WATER ALLOCATION ASSESSMENT TO SUPPORT IWRM IN THE MAJOR RIVER BASINS OF MYANMAR: NOW AND IN THE FUTURE

M.Sc. Thesis

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TU Delft Delft University of Technology

Deltares Enabling Delta Life

Cover photo: Fishing family at MoYinGyi Wetland area – facing towards the north, looking at a floodplain of the Sittaung River – Taken around the end of November, 2013 – Rens Hasman

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Deltares and Delft University of Technology (DUT) were part in the data inventory mission to Myanmar, September till December 2013. After that, Deltares continued to develop a water demand and allocation tool (Ribasim) to support the Dutch consortium in setting up an Integrated Water Resources Management Strategy Plan for the Republic of the Union of Myanmar, under a Memorandum of Understanding (MoU) signed in 2012 between the Dutch Government and the Ministry of Transport of Myanmar

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"In many parts of the world, water scarcity is increasing and rates of growth in agricultural production have been slowing. At the same time, climate change is exacerbating risk and unpredictability for farmers, especially for poor farmers in low-income countries…These interlinked challenges are increasing competition between communities and countries for scarce water resources, aggravating old security dilemmas, creating new ones and hampering the achievement of the fundamental human rights to food, water and sanitation."

- United Nations Secretary-General Ban Ki-moon at the World Water day 2014

Photo: MoYingGyi Wetland Area (Bago Division) – *Rens Hasman*

Abstract

The opportunities for Myanmar to develop its socioeconomics with foreign investors and relations after the political isolation over the last decades are growing for the different stakeholders in the country to exploit the natural resources to country is rich of. These opportunities lead to the strategy of the government to change from a sectorial oriented to an integrated approach to develop the country in a sustainable way in a river basin wide vision. The cornerstones of the development of Myanmar's economics are the water, energy and food sectors, where all are interlinked and proper planning is crucial to develop them all in a sustainable way. The development of an Integrated Water Resources Management (IWRM) Strategy Plan is crucial to integrate the different strategies and visions of the individual stakeholders into national wide visions and/ or long term strategies.

This study focusses on better understanding of the water resources system (WRS) in both present and future situation, following the socioeconomic trends found in literature. A water demand and allocation simulation package (Ribasim) is used to assess the water availability, demand and allocation for the major river basins in Myanmar, namely the Ayeyarwady, Salween, Sittaung, Bago and Myit Ma Hka River basins. Ribasim is a zero- dimensional modelling simulation program which is able to calculate the water demand and allocation over a certain simulation period. The input data for the models are data collected during a field visit to the involved ministries in Myanmar. Validation of the following input parameters are recommended to be obtain in the field to increase a better understanding of the WRS: cropping patterns, efficiency of the irrigation fields, available storage, actual rainfall and evaporation and operation management rules of multi-purpose dams.

For both the current and most extreme future development in the socioeconomics, the water utilisation on river basin level is low and is not restricting for the development of the country's economy. The utilisation of the available fresh water resources on basin scale is low, with only 4.0% and 7.4%. This is averaged over the major river basins (Ayeyarwady, Salween, Sittaung, Bago and Myit Ma Hka), where the agricultural sector accounts for 83% to 88% of the total withdrawal. The future situation is analysed with different socioeconomic trends as input, affecting the WRS. One of the major trends is the agricultural sector. The irrigated area is planned to increase with a factor two, from 1.1 million ha to 2.2 million ha, resulting in an increase of demand of 131%. Developing the irrigation areas, results in a higher base flow during the dry season. Improving the irrigation scheme efficiency with 25% on the other hand results in an increase of the cultivated area of 12.5% and 16.7% respectively for the actual and proposed irrigation area. This results in the decrease of the drained water and a reduction in the base flow. For developed irrigation areas in the Sittaung, Bago, Myit Ma Hka and the Ayeyarwady Basins this can become critical for the salinity intrusion in the delta, with water quality issues as a consequence. . For the production of hydropower this results in a longer period of time the stored water can be released through the turbine. Multi-purpose reservoirs can contribute to an integrated and sustainable water management. The water scarcity level assessed on the local scale for the Magway and Minbu Region in the Central Dry Zone is observed to be severe (23.5%) for the available storage capacity. In conclusion, involvement of all sectors in the (modelled) water allocation assessment will increase the understanding and awareness of the WRS for the stakeholders and benefits to the IWRM process in Myanmar with the objective of an environmental, social and economical sustainable development of the countries water resources.

Conversion Table

Length

1 inch (in)	0.0254 m
1 foot (ft)	0.3048 m
1 meter (m)	39.37 inch (m)
1 meter (m)	3.28 feet (ft)
1 square foot (ft^2)	0.0929 m^2
1 acre	4046.86 m^2
1 acre	0.404686 ha

Area

1 square meter (m^2)	10.76 square feet (f^2)
1 square meter (m^2)	0.00024 acres
1 hectare (ha)	2.47 acre
1 square miles (sq-miles)	259 hectare (ha)
1 hectare (ha)	0.003861 square miles (sq-mil)

Volume

1 cubic foot (ft^3)	0.0283 m^3
1 cubic meter (m^3)	35.315 cubic feet (ft^3)
1 acre feet	0.0012335 10^6
1 acre feet	1233500 m^3
1 m^3	0.000811 Acre feet (Ac-ft)

Abbreviations, symbols and glossary used in the report and appendices

Ac-ft	Acre feet
Aye	Ayeyarwady river basin
Bag	Bago river basin
d	Dam (used in Mastersheet)
D	Domestic water use
d/ rr	Dam or run of river (unknown) (used in Mastersheet)
Dec	decimals
DHPI	Department of Hydropower Planning and Implementation, MoE
DMH	Department of Meteorology Department – Ministry of Transport
DoI	Department of Irrigation, Ministry of Agriculture and Irrigation
DS	Dead storage capacity
EFR	Environmental Flow Requirement
FC	Flood Control
FS	Full storage capacity
Ft	feet
Ha	Hectares
HP	Hydropower
I	Irrigation
Irrawaddy	English name - Ayarwaddy –Used name in report: Ayeyarwady
IWMI	International Water Management Institute
IWRM	Integrated water resource management
JICA	Japan International Cooperation Agency
LIFT	Livelihoods and Food Security Trust Fund
M	meter
Mm^3	Million cubic metric meter
MoAI	Ministry of Agriculture and Irrigation
MoE	Ministry of Electro Power
MoF	Ministry of Forestry
MoT	Ministry of Transport
MW	Mega Watts
Myi	Myit Ma Hka river basin
N	Navigation
NEPS	National Engineering and Planning Services
o	O – other structure (used in Mastersheet)
O&M	Operation and Maintenance
OID	Object ID
P	Pump (used in Mastersheet)
PWS	Public water supply
Rp	River pump (used in Mastersheet)
rr	Run of river (used in Mastersheet)
s	Sluice (used in Mastersheet)
S	Salt instruction control
Sit	Sittaung river basin
Sqr mile	Square miles
t	Tank (used in Mastersheet)
Thanlwin	Salween river – Myanmar name
w	Weir (used in Mastersheet)
Yr	year
WRUD	Water Resources Utilisation Department
AD	Agricultural Department, Ministry of Agriculture and Irrigation

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1. Introduction

This chapter illustrates the motivation for this research: the support for the planners in the water resources system of Myanmar. First, a brief introduction about the changes in the countries policies and sectors and what the affect is on the water resources system. The term Integrated Water Resources management in relation to Myanmar is introduced. The In the problem statement, the research objectives are mentioned, which will be discussed in more detail in chapter 2 and 3.

Head regulator at KoDuKwe Dam, Bago River basin – Photo: Rens Hasman

1.1. Development of Myanmar

The opportunities for Myanmar's socioeconomic development are increasing with cooperation of foreign investors and relations. The different stakeholders are making long term plans to exploit the available resources in the country. The development can stimulate the national's economy and fight poverty, especially in the rural regions. Water is one of the cornerstones for almost all daily life needs and activities. The other two are energy and food, which all are interlinked; together they form the water, energy and food nexus. Myanmar has abundant water resources, but they are unevenly distributed in time and space (FAO, 2010). Over 80% of the annual water, enters the system during the monsoon season, i.e. half -May – end of October. With the increase of population and enhanced need for water for economic activities, food security, sanitation and hygiene, there is an increasing pressure on utilisation of the water resources by all sectors in the water resources system (WRS) (I&E, 2013), posing also many social and ecological threats (Schmidt, 2012). The foreseen impact on the water resources system as a consequence of the planned developed and the increasing awareness of a sustainable approach, initiated the government of Myanmar to change its national policy from a sectorial to an integrated approach.

The water, energy and food sectors are strongly interlinked and good planning and coordination is required to sustainably develop these sectors parallel to each other. Exploitation of the available water resources in the country is likely to happen (FAO, 2010). The increasing economy and people's welfare demands the usage of electricity for daily use and production of goods, and processing of food. Myanmar has the lowest energy consumption and electrification rate in Southeast Asia whereas electricity production potential is large due to the high potential of hydropower projects in the hilly and mountainous region.

The irrigated agriculture is the largest water consumer in the country, which is good for 90% of the total withdrawal (FAO, 2010). The most important stakeholders in the river basins of Myanmar in relation to the water utilisation are also important drivers for the country's economy. The two major sectors that will experience rapid development and boost the (socio-) economics are the hydropower and agricultural/irrigation sectors (Kattelus, M et al., 2013), since there are abundant land and water resources available to be exploited. The change in a political climate to a more international and market oriented economy gives the opportunity for rapid development of the socioeconomic system.

In July 2013 Myanmar's National Water Resources Committee (NWRC) has been assigned has asked the Dutch Government to guide the process of the integration of all involved sectors using an Integrated Water Resources Management (IWRM) to develop the country and its resources in a sustainable way on the short-medium and long term. This committee includes representatives of all sectors involved in the WRS and is chaired by the ministry of Transport. In April 2013 a Memorandum of Understanding (MoU) was signed with the Ministry of Transport to develop this plan together with the Dutch water sector.

1.2. **The concept of Integrated Water Resources Management**

The concept of IWRM has been developed since the beginning of the nineties. The IWRM approach focusses on the increasing pressure on water resources system and the interaction with the socioeconomic development in a river basin. Water surplus and shortages forced many countries to reconsider the management options of their water resources and its infrastructure. As a result water resources management (WRM) has undergone a drastic change world-wide, moving from a supply-oriented, engineering based approach towards a demand oriented and multi-sectorial approach.

Definition of IWRM:

IWRM is a process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems

To achieve sustainable development of a region or country, the integrating of all stakeholders would be preferred in the process of developing the water resources system. IWRM is a process in which the objective that the involved stakeholders will gradually implement the integrated approach by the stakeholder in their decision and management practices. The IWRM approach is not just a framework that can be blindly applied to any river basin or country; it must be applied to the particular situation of the area where different geographic, hydro-meteorological conditions, as well as the social and cultural aspect of the country or countries are location specific..

The consensus between experts from all over the world on the implications of IWRM is reflected in the Dublin Principles 1992 (GWP, 2000), which have been universally accepted.

Dublin Principles

i. Water is a finite, vulnerable and essential resource, essential to sustain life, development and the environment.
ii. Water resources development and management should be based on a participatory approach, involving users, planners and policy makers at all levels.
iii. Woman play a central role in the provision, management and safeguarding of the water.
iv. Water has an economic value in all its competing uses and should be recognized as an economic good.

During the 2nd World Water Forum, held in The Hague in March 2000 - Ministerial Declaration of The Hague on Water Security in the 21st Century - on Water Security in the 21st Century, (Hague, 2000)Schmidt, 2012, country delegations committed themselves to providing “Water Security”. Water security implies ensuring the following targets:

i. Fresh water, coastal and related ecosystems are protected and improved;
ii. Sustainable development and political stability are promoted;
iii. Every person has access to enough safe water at an affordable cost to lead a healthy and productive life; and
iv. The vulnerable are protected from the risks of water related hazards.

In Appendix A the concept of IWRM is explained in more detail.

1.3. **Integrated Water Resources Management Strategy Plan in Myanmar**

Having established a growth-oriented macroeconomic policy framework in the course of implementing stabilization and structural adjustment programmes, a number of market-oriented Asian countries, such as Bangladesh, Indonesia and the Philippines, have moved on to sectorial reforms (Fischer, 2008). Myanmar is aiming for the same development, where the involved ministries in the WRS together with national universities have formed a NWRC to integrate the individual visions and strategies of all involved stakeholder. The objective is to develop from a sectorial to an integrated system under the lead of the Dutch government and great a National IWRM Strategy Plan to plan the development of the WRS on the short- medium and long term in a sustainable way. By this means the benefits and interlinkages can be strengthened and the negative effects can be limited or mitigated in to create wider support for policies and strategies for a sustainable development. In the strategy plan, the three cornerstones of the water, energy and food sector should be interlinked to maximise the benefits for all and to minimise the negative effects to others. Only one single approach is not durable, so integrated long term planning is desired (Bazilian et al., 2011).

