YCDC should revise these new projects concerning with capacity and time horizon of the projects.

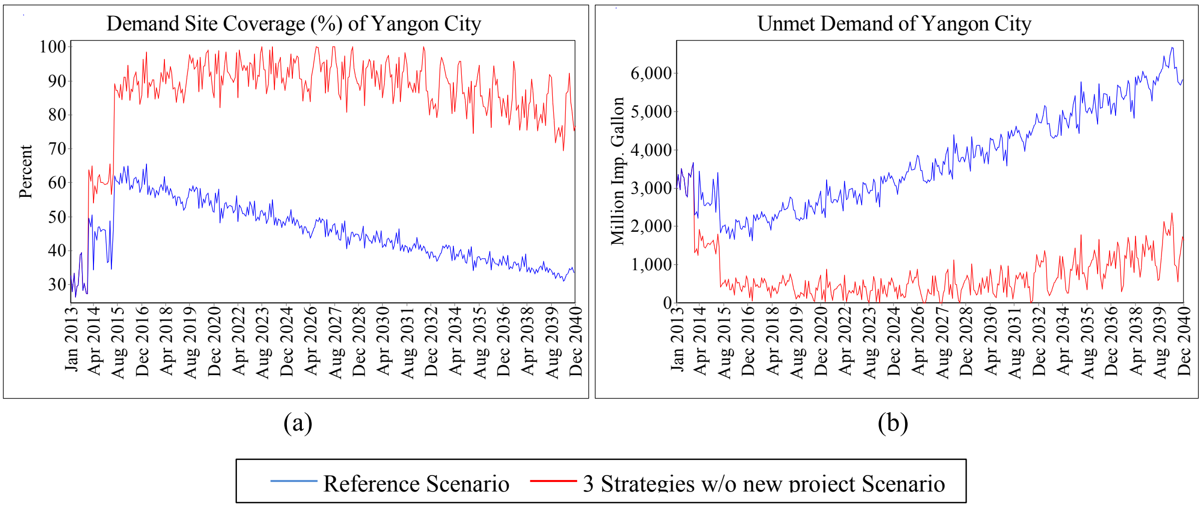


Figure 6.19: (a) Demand Site Coverage and (b) Unmet Demand of Yangon City under Reference Scenario and 3 Strategies w/o new project Scenario (2013-2040)

In conclusion, management strategies studied in this thesis are significantly effective on the development of YCWSS for the future water demand. This analysis pointed out that implementing all strategies in the system can encounter well the worst situation in the future, such as high population growth rate, high water consumption rate. Moreover, implementing only three strategies without implementing new projects can adapt the Reference Scenario situation effectively for the whole simulation period (2014-2040).

7 Discussions, Conclusions and Recommendations

7.1 Discussions and Conclusions

The overall objective of this study was to develop Water Evaluation And Planning (WEAP) model for the simulation of current water supply system of Yangon City and for the evaluation of different external changes scenarios and different water management strategies for the future water supply against the growing water demand. In this study, external driven scenarios under different population growth rate, higher water consumption rate, and climate change, were constructed to reflect the impact on future trends of water supply sources and a demand site, Yangon City. Moreover, management scenarios under both demand side and supply side were constructed by taking into account the different operating policies and strategies that may affect water demand and water supply. This study mainly focused on the water demand coverage and unmet demand of Yangon City for long-term planning of YCWSS, and the current accounts year was used as 2013 to simulate the study time horizon from 2014 until 2040.

This study used only one demand site, Yangon City, with aggregate method to analyse the water availability in city level. Annual demand with monthly variation method was used to determine the monthly water demand of Yangon City. Since there was no measured data for monthly demand variation of Yangon City, the monthly water consumption data derived from water bill income of YCDC was used to calculate the demand monthly variation. Consequently, the result of this model has been influenced by this empirical data, having the lowest water demand on March due to the financial management policy for the budget year in YCDC and in Myanmar.

This study applied Rainfall Runoff (Simplified Coefficient) method to generate runoff from rainfall, and the weakness of this method is not taking into account some hydrological complex processes such as infiltration, percolation, and runoff concentration time etc. Thus, the results of WEAP model was illustrated that the simulated reservoir storage volumes were larger than the observed volumes of the reservoirs and the time intervals of the highest and lowest water levels of the reservoirs in model simulated results were earlier than that in actual cases. In this study, groundwater was simulated assuming possible data in some parameters due to the lack of proper documents and reliable research paper. Similarly, rivers that will use in future water supply projects for Yangon City were simulated by using minimum flow data of these rivers from the flow measurement reports of MoAI.

In this study, Reference Scenario was created using current accounts data to evaluate the current water supply- system of Yangon City and its future trends in both supply sources and demand sites. According to the analysis of Reference Scenario, the following main results can be discussed.

- It was verified that the average demand coverage of Yangon City in 2013 was about 31 % and the supply delivered amount to Yangon City in 2013 was 47.94 MGD. Therefore, YCWSS could supply water only one-third of city dwellers in 2013.
- It was noticeable that the average demand coverage of Yangon City would jump to about 46% in 2014 because of the 2^{nd} phase of Ngamoeyeik WTP project, and go up to about 60% in 2016 because of Lagunpyin water supply project.
- However, the results pointed out that the average demand coverage of Yangon City will fall gradually until to reach about 33% in 2040.
- It was remarkable that the average unmet demand of Yangon City in 2040 will be 202 MGD and the maximum unmet demand will be 223 MGD in April 2040. Thus, YCWSS will be needed to extend by implementing new projects to improve the water availability in Yangon City.
- It was obvious that the surface water sources and the reservoirs of YCWSS will operate well until 2040, but the groundwater source of YCDC tube wells will be exhaustible at the end of 2040.

In this study, four external driven scenarios and four management options were created to analyse the impacts of external alternatives on YCWSS and the benefits of water management strategies for the water availability of Yangon City. Based on these different scenarios analysis data, the following facts can be extracted.

- In High Population Growth Scenario, the demand coverage of Yangon City will decline considerably comparing with the results of Reference Scenario, the average coverage in 2040 will be 23%, and the average unmet demand in 2040 will be 300 MGD.
- In Low Population Growth Scenario, the demand coverage of Yangon City will incline markedly, and the average coverage in 2040 will get 42% and the average unmet demand in 2040 will become 133 MGD.
- In Higher Living Standards Scenario, there will be a noticeable negative impact on the demand coverage of Yangon City, and the average water coverage in 2040 will get only 21% and the average unmet demand will rise until 314 MGD.

- In Climate Change Scenario using GCM: CMIP5 full set climate data for RCP 6.0 scenario, there will be no effect on the water demand coverage of Yangon City getting exactly the same results as Reference Scenario. The average demand coverage under this scenario will be 33%, and the unmet demand in Yangon City will be 202 MGD.
- In DSM - Water Pricing Policy Scenario, the demand coverage of Yangon City will improve moderately to get the average demand coverage in 2040 is 40%, and the average unmet demand in 2040 is 145 MGD.
- In DSM - Sustainable Water Source Scenario introducing rainwater harvesting to public, the demand coverage of Yangon will be affected marginally and the average water-demand coverage and the average unmet demand of Yangon City will become 36% and 192 MGD in 2040.
- In SSM - NRW Control Scenario, there will show huge improvement in demand coverage of Yangon City giving 61% for the average coverage in 2040 and 118 MGD for the average unmet demand in 2040.
- In SSM - Alternative Supply Source Scenario considering the two new water supply projects from rivers and abandoning Groundwater sources, the demand coverage will achieve the reliable stage by providing the average water-demand coverage of Yangon City in 2040 will be 100% together with no unmet demand.

In this study, strategic development options for YCWSS to adapt the external alternatives was analysed by integrating these different scenarios, and this adaptation analysis illuminated two important deductions regarding the improvement of YCWSS.

As a first deduction, integrating all management options that were discussed in this study can adapt in the worst situation of Yangon City in future that is Yangon City will have high population growth rate and higher water consumption rate because of economic growth and higher living standards. According to the simulation result for HPG, HLS with four management strategies will obtain 100% demand coverage with no unmet demand situation in 2040.

As a second one, implementing three water management options without implementing any extension and any new projects in the system under the current situation of YCWSS can adapt well in the future until 2040. The simulated results for three strategies without new projects scenario under the current accounts highlighted that the average demand coverage in Yangon City can get 80% in 2040 accompanied with the unmet demand 50 MGD.

To be concluded, water pricing policy and NRW control are the two main keys to improve the situation of YCWSS effectively from economical and environmental point of views. Both management strategies have multi-advantages, for example, practising water pricing policy not only control the public water consumption but also help to get a higher income in water authorities. Similarly, NRW control can improve the water supply service both in quantitatively and qualitatively. Moreover, RWH can be considered a feasible water management strategy in urban areas because RWH in urban areas can reduce not only the demand on water supply facilities but also the demand on urban drainage system controlling the runoff and reducing the urban flood. The result of this study confirmed that water managers and local authorities of YCDC should formulate urgently these sustainable water management options for YCWSS until to achieve the future targets and revised study for the implementation of new water supply projects should be done.

7.2 Recommendations

This study clearly recommended that WEAP is powerful in evaluating the current situation and future options in water supply system. WEAP can evaluate all aspects of the water system including rainfall-runoff, demand, supply, streamflow, groundwater, quality, and finance. WEAP can support results of the analysis on many spatial and temporal levels, such as all or selected demand sites, all or selected supply sources, yearly long-time data, monthly long-time data, monthly average, and selected years, showing in several formats such as charts, tables, and maps. One of the strengths of WEAP is that additional or more accurate data can be added directly to the developed model and simulation can be performed in a few minutes. For example, a water quality analysis or financial analysis can be done very easily with this YCWSS-WEAP model. WEAP model is based on a well-structured approach, and that ensures fast in model development, ease in precise-analysis, and flexible in scenarios creation. In this study, WEAP could assist water planners and policy makers in decision making for future management of the water supply-demand system. Another advantage of the WEAP model is the support from the developers in terms of publications, tutorial, user guide, discussion in user forum and software free-support to governmental and academic users from developing countries.

The application of WEAP in YCWSS demonstrated the advantages of some integrated water management strategies for the impacts of external alternatives but also pointed out several requirements to understand deeply for future changes and management options in

YCWSS. Based on these requirements, the following potential useful recommendations are suggested.

- Institutional policy and the participation of the local community should combine to achieve the implementation of management strategies, such as RWH harvesting, NRW control plan, and water-pricing policy successfully.
- Local authorities should initiate laws and regulations concerning about these management strategies and educate citizens about these strategies in the mass media to improve citizens' awareness.
- Scenarios analysis results from this study should be used in discussion among water planners, decision makers, and local authorities relating with management plans for the improvement of YCWSS.
- To fully analyse the water supply demand analysis of different zones in Yangon City, the disaggregation process should be extended using the detailed data of demand sites and water uses including future industrial zones, which may be sensitive to YCWSS.
- The hydrology of the catchments should be modeled using the other more detail method of WEAP, such as soil moisture model or MABIA method, to perform better with the availability of more data. Otherwise, rainfall-runoff models should be linked with this model if rainfall runoff processes are critical aspects for future projects.
- Water quality study of YCWSS should be integrated with this model by adding water quality data of supply sources to analyse the water quality of the system and to develop a quality management plan.
- Cost analysis should be advanced in this model using actual financial data of YCDC and EDWS to study the costs and benefits of the system and to get the water price for water pricing policy.
- Groundwater model for Yangon City should be developed by using a proper groundwater-modelling tool, like as MODFLOW, to get a reliable data for the groundwater analysis for Yangon City linking with this WEAP model.
- Climate change scenario in this model should need to be expanded considering different future climate-change models with different scenarios for a more robust climate change analysis on YCWSS.

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Appendices

APPENDIX A: JICA & YCDC households interview survey (2012)

Table A.1: (Q47i) Source of Water by Purpose

Source of Water by Purpose												
			Piped Water Supply System by YCDC	Public Well/Tap	Private Tube Well	Neigh-bors' Well/Tap (Free of Charge)	Bottled Water	Water Vend-er	Rain/ Creek / Ca-nal/ Pond	None	No Answer	**Total**
No.	For Drink-ing	Main Source	1,209	169	1,700	528	4,517	709	1,212	21	4	**10,069**
		Supplemental Source (Multiple Choice: 2)	6	9	31	15	44	39	72	10,040	0	**10,256**
	For Other Use	Main Source	3,370	236	3,738	900	12	873	899	41	0	**10,069**
		Supplemental Source (Multiple Choice: 2)	19	10	93	23	6	63	25	10,024	0	**10,263**
% to Total	For Drink-ing	Main Source	12.0	1.7	16.9	5.2	44.9	7.0	12.0	0.2	0.0	**100.0**
		Supplemental Source (Multiple Choice: 2)	0.1	0.1	0.3	0.1	0.4	0.4	0.7	97.9	0.0	**100.0**
	For Other Use	Main Source	33.5	2.3	37.1	8.9	0.1	8.7	8.9	0.4	0.0	**100.0**
		Supplemental Source (Multiple Choice: 2)	0.2	0.1	0.9	0.2	0.1	0.6	0.2	97.7	0.0	**100.0**

Table A.2: (Q47ii)Expenditure by Purpose

		For Drinking	For Other Use
Main Source	No. of Household who Answered	5,567	5,376
	Maximum	150,000	270,000
	Minimum	0	0
	Average	5,636	4,477
	Median	1,200	700
Supplemental Source (Multiple Choice: 2)	No of Household who Answered	77	116
	Maximum	90,000	36,000
	Minimum	0	0
	Average	3,997	6,102
	Median	0	0

Table A.3: (Q48a) Payment Mode, To Whom Answered "Piped Water Supply System by YCDC" in Q47

No.	Payment Mode			
	Flat Rate	Metered	No Answer	**Total**
	1,041	1,790	570	**3,401**
%	30.6%	52.6%	16.8%	**100.0%**

Table A.4: (Q48b) Ownership of Meter, To Whom Answered "Piped Water Supply System by YCDC" in Q47

No.	Ownership of Meter			
	Yes	No	No Answer	**Total**
	2,132	702	567	**3,401**
%	62.7%	20.6%	16.7%	**100.0%**

Table A.5: (Q48c) Operationality of Meter, To Whom Answered, "Piped Water Supply System by YCDC" in Q47

No.	Operationality of Meter			
	Yes	No	No Answer	**Total**
	2,003	125	4	**2,132**
%	93.9%	5.9%	0.2%	**100.0%**

Table A.6: (Q48d) Duration of Water Supply Hour (Hours), To Whom Answered "Piped Water Supply System by YCDC" in Q47

No.	Duration of Water Supply Hour (Hours)						
	Less than 3	4 ~ 6	7 ~ 12	13 ~ 18	19 ~ 24	No Answer	**Total**
	1,223	334	321	144	809	570	**3,401**
%	36.0%	9.8%	9.4%	4.2%	23.8%	16.8%	**100.0%**

Table A.7: (Q48e) Usage of Water Pump Tank, To Whom Answered "Piped Water Supply System by YCDC" in Q47

No.	Usage of Water Pump Tank			
	Yes	No	No Answer	**Total**
	1,342	1,492	567	**3,401**
%	39.5%	43.9%	16.7%	**100.0%**

Table A.8: (Q48f) Average Water Consumption (Gallon), To Whom Answered "Piped Water Supply System by YCDC" in Q47

No.	Average Water Consumption (Gallon)							
	Less than 50	51 ~ 100	101 ~ 200	201 ~ 300	301 ~ 400	More than 400	No Answer	**Total**
	580	1,344	608	183	71	48	567	**3,401**
%	17.1%	39.5%	17.9%	5.4%	2.1%	1.4%	16.7%	**100.0%**

Table A.9: (Q48g) Satisfaction of Current Service Level of Water, To Whom Answered "Piped Water Supply System by YCDC" in Q47

Satisfaction of Current Service Level of Water								
		Highly Unsatisfied	Unsatisfied	So-so	Satisfied	Highly Satis-fied	No An-swer	**Total**
Number	Water Pressure	48	476	773	1,520	9	575	**3,401**
	Hours of Supply	51	515	693	1,540	36	566	**3,401**
	Water Quantity	30	346	777	1,664	17	567	**3,401**
	Water Quality	80	673	573	1,479	30	566	**3,401**
	Price	30	186	1,015	1,547	42	581	**3,401**
% to Total	Water Pressure	1.4%	14.0%	22.7%	44.7%	0.3%	16.9%	**100.0%**
	Hours of Supply	1.5%	15.1%	20.4%	45.3%	1.1%	16.6%	**100.0%**
	Water Quantity	0.9%	10.2%	22.8%	48.9%	0.5%	16.7%	**100.0%**
	Water Quality	2.4%	19.8%	16.8%	43.5%	0.9%	16.6%	**100.0%**
	Price	0.9%	5.5%	29.8%	45.5%	1.2%	17.1%	**100.0%**

Table A.10: (Q48h) Reason of Non-Satisfaction to Water Quality, To Whom Answered "Highly Unsatisfied" or "Unsatisfied" for Water Quality in Q48g

No.	Reason of Non Satisfaction to Water Quality						
	Colour	Turbidity	Odour	Taste	Unsanitized	No Answer	**Total**
	127	255	88	16	242	773	**1,501**
%	8.5%	17.0%	5.9%	1.1%	16.1%	51.5%	**100.0%**
%	17.4%	35.0%	12.1%	2.2%	33.2%		

Table A.11: (Q50) Ideal Water Consumption Volume (Times)

No.	Ideal Water Consumption Volume (Times)							
	1.0	1.25	1.5	2.0	3.0	More than 3.0	No Answer	**Total**
	7,432	778	424	1,125	131	178	1	**10,069**
%	73.8%	7.7%	4.2%	11.2%	1.3%	1.8%	0.0%	**100.0%**

Table A.12: (Q51) Treatment of Drinking Water

No.	Treatment of Drinking Water							
	Boiled	Filtered	Boiled and Filtered	Buy Mineral Water	No Treat-ment	Purification Equipment	No Answer	**Total**
	417	4,111	785	4,500	47	208	1	**10,069**
%	4.1%	40.8%	7.8%	44.7%	0.5%	2.1%	0.0%	**100.0%**

Table A.13: (Q52) Water-borne Disease

		Water-borne Disease			
		Yes	No	No Answer	**Total**
Number	Diarrhoea	141	9,927	1	**10,069**
	Dysentery	61	10,007	1	**10,069**
	Cholera	6	10,062	1	**10,069**
	Infectious Hepatitis	15	10,053	1	**10,069**
	Typhoid or Paratyphoid	10	10,058	1	**10,069**
	Malaria	8	10,060	1	**10,069**
	Dengue Fever	42	10,026	1	**10,069**
	Others	38	10,020	11	**10,069**
% to Total	Diarrhoea	1.4%	98.6%	0.0%	**100.0%**
	Dysentery	0.6%	99.4%	0.0%	**100.0%**
	Cholera	0.1%	99.9%	0.0%	**100.0%**
	Infectious Hepatitis	0.1%	99.8%	0.0%	**100.0%**
	Typhoid or Paratyphoid	0.1%	99.9%	0.0%	**100.0%**
	Malaria	0.1%	99.9%	0.0%	**100.0%**
	Dengue Fever	0.4%	99.6%	0.0%	**100.0%**
	Others	0.4%	99.5%	0.1%	**100.0%**

Table A.14: Q53 Frequency of Infection

	Frequency of Infection						
	1	2 ~ 5	6 ~ 10	11 ~ 20	More than 20	No Answer	**Total**
No.	121	109	7	1	1	1,391	**1,630**
%	7.4%	6.7%	0.4%	0.1%	0.1%	85.3%	**100.0%**

Table A.15: Q54 Willingness to Pay for Water Service (kyat/month)

		Willingness to Pay for Water Service (kyat/month)								
		Less than 500	501 ~ 1,000	1,001 ~ 2,000	2,001 ~ 3,000	3,001 ~ 5,000	5,001 ~ 7,000	More than 7,000	No Answer	**Total**
Number	For 24 Hours' Water Supply (Untreated)	2,680	2,737	1,461	1,124	692	143	1,231	1	**10,069**
	For 24 Hours' Drinkable Water Supply	2,279	2,191	1,557	1,221	1,040	264	1,516	1	**10,069**
% to Total	For 24 Hours' Water Supply (Untreated)	26.6%	27.2%	14.5%	11.2%	6.9%	1.4%	12.2%	0.0%	**100.0%**
	For 24 Hours' Drinkable Water Supply	22.6%	21.8%	15.5%	12.1%	10.3%	2.6%	15.1%	0.0%	**100.0%**

APPENDIX B: MoAI River water source survey (2013)

The Republic of The Union of Myanmar
Ministry of Agriculture and Irrigation
Irrigation Department

Report of the Flow Measurement by Using River Surveyor M-9 at Htantapin Township, Kokkowa River

Hydrology Branch
2013, April, (20)

Report of the Flow Measurement by Using River Surveyor M-9 at Htantapin Township , Kokkowa River

Introduction

1. Hydrology Branch was given the assignment to take the flow measurement at Kokkowa river by using the River surveyor M-9. This assignment was given by the HeadOffice, Irrigation Department, Letter No. 1804/Siman-1 dated on (14.3.2013) and to assist (YCDC) (The Project for the Improvement of water supply, sewerage and Drainage system in Yangon City) .

Location of Station

2. Water level station at Kokkowa river, Htantapin Township, Yangon Region, as indicated in Annex (1).

Field Observation

3. Measuring Discharge by using River Surveyor M-9 and taking survey data in both side of River bank and water level were carried out by staff of Hydrology Branch at (20.3.13). The Six no. of Discharge measurements by Boat were taken at that time. Cross Sections and velocity distribution of each measurement are as shown in Annex 4-9. Measuring Time is from 6:20 A.M to 7:15 AM.

Results

4. The result for 6 no. of flow measurements are as shown in Annex (2). According the results of six flow measurement, three result should be used to compute the mean discharge and as shown in Annex (3). Detail results are as followed.

-2-

Sr. No	Station	Width (m)	Area (m^2)	Velocity (m/s)	Total Mean Discharge (Q) m^3/sec
1.	Water level station (Kokkowa River)	222.65	1908.4	0.646	1233.613

Water level of Kokkowa river station at (20.3.13) time (6:20) A.M is (0.23) ft.

Remark

Numbers of Measuring of discharge by using River Surveyor M9 are Six Times. But only three result of measurement is good. Results of three measurements are considered unreliable, because of the tide effect. Therefore only three times measured results should be used reliably.

Discharge Measurement Summary

Date Measured: Wednesday, March 20, 2013

Site Information

Site Name	kokkowa
Station Number	1
Location	WL station

Measurement Information

Party	hydro
Boat/Motor	boat
Meas. Number	3

System Information

System Type	RS-M9
Serial Number	2365
Firmware Version	2,00
Software Version	2,70

System Setup

Transducer Depth (m)	0,08
Salinity (ppt)	0,0
Magnetic Declination (deg)	0,8

Units

Distance	m
Velocity	m/s
Area	m2
Discharge	m3/s
Temperature	degC

Discharge Calculation Settings

Track Reference	Bottom-Track	Left Method	Sloped Bank
Depth Reference	Vertical Beam	Right Method	Sloped Bank
Coordinate System	ENU	Top Fit Type	Power Fit
		Bottom Fit Type	Power Fit

Discharge Results

Width (m)	222,65
Area (m2)	1,908,4
Mean Speed (m/s)	0,646
Total Q (m3/s)	1,233,613

Measurement Results

Tr		Time			Distance				Mean Vel		Discharge							%
#		Time	Duration	Temp.	Track	DMG	Width	Area	Boat	Water	Left	Right	Top	Middle	Bottom	Total	MBTotal	Measured
1	R	6:35:32 AM	0:05:07	20,1	233,36	218,11	222,21	1,814,5	0,768	0,686	0,10	-0,53	79,17	1,001,00	188,04	1,277,097	-	78,1
2	L	6:41:20 AM	0:05:49	20,2	225,67	218,25	222,25	1,895,7	0,647	0,656	0,64	-0,42	72,01	987,13	183,79	1,243,069	-	79,4
3	R	6:48:[illegible] AM	0:05:25	20,3	231,62	219,58	223,99	1,815,1	0,713	0,608	0,36	0,04	72,17	918,27	188,04	1,179,075	-	77,6
			Mean	20,2	230,22	218,65	222,65	1,908,4	0,706	0,646	0,30	-0,30	74,72	968,13	189,95	1,233,613	0,000	78,3
			Std Dev	0,1	3,23	0,67	0,67	9,6	0,047	0,021	0,05	0,29	3,23	35,72	5,97	40,573	0,000	0,6
			COV	0,2	0,014	0,003	0,003	0,005	0,066	0,032	0,486	-0,807	0,043	0,037	0,031	0,033	0,000	0,008

Exposure Time: 0:16:21

Tr1=20130320063529r.rivr; Tr2=20130320064119r.rivr; Tr3=20130320064807r.rivr;

Comments

Tr1=20130320063529r.rivr - 0,23 ft; Tr2=20130320064119r.rivr - ; Tr3=20130320064807r.rivr - ;

Compass Calibration

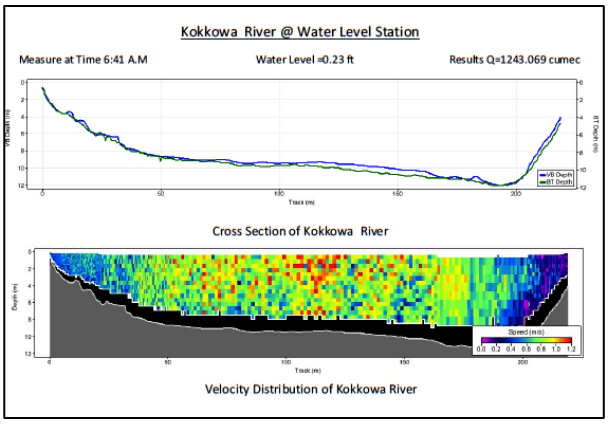
Results: PASS
Score is excellent.
Magnetic interference is very low.

Calibration score: M4.00Q9

System Test

System Test: PASS

Parameters and settings marked with a * are not constant for all files. Report generated using SonTek RiverSurveyor Live v2.70



The Republic of The Union of Myanmar
Ministry of Agriculture and Irrigation
Irrigation Department

Report of the Flow Measurement by Using River Surveyor M-9 at Kawhmu Township,Toe River

Hydrology Branch
2013, April, (18)

Report of the Flow Measurement by Using River Surveyor M-9 at Kawhmu Township , Toe River

Introduction

1. Hydrology Branch was given the assignment to take the flow measurement at Toe river near Kyaik Htaw village by using the River surveyor M-9. This assignment was given by the Head Office. Irrigation Department Letter No. 1804/Siman-1 dated at (14.3.13) and to assist (YCDC) (The Project for the Improvement of water supply, sewerage and Drainage system in Yangon City) .

Location of Station

2. Water level station at Toe river near Kyaik Htaw village, Kawhmu Township, Yangon Region, as indicated in Annex (1).

Field Observation

3. Measuring Discharge by using River Surveyor M-9 and taking survey data in both side of River bank and water level were carried out by staff of Hydrology Branch at (18.3.13). The three no. of Discharge measurements by Boat were taken at that time. Cross Sections and velocity distribution of each measurement are as shown in Annex 4-6. Measuring Time is from 3:15 P.M to 4:15 P.M.

Results

4. The result for Three no of flow measurements are as shown in Annex (2). According the result of one flow measurement, One result should be used to compute the mean discharge and as shown in Annex (3). Detail results are as followed.

-2-

Sr. No	Station	Width (m)	Area (m^2)	Velocity (m/s)	Total Discharge (Q) m^3/sec
1.	Kyaik Htaw Water level station (Toe River)	953.9	4193.9	0.46	1930.544

Water level of Toe river station at (18.3.13) time (3:15) Pm is (52) cm.

Remark

Numbers of Measuring of discharge by using River Surveyor M9 are three times. But only one result of measurement is good. Results of two measurements are considered unreliable, because of the tide effect. Therefore only one time measured result should be used reliably.