Integrated water resources management, including the integration of land- and water-related aspects, should be carried out at the level of the catchment basin or sub-basin (UN, 1997). Water withdrawals in China, Thailand, and Vietnam are close to 20% of total annual internally renewable resources. According to the United Nations (UN, 1997; UNESCAP, 1998), when withdrawals exceed this threshold level, water tends to become a limiting factor in national socioeconomic development. A countries overall strategy to benefit the macroeconomic includes the policies and strategies of the involved sectors on a national level. Micro scale development, such as public water consumption and food production, can be included in the macro scale planning. In assessment of the water resources allocation on micro scale, macro scale strategies can be tested and recommendations can be formulated at each spatial scale for the water resources planners.

1.3.1. Relevance of an IWRM Strategy Plan

The National IWRM Strategy Report of Myanmar will include the integration of the individual strategies and visions into one nationwide master plan in a sustainable way. The adaptation of a changing climate is included as well. scales seeks for linkages between the water, food and energy sectors, both on the level of resource use as well as the institutional aims for maximising the benefits in all sectors (Hoff, 2011). Ministries involved in the conservation of the environment and forestry are also included in the NWRC. The concept of ecosystem services or the use of natural resources is in its infancy in Myanmar (Hulsman & Rutten, 2013).

One of the two most dominant sectors in the WRS is the agricultural sector which includes 70% of total employed people involved and makes up for 48% of the GDP in 2004 (World Bank, 2014) and 36% in 2010 (Trading Economics, 2014): showing a decline since 1993 (World Bank, 2014). One of the main focuses of the government is the development of the irrigation sector to improve the food security by increasing the food production and to stimulate the export of processed products. It is an important sector for the country's economy and rural development, which largely depends on the small scale farming and fisheries (NAPA, 2012). Over the last years, the government aimed to develop irrigation projects to produce a surplus in rice, the basic food for all people, especially the rural poor, (MoAI, 2006). Paddy was to most dominant crop that used the irrigated water since the government required the farmers to use the water for paddy only, regardless of the local conditions and knowledge. This is changing. With the new land and investment legislation, the government aims to expand exports and exploit natural resources by increasing private sector involvement (Kattelus, M et al., 2013). The change to a more market oriented economy gives the opportunity to produce a variety of foods, which can make profit when processed and exported. This will result in the change of crops cultivated and the number of cropping cycles per year (multi-cropping) (ID, 2007). The new private actors and the commercialised agriculture are likely to impact the status of subsistence farmers and their resource security (Kattelus, M et al., 2013). The irrigation areas have an high potential to being developed and improved: only 20% of the potential area is made ready, of which 50% actually is supplied by irrigated water (ID, 2013). Increasing the number and size of the irrigation areas, together with the change multi-cropping cultivation in areas with sufficient water resources available can boost the food production and rural development.

The second most important sector in the water resources system (WRS) is the energy sector. The rapid demand in energy and the potential hydropower development makes the energy sector a crucial player in the WRS. Currently the energy per capita in Myanmar is very low compared to the more developed neighbouring countries, with only 110 kWh/capita/year. Only Cambodia has lower electricity consumption per capita, but the GDP per capita is higher for this country. One of the links between the energy and water sector are the planned (and developed) hydropower dams to which affect the flow regime. The development of the socioeconomics in the country results in an increase in demand of electricity. A high potential of energy production is ready to be exploited by foreign investors and contractors in large scale hydropower dam projects to generate electricity to meet the country's electricity demand and to export to neighbouring countries, which will be approximately 90%. The policies in China, Bangladesh and Thailand strive to increase the electricity rate in short term (ADB, 2012b). The hydropower potential of Myanmar is estimated to be as much as 100,000 MW, and according to ADB (2012c) the planned large hydropower projects have a total installed capacity of around 50,000 MW.

1.4. **Problem statement**

In the IWRM process, the inception phase where the water resources system will be identified is prior to the development of (long- term) strategies and integration of all involved strategies. Long-term objectives and planning are needed to cope with future changes and an increased pressure on Myanmar's precious resources. The analyses of Kattelus, M et al. (2013) illustrates that hydropower, energy access, land ownership and food security are elements of the current development challenges in Myanmar that are closely interlinked but not governed holistically by the different actors involved. The understanding of the current natural resources system and the interaction of the stakeholders operating in the river basin is the first step in the inception phase. The extensive research done of the institutional setting, (hydroelectric-) power production and agricultural sectors in Myanmar by (Kattelus, M., 2009b; Kattelus, M et al., 2013) recommends to look close to the close links in the agricultural and energy sector through land and water resources and look for synergies. The assessment of water allocation on river basin and local scale will give insight in the important characteristics and interactions present in the water, energy and food nexus in relation to the WRS at reconnaissance level. The interlinkages in the nexus can be used as cornerstones to develop strategies to develop Myanmar in a sustainable way. This water allocation assessment includes the identification of the water availability, demand of the different stakeholders, allocation and utilisation in the water resources system in the present situation.

More analysis to the cross sectorial linkages are desired (Kattelus, M et al., 2013). One of the challenges in the development of Myanmar is that the lack of good quality data and the availability and accessibility of the data on the WRS. This hinders a deep and detailed analyse of the interactions between the related sectors After the field visit it was understood after discussions with the involved stakeholders that much more collaboration and coordination is needed and desired in the water sectors of Myanmar. Even the collaboration and integration with the same ministry is not going smoothly due to the lack of good infrastructure. Also during the field visit as part a data collection phase by Deltares and Delft University of Technology (DUT) at the end of 2013[1], it became clear that data is often scarce, scattered, not readily accessible, inconsistent, and might be unreliable since the method to obtain the data is outdated. Also the poor infrastructure hinders good data sharing and data management. In the initial phase the scale of the assessment is done on basin scale. The completeness of the data available and received for conducting the water allocation assessment influences the simulation output, which is a representation of reality. Understanding parameters influencing the WRS system, both related to the natural system as well related to the infrastructure and management strategies, will improve the support for good data collection and management to support IWRM which benefits synergies and support amongst stakeholders in relation to their interests in relation to the behaviour of the system.

[1] *This project was part of the signed MoU between the Dutch Government and the Ministry of Transport, chair of the NWRC, 2012*

Also the impact of socioeconomic development on the future WRS, will be part of the IWRM Strategy report has to be understood before implementing strategies and drawing up long term plans. With the country that is opening up for the private sector and foreign investors Myanmar foresees that an integrated approach between the ministries is crucial for a sustainable development and guide it into a direction in where broader understanding and support can be generate for proposed management strategies. The development of the socioeconomics is likely to go fast and to have large impact on the WRS. Changes in the WRS due to internal or external factor will have an impact on the individual stakeholders, as well on the complete system. The water resources the country is rich of, gives opportunities for the socioeconomic system to develop and to stimulate the country's economic development and fight the poverty and improve food security and to improve the accessibility to drinking water and energy for all people. The impact of these developments on the WRS should be identified so that negative effects can be mitigated or limited or those new opportunities can be identified.

The temporal and spatial distribution of the water resources within a river basin is uneven. To assess the water allocation on the local or sub-basin scale, a case area can be used. For the development of the WRS four geographical regions can be identified in Myanmar, each with its own specific WRS. One of them is the Central Dry Zone is a vulnerable region due to the lack of available water in the dry season. The Magway and Minbu Region, located in the southern part of this Central Dry Zone, will be used as case area to assess the water allocation on regional scale for the present and future situation.

The focus of the report is to assess the water allocation in the major river basins of Myanmar in the current and future situation. In the following chapter, 2, the research questions are formulated who are based on the problem statement. Four sub-research questions are formulated, each related to a separate focus of the assessment. From these four questions, answering of the overall research is the objective of this research. The methodology of the research is explained in chapter 3. Here the methods of input data collection and water allocation assessment are discussed. Also the limitation of this research is included in this chapter. In Chapter 4 the current status of the WRS is indicated, starting with the water available in Myanmar, following by a description of the involved stakeholders. In the second part this chapter, the water availability in each individual river basin is discussed. The previous chapter focussed on the current situation of the major river basins in the country. The regional variation in Myanmar is large. The most vulnerable part of the country as it comes to water availability is the central part. In the southern part of this region, a case area is used what the current is of this Magway and Minbu region. With the water allocation assessed on a river basin and local scale, the impact of the individual (input) parameters are identified in chapter 5. A sensitivity analyses is carried for different parameters. This results in a score card where the impacts of the parameter on the water allocation assessment versus the uncertainty or availability are compared of relative importance. With this score card and sensitivity analysis, recommendations for data collection to improve the IWRM process is drawn. This process is done in chapter 0. In chapter 7, the future of Myanmar's is likely to have impact on the WRS. Different futures are assessed by simulating socioeconomic trends. In the discussion section the research process and outcome is discussed in chapter 8. The overall conclusions and recommendations for the WRS in the present and future situation are formulated in chapter 9. These conclusions answers each individual formulated research question.

2. Research questions

2.1. Research objective

The overall objective of this research is to assess the water resources system in Myanmar by means of analysing the water availability, utilisation and demand of its major river basins. This research will assist the planners to better understand the behaviour of the system in the present and future situation. If the system behaviour is better understood, negative impact due to changes in the system can be mitigated or minimised, or a priority list of investments in the development of WRS can be formulated based on the expected improvement.

2.2. Research questions

In conclusion of the problem statement and the research objective to **main research question** is the following:

What recommendations can be drawn from the water allocation assessment to support IWRM in Myanmar?

To provide structure in the research process the next four research questions (RQ) form the basis of the assessment and together answer the main research question:

(RQ1): What is the current water resources system in the major river basins of Myanmar?

(RO2): What are the relevant parameters for the assessment of the water resources system?

(RQ3): How will the water resources system change based on the expected socioeconomic development?

(RQ4): What is the current and future water resources system for the case area Magway and Minbu Region?

Definition of water resources system: the water availability, water demand by the stakeholders and the allocation with the river basins. The interaction with the socioeconomic development

3. Methodology

A common framework used for an IWRM study is the one described in the book about Water Resources Systems - Planning and Management by Louks and Van Beek (2005), see Figure 2.2.1. The development of IWRM should not be seen as an path with a clear start and end, but it is a repetitive and iterative process which step-by-step increase the level of detail. Every step in the process shown in Figure 2.2.1 can be split up in three phases: *interception, development and selection* phase. Since the IWRM process of Myanmar is it the early start of development, the level of detailed study cannot be reached yet. First an assessment on basin scale will have to be carried to understand the interlinkages between the stakeholders and the data needed when increasing the level of detail to improve the accuracy of the modelling input data.

Ideally, the development of IWRM project includes to involvement of the stakeholders along the process. This will create understanding, recognition and ownership, (Louks & Van Beek, 2005). In the following sections, the structure of the report is explained, which firstly highlights the research questions and which approach is used to answer these individual questions. All research questions will together answer the overall research question and research objective.

Outlet of MoYinGyi Lake towards Bago- Sittaung Canal, Sittaung Basin

The *interception phase* includes the description of the WRS, which describes the characteristics of the stakeholders, the available water in the system (runoff: output of the hydrological model WFlow; available storage capacity), the definition of the criteria on how and on what scale the system is tested. The network of the WRS is built up to be used for the assessed, which is done based on the requirements or wishes of the clients or users interest. The boundaries and input characteristics are also a result of the requirements of the client or the user's interest.

The *development phase* includes a more detailed description of the WRS based on the data collected from the involved stakeholders, different departments and ministries in this case. An analysis is carried out with a water demand and allocation software package (Ribasim) to simulate the actual demand over a certain simulation period. The administrative and institutional system is important to include also in the IWRM process, but this is not part of this research.

In the *selection phase* the current system is understand, and future scenario's and (management) strategies are defined and simulated with the models. An understanding of the quality, sensitivity and/ or reliability of the (input) data is part of the recommendations for the status of the WRS. Based on the status of the present and future behaviour of the WRS together with the understanding of the important parameters and data, the overall conclusions and recommendations can be presented and discussed with the planners and/or decision makers in the WRS.