Discharge Measurement Summary

Date Measured: Monday, March 18, 2013

Site Information		Measurement Information	
Site Name	Toe River	Party	Hydro
Station Number	1	Boat/Motor	Boat
Location	Toe	Meas. Number	1

System Information		System Setup		Units	
System Type	RS-M9	Transducer Depth (m)	0.08	Distance	m
Serial Number	2365	Salinity (ppt)	0.0	Velocity	m/s
Firmware Version	2.00	Magnetic Declination (deg)	0.8	Area	m2
Software Version	2.70			Discharge	m3/s
				Temperature	degC

Discharge Calculation Settings				Discharge Results	
Track Reference	Bottom-Track	Left Method	Sloped Bank	Width (m)	953.90
Depth Reference	Vertical Beam	Right Method	Sloped Bank	Area (m2)	4,193.9
Coordinate System	ENU	Top Fit Type	Power Fit	Mean Speed (m/s)	0.460
		Bottom Fit Type	Power Fit	Total Q (m3/s)	1,930.544

Measurement Results

Tr		Time			Distance				Mean Vel		Discharge							%
#		Time	Duration	Temp.	Track	DMG	Width	Area	Boat	Water	Left	Right	Top	Middle	Bottom	Total	MBTotal	Measured
1	1	3:16:36 PM	0:13:29	30.5	958.68	943.90	953.90	4,193.9	1.185	0.460	0.00	0.25	158.00	1,453.73	318.53	1,930.544	--	75.3
			Mean	30.5	958.68	943.90	953.90	4,193.9	1.185	0.460	0.00	0.25	158.00	1,453.73	318.53	1,930.544	0.000	75.3
			Std Dev	0.0	0.00	0.00	0.00	0.0	0.000	0.000	0.00	0.00	0.00	0.00	0.00	0.000	0.000	0.0
			COV	0.0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Exposure Time: 0:13:29
Tr1=20130318151636r.rivr;

Comments

Tr1=20130318151636r.rivr - 52 cm;

Compass Calibration

Results: PASS
Score is excellent.
Magnetic interference is very low.

Calibration score: M7.00Q9

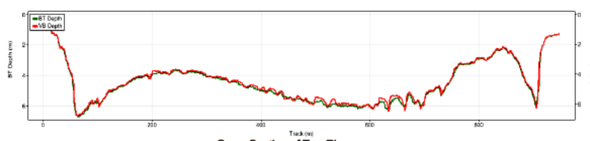
System Test

System Test: PASS

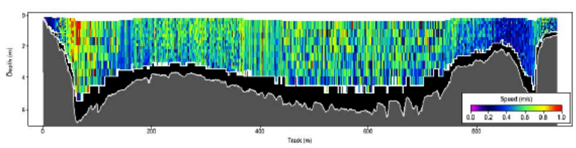
Parameters and settings marked with a * are not constant for all files.
Report generated using SonTek RiverSurveyor Live v2.70

Toe River @ Water Level Station

Measure at Time 3:16 P.M Water Level = 0.52 m Results Q = 1930.544 cumec



Cross Section of Toe River



Velocity Distribution of Toe River

APPENDIX C: DMH Climate data and Model Input data

DEPARTMENT OF METEOROLOGY AND HYDROLOGY

STATION :HMAWBI

MONTHLY RAINFALL(mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	1	1	21	0	251	677	603	415	252	285	20	Trace
2002	0	0	Trace	Trace	253	588	509	579	597	93	200	18
2003	6	0	1	3	249	727	387	484	389	66	2	0
2004	7	0	0	Trace	529	795	407	661	414	87	0	0
2005	0	0	0	Trace	76	378	637	548	403	182	67	50
2006	0	0	Trace	152	160	248	617	519	412	142	0	0
2007	0	0	Trace	2	732	500	540	374	571	269	23	0
2008	16	28	Trace	148	580	334	634	452	326	137	12	0
2009	0	0	0	104	279	468	665	370	399	125	Trace	0
2010	8	0	0	0	253	434	278	399	230	229	0	61
2011	81	0	108	Trace	284	789	490	357	453	118	Trace	Trace
2012	Trace	Trace	Trace	18	113	492	686	745	481	73	128	2
2013	Trace	1	0	0	222	543	590	759	603	254	25	Trace

STATION : HMAWBI

MONTHLY MEAN RELATIVE HUMIDITY (%) AT (09:30)hrs MST

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	63	72	71	66	81	89	92	88	88	86	71	69
2002	65	67	75	66	74	89	92	91	89	79	80	74
2003	72	65	65	68	81	88	87	91	88	79	66	66
2004	64	67	71	61	82	91	88	92	88	79	68	61
2005	69	72	67	63	72	89	90	89	93	80	76	78
2006	73	69	75	69	80	90	93	94	89	79	68	64
2007	65	56	65	60	84	87	90	89	92	83	77	70
2008	70	66	72	73	87	89	92	91	89	84	73	67
2009	68	76	81	70	81	89	92	91	90	86	72	66
2010	67	70	78	69	73	87	89	92	89	85	69	72
2011	73	72	76	70	85	92	91	92	90	83	68	67
2012	67	75	78	73	79	89	91	91	86	79	79	73
2013	70	67	71	65	72	88	93	93	93	84	75	71

အိအိဖင်
ဦးစီးအရာရှိ
မိုးလေဝသနှင့်ဇလဗေဒညွှန်ကြားမှုဦးစီးဌာန

DEPARTMENT OF METEOROLOGY AND HYDROLOGY

STATION : HMAWBI

MONTHLY MEAN RELATIVE HUMIDITY (%) AT (18:30)hrs MST

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	50	43	52	36	81	90	90	90	87	83	72	65
2002	58	43	37	43	72	91	92	93	88	77	76	68
2003	63	44	41	48	79	95	87	92	90	76	67	67
2004	53	39	35	44	80	89	90	94	90	80	70	59
2005	52	37	39	44	69	92	93	95	93	88	88	82
2006	69	46	42	54	80	90	97	93	93	88	70	73
2007	65	42	39	42	87	90	91	94	94	88	80	70
2008	63	55	50	57	86	91	94	90	91	86	79	74
2009	62	46	47	60	78	93	94	89	92	85	73	66
2010	53	39	44	41	67	89	89	90	90	89	71	74
2011	67	52	59	56	88	94	93	94	95	91	78	64
2012	51	51	55	53	80	91	94	93	90	86	85	73
2013	59	52	47	43	71	91	93	94	93	86	81	70

STATION : HMAWBI

MONTHLY MEAN MAXIMUM TEMPERATURE (°C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	33.5	35.1	35.8	39.9	32.8	30.8	30.6	30.5	31.3	32.4	32.5	32.4
2002	32.4	36.0	37.5	39.4	34.6	30.9	30.5	30.1	31.0	33.8	33.7	32.5
2003	32.2	36.1	37.0	38.7	33.8	30.6	31.0	30.3	31.4	34.7	35.4	34.5
2004	34.6	34.9	37.8	39.0	33.1	30.4	30.5	29.7	31.8	34.2	35.5	32.2
2005	33.5	36.5	38.3	39.1	35.9	31.2	30.5	30.6	30.8	34.2	32.7	31.4
2006	32.7	35.6	37.7	36.7	32.7	31.4	30.1	29.9	31.1	33.4	35.9	33.9
2007	33.4	34.9	37.4	39.4	32.1	32.2	30.4	30.7	30.7	33.2	33.0	32.2
2008	33.0	34.0	36.8	35.9	31.2	30.8	30.4	30.8	31.6	33.0	33.0	33.3
2009	32.5	35.5	37.4	36.4	33.7	30.9	29.8	30.9	30.9	32.9	34.7	33.5
2010	33.1	35.2	37.0	39.4	36.1	31.3	31.1	30.0	31.4	32.0	34.3	32.0
2011	31.1	33.7	33.2	36.2	32.2	30.3	30.2	29.7	30.0	32.2	35.0	34.1
2012	34.7	36.6	37.6	38.2	34.7	30.6	29.8	29.3	31.0	33.1	33.4	32.7
2013	32.8	36.7	37.9	39.2	35.4	30.6	29.0	29.6	30.3	31.7	33.0	30.2

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DEPARTMENT OF METEOROLOGY AND HYDROLOGY

STATION : HMAWBI

MONTHLY MEAN MINIMUM TEMPERATURE (°C)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	16.5	17.4	22.2	24.0	24.6	24.0	23.7	23.8	23.9	23.5	19.4	18.8
2002	16.1	18.2	20.1	23.1	24.6	24.1	24.0	23.5	23.5	23.2	21.7	17.8
2003	14.8	17.3	20.7	24.1	23.6	23.0	23.5	24.0	23.5	21.8	18.5	16.8
2004	16.0	17.2	20.5	23.5	24.8	24.2	24.3	24.2	23.9	22.9	21.2	15.6
2005	15.3	18.0	19.2	22.2	23.2	23.8	23.5	21.9	21.3	21.4	19.8	17.8
2006	16.1	17.1	19.9	21.2	21.6	22.9	24.1	23.4	24.0	23.1	19.7	15.5
2007	14.7	16.9	19.1	23.1	24.7	25.4	24.8	24.7	24.7	24.0	21.8	16.6
2008	16.6	16.8	20.9	24.2	24.3	24.5	24.4	24.3	23.9	24.0	20.5	16.2
2009	16.4	17.8	22.1	23.9	24.6	24.5	24.2	24.4	24.7	24.5	21.4	16.9
2010	18.6	17.6	22.4	24.6	25.7	25.3	24.9	24.2	24.5	24.1	21.2	18.5
2011	16.7	18.0	20.8	23.8	24.9	24.9	24.5	24.6	24.6	23.7	21.0	18.1
2012	14.9	15.8	19.9	23.7	24.5	24.3	24.3	24.1	24.3	24.1	22.9	17.1
2013	14.9	18.3	20.2	22.4	24.1	23.7	23.0	23.2	23.2	23.1	21.9	16.2

STATION : HMAWBI

MONTHLY MEAN WIND SPEED (mph)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	0.8	1.2	1.9	1.9	1.8	1.4	1.4	1.3	0.9	0.8	1.1	0.8
2002	0.8	1.0	1.4	2.5	2.8	1.5	1.5	1.6	1.3	0.6	0.8	0.7
2003	0.7	1.1	1.6	2.5	2.0	1.5	2.0	1.2	1.0	0.9	0.7	0.9
2004	0.9	1.5	2.1	2.4	2.3	2.1	1.5	1.5	1.0	0.8	0.9	1.1
2005	1.6	1.7	2.0	2.9	3.0	2.3	2.2	2.0	1.6	1.2	0.8	1.2
2006	1.0	1.4	1.8	3.1	2.7	2.8	3.0	2.7	2.1	1.1	1.2	0.8
2007	1.0	1.2	2.0	2.8	2.5	2.3	1.8	1.9	1.2	0.9	1.1	0.8
2008	1.2	1.2	2.1	2.3	3.4	2.7	2.3	2.8	2.2	1.5	0.9	1.3
2009	1.4	1.1	1.5	2.4	2.2	3.1	2.8	2.0	1.6	1.5	1.1	0.9
2010	1.0	1.2	1.6	2.6	2.6	1.9	1.5	2.0	1.8	1.5	1.1	1.0
2011	0.9	0.8	2.4	1.3	1.5	2.1	1.6	2.0	1.7	1.3	0.9	1.2
2012	1.3	1.5	1.9	2.4	2.4	2.2	1.6	2.0	1.9	1.5	1.1	1.0
2013	0.9	1.2	1.9	2.7	3.5	2.3	2.6	2.2	1.6	1.7	1.1	1.6

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DEPARTMENT OF METEOROLOGY AND HYDROLOGY

STATION :MINGALADON

MONTHLY RAINFALL(mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	0	Trace	36	0	380	519	544	430	196	318	34	7
2002	0	0	0	4	390	617	418	584	564	111	272	30
2003	3	0	3	0	336	651	255	466	413	59	5	0
2004	3	0	0	2	428	807	443	768	346	49	1	0
2005	0	0	15	22	175	533	545	473	600	168	61	0
2006	0	0	0	149	237	290	711	617	329	128	0	0
2007	0	0	0	Trace	702	538	760	452	735	260	3	0
2008	4	13	17	121	583	294	557	441	418	309	45	0
2009	0	0	Trace	29	344	559	859	383	523	124	16	0
2010	Trace	0	0	0	300	436	312	446	272	308	14	11
2011	50	Trace	97	8	283	587	719	633	423	154	0	0
2012	0	0	13	5	119	402	693	824	358	96	129	5
2013	3	0	0	0	120	441	591	474	608	230	64	0

STATION :MINGALADON

MONTHLY MEAN RELATIVE HUMIDITY (%) AT (09:30)hrs MST

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	69	79	78	71	82	88	92	91	88	88	74	75
2002	75	75	77	91	78	90	91	90	89	84	82	89
2003	75	69	72	74	82	89	88	91	91	82	71	72
2004	71	73	77	67	84	89	90	93	89	80	72	71
2005	75	75	71	71	78	90	93	89	91	83	78	76
2006	80	69	79	75	81	87	90	92	87	80	71	74
2007	82	78	78	65	85	86	89	89	91	86	75	68
2008	71	65	70	76	84	87	87	89	89	87	75	73
2009	72	77	77	70	82	85	92	89	87	87	75	72
2010	85	69	77	71	71	87	87	89	88	83	73	74
2011	77	77	74	74	83	88	89	90	91	83	71	70
2012	73	77	77	72	79	89	92	94	91	84	84	79
2013	74	73	74	70	78	88	90	91	92	85	82	84

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DEPARTMENT OF METEOROLOGY AND HYDROLOGY

STATION :MINGALADON

MONTHLY MEAN RELATIVE HUMIDITY (%) AT (18:30)hrs MST

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	49	48	58	48	84	86	90	92	88	83	67	63
2002	54	48	47	42	76	93	91	93	88	80	75	58
2003	59	45	47	58	82	93	87	92	91	76	62	57
2004	55	48	50	50	85	88	91	94	89	78	65	59
2005	55	41	49	54	76	93	91	92	91	78	77	71
2006	59	45	50	63	80	88	95	90	88	82	64	66
2007	66	60	57	49	84	89	90	92	93	82	70	57
2008	55	46	46	61	85	89	92	89	90	83	73	65
2009	57	49	53	62	80	92	93	87	90	84	68	60
2010	47	46	53	52	70	86	85	88	88	87	68	66
2011	64	52	67	59	85	90	91	94	93	83	66	61
2012	56	51	54	59	75	89	92	95	87	83	82	70
2013	58	48	50	51	76	93	95	92	93	85	85	81

STATION :MINGALADON

MONTHLY MEAN MAXIMUN TEMPERATURE

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	33.7	34.7	35.1	38.7	32.3	30.4	30.1	30.1	30.7	31.7	31.6	32.0
2002	31.9	35.6	37.2	38.4	33.6	30.4	30.4	29.7	30.3	32.7	32.0	31.8
2003	31.4	35.3	36.5	37.8	33.5	30.6	30.7	30.3	30.6	33.2	34.4	32.4
2004	33.4	34.3	36.5	37.9	32.5	30.5	30.3	29.6	31.2	32.7	34.4	32.2
2005	32.7	36.3	36.9	38.3	35.5	31.3	30.3	30.4	30.6	33.2	32.8	31.4
2006	32.8	35.1	36.5	35.8	31.9	31.2	30.5	30.1	30.9	32.3	33.5	31.6
2007	32.2	33.7	36.2	38.1	31.6	31.4	29.9	30.0	29.6	31.3	32.1	32.1
2008	32.1	33.4	36.2	35.0	31.1	30.3	30.1	30.2	30.6	31.8	32.0	31.1
2009	31.4	34.7	36.6	36.0	33.4	30.9	29.7	30.7	31.0	32.3	34.0	32.4
2010	33.3	35.2	37.1	39.4	36.5	31.4	31.4	30.0	31.5	31.4	33.3	31.6
2011	31.2	33.9	33.6	36.4	32.5	31.0	30.2	29.9	30.5	32.0	33.4	32.5
2012	33.3	36.0	36.8	38.0	34.6	30.6	29.8	29.4	31.4	33.3	33.2	32.8
2013	32.8	36.5	37.2	38.2	34.8	30.8	29.7	30.4	30.4	31.8	32.9	30.0

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DEPARTMENT OF METEOROLOGY AND HYDROLOGY

STATION :MINGALADON

MONTHLY MEAN MINIMIN TEMPERATURE

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	17.7	19.4	22.6	23.8	24.7	24.1	23.9	24.4	24.1	24.0	20.8	19.6
2002	17.4	19.5	20.7	23.4	24.4	24.9	24.8	23.8	24.3	24.2	22.8	19.0
2003	17.5	19.5	21.0	23.3	24.0	23.6	24.1	23.5	23.4	23.7	21.0	19.1
2004	17.4	18.0	21.0	23.6	24.5	23.9	23.4	23.6	23.7	23.5	22.4	17.8
2005	18.4	19.3	22.1	23.8	24.9	24.8	24.3	24.4	24.4	24.0	22.4	19.9
2006	18.1	19.1	22.2	23.7	24.6	24.6	23.6	23.5	23.4	23.9	21.3	16.5
2007	16.5	17.6	20.3	24.2	24.7	25.0	24.7	24.1	24.2	23.4	21.5	16.8
2008	16.6	16.6	19.1	21.6	21.7	21.2	21.5	20.4	20.0	20.2	20.1	17.1
2009	16.4	23.7	22.5	24.1	24.2	24.2	24.0	24.4	23.9	24.5	22.3	18.0
2010	19.0	18.7	22.6	24.6	25.8	24.8	24.4	23.8	24.0	24.0	22.7	19.6
2011	19.0	19.9	21.8	24.8	25.0	24.7	24.5	24.6	24.4	24.4	22.1	20.6
2012	18.6	19.9	22.7	25.3	25.5	24.8	24.3	24.1	24.5	25.0	24.5	20.1
2013	18.9	22.2	23.1	24.8	25.1	24.2	23.2	23.4	23.9	23.8	23.1	18.6

STATION :MINGALADON

MONTHLY MEAN WIND SPEED (mph)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	5.0	4.3	6.2	6.8	7.0	6.7	6.2	7.9	5.4	4.9	5.9	5.0
2002	4.5	4.0	5.2	5.5	9.3	6.9	6.8	6.9	2.3	3.6	4.9	4.2
2003	4.2	4.8	4.8	6.2	6.4	6.2	6.6	5.1	5.0	4.2	4.4	4.6
2004	4.2	4.3	5.4	6.0	5.9	7.1	5.6	5.7	1.8	4.0	4.7	4.0
2005	4.1	3.8	4.3	5.5	6.3	5.6	5.9	5.6	5.1	4.3	3.7	4.5
2006	5.5	5.1	5.2	7.0	7.3	6.9	5.4	7.8	6.2	6.4	6.6	6.0
2007	4.4	4.2	4.4	5.4	6.4	4.6	4.9	5.4	3.9	4.1	4.4	4.1
2008	4.2	4.4	5.0	4.6	8.3	5.1	5.0	4.9	1.9	3.6	4.1	3.9
2009	2.6	4.1	4.5	5.8	1.7	4.9	5.8	4.6	1.8	3.6	4.3	4.2
2010	3.9	1.9	1.9	2.4	6.7	1.9	4.0	3.5	3.8	1.6	4.0	3.6
2011	4.0	1.4	1.7	3.8	1.6	4.7	3.9	4.3	4.1	3.1	3.9	4.4
2012	3.8	4.0	4.6	5.5	5.2	5.8	3.9	4.3	4.1	3.7	3.6	3.5
2013	3.7	4.0	4.9	6.0	5.9	4.7	5.4	5.7	5.6	4.8	4.9	4.6

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DEPARTMENT OF METEROLOGY AND HYDROLOGY

Monthly Mean Evaporation(mm)

Station : kaba-aye

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001	4.7	5.8	5.5	8.0	4.2	3.0	2.7	3.0	3.8	4.0	4.5	4.2
2002	2.8	4.6	5.3	5.6	4.3	2.9	2.4	2.4	2.5	3.0	3.1	2.7
2003	2.8	3.9	5.0	5.9	4.0	2.8	3.0	2.1	2.6	3.5	3.8	3.3
2004	2.6	3.2	5.0	5.9	3.8	3.3	2.0	1.5	2.2	2.8	3.3	3.0
2005	3.2	4.2	5.0	5.4	3.8	2.4	2.7	2.7	2.7	3.6	3.2	2.9
2006	2.8	4.2	4.9	5.2	3.7	2.2	2.3	2.3	2.5	3.1	4.0	4.1
2007	2.8	4.2	4.9	5.2	3.7	2.2	2.3	2.3	2.5	3.1	4.0	4.1
2008	3.4	4.3	4.9	4.8	2.6	2.3	1.9	2.0	2.4	2.8	3.6	3.7
2009	4.0	4.3	5.1	4.2	3.6	1.9	1.9	2.0	2.9	3.2	4.0	3.2
2010	3.2	4.5	5.4	5.9	5.3	2.5	2.3	2.2	2.3	2.7	3.8	3.4
2011	3.1	4.1	3.9	5.5	3.3	2.3	2.3	2.4	2.8	3.7	4.7	3.9
2012	3.7	5.0	5.8	6.3	4.7	2.1	2.1	2.4	3.5	4.4	4.0	3.7
2013	4.1	5.9	6.1	6.9	4.5	1.9	1.4	2.0	2.0	3.4	4.2	2.7

DEPARTMENT OF METEOROLOGY AND HYDROLOGY

STATION : KABA-AYE

MONTHLY MEAN SUNSHINE HOURS

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2007	8.0	8.5	8.9	8.6	3.5	2.0	1.6	1.4	1.8	4.1	8.3	7.8
2008	7.4	8.1	7.9	6.7	2.6	2.1	1.9	2.5	3.2	4.9	7.9	8.6
2009	8.7	8.2	7.7	7.3	5.3	1.6	1.6	3.0	2.8	5.2	8.5	8.6
2010	7.8	9.1	7.5	9.0	6.8	2.3	3.1	2.0	3.2	6.0	8.8	8.2
2011	8.0	9.3	6.8	8.8	4.0	1.8	2.6	1.7	2.2	5.2	8.9	7.8
2012	8.9	8.4	8.2	8.4	4.4	1.9	1.4	1.5	3.8	6.5	6.4	8.3
2013	8.9	8.7	8.9	9.2	5.5	2.4	1.7	2.2	2.8	5.6	7.6	7.8

Table C1: Monthly variation demand in Yangon City (2007-2013)

Month	Water consumption units per connection	Monthly variation (%)	Month	Water consumption units per connection	Monthly variation (%)
Apr-07	44.5	9.0575	**Oct-10**	40.4	8.5892
May-07	42.2	8.5756	**Nov-10**	40.2	8.5532
Jun-07	43.2	8.7947	**Dec-10**	40	8.4949
Jul-07	41.1	8.3553	**Jan-11**	39	8.1451
Aug-07	40.9	8.3125	**Feb-11**	37.7	7.879
Sep-07	40.9	8.3149	**Mar-11**	37.4	7.826
Oct-07	41.5	8.4485	**Apr-11**	39.4	8.2304
Nov-07	40.3	8.2001	**May-11**	39.3	8.2112
Dec-07	41.7	8.4763	**Jun-11**	39.9	8.3297
Jan-08	41.1	8.5892	**Jul-11**	39.7	8.3048
Feb-08	37.7	7.8867	**Aug-11**	40.5	8.4719
Mar-08	37.3	7.8112	**Sep-11**	40.6	8.4779
Apr-08	42	8.7835	**Oct-11**	41.2	8.6135
May-08	39.3	8.227	**Nov-11**	42.2	8.829
Jun-08	39	8.1609	**Dec-11**	41.5	8.6815
Jul-08	41.2	8.6112	**Jan-12**	38.1	8.4648
Aug-08	41.2	8.6164	**Feb-12**	37.1	8.2386
Sep-08	40.7	8.5079	**Mar-12**	39.2	8.6992
Oct-08	39.7	8.2958	**Apr-12**	39.8	8.8296
Nov-08	40.4	8.4424	**May-12**	40	8.8943
Dec-08	38.6	8.0668	**Jun-12**	37.4	8.3157
Jan-09	35.5	8.1306	**Jul-12**	38	8.4399
Feb-09	34.9	7.9776	**Aug-12**	36.4	8.0927
Mar-09	34.3	7.8463	**Sep-12**	35.8	7.9591
Apr-09	37.3	8.5283	**Oct-12**	36.1	8.0102
May-09	37.5	8.5808	**Nov-12**	36	8.0005
Jun-09	37.1	8.4823	**Dec-12**	36.3	8.0555
Jul-09	36.4	8.3274	**Jan-13**	36.1	7.9481
Aug-09	36.1	8.2474	**Feb-13**	37.4	8.2521
Sep-09	36	8.2442	**Mar-13**	35.9	7.9021
Oct-09	36.5	8.3597	**Apr-13**	38.6	8.5013
Nov-09	37.8	8.6527	**May-13**	37.9	8.358
Dec-09	37.7	8.6226	**Jun-13**	37.6	8.2829
Jan-10	36.5	7.7515	**Jul-13**	37.2	8.1985
Feb-10	36.9	7.8411	**Aug-13**	36.7	8.0888
Mar-10	35.7	7.5865	**Sep-13**	38.2	8.4129
Apr-10	40.1	8.5196	**Oct-13**	38.2	8.4256
May-10	39.6	8.4073	**Nov-13**	39.2	8.6421
Jun-10	40.3	8.5623	**Dec-13**	40.8	8.9872
Jul-10	39.9	8.4762	**Jan-14**	38.8	7.8972
Aug-10	40.2	8.5483	**Feb-14**	38.4	7.8169
Sep-10	40.8	8.6702	**Mar-14**	38.1	7.7496

Table C2: Monthly water charges income of EDWS, YCDC (2007-2013)

Month	Domestic connection	Income (MMK)	Commercial connection	Income (MMK)	Month	Domestic connection	Income (MMK)	Commercial connection	Income (MMK)
Apr-07	71381	89074979	8116	43423269	Oct-10	124555	131195765	10367	51730368
May-07	75598	94412200	8155	40645733	Nov-10	125281	130621121	10412	51839332
Jun-07	76126	92146291	8263	42998898	Dec-10	124485	130489818	10431	51411108
Jul-07	77546	89582445	8367	41403597	Jan-11	124666	126688194	10356	49897496
Aug-07	77848	85436021	8394	41943709	Feb-11	124814	124417410	10328	48018025
Sep-07	78900	86015082	8452	42335309	Mar-11	125381	125532395	10339	47602294
Oct-07	79237	88500815	8560	43421456	Apr-11	125147	128840403	10319	50175817
Nov-07	78053	89812495	8427	40764217	May-11	126309	128023606	10326	50294265
Dec-07	78595	88886117	8764	44468943	Jun-11	127024	131128728	10332	50954237
Jan-08	80410	86052738	8891	45034697	Jul-11	128636	133638054	10308	50552136
Feb-08	81923	82113927	8943	41522576	Aug-11	131798	137323901	10447	52475475
Mar-08	87402	90022859	9116	41466297	Sep-11	132699	141503997	10537	52613580
Apr-08	89850	97060885	9181	47687546	Oct-11	134510	146842847	10608	53651378
May-08	91470	90741385	9143	44873908	Nov-11	135748	149566812	10798	56173870
Jun-08	92527	100324596	9249	43749684	Dec-11	136590	150905749	10962	55790132
Jul-08	94824	101949414	9505	48232695	Jan-12	137665	146407398	12227	56491560
Aug-08	96015	104250531	9652	48872239	Feb-12	138895	143782917	12259	55202205
Sep-08	98376	104707539	9842	49342930	Mar-12	139670	148431071	12349	59075402
Oct-08	99460	104999921	9909	48251841	Apr-12	141773	224461151	12868	89969378
Nov-08	101687	106269973	10050	50172471	May-12	143197	227583920	13008	91683476
Dec-08	102103	105551940	10039	47500499	Jun-12	143779	224731587	12986	84511908
Jan-09	102429	98413326	10043	43876905	Jul-12	144902	223460311	13211	87947374
Feb-09	102562	96653898	10049	43126467	Aug-12	144782	215485810	13183	84113716
Mar-09	103285	98301032	10091	42282638	Sep-12	144801	214605197	13173	82410110
Apr-09	107945	116770350	10235	45722797	Oct-12	145376	215418416	13249	83559720
May-09	110987	120999214	10320	46345128	Nov-12	145701	216707478	13209	83089238
Jun-09	112099	118963537	10337	46154803	Dec-12	146652	219825623	13336	84421040
Jul-09	112936	114948553	10312	45594693	Jan-13	147510	221376830	13770	86513660
Aug-09	115163	117168012	10398	45420990	Feb-13	148287	215788176	13452	89363418
Sep-09	116042	117983199	10432	45556842	Mar-13	148717	215104381	13592	85694320
Oct-09	116717	117156806	10408	46450254	Apr-13	149238	229809904	13624	92452260
Nov-09	117110	116307820	10423	48728727	May-13	149714	229533964	13738	91377208
Dec-09	117237	115515741	10436	48692337	Jun-13	150725	235330936	14532	95056786
Jan-10	118094	114078920	10475	47190339	Jul-13	151719	240057066	15498	99663996
Feb-10	118629	114117267	10461	47865623	Aug-13	153037	248392928	16078	100813626
Mar-10	118907	114954099	10447	45804002	Sep-13	153398	255362616	16296	106603572
Apr-10	117640	125968836	10399	51111158	Oct-13	154473	262356068	16449	107120110
May-10	119363	127839550	10288	49724628	Nov-13	154960	267277471	16449	110131872
Jun-10	121620	134696554	10273	50281123	Dec-13	156439	272886034	16463	115495758
Jul-10	121831	135824692	10287	49601881	Jan-14	157382	274070046	16538	108977478
Aug-10	122871	134719562	10368	50802022	Feb-14	160788	278656076	16623	108267926
Sep-10	123805	136310662	10359	51607039	Mar-14	162184	280795316	16621	107081870