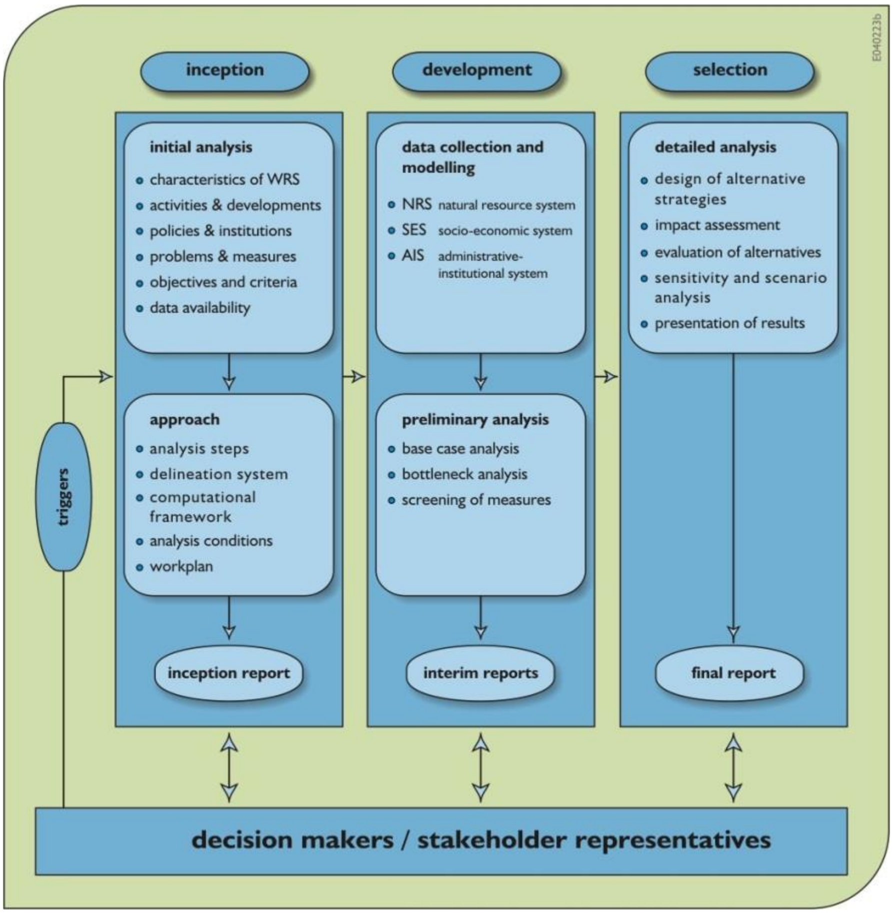


Figure 2.2.1 Analytical framework for water resources studies, used as framework for this research also. Not every component is included since the focus lies on the natural resources system only – Source: (Louks & Van Beek, 2005)

3.1.1. Systems boundary: major river basins of Myanmar

The focus of the assessment is on the major river basins in Myanmar: Ayeyarawdy, Salween, Sittaung, Bago and Myit Ma Hka Rivers. Their basins cover for approximately 75% of the country and include most of the fresh water available in the country. The other regions in the country are mostly along the coast, which include small rivers straight from the hills towards to ocean, see Figure 2.2.2. The Ayeyarwady, Sittaung, Bago and Myit Ma Hka Rivers are almost completely located with Myanmar's borders[2]. The lower part of the Salween River located in Myanmar, and flows partly over the Thai border near the mouth of the river. The administrative units, called States and Divisions are spread across the watershed area of the rivers, see Figure 2.2.2. Since the major river basins cover a large part of the countries surface and has a majority of the available water resources, the assessment excludes the minor river basins, mostly located along the coast. Those small rivers are relative very short and have little large scale activity.

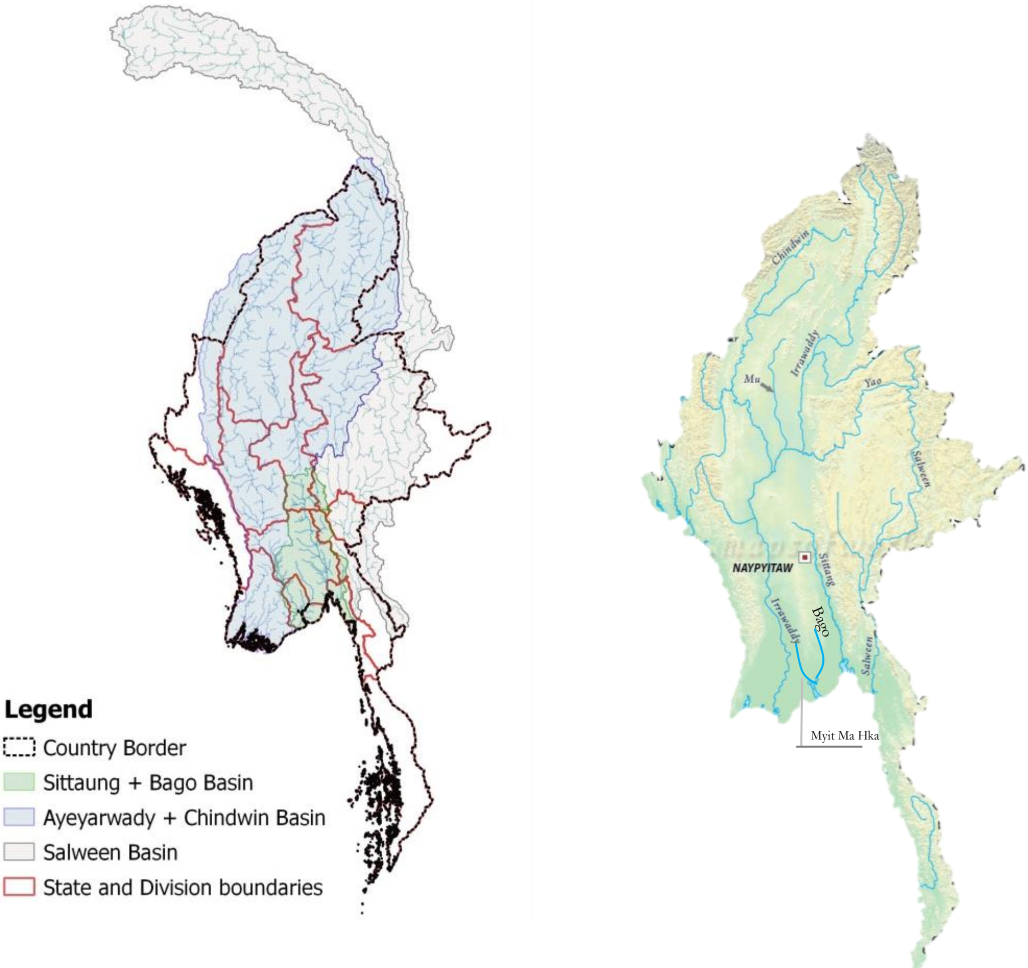


Figure 2.2.2 (left) – The boundaries of the major river basins of Myanmar, State/ Division boundaries and countries border. (right) Myanmar's major river basins: Ayeyarwady (Irrawaddy), Salween (Thanlwin), Sittaung (Sittoung), Bago River (Pegu River) and Myit Ma Hka River. The Myit Ma Hka River flows parallel to the Ayeyarwady and are connected near Yangon City.

[2] *The catchment of the Ayeyarwady river is for 95% located within Myanmar's borders*

3.1.2. Structure of report

In the chapters, references can be made to an appendix including a more detailed description to support the found conclusions and assumption. The assessment of the water resources system is done by using the available online literature, data collected during a three monthly field trip to Myanmar and a water demand and allocation model (Ribasim) of the WRS. During the field trip several meetings, interviews and discussions were held to better understand the WRS. In the data collection and system analyses of the water resources and social- economics system two reports were produced which served as a start for this research (Hasman, 2013; Hulsman & Rutten, 2013). The host of the trip was the Irrigation Department (ID), Ministry of Agriculture and Irrigation (MoAI), which resulted in that most information is collected from this stakeholder. After the data collection phase, which included also the first step in the model development process, a more in depth literature study was conducted. A hydrologist of Deltares, together with a student of DUT made a hydrological model (WFlow see section 6.1.1) to produce input time series for the variable inflow for the Ribasim model, see section 6.1.1. Together with the knowledge gathered in the field the as well with more modelling experience the model has been made ready to assess the present day situation of the WRS with the most important stakeholders included, see Chapter 3.1.1. For each river basin a separate model is made to assess the water demand and allocation on different spatial and temporal scale. With these models, the present day situation of the WRS is assessed. In the presentation of the data throughout this report, each river basin has its own colours, which an example is shown in Figure 2.2.3. The full modelling development process is described in Appendix P.

The Ribasim model development is an iterative process where step by step the behaviour of the model and system is understood. With the obtained knowledge of the system by analysing the model output, the collected literature a sensitivity analysis on the input parameters, the quality of the input data is discussed in Chapter 5.2.1, recommendations are formulated directed to planners in the WRS.

These recommendations are given about the importance or relevance of the individual input parameters on the overall water resources assessment in a river basin. With this knowledge, the future situation for the WRS under a changing climate is assessed, see Chapter 7. The changing environment are defined in separate cases, strategies and scenario's, representing the visions/ future developing plans and the changing external factors affecting the WRS respectively.

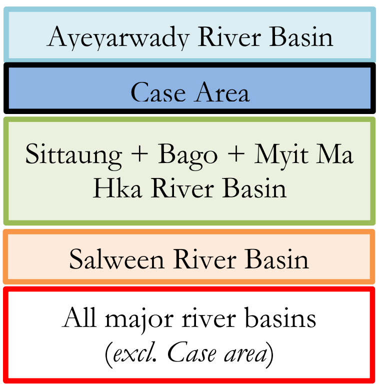


Figure 2.2.3 Colour schemes for individual major river basin

At the end of this report, Chapter 0, the outcome and behaviour of the model is discussed based on the outcome of the current case situation. The current and future situation of the WRS is described on river basin scale, where the Magway and Minbu Region is used as a Case Area to assess the local or regional WRS.

With this Case Area, the sensitivity analysis is carried out, together with the an analysis about water scarcity in this region. The output of these two analysis, together with the basin wide conclusions, recommendations to the water resources planners are given on both spatial scale. The Case Area is described in Chapter 5. Also the importance of a water demand and allocation in relation to an IWRM is explained. In the conclusion the overall performance of the WRS is given, which explains the interaction and advantages Myanmar can obtain in the development of its WRS in a sustainable way.

3.2. Research Approach

Following from the problem statement, the research questions have been formulated. To answer the overall research questions, sub- questions have been formulated which are answered first to at the end come to the overall recommendation for the planners in the WRS of Myanmar. To provide structure in the research process four research questions (RQ#) are formulated that will assist answering the main research question, see Figure 3.2.1.

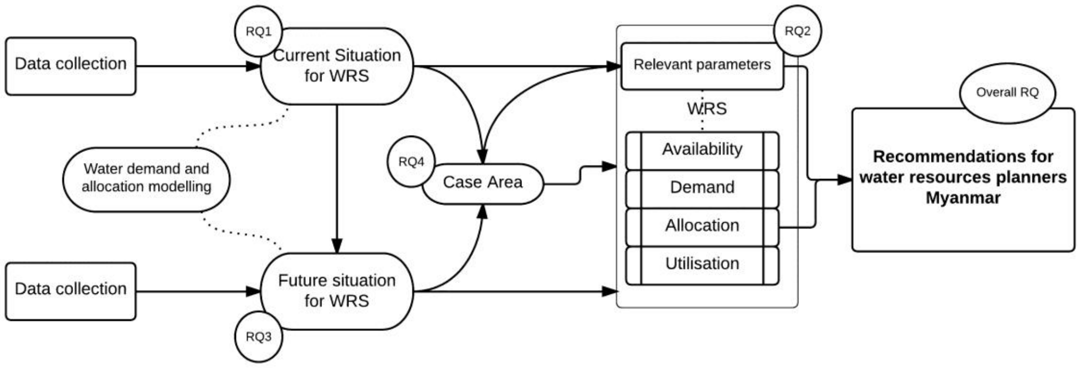


Figure 3.2.1 Research approach - relation of the research questions (RQ#) to the overall objective

3.2.1. (RQ1) What is the current water resources system in the major river basins of Myanmar?

The first question focusses on the assessment of the water availability, demand and allocation of the major river basins on basin scale, the current status is assessed. Three means are used to come to this overall identification One method is by conducting a literature study about the stakeholders and the WRS in Myanmar, 2) was a field trip of 3 months to Myanmar to collect data from the involved stakeholders, which were part of the signed MoU. 3) the collected data and information found in the literature, a water demand and allocation model (Ribasim) is used to assess the simulated outcome of the water availability, demand and allocation. In this simulation package, 3 network schematisations are made for the major river basins with the most dominant stakeholders included.

3.2.2. (RQ2) What are the relevant parameters for the assessment of the water resources system?