Table C3: Effective precipitation (%) of Hmawbi station (1991-2013)

Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp
Jan-91	100.00	Nov-94	100.00	Sep-98	85.85	Jul-02	19.12	May-06	80.21	Mar-10	100.00
Feb-91	100.00	Dec-94	100.00	Oct-98	75.23	Aug-02	13.97	Jun-06	38.83	Apr-10	100.00
Mar-91	100.00	Jan-95	100.00	Nov-98	100.00	Sep-02	14.72	Jul-06	14.57	May-10	61.51
Apr-91	100.00	Feb-95	100.00	Dec-98	100.00	Oct-02	100.00	Aug-06	16.49	Jun-10	21.22
May-91	100.00	Mar-95	100.00	Jan-99	100.00	Nov-02	54.75	Sep-06	26.00	Jul-10	35.68
Jun-91	18.52	Apr-95	100.00	Feb-99	100.00	Dec-02	100.00	Oct-06	79.25	Aug-10	21.52
Jul-91	14.49	May-95	57.02	Mar-99	100.00	Jan-03	100.00	Nov-06	100.00	Sep-10	39.39
Aug-91	13.89	Jun-95	15.12	Apr-99	91.43	Feb-03	100.00	Dec-06	100.00	Oct-10	44.00
Sep-91	32.83	Jul-95	18.17	May-99	24.99	Mar-03	100.00	Jan-07	100.00	Nov-10	100.00
Oct-91	76.29	Aug-95	26.61	Jun-99	19.16	Apr-03	100.00	Feb-07	100.00	Dec-10	100.00
Nov-91	81.15	Sep-95	18.46	Jul-99	11.97	May-03	58.76	Mar-07	100.00	Jan-11	100.00
Dec-91	100.00	Oct-95	87.28	Aug-99	16.17	Jun-03	13.49	Apr-07	100.00	Feb-11	100.00
Jan-92	100.00	Nov-95	100.00	Sep-99	26.67	Jul-03	24.67	May-07	14.82	Mar-11	100.00
Feb-92	100.00	Dec-95	100.00	Oct-99	49.57	Aug-03	19.34	Jun-07	17.94	Apr-11	100.00
Mar-92	100.00	Jan-96	100.00	Nov-99	100.00	Sep-03	25.84	Jul-07	15.73	May-11	38.97
Apr-92	100.00	Feb-96	100.00	Dec-99	100.00	Oct-03	100.00	Aug-07	21.72	Jun-11	10.53
May-92	76.62	Mar-96	100.00	Jan-00	100.00	Nov-03	100.00	Sep-07	13.50	Jul-11	18.79
Jun-92	19.22	Apr-96	100.00	Feb-00	100.00	Dec-03	100.00	Oct-07	35.03	Aug-11	23.01
Jul-92	13.48	May-96	30.31	Mar-00	100.00	Jan-04	100.00	Nov-07	100.00	Sep-11	17.55
Aug-92	14.08	Jun-96	19.28	Apr-00	100.00	Feb-04	100.00	Dec-07	100.00	Oct-11	85.64
Sep-92	24.43	Jul-96	22.64	May-00	28.75	Mar-04	100.00	Jan-08	100.00	Nov-11	100.00
Oct-92	42.90	Aug-96	18.73	Jun-00	16.47	Apr-04	100.00	Feb-08	100.00	Dec-11	100.00
Nov-92	100.00	Sep-96	23.42	Jul-00	16.51	May-04	27.02	Mar-08	100.00	Jan-12	100.00
Dec-92	100.00	Oct-96	45.58	Aug-00	24.19	Jun-04	11.36	Apr-08	100.00	Feb-12	100.00
Jan-93	100.00	Nov-96	70.07	Sep-00	32.43	Jul-04	23.76	May-08	17.21	Mar-12	100.00
Feb-93	100.00	Dec-96	100.00	Oct-00	97.43	Aug-04	12.33	Jun-08	26.23	Apr-12	100.00
Mar-93	100.00	Jan-97	100.00	Nov-00	100.00	Sep-04	23.62	Jul-08	13.50	May-12	100.00
Apr-93	100.00	Feb-97	100.00	Dec-00	100.00	Oct-04	100.00	Aug-08	20.16	Jun-12	17.56
May-93	52.92	Mar-97	100.00	Jan-01	100.00	Nov-04	100.00	Sep-08	27.88	Jul-12	11.84
Jun-93	21.46	Apr-97	100.00	Feb-01	100.00	Dec-04	100.00	Oct-08	74.90	Aug-12	10.74
Jul-93	21.84	May-97	95.28	Mar-01	100.00	Jan-05	100.00	Nov-08	100.00	Sep-12	19.71
Aug-93	9.20	Jun-97	21.83	Apr-01	100.00	Feb-05	100.00	Dec-08	100.00	Oct-12	100.00
Sep-93	21.88	Jul-97	12.06	May-01	53.48	Mar-05	100.00	Jan-09	100.00	Nov-12	77.34
Oct-93	100.00	Aug-97	12.37	Jun-01	13.91	Apr-05	100.00	Feb-09	100.00	Dec-12	100.00
Nov-93	100.00	Sep-97	22.85	Jul-01	14.86	May-05	100.00	Mar-09	100.00	Jan-13	100.00
Dec-93	100.00	Oct-97	51.85	Aug-01	21.36	Jun-05	22.30	Apr-09	100.00	Feb-13	100.00
Jan-94	100.00	Nov-97	100.00	Sep-01	41.55	Jul-05	14.11	May-09	46.22	Mar-13	100.00
Feb-94	100.00	Dec-97	100.00	Oct-01	35.79	Aug-05	15.50	Jun-09	18.01	Apr-13	100.00
Mar-94	100.00	Jan-98	100.00	Nov-01	100.00	Sep-05	22.70	Jul-09	12.35	May-13	66.19
Apr-94	100.00	Feb-98	100.00	Dec-01	100.00	Oct-05	60.81	Aug-09	25.81	Jun-13	16.74
May-94	87.15	Mar-98	100.00	Jan-02	100.00	Nov-05	100.00	Sep-09	21.58	Jul-13	13.87
Jun-94	14.09	Apr-98	100.00	Feb-02	100.00	Dec-05	100.00	Oct-09	83.33	Aug-13	11.11
Jul-94	13.02	May-98	65.74	Mar-02	100.00	Jan-06	100.00	Nov-09	100.00	Sep-13	13.88
Aug-94	11.59	Jun-98	18.81	Apr-02	100.00	Feb-06	100.00	Dec-09	100.00	Oct-13	41.01
Sep-94	25.19	Jul-98	27.90	May-02	54.77	Mar-06	100.00	Jan-10	100.00	Nov-13	100.00
Oct-94	100.00	Aug-98	16.15	Jun-02	14.23	Apr-06	100.00	Feb-10	100.00	Dec-13	100.00

Table C4: Effective precipitation (%) of Mingalardon station (1991-2013)

Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp
Jan-91	100.00	Nov-94	100.00	Sep-98	66.11	Jul-02	23.66	May-06	58.99	Mar-10	100.00
Feb-91	100.00	Dec-94	100.00	Oct-98	59.48	Aug-02	14.07	Jun-06	35.48	Apr-10	100.00
Mar-91	100.00	Jan-95	100.00	Nov-98	100.00	Sep-02	15.69	Jul-06	12.91	May-10	60.76
Apr-91	100.00	Feb-95	100.00	Dec-98	100.00	Oct-02	100.00	Aug-06	14.62	Jun-10	21.26
May-91	100.00	Mar-95	100.00	Jan-99	100.00	Nov-02	45.27	Sep-06	33.74	Jul-10	33.68
Jun-91	15.50	Apr-95	100.00	Feb-99	100.00	Dec-02	100.00	Oct-06	100.00	Aug-10	19.81
Jul-91	10.89	May-95	64.16	Mar-99	100.00	Jan-03	100.00	Nov-06	100.00	Sep-10	34.63
Aug-91	15.41	Jun-95	15.97	Apr-99	52.66	Feb-03	100.00	Dec-06	100.00	Oct-10	32.61
Sep-91	67.17	Jul-95	15.45	May-99	28.36	Mar-03	100.00	Jan-07	100.00	Nov-10	100.00
Oct-91	76.86	Aug-95	25.17	Jun-99	22.58	Apr-03	100.00	Feb-07	100.00	Dec-10	100.00
Nov-91	100.00	Sep-95	19.34	Jul-99	18.39	May-03	50.84	Mar-07	100.00	Jan-11	100.00
Dec-91	100.00	Oct-95	44.96	Aug-99	16.25	Jun-03	15.25	Apr-07	100.00	Feb-11	100.00
Jan-92	100.00	Nov-95	100.00	Sep-99	28.06	Jul-03	39.39	May-07	16.47	Mar-11	100.00
Feb-92	100.00	Dec-95	100.00	Oct-99	30.37	Aug-03	20.16	Jun-07	17.12	Apr-11	100.00
Mar-92	100.00	Jan-96	100.00	Nov-99	100.00	Sep-03	24.04	Jul-07	11.46	May-11	39.76
Apr-92	100.00	Feb-96	100.00	Dec-99	100.00	Oct-03	100.00	Aug-07	18.45	Jun-11	15.18
May-92	100.00	Mar-96	100.00	Jan-00	100.00	Nov-03	100.00	Sep-07	10.53	Jul-11	13.11
Jun-92	26.80	Apr-96	100.00	Feb-00	100.00	Dec-03	100.00	Oct-07	38.63	Aug-11	13.17
Jul-92	15.53	May-96	42.39	Mar-00	100.00	Jan-04	100.00	Nov-07	100.00	Sep-11	19.22
Aug-92	19.62	Jun-96	18.12	Apr-00	100.00	Feb-04	100.00	Dec-07	100.00	Oct-11	70.25
Sep-92	32.83	Jul-96	21.77	May-00	51.95	Mar-04	100.00	Jan-08	100.00	Nov-11	100.00
Oct-92	41.82	Aug-96	14.59	Jun-00	16.70	Apr-04	100.00	Feb-08	100.00	Dec-11	100.00
Nov-92	100.00	Sep-96	17.86	Jul-00	26.27	May-04	33.54	Mar-08	100.00	Jan-12	100.00
Dec-92	100.00	Oct-96	55.01	Aug-00	27.16	Jun-04	11.78	Apr-08	100.00	Feb-12	100.00
Jan-93	100.00	Nov-96	90.48	Sep-00	21.99	Jul-04	21.69	May-08	18.98	Mar-12	100.00
Feb-93	100.00	Dec-96	100.00	Oct-00	65.40	Aug-04	10.33	Jun-08	30.82	Apr-12	100.00
Mar-93	100.00	Jan-97	100.00	Nov-00	100.00	Sep-04	28.27	Jul-08	15.92	May-12	100.00
Apr-93	100.00	Feb-97	100.00	Dec-00	100.00	Oct-04	100.00	Aug-08	21.16	Jun-12	22.61
May-93	59.61	Mar-97	100.00	Jan-01	100.00	Nov-04	100.00	Sep-08	20.89	Jul-12	11.85
Jun-93	25.33	Apr-97	100.00	Feb-01	100.00	Dec-04	100.00	Oct-08	33.31	Aug-12	9.29
Jul-93	22.95	May-97	48.36	Mar-01	100.00	Jan-05	100.00	Nov-08	100.00	Sep-12	27.23
Aug-93	14.86	Jun-97	23.38	Apr-01	100.00	Feb-05	100.00	Dec-08	100.00	Oct-12	100.00
Sep-93	24.76	Jul-97	13.50	May-01	37.44	Mar-05	100.00	Jan-09	100.00	Nov-12	83.72
Oct-93	100.00	Aug-97	12.11	Jun-01	19.54	Apr-05	100.00	Feb-09	100.00	Dec-12	100.00
Nov-93	100.00	Sep-97	18.44	Jul-01	16.70	May-05	91.05	Mar-09	100.00	Jan-13	100.00
Dec-93	100.00	Oct-97	60.90	Aug-01	20.55	Jun-05	15.98	Apr-09	100.00	Feb-13	100.00
Jan-94	100.00	Nov-97	100.00	Sep-01	55.10	Jul-05	16.50	May-09	36.50	Mar-13	100.00
Feb-94	100.00	Dec-97	100.00	Oct-01	34.31	Aug-05	18.48	Jun-09	15.72	Apr-13	100.00
Mar-94	100.00	Jan-98	100.00	Nov-01	100.00	Sep-05	15.85	Jul-09	9.49	May-13	100.00
Apr-94	100.00	Feb-98	100.00	Dec-01	100.00	Oct-05	73.44	Aug-09	25.98	Jun-13	20.75
May-94	70.22	Mar-98	100.00	Jan-02	100.00	Nov-05	100.00	Sep-09	16.63	Jul-13	13.95
Jun-94	13.46	Apr-98	100.00	Feb-02	100.00	Dec-05	100.00	Oct-09	86.50	Aug-13	18.51
Jul-94	11.29	May-98	49.54	Mar-02	100.00	Jan-06	100.00	Nov-09	100.00	Sep-13	13.82
Aug-94	11.38	Jun-98	23.14	Apr-02	100.00	Feb-06	100.00	Dec-09	100.00	Oct-13	48.66
Sep-94	23.31	Jul-98	29.67	May-02	40.54	Mar-06	100.00	Jan-10	100.00	Nov-13	100.00
Oct-94	69.71	Aug-98	20.07	Jun-02	13.47	Apr-06	100.00	Feb-10	100.00	Dec-13	100.00

Table C5: Reference Evapotranspiration ETo (mm) of Hmawbi station (1991-2013)