The collected data used to assess the current status of the WRS (RQ1) is reviewed by means of a sensitivity analysing and a validation process. The sensitivity is done on very local scale (one irrigation area + reservoir) and a Case Area, which results in recommendations for the parameters with different levels of impact on the overall water demand, supply and/or allocation and rate of uncertainty and availability. Based on these characteristics, at the end of that chapter practical measures can be defined to improve the operation of the

WRS or parameters are indicated which are important to increase or improve the accuracy of the water balance calculation.

3.2.3. (RQ3) How will the water resources system change based on the expected socioeconomic development?

Because the IWRM Strategy report focusses on the development of the system, the future system is analysed according to the same method The same models used as for RQ1, the present status of the WRS, but the input parameters are changed corresponding to certain trends, cases of scenarios. The expected socioeconomic development is mainly found in literature, data collected from the involved stakeholders during the field trip and based on (local) newspapers available online. These scenarios are put in the same model used for the present situation (RQ1), with changed input parameters. Trends refer to the development of the socioeconomic, where cases explain management strategies of the irrigation areas.

3.2.4. (RQ4) What is the current and future water resources system for the case area Magway and Minbu Region?

The status of the current and future system is done on basin scale, where this Case Study is used to assess the status of the water allocation on a more regional scale, see RQ2. The same model is used, but the case ara is cut off to be analysed separately. Different regions can be defined in Myanmar which have high potential for socioeconomic development. The Magway and Minbu Region is located within the Dry Zone and is chosen to assess the water availability, demand and allocation on a more local scale.

The assessment is carried out with a water demand and allocation model for the major river basins. A holistic approach of the stakeholders in the model development aims to guide the development of knowledge and available of reliably and quality data to address to nexus approach that can contribute towards a sustainable and cross- sectorial development in Myanmar. Another objective is to assess the changes of the developed system with the present day situation.

The overall research questions reads:

3.2.5. *What recommendations can be drawn from the water allocation assessment to support IWRM in Myanmar*?

With understanding of the availability, demand and allocation of the water resources for the present and developed socioeconomic system in Myanmar on both river basin scale and local scale (Case Area), and inside in the quality of the available (input) data, recommendations can be formulated to support the IWRM in Myanmar.

3.3. **Water demand and allocation model (computed based model)**

3.3.1. Water demand and allocation model: Ribasim

The assessment is carried with a water demand and allocation tool for which the collected data in the field together with information found in literature are used as input. It is a node-link structure which is a schematisation of the spatial relationship between physical entities in the river basin. From (Krogt & Boccalon 2013) The *Ribasim* (RIver BAsin SIMulation) software package performs simulation in a river basin for a particular development scheme in a defined hydrological scenario with given hydrologic time series. The program uses these time series and scenario to run simulations to calculate the water balance for the requested water system: river basin, catchment area, operation of dam. The water balance is made for the natural processes (e.g. precipitation, evaporation) and the social- economic system (e.g. water demand, hydropower). See section 6.1.3 for an explanation of the water balance. The integrated approach in the water system and its surroundings is the basis for long term, sustainable management of the environment and basin. Multi sector planning to allocate scarce resources at the river basin level is increasingly needed in the water sector, where trade-offs need to be made by water managers, governmental agencies and users.

The assessment of the current is situation is done by analysing the performance and characteristics of the stakeholders involved. For the future situation, the development trends are tested under different conditions. These conditions are tested in different *cases* or *scenarios*. In each case represents a certain status or performance of the network, which includes the different ways of operation, usage and maintenance of the infrastructure. To see how the water allocation and demand changes, the different cases made with planned projects, different management options and/ or scenarios changes like urbanization or climate change, that can be analysed after having run the simulation multiple times. The types of analyses addressed by the model are:

- ❖ Evaluation of the limits on resources and/ or the potential for development in an area;
- ❖ Evaluation of measures to improve the water supply or water quality situation;
- ❖ Evaluation of the origin of every location in the river basin (for water quality)

3.3.2. Application

The schematisation of the water resources system is following the river lay out of the basins. The spatial resoluation had a degree of freedom throughout the model development process. From the client so to speak, the NWRC, no boundaries were given about these details. For many dams and irrigation areas, the model represents one- to- one with reality. So for each reservoir in reality, one reservoir has been added in the schematisation. For a water resources study on basin scale this is too detailed. However, with the eye on the future use of the water demand and allocation tool in the IWRM, the regional details were preferred over simplifications. This results in that for this study, also a case area can be used, to analyse the status of the individual reservoirs and irrigation areas. With the knowledge obtained from the regional analysis, the overall model can be improved. The Central Dry Zone for example, is of high interest by Deltares to analyse the water allocation on sub-basin level. See Appendix D for the network schematisations of all river basins.

The simulation period of the modelling exercises is 1998 to 2009 for which the hydrological model was prepared. The time-step for the simulations is half-monthly, which is small enough to see the seasonal variation, but too large for the assessment of inflow after individual rain events. This tool is able to analyse the behaviour of the water allocation under various hydrological conditions, and where different operational strategies can be tested, see Figure 3.3.1. flow balances are calculated for each node at each time period, and flow transport in the basin is calculated based on the spatial linkages in the river basin network. For the assessment of the status of the WRS under different conditions, different *cases* can be run, each with different settings or input parameters. A more comprehensive description of the tool can be found in Appendix P – Model Development. Here also the network schematisation of the river basins can be found. In that appendix the model development process has been discussed. There is described what assumptions have been made to schematise the WRS. Also, the recommendations for the development of the model and calibration steps needed are discussed here. This links to the objective of RQ4.

As explained in the introduction of the methodology, the IWRM should be done parallel with stakeholders to improve the integration and support of the whole process. Also the model development should include the agreement and knowledge of the local experts. During the field visit, an initial start has been made in the development of the model. The network of the Sittaung, Bago, Myit Ma Hka and the lower part of the Ayeyarwady River basin were verified by varies people of different offices of the Irrigation Department (ID), MoAI. Unfortunately, due to the political isolation in the country, very limited knowledge is present and experience with computer based modelling. Therefore, most of the model development was done by the author itself, as well as the data collection and requesting. Capacity building for these applications is desirable by the involved ministries.

Under the '*Data collection and system analyses project*' of Deltares and Delft University of Technology (DUT), a trip was made to Myanmar from September till November 2014 to collect to data related to the WRS the necessary data needed to analyse the status and operation of the water resources system of Myanmar. Most data has been collected about irrigation systems since the author was hosted by the Irrigation Department (ID), Ministry of Agriculture and Irrigation (MoAI) during the stay. Multiple field trips to surface water reservoirs and irrigation projects together with discussions with retired engineers an impression of the irrigation systems has been obtained. In the period from February till May 2014 a college student from Wageningen University and Research Centre (WUR) continued the data collection and received more information from the Agricultural Department (AD).

With the information and data collected, an interim report was written that describes the WRS, (Hasman, 2013), of the major river basins of Myanmar, which includes a description the natural resources system as well the socioeconomic situation. This MSc. research continues on the work of the interim report, and has the main objective to analyse the system with the use of a water demand and allocation model of Deltares: Ribasim (River Basin Simulation, (Krogt & Boccalon 2013). In Appendix O the system description is presented. This main report gives insight in the interactions between hydrological, natural and socioeconomic processes present in the WRS of the main river basins of Myanmar in the present situation, and in the future situation. In the appendices the analysis, process, (raw) data and system description can be found.

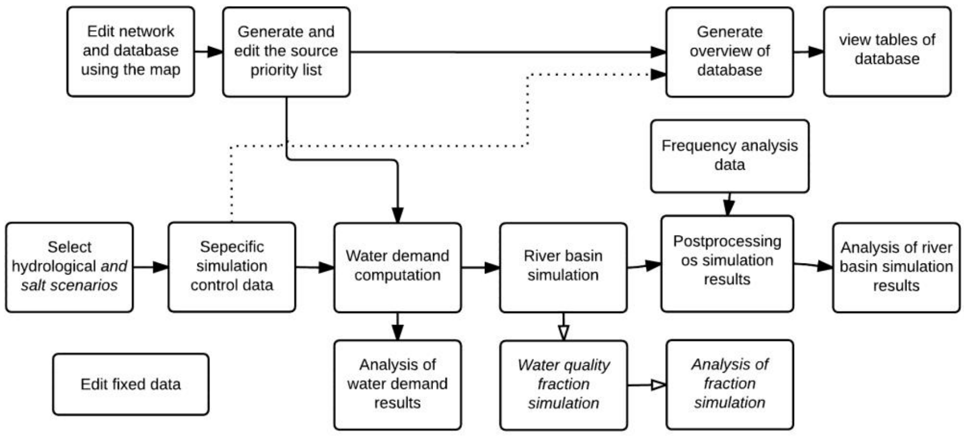


Figure 3.3.1 Ribasim working process. The start of the simulation process is to define a prepared hydrological scenario, which include runoff, rainfall and evaporation time series. Then, the desired simulation period and time steps are selected. For this assessment the assessment is carried out half-monthly basis and the simulation period is 1998 to 2009. The network of the river basin is included, with the input data for each *node*, representation a specific stakeholder in in the network. Based on the variable inflow and the characteristics included in the nodes, the demand is calculated. Besides this calculation, many other features can be obtained from the database stored after a simulation. The italic text indicates that these options are not used for this assessment.

3.4. **Literature study**

Online scientific literature, news articles and discussion papers are important sources of information as input for the assessment. Mainly the future system is defined based on the literature. In the system analyses, appendix O, an overview of the important collected data is found. The available literature about the WRS of Myanmar is limited, where most refer to one source: (FAO, 2010). The Case Area is chosen, partly because of its relevance for detailed assessment in available literature, but also based on the outcome of IWRM workshop given by UNESCO-IHE in Myanmar with involved stakeholders, (UNESCO-IHE & MandalayTechnology, 2014).

3.4.1. Data collection

During the field visit of 3 months in total, multiple side visits and discussions about the WRS were held with different departments and ministries. Under the signed MoU it was agreed between the involved ministries in Myanmar and the Dutch government to share the requested data to the Dutch consortium to draw up the IWRM Strategy Plan. As part of the data collection phase, official data request letters were written to the concerned department or ministry, explaining the objective of the data collection (the model development) and the relation with the MoU. Since the management structure in Myanmar is very much hierarchical, these requests have to be approved by the Director General himself, before handing over the data. The The outcome of these discussions are used as a reference. An overview of the people and department who had relevant information to be used as input for the assessment, are listed in Appendix B. Mostly the objective was when visiting different offices, was to collect the raw data about the WRS, and type to understand its present day status. The field visit was part of a data collection study, done by Deltares and Delft University. In the report Hulsman and Rutten (2013) produced by Deltares and DUT after the data collection mission the available data in Myanmar is described, together with an overview of the stakeholders. The field trip by the author, was a preparation for the actual master thesis, where the Hasman

(2013) reports also describes the available data but also includes a systems description and initial model set up. Only data of governments is collected now; the private sector is not included in the assessment yet. The government has still a very high stake and control in the operation of most sectors in Myanmar.

3.4.2. Data availability

In international literature on the water resources is very limited and most refer to the same source, e.g. the Myanmar page of the Food and Agriculture Organisation, (FAO, 2010). This data is on basin scale but the data availability on local scale is still very limited. For the Central Dry Zone the (McCartney et al., 2013). Ample descriptive data is available online from various international organizations International initiatives to collect, manage and store data on Myanmar are varying in success. The most successful initiatives are www.themimu.org, www.fao.org, www.burmalibrary.org and (Burma Library, 2012; Library, 2014) Developments in global databases with remote sensing data, ground observations, reanalysis product etc. are going fast and a lot of data is free of largely available.

However, due to poor internet infrastructure these databases are difficult to access in Myanmar, and awareness about the existence of these databases is low. Another concern is that the quality of high level remote sensing or reanalysis product depends on the number of ground observations made available by the country itself for validation. Myanmar does not contribute yet to these validation systems, (Hulsman & Rutten, 2013).

For data that is available within the different ministries, it is not easily shared between other ministries. The objective of the data collection phase was the first step in the exchange of data between the involved stakeholders. A consequence is this lead to parallel data collection, for example precipitation data is collected by three different ministries and departments: DMH, MoT – AD and ID, MoAI. Both have a different objective with the collected data. This results in that the spatial distribution of the rain gauges is not uniform over the country but clustered in central and southern part. Subsequently, this data is collected with different methods, stored in a different manner and not cross- referenced, compared or validated.

Selling the data to other ministries is part of the business a department or ministry is earning money. Sharing this data will reduce the income of the department. When during the IWRM process the data becomes available for the integrated parties involved, the way of earning money should be reconsidered.

A specific issue regarding data sharing and ownership is the relationship between the Department of Meteorology and Hydrology (DMH) under the Ministry of Transport (MOT) and the other departments and ministries. DMH is well valued within the government for the quality and quantity of their data but the usage of their data by other departments is suboptimal due to the relatively high costs. Also departments see themselves forced to collect data themselves, which often leads to uncoordinated data collection efforts and scattered data-sets.

3.5. Limitations of research

The assessment of the water resources system focusses on the allocation of the water over the most dominant stakeholders: irrigated land for agriculture, domestic water sector, including industries and public water, and the hydropower reservoirs.

- Water quality is an important part in the IWRM study where water pollution can have large impact on the system. However, this aspect is not included in the water allocation analysis or system description.
- Administrative and institutional assessment is not included in the assessment of the water resources system
- The agricultural crops cultivated in the monsoon are not included, which is mostly rain-fed paddy.
- An economic analysis is not included, like a cost- benefit analysis
- The agricultural practices, like changing cropping patterns is not included
- The calibration of the individual irrigation projects (reservoir/ pump + irrigation area) is not down on the very local scale. The assessment of the operation practices of the a single reservoir is not included in the model
- The cropping patterns are included based on the State/ Division the irrigation area is located in. Regional and local variation is thus not included, but likely to vary within a State/ Division.
- Data on groundwater is very scarce in Myanmar. The amount of recharge and available storage in the aquifers is unknown. In the assessment, with the available water there is referred to (surface runoff). Withdrawal from aquifers is not included in the assessment.
- Only for one case the regional water allocation and utilisation have been assessed
- For the stakeholders fisheries, aquaculture, navigation and environment no boundary conditions have been formulated. The impacts of the water allocation on these stakeholders were based on expert judgement and gut feeling. Data on these sectors are very limited or not available in literature to define boundary conditions. Also no data has been collected during the field visit.

This section concludes the introduction of this research. This chapter mentioned the change in Myanmar from a sectorial approach of managing and planning the water resources system, to an integrated approach, where the NWRC together with a Dutch consortium is drawing up an IWRM Strategy Plan. In the next chapter the present status of the WRS system is described with data collected during a field visit, literature and the outcome of a water demand and allocation model. In the next chapter the overview of the water availability and usage is shown for all major river basins.

4. Water Resources System in Myanmar – *Present Situation Part 1 – Myanmar introduction and Important Stakeholders*

In Part of the Chapter 4, an introduction describes the socioeconomic characteristics of Myanmar. After that, the available water in the river basins is presented for the simulation period 1998 – 2009, where a water demand and allocation model (Ribasim) is used, with input from a hydrological model (WFlow). This chapter, both Part 1 and 2, answers RQ1: *What is the current water resources system in the major river basins of Myanmar?* It focusses on analysing the water availability, demand and allocation for the different sectors on basins scale. In the following Chapter 5 the assessment is done on regional scale for the Case Area. The data used to do this assessment is discussed in the Chapter 0.

Paddy field near Waw, Bago Divison, Sittaung River Basin – Photo by Rens Hasman – End of October 2013

This chapter includes many information about the water availability, the demand of the stakeholders and a description about them. Below the content is shown of the chapter, which is split up in two parts.

This chapter includes a lot of information about the WRS. To guide the reader the content of the chapter is shown below. The first part focusses on the stakeholders in the system and the second part focusses on the available resources in the system.

Water Resources System in Myanmar – Present Situation
Part 1 – Myanmar introduction and Important Stakeholders

- Myanmar Water Resources System
- Water availability in the major River Basins of Myanmar
- Groundwater
- Surface water reservoirs
- Irrigated agricultural land
- Domestic water consumption
- Energy demand and production
- Other important stakeholders in the WRS

Water Resources System in Myanmar – Present Situation
Part 2 - Water Resources – River basins

- Other river basins in Myanmar
- Water Resources - Salween River Basin
- Sittaung, Bago and Myit Ma Hka River Basin
- Water Resources - Ayeyarwady River Basin

4.1. **Myanmar Water Resources System**

Myanmar is a large country situated in Southeast Asia between North Latitude 19°32' to 28°31' and East Longitude 92°29' to 101°10'. Its total land area is 676,565 km^2. It has five neighbouring countries: Bangladesh, India, China, Laos PDR and Thailand. The two largest rivers in the country are the Ayeyarwady River, often referred in literature to the Burmese name 'Irrawaddy', and the Salween River, also named Thanlwin, where the Chinese call it the Nu River. The Sittaung River (Sittoung) is an important basin for because it has much agricultural land. Ninety per cent of the total drainage area of the Ayeyarwady River is situated in Myanmar, covering about three-fifths of Myanmar's surface area, which has a population of around 37.2 million (Varis et al., 2012). The Salween River has little possibilities for cultivation since it has very limited riverine flat land (Magee & Kelley, 2009). Topographically, the country can be divided into five regions: northern and western mountains, the eastern plateau (Shan plateau), the central basin and coastal strip. The country has varied features ranging from mountains at an elevation of more than 5,800m in the north to delta in the south. In between, there are plateaus with heights of around 2,000m and the fertile floodplains of Irrawaddy River. Due to different soil types and elevations, the land-use in Myanmar various from region to region. The percentage of paved area is limited and forests and woodlands account for 49% of the total land area. The net sown area in 2012 is around 13.58 million ha, (MoAI, 2013a), and is 20% of total land area of Myanmar, see Table 4.1.1.

Table 4.1.1 Land use in Myanmar. The net-sown area is the area used for cultivating crops, including irrigation areas, important for the water allocation assessment - Source: (FAO, 2010)

Type of land	*Area (km^2)*	*Percentage (%)*
Reserved forests	16,895	25
Current fallow	242	0
Net sown	11,974	18
Occupied area	12,216	18
Culturable waste	5,609	8
Other woodland	16,253	24
Others	4,464	7
Total	**67,652**	**100**

Since for 2 of 3 major river basins are within the boundary of Myanmar itself, the administration and (water) management challenges are mostly between the 17 States/ Divisions and the different concerned ministries, see Figure 2.2.2. The Ayeyarwady has its catchment for over 95% within the country borders, were the Salween River has its origin and approximately half of its catchment in Peoples Republic of China. The Sittaung, Bago and Myit Ma Hka Rivers are completely situated with the country's borders. Also along the coast, the watersheds are largely located within Myanmar itself. This has a great benefit to not have to make comprises with riparian countries.

4.2. Water availability in the major River Basins of Myanmar

4.2.1. Climate

Myanmar has three distinct spells as the dry, wet and cold (winter) season. The rainy season stretches from half May to around half October and the cold season from November to January. 90% of the annual rainfall occurs between half-May and mid-October and is monsoonal (Mying, 2008; Ti & Facon, 2004). Precipitation is strongly affected by the topography of the land: the north-south alignments of the valleys and ranges divide the country into alternate zones of heavy and scanty precipitation. The south- west monsoon brings rain to the region for a half-a-year period. In the deltaic area the annual rainfall is around 2030 mm to 3050 mm, 2030 to 3810 in the north, even more in Rahkine and Tanintharyi State up to 5080 mm. The dryer areas receive only 500 - 760mm, which are situated in the central Ayeyarwady region, the Central Dry Zone. This region is called the Central Dry Zone, where the temperature can reach over 40°C. The country can roughly be divided into three agro-ecological zones. 1) The "wet zone" in the southern coastal and delta area, including Yangon, Ayeyarwady Delta, Bago (East and West), Tanintharyi regions, and Rakhine and Mon states: around 26% of the country. 2) The "Dry Zone" of central Myanmar, including Magwe, Lower Ayeyarwady, Mandalay and Sagaing regions; around 26% of the country. 3) The intermediate areas including Kachin, Kayah, Kayin, Chin and Shan States: around 48% of the country (Htay, 2013). Seasonal temperatures do not vary much in the southern parts of the country. Myanmar's west coast is subjected to frequent tropical storms and cyclones during October to December with a secondary peak in April to May (NAPA, 2012).

In Appendix F the average spatial distribution of the yearly average rainfall is shown for whole Myanmar, where clearly the differences can be observed of the spatial distribution of the water availability.

4.2.2. Available rainfall data

Throughout Myanmar it is reported that since the 1970s, the onset of the southwest monsoon has been increasingly delayed (i.e. later in the year) whilst simultaneously its withdrawal has been increasingly advanced (i.e. earlier in the year). Consequently, during the period 1988- 2000, the average duration of the southwest monsoon was three weeks shorter in northern Myanmar and one week shorter in other parts of the country, when compared to the total period 1951 to 2000. Superimposed on the trend of shortening monsoon, the duration of rainfall events is reported to be decreasing and their intensity increasing in the Dry Zone (Lwin, 2002). However, it seems that to date no rigorous statistical analysis of past rainfall trends has been conducted in Myanmar. However, currently, there is little understanding of how rainfall is spatially distributed within the Dry Zone and how rainfall patterns have changed or are changing over time, (McCartney et al., 2013).

For the calculation of the available water in the basin, the output of a hydrological model (WFlow) is used. The output of that model produced the variable inflow at locations of dams and control nodes/ measuring stations in the main rivers. These time series are used in the water demand and allocation as input for the available water in the (sub) basins. In the section 6.1.1 the model input is described for this model. The produced time series with this model are for the period 1998 to 2009 only.

4.2.3. Available water: Simulated runoff

The simulated yearly inflow into the rivers basin are computed by the hydrological model WFlow where a total simulation of period of 10 years, 1998 to 2009 is used for the water resources assessment study are shown in Table 4.2.1. The variation of the yearly inflow is shown in Table 4.2.1. The Case Area is located in the Ayeyarwady River basin. For the explanation and location of the Magway and Minbu case are see Chapter 5. This region is used for the water allocation assessment on regional scale.

Table 4.2.1 Simulated available water resources per river basin and total for Myanmar's major river basins (km³/year) – These values are the total runoff simulated by the hydrological model Wflow

	Available water resources (km³/year)				
Simulation year	Ayeyarwady	Case Area	Sittaung. Bago & Myit Ma Hka	Salween	Major River Basins total
1998	370	13	39	221	630
1999	426	24	71	284	781
2000	433	23	58	288	779
2001	501	25	71	313	884
2002	431	28	76	258	765
2003	399	20	57	232	688
2004	442	33	63	276	781
2005	379	25	71	273	723
2006	404	46	56	273	733
2007	443	38	58	271	772
2008	407	25	65	289	762
2009	313	19	53	207	574
Average	**412**	**26**	**62**	**265**	**739**
Relative standard deviation (%)	*10*	*32*	*16*	*11*	*10*

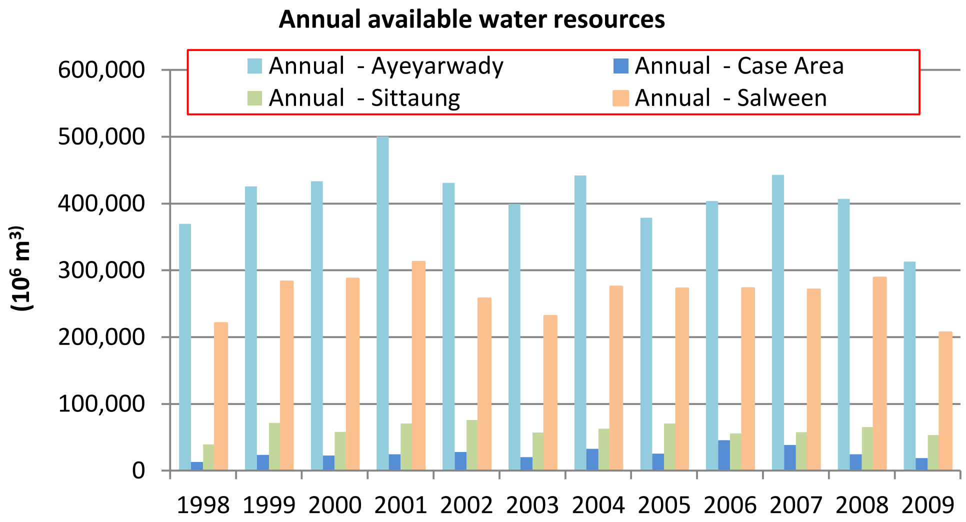


Figure 4.2.1 Annual available water resources per river basin – for simulated of period 1998 to 2009 – total runoff in the river basins simulated by the hydrological model WFlow

The volume of inflow into the watersheds (km³), according to Ti and Facon (2004), is the potential water resources for the country of Myanmar. This includes only the runoff from the catchments that are located within Myanmar's territory. For the Salween River this is therefore, an underestimation of the potential fresh water runoff for this river basin. In Table 4.2.2 the simulated runoff is presented for all the major river basins. The start of the monsoon season is set to 15th of May till 16th of November after oral communication with staff of ID, MoAI during the field trip in 2013. The total available volume of fresh water inflow from the catchment is estimated at 739 km³ from the catchment of the river basins with a total area of 784,800 km². In the most right column of Table 4.1.1 the share of the river basins used in this project is presented. In total, the major river basins make up for 71% of the potential available water resources of the country, (Ti & Facon, 2004). The remaining 29% belong to the Bilin River (3%), rivers in Rakhine State (13%), Taninthary Division (12%), and the Mekong River (2%), and accounts for 30% according to the simulated variable flow in the major rivers basins, see Table 4.10.1. In Myanmar there is yearly a total of 1057.98 km³ renewable water available. According to FAO (2010) it is 1,167.8 km3/year. For the Ayeyarwady Basin the inflow is much higher, according to FAO compared to the simulated situation.