Month	ETo	Month	ETo	Month	ETo	Month	ETo	Month	ETo	Month	ETo
Jan-91	111.29	Nov-94	111.30	Sep-98	105.60	Jul-02	97.34	May-06	128.34	Mar-10	137.95
Feb-91	117.60	Dec-94	110.05	Oct-98	112.84	Aug-02	80.91	Jun-06	96.30	Apr-10	176.10
Mar-91	155.00	Jan-95	109.43	Nov-98	104.40	Sep-02	87.90	Jul-06	89.90	May-10	155.62
Apr-91	157.20	Feb-95	115.36	Dec-98	104.16	Oct-02	118.42	Aug-06	85.56	Jun-10	92.10
May-91	135.47	Mar-95	145.70	Jan-99	102.92	Nov-02	109.50	Sep-06	107.10	Jul-10	99.20
Jun-91	91.50	Apr-95	164.40	Feb-99	108.92	Dec-02	102.30	Oct-06	112.53	Aug-10	85.87
Jul-91	88.66	May-95	145.39	Mar-99	152.83	Jan-03	99.20	Nov-06	106.20	Sep-10	90.60
Aug-91	75.02	Jun-95	91.50	Apr-99	134.40	Feb-03	111.72	Dec-06	98.27	Oct-10	100.75
Sep-91	90.60	Jul-95	91.76	May-99	117.18	Mar-03	151.28	Jan-07	97.96	Nov-10	112.20
Oct-91	107.57	Aug-95	86.49	Jun-99	88.50	Apr-03	179.10	Feb-07	105.56	Dec-10	97.65
Nov-91	112.80	Sep-95	98.40	Jul-99	84.63	May-03	146.32	Mar-07	152.21	Jan-11	96.10
Dec-91	105.09	Oct-95	113.46	Aug-99	85.56	Jun-03	98.10	Apr-07	176.70	Feb-11	106.40
Jan-92	109.12	Nov-95	105.90	Sep-99	93.60	Jul-03	95.48	May-07	108.50	Mar-11	130.20
Feb-92	122.67	Dec-95	110.67	Oct-99	100.13	Aug-03	93.62	Jun-07	89.70	Apr-11	144.30
Mar-92	155.62	Jan-96	110.36	Nov-99	102.60	Sep-03	100.50	Jul-07	84.94	May-11	110.67
Apr-92	158.70	Feb-96	118.03	Dec-99	104.16	Oct-03	116.87	Aug-07	81.22	Jun-11	83.10
May-92	147.87	Mar-96	157.79	Jan-00	122.14	Nov-03	95.10	Sep-07	77.10	Jul-11	92.07
Jun-92	96.30	Apr-96	153.60	Feb-00	114.26	Dec-03	105.71	Oct-07	94.24	Aug-11	82.15
Jul-92	90.21	May-96	122.14	Mar-00	149.42	Jan-04	105.71	Nov-07	109.20	Sep-11	79.50
Aug-92	83.08	Jun-96	98.70	Apr-00	144.90	Feb-04	112.81	Dec-07	93.31	Oct-11	101.06
Sep-92	88.20	Jul-96	98.27	May-00	130.51	Mar-04	159.96	Jan-08	98.27	Nov-11	112.50
Oct-92	101.68	Aug-96	89.90	Jun-00	90.90	Apr-04	173.10	Feb-08	106.72	Dec-11	103.85
Nov-92	108.30	Sep-96	99.30	Jul-00	90.83	May-04	142.91	Mar-08	145.70	Jan-12	108.19
Dec-92	110.67	Oct-96	107.57	Aug-00	88.04	Jun-04	90.30	Apr-08	149.70	Feb-12	118.03
Jan-93	106.64	Nov-96	104.40	Sep-00	88.20	Jul-04	96.72	May-08	99.82	Mar-12	145.70
Feb-93	117.60	Dec-96	104.47	Oct-00	102.30	Aug-04	81.53	Jun-08	87.60	Apr-12	163.50
Mar-93	157.79	Jan-97	106.64	Nov-00	111.90	Sep-04	97.80	Jul-08	85.56	May-12	124.62
Apr-93	165.00	Feb-97	117.04	Dec-00	107.26	Oct-04	105.71	Aug-08	91.14	Jun-12	86.40
May-93	144.46	Mar-97	153.45	Jan-01	100.13	Nov-04	116.70	Sep-08	90.90	Jul-12	81.22
Jun-93	101.10	Apr-97	162.00	Feb-01	113.40	Dec-04	101.99	Oct-08	102.61	Aug-12	79.98
Jul-93	99.82	May-97	155.31	Mar-01	156.24	Jan-05	110.36	Nov-08	103.80	Sep-12	94.80
Aug-93	80.60	Jun-97	100.20	Apr-01	177.90	Feb-05	122.08	Dec-08	102.30	Oct-12	114.39
Sep-93	89.70	Jul-97	84.63	May-01	134.23	Mar-05	159.65	Jan-09	105.09	Nov-12	99.00
Oct-93	129.89	Aug-97	89.90	Jun-01	94.20	Apr-05	186.60	Feb-09	105.00	Dec-12	99.20
Nov-93	117.60	Sep-97	82.50	Jul-01	89.59	May-05	148.49	Mar-09	140.12	Jan-13	98.58
Dec-93	107.88	Oct-97	115.63	Aug-01	88.66	Jun-05	84.30	Apr-09	150.90	Feb-13	111.44
Jan-94	110.36	Nov-97	103.20	Sep-01	104.70	Jul-05	89.90	May-09	128.96	Mar-13	147.56
Feb-94	117.04	Dec-97	107.26	Oct-01	101.99	Aug-05	84.94	Jun-09	84.30	Apr-13	177.30
Mar-94	145.70	Jan-98	108.50	Nov-01	89.40	Sep-05	91.50	Jul-09	82.15	May-13	146.94
Apr-94	164.40	Feb-98	113.96	Dec-01	95.17	Oct-05	110.67	Aug-09	95.48	Jun-13	90.90
May-94	124.62	Mar-98	158.41	Jan-02	100.13	Nov-05	98.10	Sep-09	86.10	Jul-13	81.84
Jun-94	88.50	Apr-98	152.70	Feb-02	113.12	Dec-05	103.54	Oct-09	104.16	Aug-13	84.32
Jul-94	87.73	May-98	147.25	Mar-02	153.14	Jan-06	103.85	Nov-09	112.20	Sep-13	83.70
Aug-94	79.05	Jun-98	96.30	Apr-02	181.80	Feb-06	115.92	Dec-09	100.44	Oct-13	104.16
Sep-94	92.70	Jul-98	94.86	May-02	138.57	Mar-06	153.76	Jan-10	99.20	Nov-13	105.00
Oct-94	119.35	Aug-98	92.38	Jun-02	83.70	Apr-06	174.90	Feb-10	110.32	Dec-13	96.10

Table C6: Reference Evapotranspiration ETo (mm) of Mingalardon station (1991-2013)

Month	ETo	Month	ETo	Month	ETo	Month	ETo	Month	ETo	Month	ETo
Jan-91	126.17	Nov-94	120.30	Sep-98	107.10	Jul-02	98.89	May-06	139.81	Mar-10	141.67
Feb-91	128.24	Dec-94	120.90	Oct-98	117.18	Aug-02	82.15	Jun-06	102.90	Apr-10	171.30
Mar-91	159.96	Jan-95	124.31	Nov-98	114.00	Sep-02	88.50	Jul-06	91.76	May-10	182.28
Apr-91	171.00	Feb-95	126.28	Dec-98	115.01	Oct-02	128.03	Aug-06	90.21	Jun-10	92.70
May-91	165.23	Mar-95	150.66	Jan-99	117.80	Nov-02	123.60	Sep-06	111.00	Jul-10	105.09
Jun-91	93.60	Apr-95	178.80	Feb-99	119.84	Dec-02	124.31	Oct-06	128.96	Aug-10	88.35
Jul-91	90.83	May-95	147.56	Mar-99	157.79	Jan-03	128.65	Nov-06	143.70	Sep-10	94.20
Aug-91	77.19	Jun-95	93.60	Apr-99	146.40	Feb-03	152.60	Dec-06	132.68	Oct-10	100.44
Sep-91	92.70	Jul-95	93.93	May-99	119.97	Mar-03	185.69	Jan-07	121.21	Nov-10	131.40
Oct-91	112.22	Aug-95	88.35	Jun-99	90.30	Apr-03	202.50	Feb-07	127.96	Dec-10	117.49
Nov-91	122.10	Sep-95	100.20	Jul-99	86.80	May-03	170.81	Mar-07	168.02	Jan-11	119.66
Dec-91	115.94	Oct-95	117.80	Aug-99	87.42	Jun-03	99.30	Apr-07	200.70	Feb-11	115.08
Jan-92	123.69	Nov-95	115.50	Sep-99	95.70	Jul-03	100.44	May-07	115.63	Mar-11	126.17
Feb-92	133.98	Dec-95	121.21	Oct-99	105.09	Aug-03	93.93	Jun-07	92.10	Apr-11	166.50
Mar-92	160.58	Jan-96	125.24	Nov-99	112.20	Sep-03	99.30	Jul-07	87.11	May-11	112.53
Apr-92	172.50	Feb-96	129.34	Dec-99	115.01	Oct-03	129.89	Aug-07	83.39	Jun-11	89.10
May-92	149.73	Mar-96	162.75	Jan-00	136.40	Nov-03	128.70	Sep-07	77.40	Jul-11	94.24
Jun-92	98.10	Apr-96	167.10	Feb-00	125.57	Dec-03	136.09	Oct-07	100.44	Aug-11	83.39
Jul-92	92.38	May-96	124.62	Mar-00	154.38	Jan-04	138.88	Nov-07	125.70	Sep-11	81.30
Aug-92	84.94	Jun-96	100.20	Apr-00	157.80	Feb-04	140.36	Dec-07	125.24	Oct-11	108.19
Sep-92	90.60	Jul-96	100.13	May-00	132.99	Mar-04	186.31	Jan-08	126.48	Nov-11	132.60
Oct-92	106.64	Aug-96	91.45	Jun-00	92.70	Apr-04	205.50	Feb-08	141.52	Dec-11	129.89
Nov-92	117.60	Sep-96	101.10	Jul-00	93.00	May-04	143.53	Mar-08	177.32	Jan-12	132.37
Dec-92	121.21	Oct-96	112.22	Aug-00	89.90	Jun-04	95.10	Apr-08	155.70	Feb-12	143.55
Jan-93	121.52	Nov-96	114.00	Sep-00	90.60	Jul-04	96.10	May-08	110.67	Mar-12	171.12
Feb-93	128.24	Dec-96	115.32	Oct-00	107.26	Aug-04	79.36	Jun-08	90.60	Apr-12	189.30
Mar-93	162.75	Jan-97	121.52	Nov-00	120.90	Sep-04	97.80	Jul-08	88.66	May-12	140.43
Apr-93	179.40	Feb-97	127.96	Dec-00	118.11	Oct-04	118.11	Aug-08	93.31	Jun-12	90.90
May-93	146.63	Mar-97	158.41	Jan-01	148.80	Nov-04	144.60	Sep-08	87.30	Jul-12	82.15
Jun-93	102.60	Apr-97	176.40	Feb-01	142.52	Dec-04	127.10	Oct-08	102.92	Aug-12	76.57
Jul-93	101.68	May-97	157.17	Mar-01	185.69	Jan-05	133.61	Nov-08	120.30	Sep-12	97.50
Aug-93	82.77	Jun-97	101.70	Apr-01	223.20	Feb-05	145.88	Dec-08	119.04	Oct-12	121.52
Sep-93	92.10	Jul-97	86.80	May-01	142.29	Mar-05	183.21	Jan-09	117.18	Nov-12	108.00
Oct-93	133.30	Aug-97	91.45	Jun-01	101.40	Apr-05	205.80	Feb-09	150.36	Dec-12	117.80
Nov-93	126.60	Sep-97	85.20	Jul-01	90.83	May-05	159.34	Mar-09	169.88	Jan-13	127.72
Dec-93	118.42	Oct-97	119.97	Aug-01	88.35	Jun-05	85.20	Apr-09	176.10	Feb-13	143.36
Jan-94	125.24	Nov-97	112.80	Sep-01	108.00	Jul-05	89.90	May-09	125.55	Mar-13	180.42
Feb-94	127.96	Dec-97	118.11	Oct-01	109.12	Aug-05	87.42	Jun-09	87.90	Apr-13	206.40
Mar-94	150.66	Jan-98	123.38	Nov-01	120.60	Sep-05	95.10	Jul-09	81.53	May-13	152.21
Apr-94	178.80	Feb-98	124.88	Dec-01	127.41	Oct-05	123.38	Aug-09	99.51	Jun-13	91.50
May-94	127.10	Mar-98	163.37	Jan-02	133.92	Nov-05	114.60	Sep-09	87.00	Jul-13	82.46
Jun-94	90.30	Apr-98	166.50	Feb-02	144.20	Dec-05	124.93	Oct-09	107.26	Aug-13	87.73
Jul-94	89.90	May-98	149.11	Mar-02	195.30	Jan-06	138.26	Nov-09	133.20	Sep-13	84.00
Aug-94	81.22	Jun-98	98.10	Apr-02	200.40	Feb-06	155.12	Dec-09	128.65	Oct-13	111.91
Sep-94	95.10	Jul-98	97.03	May-02	158.10	Mar-06	182.59	Jan-10	127.41	Nov-13	115.80
Oct-94	123.38	Aug-98	93.93	Jun-02	83.10	Apr-06	194.10	Feb-10	120.12	Dec-13	105.09

Table C7: Precipitation (mm) of Hmawbi station (1991-2013)