During the dry season from November until April water scarcity causes problems especially in the central dry zone but also in other parts of the country. As the discharges in rivers follow closely the pattern of rainfall, the runoff varies substantially between seasons. The temporal variations in renewable water resources brings challenges to supplying water for irrigation and other purposes during the northeast monsoon and the dry inter monsoon season, and also limits the all year around crop production, (Kattelus, M. et al., 2009; McCartney et al., 2013). The problem in de delta area is they have limited possibilities to store sufficient water for till the end of the drought period. At the end of that period the groundwater is not suitable for drinking water due to the salinity level.

Table 4.2.2 Simulated runoff for the major river basins (km³/year) per season – Averaged over the simulation period 1998 to 2009

River basin	*Dry season (km³) (½Nov – ½May)*	*Monsoon Season (km³) (½ May – ½ Nov)*	*Total (km³)*	*Relative St. Deviation.*	*Inflow (%) according*
Ayeyarwady	41.8 (10.2%)	370.4 (89.4 %)	412.2	0.11	42
Case Area	2.6 (9.7 %)	23.9 (90.4 %)	25.5	0.32	-
Sittaung, Bago & Myit Mha Hka	4.8 (7.7%)	56.8 (92.3 %)	61.6	0.16	5
Salween	30.0 (11.3 %)	235.4 (88.7 %)	265.4	0.11	24
Total	79.2	686.5	739.7	0.10	100

Table 4.2.3 Average river discharge runoff for the major river basins (m³/s) – Averaged over the simulation period 1998 – 2009. The time step in the simulation for the lowest discharge is shown in the last column. The simulation is done on half-monthly scale.

River basin	*Yearly averaged river discharge (m³/s)*	*Standard Deviation*	*Relative St. Deviation (%)*	*Average low*	*Average high*	*Lowest discharge (time step)*
Ayeyarwady	12,824	1,404	10.1	1,659	35,115	March (1st)
Sittaung	1,246	219	17.6	61	3,777	April (1st)
Bago	143	26	18.0	15	455	February (2nd)
Myit Mha Hka	410	82	20.0	13	1,312	March (2nd)
Salween	8,344	923	11.0	881	21,534	February (2nd)

For the total available water over the seasons per river basin see the following sections:

- Salween Section 4.11
- Sittaung, Bago and Myit Ma Hka Section 4.12
- Ayeyarwady Section 4.13

4.2.4. Water consuming stakeholders

The consuming stakeholders in the river basins are the agricultural, irrigation sector (Section 4.6) and domestic sector (Section 4.7) which include the public and industrial sector. In this assessment only the irrigation sector is included. So the rain fed crops in the monsoon season are not included in the overall assessment. The Case 2 (C2 in short) situation and the term *actual* refer to the present situation, or actual supplied irrigated area with a certain efficiency rate, see Section 4.6 for the full description of this stakeholder.

The water demand of the current irrigation areas account for 87.82 % of the total water consumption in the major river basins, where public and industrial water withdrawal only account for 9.85 and 2.33 % respectively. The total withdrawal by all sectors in the basin relative to the inflow is only 4.05%. This is small compared to the available water, where in the Ayeyarwady River basin, the water utilisation is the largest with 5.95%

Table 4.2.4 Annual water use per water consumptive sector in the major river basin for the major compared with the annual available water resources (km³)

River Basin	*ANNUAL AVERAGE WATER USAGE (km³/year)*					
	Water Availability	Irrigation demand	Industry demand	Public demand	Total water usage (km³)	Share withdrawal over availability (%)
Ayeyarwady	412.241	22.656	0.313	1.903	24.559	5.96
Sittaung, Bago and Myit Ma Hka	61.503	2.754	0.244	0.761	3.517	5.72
Salween	265.394	0.908	0.174	0.287	1.196	0.45
Total	**739.138**	**26.319**	**0.697**	**2.952**	**29.968**	4.05
Withdrawal total share of availability (%)		87.82	2.33	9.85	100	

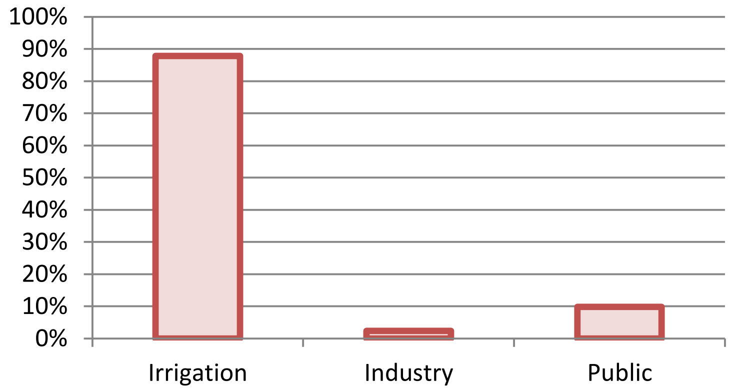
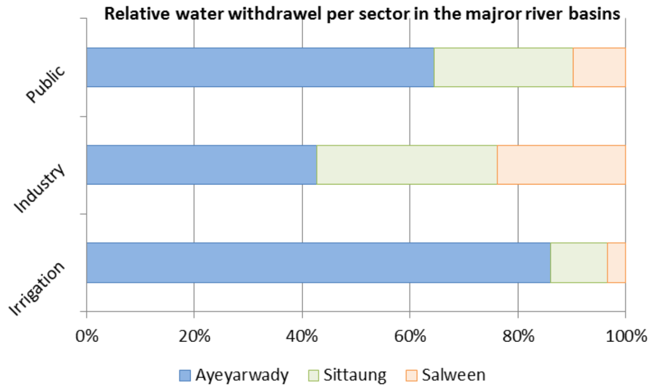


Figure 4.2.2 Total Water consumption per sector for the major river basins as a percentage of the total withdrawal by irrigation

These figures give an overview of the relative importance of the individual stakeholders, relative to the available water in the system.



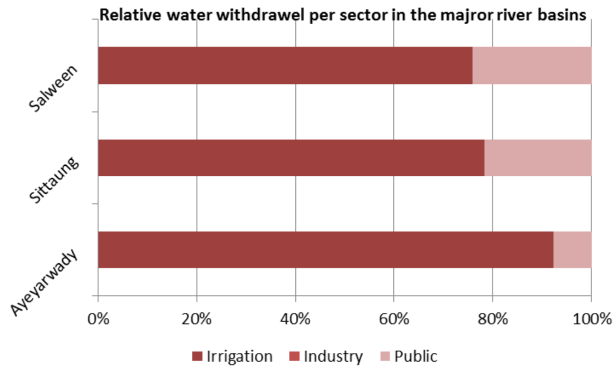


Figure 4.2.3 Relative importance of water consuming sectors irrigation, industry and public water consumption in the major river basins

Table 4.2.5 Total water use versus availability (2011) – Source of water availability and withdrawal for other countries than Myanmar: (AQUASTAT, 2014). For Myanmar these are outcome of the simulation. The water withdrawal per capita is the largest in Myanmar compared with countries in the same region.

Country	*Population (2013)*	*Internal renewable freshwater availability (km³/year)*	*Total water withdrawal (km³/year)*	*Availability of internal available water m³/cap/year*	*Withdrawal share of availability (%)*	*Withdrawal m³/cap/year*
Vietnam	91.68	359.40	82.03	3,920	22.82	895
Thailand	67.01	224.50	57.31	3,350	25.53	855
Bangladesh	156.60	105.00	35.87	670	34.16	229
Cambodia	15.14	120.60	2.18	7,966	1.81	144
Ayeyarwady	34.31	412.24	25.00	12,015	5.96	716
Sit, Bag, Myit	16.68	61.50	4.00	3,687	5.72	211
Bago, Myit Ma Hka	9.58	21.82	-	2,278	-	-
Sittaung	7.10	39.68	-	5,589	-	-
Salween (total)	10.00	265.39	1.20	26,539	0.45	120
Salween (Myanmar)	4.99	216.00		43,287	0.55	240
Major river basins Myanmar	55.69	739.14	29.97	13,272	4.05	535
Major river basins Myanmar (internal)		689.74		12,321	4.35	

For the communication to planners in the WRS, the available water resources and the water utilisation per capita are numbers which easily can be compared with references countries or regions. The water utilisation in Southeast Asia is high compared with that in the major river basins and Myanmar total, see Figure 4.2.4. As stated in the introduction of this report, a water utilisation of more than 20% is considered to be a limitation factor for a country's economic development. Myanmar has in the current status and on national level still plenty of available water that can be used without creating negative effects for the people, sectors and the environment. This does not represent the water availability and utilisation on local scale.

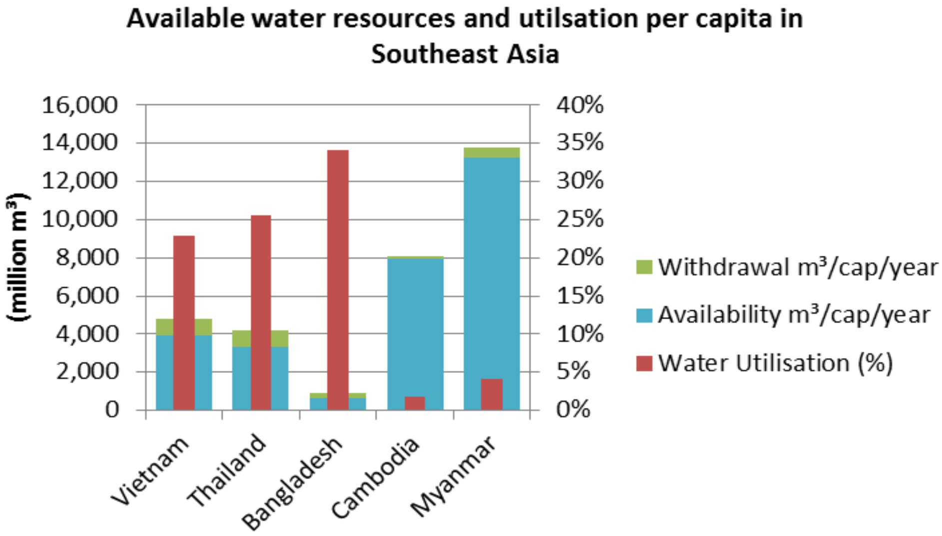


Figure 4.2.4 Available water resources and utilisation per capita in Southeast As can be seen, the water utilisation in Myanmar is low compared to other countries in the region, with 13.272 m^3/capita/ year

In comparison with the internal water availability in other countries in South East Asia, the amount water withdrawal in relation to the total available freshwater resources and the fresh water availability per capita are shown Table 4.2.5. The water availability per capita in Myanmar is the largest in the region, especially in the Salween Basin. For the major rivers basins the available water is 13,272 m^3/capita/ year. For the major rivers the available water resources per capita is largely variable: Ayeyarwady has 12,015 m^3/s, Sittaung, Bago& Myit Ma Hka 3,687 m^3/s and 26,539 m^3/s is available in the full Salween Basin. The water withdrawal by the users in Myanmar is still relative low compared to Viet Nam and Thailand where the water use is 22.82% and 25.53 m^3/s of the yearly internal renewable freshwater. The water availability does not include the inflow from external sources, like rivers (Mekong in this case). According to the United Nations the threshold of 20% water withdrawal is exceeded, water tends to become a limiting factor in national socioeconomic development (UN, 1997; UNESCAP, 1998). Myanmar is with 5.96% in the Ayeyarwady River Basin, far from close to this threshold. Water is thus not a limiting factor for the development on the national scale. For the Ayeyarwady and Sittaung, Bago and Myit Ma Hka Rivers it can be assumed that all the water users are fully internally available.

Important note

For the research **all the available water** has been assessed for the major river basins, including the inflow from other basins. The water utilisation for the present situation is then 4.05%. In comparison with the information found for the other countries in South, Southeast Asia, where only the internal renewable water availability is considered.

4.3. **Cumulative inflow and demand of water consumptive stakeholders**

The yearly cumulative available runoff into the river basins versus the cumulative demand from the stakeholders in the basins in shown in Table 4.2.4 and Figure 4.3.1, where the columns display different information

In 1) and 2) also the situation is presented for the development (*proposed C2and C3*) of the irrigation schemes, this however will be discussed in a later Section, 0. It is assumed that all demand of the irrigation areas can be supplied by the water. For the present day situation, the irrigation area is indicated as *Actual_C2*

The columns explained:

> 1) Shows the stacked gross demand and inflow to see the overall water demand versus water availability on a yearly basis.
>
> 2) The relative cumulative gross inflow and demand. Here the ratio of the water demand over the available water can be seen. For the Salween Basin the demand was not visible on the same axis since it is that small. A secondary axis is used to highlight the magnitude differences. The Sittaung, Bago and Myit Ma Hka Basin has the relative highest utilisation of the water.
>
> 2) The cumulative demand as a percentage of the total inflow in the basin from the beginning of the year. Here, clearly the relative important of the demand in the dry season can be observed. The public and industrial demand is relatively low.

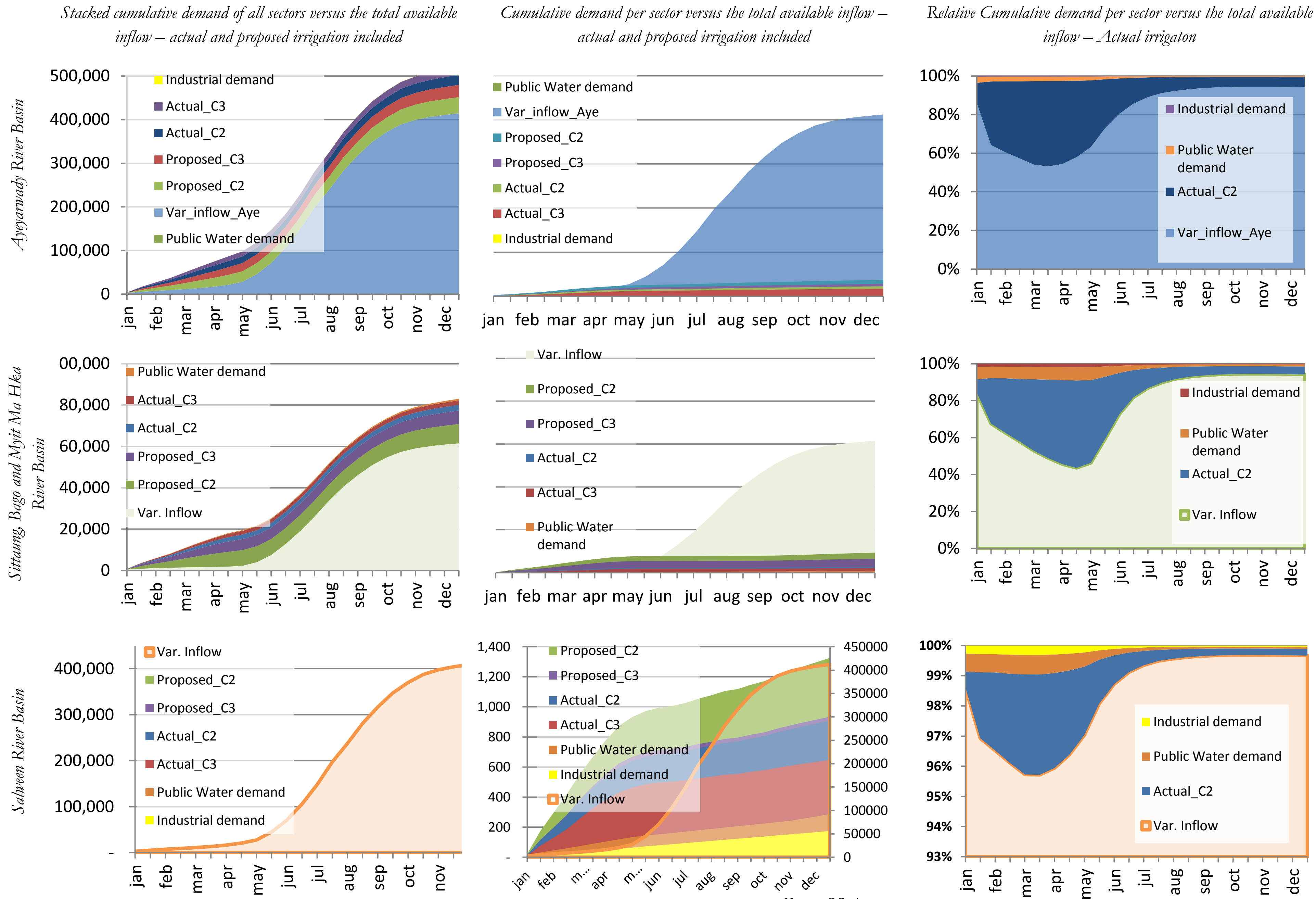


Figure 4.3.1 Cumulative Demand per sector versus inflow into the river basin (million m³) – present situation column. In these graphs the relative importance of the demand versus the inflow in time can be observed

4.4. **Groundwater**

The estimated groundwater potential in Myanmar is around 495 km^3 in eight principal river basins in Myanmar (MoAI, 2006), and 453.7 km^3 according to (FAO, 2010). Yangon and Mandalay cover the largest urban areas in Myanmar, and as the domestic sector is the largest user of groundwater, this explains the groundwater scarcity problems in these areas. Population in these districts is about 9% of the whole population of Myanmar, which makes the situation even more severe as so many people could be affected by water scarcity. Groundwater scarcity from medium to severe is located in the central and delta areas of the Irrawaddy basin. In these districts water usage is between 20% and 40% of the groundwater supply (Kattelus, M. et al., 2009). In districts like Sagaing, Mandalay, Eastern Yangon, Western Yangon, Kyaington and Lashio, located in the central and upper Irrawaddy basin and in the central part of the Salween basin, the total groundwater usage is more than 40% of the available groundwater resource. Situation is most acute in Mandalay, Eastern Yangon and Western Yangon districts, where the usage is almost 100%, (NAPA, 2012).

The frequency of occurrence and the duration of drought events will increase utilisation pressures on ground water for expanding irrigated agriculture. In addition, this trend has spawned a series of negative chain effects, including land subsidence or soil erosion, landslides, salinization of arable land, and ecosystem disruption. Rising sea-levels however, will lead to salt-water intrusion into groundwater supplies, particularly as existing water levels decrease. Ground water supplies will be particularly vulnerable to saline intrusion during the dry season as a result of low water volumes in river systems (DeltaAlliance, 2014; NAPA, 2012).

The overexploitation of groundwater resources often leads to depletion of groundwater table which decrease the accessibility. In addition, this trend has spawned a series of negative chain effects, including land subsidence or soil erosion, landslides, salinization of arable land, and ecosystem disruption. In particular, land subsidence derived from the drop of groundwater table and saltwater intrusion into arable land is the most serious problems in developing countries. These issues are related to the issues of universal access to water and wastewater services as well as food security. In addition, less groundwater resources can trigger a decrease of water flow to local streams and rivers, which jeopardizes ecosystems (Library, 2014).

In the assessment of the water allocation the groundwater is not included since the accessibility of the groundwater is not known, which is crucial for the water availability of this source in during the dry season.

4.5. Surface water reservoirs

In the river basins there are 253 surface water reservoirs located in Myanmar, of which most of them are located with the major river basins. The capacity varies between very small (< 1 million m^3) and very large (up to 37,889 million m^3). The total amount planned dams counts a total of 49, which are all hydropower, see also Section 0, according to the received data from the MoAI and the Ministry of Energy (MoE). In the table below an overview of the surface water reservoirs with their purpose is shown. The last column indicates the ratio between the Dead Storage (DS) and the Full Storage (FS) capacity of the reservoir. In the Annex P the determination of the dead storage is explained. As can be seen, the available storage in Myanmar is 119 km^3 when all hydropower dams are constructed; and 27 km^3 can used for irrigation purposes. At present, approximately 20 km^3 is available for irrigation in the major river basins. In the remaining parts of the country, the number constructed reservoirs are limited. An overview of all the reservoirs in can be found in Appendix T, which includes also the purpose of the reservoir, if known.

Table 4.5.1 Full, dead- and available storage capacities per river basin (in million m^3), sorted by the purpose of the reservoirs. The available water resources to be used by mainly the hydropower and irrigation sector are represented by the active storage capacity

River Basin (purpose)	*Full Storage Capacity*	*Dead Storage Capacity*	*Available storage capacity*	*Ratio DS/ FS (-)*
Ayeyarwady (HP + Irr)	31,971	9,249	22,722	29
Ayeyarwady (Irr + other)	35,194	10,095	25,099	29
Ayeyarwady (Irr only)	3,013	776	2,237	26
Ayeyarwady (HP only)	74,525	35,613	38,911	48
Ayeyarwady (all)	109,719	45,708	64,010	41
Case Study Area	5,784	1,822	3,962	32
Salween (irr only)	851	636	214	75
Salween (HP only)	79,266	31,240	48,839	48
Salween (all)	80,117	31,877	48,026	39
Sittaung + Bago + Myit Ma Hka (no HP)	4,100	1,034	3,065	25
Sittaung + Bago + Myit Ma Hka (HP + Irr)	9,662	5,615	4,046	58
Sittaung + Bago + Myit Ma Hka (HP only)	0	0	0	0
Sittaung + Bago + Myit Ma Hka (all)	14,191	6,866	7,325	48
Myanmar Sub- Total (irrigation)	**45,707**	**16,346**	**29,359**	**38**
Myanmar Total	**204,027**	**84,451**	**119,361**	**41**

The available storage capacity can be used for different purposes. The reservoir reaches their maximum level at the end of the monsoon season, so around the end of October, halfway November. From that point on they can supply large amounts of water needed for hydroelectric power production, for cultivating (high water demand) crops or save water that can be used to guaranty a certain discharge in the stream. In the hilly regions of Sittaung + Bago Basin and the southern part of the Ayeyarwady Basin, the reservoir also serves to control the floods during monsoon season.

Unfortunately for this research, only of a few dams it is known if they operate as multi-purpose dams. This means the combination between irrigation and domestic water supply or hydropower production. It is assumed for most reservoirs in the Ayeyarwady River basin they have a single purpose only. In the Sittaung, many reservoirs have hydropower and irrigation combined constructed and planned. The most important ones are located upstream of Yangon City.

The available storage is used in the assessment of the available water resources for the water available for irrigation in the summer and winter season. The design of the irrigation area is determined by the volume of water that flows in the reservoir during the monsoon season to fill up the storage capacity. The total surface and sub-surface runoff together with the geographical lay-out of the region determines the maximum volume of water. Most of the reservoirs used for irrigation are now located in the hilly regions and the tributaries of the big rivers, where the water spread area affects mostly only forest, or limited villages. In the development of the country, the hydropower reservoirs are planned to be constructed in the main course of the rivers also.

As can be seen in Table 4.5.1 the dead storage over full storage capacity ratio differs from basin to basin. Since for most of the reservoirs the dead storage was not collected during the data collection phase, the dead storage has been assumed by looking at a known dam in the same region. The full storage was known for all irrigation reservoirs, and with a few exceptions for all hydropower. However, it was found during the model development process that hydropower stations have a larger dead storage to full storage ratio compared to reservoirs with an irrigation purpose. This can be clearly seen in the Sittaung, Bago & Myit Ma Hka basins, where almost all known reservoirs serve for hydropower. The available storage therefore is assumed to be too low. The available storage is an important parameter together with the inflow for analysing the water availability for irrigation in the dry season. This spread of the uncertainty in the dead storage is taken into account for the availability and will be discussed at the end of the report.

4.5.1. Flood control

During formal discussions with staff of the hydrology branch, ID, it was found that reservoirs build 15 years or older, the frequency of using the spill-way, has been increased and re-designs might be necessary to avoid damage to the structures, with unforeseen consequences, Hydrology Branch (2013). Possible explanations could be the high sedimentation rate in the reservoirs or a very high runoff from the watershed, which is close to the design inflow for which the spill way level is designed. A map with the sedimentation rates for the different regions in Myanmar, can be found in (Hasman, 2013). The frequency of high inflow has increased over the years, where also high inflow over a longer sequence is observed. It was concluded that the design criteria for the design inflow is to low, so the inflow rate for which the reservoirs fills up and the spillway will be operational. Flood control is a responsibility of the Irrigation Department (ID), of the Ministry of Agriculture and Irrigation (MoAI), which includes both the construction of dikes along the rivers as well as the construction and operation of the surface water reservoirs.

4.6. **Irrigated agricultural land**

4.6.1. Agriculture

Myanmar's agricultural sector has gone through various changes in the last century. During the colonial time (1824/ 1948) the country was open to international trade and free market economy prevailed. A major expansion of rice cultivation took place, and Myanmar became the world's largest exporter of rice(UNDP, 2002 a). In the report of MoAI (2006) the agricultural sector (including crop production, livestock, fisheries and forestry) is the most important sector in the country's economy:

- It is the main source of livelihood for about 70 % of the population who live in the rural areas;
- It accounts for about 64 per cent of the labour force;
- It contributes about 41 per cent of export earnings.