Month	Pcp	Month	Pcp	Month	Pcp	Month	Pcp	Month	Pcp	Month	Pcp
Jan-91	0	Nov-94	83	Sep-98	123	Jul-02	509	May-06	160	Mar-10	0
Feb-91	0	Dec-94	3	Oct-98	150	Aug-02	579	Jun-06	248	Apr-10	0
Mar-91	6	Jan-95	0	Nov-98	83	Sep-02	597	Jul-06	617	May-10	253
Apr-91	7	Feb-95	0	Dec-98	0	Oct-02	93	Aug-06	519	Jun-10	434
May-91	26	Mar-95	0	Jan-99	0	Nov-02	200	Sep-06	412	Jul-10	278
Jun-91	494	Apr-95	0	Feb-99	6	Dec-02	18	Oct-06	122	Aug-10	399
Jul-91	612	May-95	255	Mar-99	18	Jan-03	6	Nov-06	0	Sep-10	231
Aug-91	540	Jun-95	605	Apr-99	147	Feb-03	0	Dec-06	0	Oct-10	229
Sep-91	276	Jul-95	505	May-99	469	Mar-03	1	Jan-07	0	Nov-10	0
Oct-91	141	Aug-95	325	Jun-99	462	Apr-03	3	Feb-07	0	Dec-10	61
Nov-91	139	Sep-95	533	Jul-99	707	May-03	249	Mar-07	0	Jan-11	81
Dec-91	20	Oct-95	130	Aug-99	529	Jun-03	727	Apr-07	2	Feb-11	0
Jan-92	0	Nov-95	99	Sep-99	351	Jul-03	387	May-07	732	Mar-11	108
Feb-92	6	Dec-95	0	Oct-99	202	Aug-03	484	Jun-07	500	Apr-11	0
Mar-92	0	Jan-96	0	Nov-99	48	Sep-03	389	Jul-07	540	May-11	284
Apr-92	10	Feb-96	68	Dec-99	0	Oct-03	66	Aug-07	374	Jun-11	789
May-92	193	Mar-96	7	Jan-00	0	Nov-03	2	Sep-07	571	Jul-11	490
Jun-92	501	Apr-96	31	Feb-00	1	Dec-03	0	Oct-07	269	Aug-11	357
Jul-92	669	May-96	403	Mar-00	34	Jan-04	7	Nov-07	23	Sep-11	453
Aug-92	590	Jun-96	512	Apr-00	15	Feb-04	0	Dec-07	0	Oct-11	118
Sep-92	361	Jul-96	434	May-00	454	Mar-04	0	Jan-08	16	Nov-11	0
Oct-92	237	Aug-96	480	Jun-00	552	Apr-04	0	Feb-08	28	Dec-11	0
Nov-92	33	Sep-96	424	Jul-00	550	May-04	529	Mar-08	0	Jan-12	0
Dec-92	0	Oct-96	236	Aug-00	364	Jun-04	795	Apr-08	148	Feb-12	0
Jan-93	0	Nov-96	149	Sep-00	272	Jul-04	407	May-08	580	Mar-12	0
Feb-93	0	Dec-96	0	Oct-00	105	Aug-04	661	Jun-08	334	Apr-12	18
Mar-93	0	Jan-97	0	Nov-00	1	Sep-04	414	Jul-08	634	May-12	113
Apr-93	7	Feb-97	0	Dec-00	0	Oct-04	87	Aug-08	453	Jun-12	492
May-93	273	Mar-97	5	Jan-01	1	Nov-04	0	Sep-08	326	Jul-12	686
Jun-93	471	Apr-97	41	Feb-01	1	Dec-04	0	Oct-08	137	Aug-12	745
Jul-93	457	May-97	163	Mar-01	21	Jan-05	0	Nov-08	12	Sep-12	481
Aug-93	876	Jun-97	459	Apr-01	0	Feb-05	0	Dec-08	0	Oct-12	73
Sep-93	410	Jul-97	702	May-01	251	Mar-05	0	Jan-09	0	Nov-12	128
Oct-93	83	Aug-97	727	Jun-01	677	Apr-05	0	Feb-09	0	Dec-12	2
Nov-93	0	Sep-97	361	Jul-01	603	May-05	76	Mar-09	0	Jan-13	0
Dec-93	0	Oct-97	223	Aug-01	415	Jun-05	378	Apr-09	104	Feb-13	1
Jan-94	0	Nov-97	20	Sep-01	252	Jul-05	637	May-09	279	Mar-13	0
Feb-94	0	Dec-97	0	Oct-01	285	Aug-05	548	Jun-09	468	Apr-13	0
Mar-94	107	Jan-98	0	Nov-01	20	Sep-05	403	Jul-09	665	May-13	222
Apr-94	0	Feb-98	0	Dec-01	0	Oct-05	182	Aug-09	385	Jun-13	543
May-94	143	Mar-98	0	Jan-02	0	Nov-05	67	Sep-09	399	Jul-13	590
Jun-94	628	Apr-98	10	Feb-02	0	Dec-05	50	Oct-09	125	Aug-13	759
Jul-94	674	May-98	224	Mar-02	0	Jan-06	0	Nov-09	0	Sep-13	603
Aug-94	682	Jun-98	512	Apr-02	0	Feb-06	0	Dec-09	0	Oct-13	254
Sep-94	368	Jul-98	340	May-02	253	Mar-06	0	Jan-10	8	Nov-13	25
Oct-94	34	Aug-98	572	Jun-02	588	Apr-06	152	Feb-10	0	Dec-13	0

Table C8: Precipitation (mm) of Mingalardon station (1991-2013)

Month	Pcp	Month	Pcp	Month	Pcp	Month	Pcp	Month	Pcp	Month	Pcp
Jan-91	0	Nov-94	27	Sep-98	162	Jul-02	418	May-06	237	Mar-10	0
Feb-91	0	Dec-94	0	Oct-98	197	Aug-02	584	Jun-06	290	Apr-10	0
Mar-91	0	Jan-95	0	Nov-98	11	Sep-02	564	Jul-06	711	May-10	300
Apr-91	17	Feb-95	0	Dec-98	0	Oct-02	111	Aug-06	617	Jun-10	436
May-91	42	Mar-95	0	Jan-99	0	Nov-02	273	Sep-06	329	Jul-10	312
Jun-91	604	Apr-95	0	Feb-99	0	Dec-02	0	Oct-06	128	Aug-10	446
Jul-91	834	May-95	230	Mar-99	35	Jan-03	3	Nov-06	0	Sep-10	268
Aug-91	501	Jun-95	586	Apr-99	278	Feb-03	0	Dec-06	0	Oct-10	308
Sep-91	138	Jul-95	608	May-99	423	Mar-03	3	Jan-07	0	Nov-10	14
Oct-91	146	Aug-95	351	Jun-99	400	Apr-03	0	Feb-07	0	Dec-10	11
Nov-91	21	Sep-95	518	Jul-99	472	May-03	336	Mar-07	0	Jan-11	50
Dec-91	19	Oct-95	262	Aug-99	538	Jun-03	651	Apr-07	0	Feb-11	0
Jan-92	0	Nov-95	88	Sep-99	341	Jul-03	255	May-07	702	Mar-11	97
Feb-92	0	Dec-95	0	Oct-99	346	Aug-03	466	Jun-07	538	Apr-11	8
Mar-92	0	Jan-96	0	Nov-99	65	Sep-03	413	Jul-07	760	May-11	283
Apr-92	2	Feb-96	59	Dec-99	0	Oct-03	59	Aug-07	452	Jun-11	587
May-92	129	Mar-96	4	Jan-00	0	Nov-03	5	Sep-07	735	Jul-11	719
Jun-92	366	Apr-96	45	Feb-00	0	Dec-03	0	Oct-07	260	Aug-11	633
Jul-92	595	May-96	294	Mar-00	0	Jan-04	3	Nov-07	3	Sep-11	423
Aug-92	433	Jun-96	553	Apr-00	99	Feb-04	0	Dec-07	0	Oct-11	154
Sep-92	276	Jul-96	460	May-00	256	Mar-04	0	Jan-08	4	Nov-11	0
Oct-92	255	Aug-96	627	Jun-00	555	Apr-04	2	Feb-08	13	Dec-11	0
Nov-92	14	Sep-96	566	Jul-00	354	May-04	428	Mar-08	17	Jan-12	0
Dec-92	2	Oct-96	204	Aug-00	331	Jun-04	807	Apr-08	121	Feb-12	0
Jan-93	0	Nov-96	126	Sep-00	412	Jul-04	443	May-08	583	Mar-12	13
Feb-93	0	Dec-96	7	Oct-00	164	Aug-04	768	Jun-08	294	Apr-12	5
Mar-93	0	Jan-97	0	Nov-00	2	Sep-04	346	Jul-08	557	May-12	119
Apr-93	0	Feb-97	0	Dec-00	0	Oct-04	49	Aug-08	441	Jun-12	402
May-93	246	Mar-97	0	Jan-01	0	Nov-04	1	Sep-08	418	Jul-12	693
Jun-93	405	Apr-97	37	Feb-01	0	Dec-04	0	Oct-08	309	Aug-12	824
Jul-93	443	May-97	325	Mar-01	36	Jan-05	55	Nov-08	45	Sep-12	358
Aug-93	557	Jun-97	435	Apr-01	0	Feb-05	0	Dec-08	0	Oct-12	96
Sep-93	372	Jul-97	643	May-01	380	Mar-05	15	Jan-09	0	Nov-12	129
Oct-93	106	Aug-97	755	Jun-01	519	Apr-05	22	Feb-09	0	Dec-12	5
Nov-93	18	Sep-97	462	Jul-01	544	May-05	175	Mar-09	0	Jan-13	3
Dec-93	0	Oct-97	197	Aug-01	430	Jun-05	533	Apr-09	29	Feb-13	0
Jan-94	0	Nov-97	51	Sep-01	196	Jul-05	545	May-09	344	Mar-13	0
Feb-94	0	Dec-97	0	Oct-01	318	Aug-05	473	Jun-09	559	Apr-13	0
Mar-94	114	Jan-98	0	Nov-01	34	Sep-05	600	Jul-09	859	May-13	120
Apr-94	0	Feb-98	0	Dec-01	7	Oct-05	168	Aug-09	383	Jun-13	441
May-94	181	Mar-98	0	Jan-02	0	Nov-05	61	Sep-09	523	Jul-13	591
Jun-94	671	Apr-98	11	Feb-02	0	Dec-05	0	Oct-09	124	Aug-13	474
Jul-94	796	May-98	301	Mar-02	0	Jan-06	0	Nov-09	16	Sep-13	608
Aug-94	714	Jun-98	424	Apr-02	4	Feb-06	0	Dec-09	0	Oct-13	230
Sep-94	408	Jul-98	327	May-02	390	Mar-06	0	Jan-10	0	Nov-13	64
Oct-94	177	Aug-98	468	Jun-02	617	Apr-06	149	Feb-10	0	Dec-13	0

Table C9: Precipitation (mm) of Kaba-aye station (1991-2013)

Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp	Month	Eff Pcp
Jan-91	126.17	Nov-94	120.30	Sep-98	107.10	Jul-02	98.89	May-06	139.81	Mar-10	141.67
Feb-91	128.24	Dec-94	120.90	Oct-98	117.18	Aug-02	82.15	Jun-06	102.90	Apr-10	171.30
Mar-91	159.96	Jan-95	124.31	Nov-98	114.00	Sep-02	88.50	Jul-06	91.76	May-10	182.28
Apr-91	171.00	Feb-95	126.28	Dec-98	115.01	Oct-02	128.03	Aug-06	90.21	Jun-10	92.70
May-91	165.23	Mar-95	150.66	Jan-99	117.80	Nov-02	123.60	Sep-06	111.00	Jul-10	105.09
Jun-91	93.60	Apr-95	178.80	Feb-99	119.84	Dec-02	124.31	Oct-06	128.96	Aug-10	88.35
Jul-91	90.83	May-95	147.56	Mar-99	157.79	Jan-03	128.65	Nov-06	143.70	Sep-10	94.20
Aug-91	77.19	Jun-95	93.60	Apr-99	146.40	Feb-03	152.60	Dec-06	132.68	Oct-10	100.44
Sep-91	92.70	Jul-95	93.93	May-99	119.97	Mar-03	185.69	Jan-07	121.21	Nov-10	131.40
Oct-91	112.22	Aug-95	88.35	Jun-99	90.30	Apr-03	202.50	Feb-07	127.96	Dec-10	117.49
Nov-91	122.10	Sep-95	100.20	Jul-99	86.80	May-03	170.81	Mar-07	168.02	Jan-11	119.66
Dec-91	115.94	Oct-95	117.80	Aug-99	87.42	Jun-03	99.30	Apr-07	200.70	Feb-11	115.08
Jan-92	123.69	Nov-95	115.50	Sep-99	95.70	Jul-03	100.44	May-07	115.63	Mar-11	126.17
Feb-92	133.98	Dec-95	121.21	Oct-99	105.09	Aug-03	93.93	Jun-07	92.10	Apr-11	166.50
Mar-92	160.58	Jan-96	125.24	Nov-99	112.20	Sep-03	99.30	Jul-07	87.11	May-11	112.53
Apr-92	172.50	Feb-96	129.34	Dec-99	115.01	Oct-03	129.89	Aug-07	83.39	Jun-11	89.10
May-92	149.73	Mar-96	162.75	Jan-00	136.40	Nov-03	128.70	Sep-07	77.40	Jul-11	94.24
Jun-92	98.10	Apr-96	167.10	Feb-00	125.57	Dec-03	136.09	Oct-07	100.44	Aug-11	83.39
Jul-92	92.38	May-96	124.62	Mar-00	154.38	Jan-04	138.88	Nov-07	125.70	Sep-11	81.30
Aug-92	84.94	Jun-96	100.20	Apr-00	157.80	Feb-04	140.36	Dec-07	125.24	Oct-11	108.19
Sep-92	90.60	Jul-96	100.13	May-00	132.99	Mar-04	186.31	Jan-08	126.48	Nov-11	132.60
Oct-92	106.64	Aug-96	91.45	Jun-00	92.70	Apr-04	205.50	Feb-08	141.52	Dec-11	129.89
Nov-92	117.60	Sep-96	101.10	Jul-00	93.00	May-04	143.53	Mar-08	177.32	Jan-12	132.37
Dec-92	121.21	Oct-96	112.22	Aug-00	89.90	Jun-04	95.10	Apr-08	155.70	Feb-12	143.55
Jan-93	121.52	Nov-96	114.00	Sep-00	90.60	Jul-04	96.10	May-08	110.67	Mar-12	171.12
Feb-93	128.24	Dec-96	115.32	Oct-00	107.26	Aug-04	79.36	Jun-08	90.60	Apr-12	189.30
Mar-93	162.75	Jan-97	121.52	Nov-00	120.90	Sep-04	97.80	Jul-08	88.66	May-12	140.43
Apr-93	179.40	Feb-97	127.96	Dec-00	118.11	Oct-04	118.11	Aug-08	93.31	Jun-12	90.90
May-93	146.63	Mar-97	158.41	Jan-01	148.80	Nov-04	144.60	Sep-08	87.30	Jul-12	82.15
Jun-93	102.60	Apr-97	176.40	Feb-01	142.52	Dec-04	127.10	Oct-08	102.92	Aug-12	76.57
Jul-93	101.68	May-97	157.17	Mar-01	185.69	Jan-05	133.61	Nov-08	120.30	Sep-12	97.50
Aug-93	82.77	Jun-97	101.70	Apr-01	223.20	Feb-05	145.88	Dec-08	119.04	Oct-12	121.52
Sep-93	92.10	Jul-97	86.80	May-01	142.29	Mar-05	183.21	Jan-09	117.18	Nov-12	108.00
Oct-93	133.30	Aug-97	91.45	Jun-01	101.40	Apr-05	205.80	Feb-09	150.36	Dec-12	117.80
Nov-93	126.60	Sep-97	85.20	Jul-01	90.83	May-05	159.34	Mar-09	169.88	Jan-13	127.72
Dec-93	118.42	Oct-97	119.97	Aug-01	88.35	Jun-05	85.20	Apr-09	176.10	Feb-13	143.36
Jan-94	125.24	Nov-97	112.80	Sep-01	108.00	Jul-05	89.90	May-09	125.55	Mar-13	180.42
Feb-94	127.96	Dec-97	118.11	Oct-01	109.12	Aug-05	87.42	Jun-09	87.90	Apr-13	206.40
Mar-94	150.66	Jan-98	123.38	Nov-01	120.60	Sep-05	95.10	Jul-09	81.53	May-13	152.21
Apr-94	178.80	Feb-98	124.88	Dec-01	127.41	Oct-05	123.38	Aug-09	99.51	Jun-13	91.50
May-94	127.10	Mar-98	163.37	Jan-02	133.92	Nov-05	114.60	Sep-09	87.00	Jul-13	82.46
Jun-94	90.30	Apr-98	166.50	Feb-02	144.20	Dec-05	124.93	Oct-09	107.26	Aug-13	87.73
Jul-94	89.90	May-98	149.11	Mar-02	195.30	Jan-06	138.26	Nov-09	133.20	Sep-13	84.00
Aug-94	81.22	Jun-98	98.10	Apr-02	200.40	Feb-06	155.12	Dec-09	128.65	Oct-13	111.91
Sep-94	95.10	Jul-98	97.03	May-02	158.10	Mar-06	182.59	Jan-10	127.41	Nov-13	115.80
Oct-94	123.38	Aug-98	93.93	Jun-02	83.10	Apr-06	194.10	Feb-10	120.12	Dec-13	105.09

Table C10: Net Evaporation (mm) of Hmawbi station (1991-2013)

Month	Net Eva	Month	Net Eva	Month	Net Eva	Month	Net Eva	Month	Net Eva	Month	Net Eva
Jan-91	108.4	Nov-94	46.8	Sep-98	-19	02-Jul	-434.6	06-May	-45.3	10-Mar	167.4
Feb-91	160.1	Dec-94	110.6	Oct-98	-32.3	02-Aug	-504.6	06-Jun	-182	10-Apr	177
Mar-91	184.9	Jan-95	126	Nov-98	36.2	02-Sep	-522	06-Jul	-545.7	10-May	-88.7
Apr-91	141.6	Feb-95	117.5	Dec-98	127.1	02-Oct	0	06-Aug	-447.7	10-Jun	-359
May-91	125.1	Mar-95	161.2	Jan-99	136.4	02-Nov	-107	06-Sep	-337	10-Jul	-206.7
Jun-91	-446.7	Apr-95	198.5	Feb-99	128.2	02-Dec	65.7	06-Oct	-25.9	10-Aug	-330.8
Jul-91	-573.6	May-95	-120.3	Mar-99	184.9	03-Jan	80.8	06-Nov	120	10-Sep	-162
Aug-91	-507.4	Jun-95	-537.1	Apr-99	-0.3	03-Feb	109.2	06-Dec	127.1	10-Oct	-145.3
Sep-91	-206	Jul-95	-406.8	May-99	-341.4	03-Mar	154	07-Jan	86.8	10-Nov	114
Oct-91	-35.2	Aug-95	-251.6	Jun-99	-371.9	03-Apr	174	07-Feb	117.6	10-Dec	44.4
Nov-91	-28	Sep-95	-460.5	Jul-99	-621.2	03-May	-125	07-Mar	151.9	11-Jan	15.1
Dec-91	103.5	Oct-95	-18.5	Aug-99	-439.3	03-Jun	-643	07-Apr	154	11-Feb	114.8
Jan-92	104.9	Nov-95	19	Sep-99	-248	03-Jul	-294	07-May	-617.3	11-Mar	12.9
Feb-92	97	Dec-95	115.1	Oct-99	-83.8	03-Aug	-418.9	07-Jun	-434	11-Apr	165
Mar-92	150	Jan-96	117	Nov-99	91.2	03-Sep	-311	07-Jul	-468.7	11-May	-181.7
Apr-92	161.7	Feb-96	73.4	Dec-99	150.2	03-Oct	42.5	07-Aug	-302.7	11-Jun	-720
May-92	-52.5	Mar-96	155	Jan-00	140.4	03-Nov	112	07-Sep	-496	11-Jul	-418.7
Jun-92	-442.8	Apr-96	128.1	Feb-00	149.8	03-Dec	102.3	07-Oct	-172.9	11-Aug	-282.6
Jul-92	-615.9	May-96	-270.5	Mar-00	160.8	04-Jan	73.6	07-Nov	97	11-Sep	-369
Aug-92	-539.5	Jun-96	-445.2	Apr-00	167.6	04-Feb	92.8	07-Dec	127.1	11-Oct	-3.3
Sep-92	-304.2	Jul-96	-351.8	May-00	-340.6	04-Mar	155	08-Jan	89.4	11-Nov	141
Oct-92	-153.4	Aug-96	-408.4	Jun-00	-444	04-Apr	177	08-Feb	96.7	11-Dec	120.9
Nov-92	78.5	Sep-96	-332.5	Jul-00	-454.1	04-May	-411.2	08-Mar	151.9	12-Jan	114.7
Dec-92	104.1	Oct-96	-119.2	Aug-00	-255.3	04-Jun	-696	08-Apr	-4	12-Feb	145
Jan-93	126.3	Nov-96	-35.2	Sep-00	-179.2	04-Jul	-345	08-May	-505.6	12-Mar	179.8
Feb-93	115.7	Dec-96	129.2	Oct-00	5.2	04-Aug	-614.5	08-Jun	-265	12-Apr	171
Mar-93	149	Jan-97	115.5	Nov-00	122.6	04-Sep	-348	08-Jul	-575.1	12-May	32.7
Apr-93	165.5	Feb-97	129.4	Dec-00	136	04-Oct	-0.2	08-Aug	-391	12-Jun	-429
May-93	-146.9	Mar-97	147.8	01-Jan	144.7	04-Nov	99	08-Sep	-254	12-Jul	-620.9
Jun-93	-387.6	Apr-97	107.6	01-Feb	161.4	04-Dec	93	08-Oct	-50.2	12-Aug	-670.6
Jul-93	-376	May-97	-30.5	01-Mar	149.5	05-Jan	99.2	08-Nov	96	12-Sep	-376
Aug-93	-785.6	Jun-97	-386	01-Apr	240	05-Feb	117.6	08-Dec	114.7	12-Oct	63.4
Sep-93	-315.5	Jul-97	-647.1	01-May	-120.8	05-Mar	155	09-Jan	124	12-Nov	-8
Oct-93	29.4	Aug-97	-677.5	01-Jun	-587	05-Apr	162	09-Feb	120.4	12-Dec	112.7
Nov-93	141.3	Sep-97	-307.8	01-Jul	-519.3	05-May	41.8	09-Mar	158.1	13-Jan	133.3
Dec-93	122.2	Oct-97	-134.4	01-Aug	-322	05-Jun	-306	09-Apr	22	13-Feb	164.2
Jan-94	114.9	Nov-97	73.5	01-Sep	-138	05-Jul	-553.3	09-May	-167.4	13-Mar	189.1
Feb-94	130	Dec-97	121.8	01-Oct	-161	05-Aug	-464.3	09-Jun	-411	13-Apr	207
Mar-94	34.7	Jan-98	137.1	01-Nov	115	05-Sep	-322	09-Jul	-606.1	13-May	-82.5
Apr-94	158.7	Feb-98	123.9	01-Dec	130.2	05-Oct	-70.4	09-Aug	-323	13-Jun	-486
May-94	-28.8	Mar-98	200.2	02-Jan	86.8	05-Nov	29	09-Sep	-312	13-Jul	-546.6
Jun-94	-563.7	Apr-98	228.1	02-Feb	128.8	05-Dec	39.9	09-Oct	-25.8	13-Aug	-697
Jul-94	-602.1	May-98	-30.6	02-Mar	164.3	06-Jan	86.8	09-Nov	120	13-Sep	-543
Aug-94	-625.3	Jun-98	-425.4	02-Apr	168	06-Feb	117.6	09-Dec	99.2	13-Oct	-148.6
Sep-94	-291.4	Jul-98	-269.9	02-May	-119.7	06-Mar	151.9	10-Jan	91.2	13-Nov	101
Oct-94	72.8	Aug-98	-507.1	02-Jun	-501	06-Apr	4	10-Feb	126	13-Dec	83.7

Table C11: Net Evaporation (mm) of Mingalardon station (1991-2013)

Month	Net Eva	Month	Net Eva	Month	Net Eva	Month	Net Eva	Month	Net Eva	Month	Net Eva
Jan-91	108.4	Nov-94	102.8	Sep-98	-58	02-Jul	-343.6	06-May	-122.3	10-Mar	167.4
Feb-91	160.1	Dec-94	113.6	Oct-98	-79.3	02-Aug	-509.6	06-Jun	-224	10-Apr	177
Mar-91	190.9	Jan-95	126	Nov-98	108.2	02-Sep	-489	06-Jul	-639.7	10-May	-135.7
Apr-91	131.6	Feb-95	117.5	Dec-98	127.1	02-Oct	-18	06-Aug	-545.7	10-Jun	-361
May-91	109.1	Mar-95	161.2	Jan-99	136.4	02-Nov	-180	06-Sep	-254	10-Jul	-240.7
Jun-91	-556.7	Apr-95	198.5	Feb-99	134.2	02-Dec	83.7	06-Oct	-31.9	10-Aug	-377.8
Jul-91	-795.6	May-95	-95.3	Mar-99	167.9	03-Jan	83.8	06-Nov	120	10-Sep	-199
Aug-91	-468.4	Jun-95	-518.1	Apr-99	-131.3	03-Feb	109.2	06-Dec	127.1	10-Oct	-224.3
Sep-91	-68	Jul-95	-509.8	May-99	-295.4	03-Mar	152	07-Jan	86.8	10-Nov	100
Oct-91	-40.2	Aug-95	-277.6	Jun-99	-309.9	03-Apr	177	07-Feb	117.6	10-Dec	94.4
Nov-91	90	Sep-95	-445.5	Jul-99	-386.2	03-May	-212	07-Mar	151.9	11-Jan	46.1
Dec-91	104.5	Oct-95	-150.5	Aug-99	-448.3	03-Jun	-567	07-Apr	156	11-Feb	114.8
Jan-92	104.9	Nov-95	30	Sep-99	-238	03-Jul	-162	07-May	-587.3	11-Mar	23.9
Feb-92	103	Dec-95	115.1	Oct-99	-227.8	03-Aug	-400.9	07-Jun	-472	11-Apr	157
Mar-92	150	Jan-96	117	Nov-99	74.2	03-Sep	-335	07-Jul	-688.7	11-May	-180.7
Apr-92	169.7	Feb-96	82.4	Dec-99	150.2	03-Oct	49.5	07-Aug	-380.7	11-Jun	-518
May-92	11.5	Mar-96	158	Jan-00	140.4	03-Nov	109	07-Sep	-660	11-Jul	-647.7
Jun-92	-307.8	Apr-96	114.1	Feb-00	150.8	03-Dec	102.3	07-Oct	-163.9	11-Aug	-558.6
Jul-92	-541.9	May-96	-161.5	Mar-00	194.8	04-Jan	77.6	07-Nov	117	11-Sep	-339
Aug-92	-382.5	Jun-96	-486.2	Apr-00	83.6	04-Feb	92.8	07-Dec	127.1	11-Oct	-39.3
Sep-92	-219.2	Jul-96	-377.8	May-00	-142.6	04-Mar	155	08-Jan	101.4	11-Nov	141
Oct-92	-171.4	Aug-96	-555.4	Jun-00	-447	04-Apr	175	08-Feb	111.7	11-Dec	120.9
Nov-92	97.5	Sep-96	-474.5	Jul-00	-258.1	04-May	-310.2	08-Mar	134.9	12-Jan	114.7
Dec-92	102.1	Oct-96	-87.2	Aug-00	-222.3	04-Jun	-708	08-Apr	23	12-Feb	145
Jan-93	126.3	Nov-96	-12.2	Sep-00	-319.2	04-Jul	-381	08-May	-508.6	12-Mar	166.8
Feb-93	115.7	Dec-96	122.2	Oct-00	-53.8	04-Aug	-721.5	08-Jun	-225	12-Apr	184
Mar-93	149	Jan-97	115.5	Nov-00	121.6	04-Sep	-280	08-Jul	-498.1	12-May	26.7
Apr-93	172.5	Feb-97	129.4	Dec-00	136	04-Oct	37.8	08-Aug	-379	12-Jun	-339
May-93	-119.9	Mar-97	152.8	01-Jan	145.7	04-Nov	98	08-Sep	-346	12-Jul	-627.9
Jun-93	-321.6	Apr-97	111.6	01-Feb	162.4	04-Dec	93	08-Oct	-222.2	12-Aug	-749.6
Jul-93	-362	May-97	-192.5	01-Mar	134.5	05-Jan	44.2	08-Nov	63	12-Sep	-253
Aug-93	-466.6	Jun-97	-362	01-Apr	240	05-Feb	117.6	08-Dec	114.7	12-Oct	40.4
Sep-93	-277.5	Jul-97	-588.1	01-May	-249.8	05-Mar	140	09-Jan	124	12-Nov	-9
Oct-93	6.4	Aug-97	-705.5	01-Jun	-429	05-Apr	140	09-Feb	120.4	12-Dec	109.7
Nov-93	123.3	Sep-97	-408.8	01-Jul	-460.3	05-May	-57.2	09-Mar	158.1	13-Jan	130.3
Dec-93	122.2	Oct-97	-108.4	01-Aug	-337	05-Jun	-461	09-Apr	97	13-Feb	165.2
Jan-94	114.9	Nov-97	42.5	01-Sep	-82	05-Jul	-461.3	09-May	-232.4	13-Mar	189.1
Feb-94	130	Dec-97	121.8	01-Oct	-194	05-Aug	-389.3	09-Jun	-502	13-Apr	207
Mar-94	27.7	Jan-98	137.1	01-Nov	101	05-Sep	-519	09-Jul	-800.1	13-May	19.5
Apr-94	158.7	Feb-98	123.9	01-Dec	123.2	05-Oct	-56.4	09-Aug	-321	13-Jun	-384
May-94	-66.8	Mar-98	200.2	02-Jan	86.8	05-Nov	35	09-Sep	-436	13-Jul	-547.6
Jun-94	-606.7	Apr-98	227.1	02-Feb	128.8	05-Dec	89.9	09-Oct	-24.8	13-Aug	-412
Jul-94	-724.1	May-98	-107.6	02-Mar	164.3	06-Jan	86.8	09-Nov	104	13-Sep	-548
Aug-94	-657.3	Jun-98	-337.4	02-Apr	164	06-Feb	117.6	09-Dec	99.2	13-Oct	-124.6
Sep-94	-331.4	Jul-98	-256.9	02-May	-256.7	06-Mar	151.9	10-Jan	99.2	13-Nov	62
Oct-94	-70.2	Aug-98	-403.1	02-Jun	-530	06-Apr	7	10-Feb	126	13-Dec	83.7

Observed and simulated storage volume of reservoirs in YCWSS