Myanmar's paddy fields can be found mostly in the delta and central dry zone areas (Figure 4.6.1). About 60% of the delta region, including the Ayeyarwady, Bago and Yangon region of Lower Myanmar, is largely cultivated with rain fed paddy. Irrigated paddy is cultivated mainly in the Mandalay, Sagaing and Magway regions which are located in the central dry zone of Myanmar. After the monsoon season, in summer and winter, more and more crops are being cultivated by optimising the water management practises such as irrigation from surface water reservoirs. Since 1988, many fresh water reservoirs have been constructed in the Ayeyarwady, Sittaung and Myit Ma Hka basins. Only the last years, fresh water reservoirs have been constructed in the Bago River Basin, mostly for flood control purposes.

Over the past two decades, the Government has focused on achieving rice self-sufficiency. The net sown area in 2011 is 13.58 million hectares (CSO, 2011), of which 2.12 million is irrigated area, with a full potential of 10.5 million ha, so around 20% is operational. This accounts for ~20% of the countries surface area. The rice cultivated area is nearly doubled (from 4.8 to 8 million ha of which 6.8 million ha of monsoon paddy and 1.2 million ha of summer paddy), pulses cultivated area is 4.5 million ha, is thus the second most important crop. Other important crops are sesame, groundnut, chili, onion and garlic (IFAD, 2013). The ID, MoAI had in 2011 to 2012 a total of 1,139,250 ha irrigable land developed, (MoAI, 2013a). the annual water utilisation by water used for cultivation, is 39.55 km^3. Originally, the farmers were assigned to cultivate rice with water supplied by the ID originated from a reservoir or pump installation. From that irrigated area, 27.7% is for double or multi-cropping, and is increasing since the government allows the farmers to cultivate crops best suitable for that region and to maximise income.

The cultivated areas are concentrated in the Ayeyarwady River basin, while potential for further expansion lies mainly in upper Myanmar. Namely in the Chin, Kachin and Shan states (FAO, 2011). Most of the agricultural lands are currently cultivated by small-scale farmers. The average size of the holdings is 2.27 ha; 61% of total net sown areas are held by the farm size(McCartney et al., 2013) less than 4 ha (UNDP, 2002 a). In the Central Dry Zone, the average farmland size is 2,2 ha .After decades of producing no surplus because of a low fixed minimum price for paddy to make profit by exporting it, the new objective of the government is to produce surplus paddy production for both domestic food security and promotion of export; also to achieve self-sufficiency in edible oils; and to expand production of beans, pulses and industrial crops for exports (ID, 2007). The traditional agricultural systems based on the cultivation of rice have to be transformed to sector with more variety, which is marked oriented, to achieve these objectives. The government allowing freedom of choice in agricultural production; to expand agricultural land; and to encourage the participation of private sector (UNDP, 2008).

The delta region is densely populated with a population of over three million people, and plays a dominant role in the cultivation of rice (60% of Myanmar's total rice production) in rich alluvial soil which has termed the region the Rice Bowl of Myanmar (BANCA, 2011)

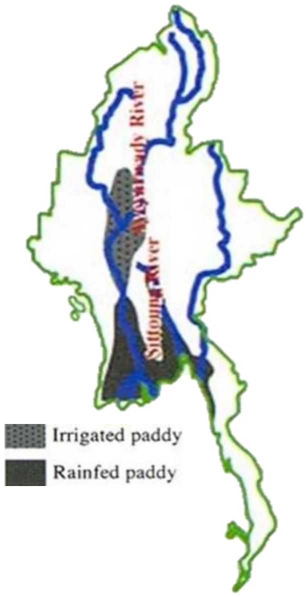


Figure 4.6.1 Irrigated versus rain-fed paddy - (Naing, 2005) – The southern part of the country is dominated with rain-fed and the central part dominated with irrigated paddy. The Sittaung Basin however is increasing the irrigaitin areas

4.6.2. Irrigation areas

The most important crop is rice, which mainly is produced during the monsoon season, but since the development of irrigation project, the production during the winter season is becoming more important. Roughly the rain-fed and irrigated paddy can be distinguished in two regions, lower Myanmar for the rain-fed, and the central part the irrigated paddy, see Figure 4.6.1. During the development of the irrigation systems after 1988 farmers were thus forced by the government to cultivate paddy in designated areas, especially those with irrigation, as a condition of access to the land and inputs, (UNDP, 2002 a). The consequences of this policy were that the yields dropped since not every region was able to cultivate rice due to climatic conditions, water availability infrastructure and soil conditions. In the last years, the farmers are able to choose which crops to cultivate, based on a free market principle and available knowledge in that region. Rice is the largest produced crop in Myanmar, mainly for local consumption. The second biggest crop are the pulses, which has been increased largely due to the liberalization of exports bringing economic incentives to the farmers, as well as the pulses' low need for irrigation water, making it cheaper to produce, (Lwin, 2002; MoAI, 2006).

There are two types of irrigation management in Myanmar: public and private schemes. Government schemes account for 53 % of weir schemes (9 in total) and 81 % of the dams (35 in total) and tanks (12 in total) (all Wells and pump irrigation, although possibly originally implemented by the services of the former Ministry of Agriculture, are mainly private (FAO, 1995). Since 1995 many irrigation schemes with dams and weirs have been developed by the government, so this ratio is much higher at the moment. (Htay, 2013). In 2011 to 2012 there were 257 dams, 27 weirs, 33 sluice gates and 48 presented in Myanmar, under control and operation by MoAI (MoAI, 2013a) leads to a contribution of 93% of dams (116 in total), 11 weirs, 18 sluices and tanks (excluding small scale tanks), 367 pumping projects. Assumed is that the scale of the private irrigation schemes is negligible, and so does the water withdrawal.

In Myanmar practice, the design of the water necessity to supply the irrigation areas use the following rules- of thumb for the different crops, (Agricultue, 2013) and (Assistant Director Design Branch, 2013). For two important crops, these design values are:

- Paddy → 1 ac-ft / 40 acres / day → 7.6 mm/day/ ha
- Beans → 1 ac- ft/ 70 acres / day → 4.4 mm/day/ ha
- River pumping design criteria (WURD) → 6 ac-ft/ acre → 3.0 mm/day/ ha

In the lower Sittaung basin, flood plains are used for agricultural purposes. During the monsoon season, the area gets flooded, so in the dry season, the land can be used to cultivate rice.

The Irrigation Department (ID) and the Water Resources Utilisation Department (WRUD) are responsible for irrigation, for dams/ reservoirs and pumps/ wells, including collecting water taxes, training people and maintaining the main infrastructure. Farmers maintain and operate the terminal units such as field ditches and watercourses (Naing, 2005). On average, 2.2 million hectares of crops are irrigated each year. The irrigated area is stable in the last five years, but is limited to only 16 % of the agricultural area. of the total summer paddy in the country, 91,5% receives irrigation water from the government: WRUD or ID, MoAI, (MoAI, 2013a). In Table 4.6.1 the total water supplied area for years 2008 till 2011 in Myanmar can be seen. The actual water supplied irrigated area is the area of the latest surveyed year (2011-201) if known; otherwise the proposed area is used. For the assessment the *actual* area is used as input for the (potential) irrigable area and the operation characteristics are those of *case 2*, see Appendix R. For the present day situation the *actual*_C2 is used to refer to the current status of the irrigation areas. It does not represent the cultivated area. If all irrigation area is in use (100%), and sufficient water is available, the cultivated area is equal to the potential or actual irrigable area. The proposed area is the area which is equipped to be irrigated. So it is the area irrigated under full capacity. The term planned area might be used, but it is not the same as the potential irrigated area. Via personal communication, the surveyed actual supplied area, is approximately 80 to 90% of irrigation area. So from this data set, 50,6% of the potential area is supplied with water. How much of this has been cultivated is unknown. In Table 4.6.2 an overview of the irrigated areas per river basin is shown and the average area of an individual irriagation project. In the Sittaung, Bago and Myit Ma Hka River basin there is a large potential of proposed area to be developed.

Table 4.6.1 Water supplied area (ha) according to ID, MoAI for the actual (current) situation and proposed (planned development future situation)

Total water supplied area by irrigation (ha)	*2008-2009*	*2009-2010*	*2010-2011*	*2011-2012*	*Proposed (ha)*	*Actual (ha)*
	1,039,205	1,035,660	1,021,272	980,824	2,249,055	1,138,436

The amount of runoff that can be stored in surface water reservoirs for irrigation areas has a storage capacity of 18,000 million m^3 in 2009, (OECD, 2014), and 22.966 million m^3, (MoAI, 2013a), see section 4.5 and Table 4.6.4. The farmland that is referred to by (Ti & Facon, 2004) is probably developed and operated by the Water Resources Utilisation Department (WRUD), MoAI. Privately owned pump stations and tube wells are than not included in these numbers.

Currently, river pumping covers 38.1% of the irrigated area, dam and river diversion 29.2% and groundwater irrigation 6.0%, (MOAI, 2013) adopted by (OECD, 2014). More than 75.0% of the total irrigation area is sown to rice, but vegetables, pulses and sesame are grown under irrigation (UNDP, 2002). Despite such progress, the proportion of the sown area under irrigation in Myanmar remained low (17.1%), compared to neighbouring countries: Bangladesh (57.5%), China (47.3%), India (33.8%), Viet Nam (31.39%), Thailand (26.5%) or Lao PDR (22.3%).

With a total potential irrigable area of 10.53 million ha, there is still a large scope for developing irrigation infrastructure (ARCD, 2011). Only 10,8% is currently actively supplied with water.

Table 4.6.2 Actual and Proposed irrigation area per river basin – and the averaged surface area for the actual and proposed areas in the individual river basins.

River Basin	*Actual Irrigation Area (ha)*	*Proposed Irrigation area (ha)*	*Increase Actual → Proposed (%)*	*Average surface area (ha) – Actual*	*Average surface area (ha) - Proposed*
Ayeyarwady	923,866	1,535,973	66.3	10,265	15,515
Case Study Area	146,155	238,914	63.5	7,900	10,873
Salween	51,145	86,836	69.8	3,653	5,427
Sittaung + Bago + Myit Mha Hka	166,997	612,975	267.1	4,175	12,510
Myanmar Total	**1,138,436**	**2,249,055**	**92.1**	**10,265**	**15,515**

It is estimated that there is a total of approximately 350,000 ha of formal command area in the Central Dry Zone. A small proportion of this is supplied by groundwater but the majority is gravity-diversion and pumped surface water schemes. Current irrigation is primarily supplementary to extend the wet season growing period or protect wet season crops, rather than full dry season irrigation, (McCartney et al., 2013).

4.6.3. Field water requirements

The demand of the crops at the irrigation areas are calculated based on the initial soil moisture content, crop specific water requirements, reference crop evapotranspiration, irrigation field efficiency, other losses like percolation. In section 6.1.3 the equations are provided how much the actual water requirements are needed. Based on the actual field water content, the demand for water to the system is calculated for every time step. For the supply of water to the irrigation areas, an upstream surface water reservoir or river is asked to provide the required amount of water. The full amount of available water is release from a dam to meet the demand for every individual time step. In the assessment, no water is saved to meet the demand for the whole the dry season for certain part of an irrigation areas. It is possible that the demand cannot be fulfilled at the end of the growing season, so larger parts of the crops are lost.

4.6.4. Demand of irrigation areas

For the performance of the irrigation systems, the settings of C2 are used, which represent the operation and status of the irrigation field at he present day situation with an average efficiency of 32%. The different input parameters are discussed in Appendix R, and are based on both literature from the FAO, (Brouwer et al., 1989a; FAO, 1977) and personal communication with experts experienced in the irrigation system of Myanmar, (NEPS, 2013b). The irrigation withdrawal per basin is obtained from the gross water supplied water to the fields from the network, which is either a reservoir or a river source. Current stakeholders are state owned (ministries) projects. No private projects (sides) are part of the model. Since the state does not own the full 100% of the data, the outcome of the water demand and allocation is not a fully representation of all stakeholders in the WRS of Myanmar. More insight in the contribution and operation of the private actors is recommended. The demand (10^6 m^3) per time step is shown in Figure 4.6.2 for the major river basins and the Magway and Minbu case area. The average cultivated area per river basin represents the actual area cultivated to have received sufficient to grow the crops. When the crops receive to less water, or other words, when shortages occur, (parts) of the crops will wilt and will not be cultivated. In total 80% of the irrigated area is actually cultivated

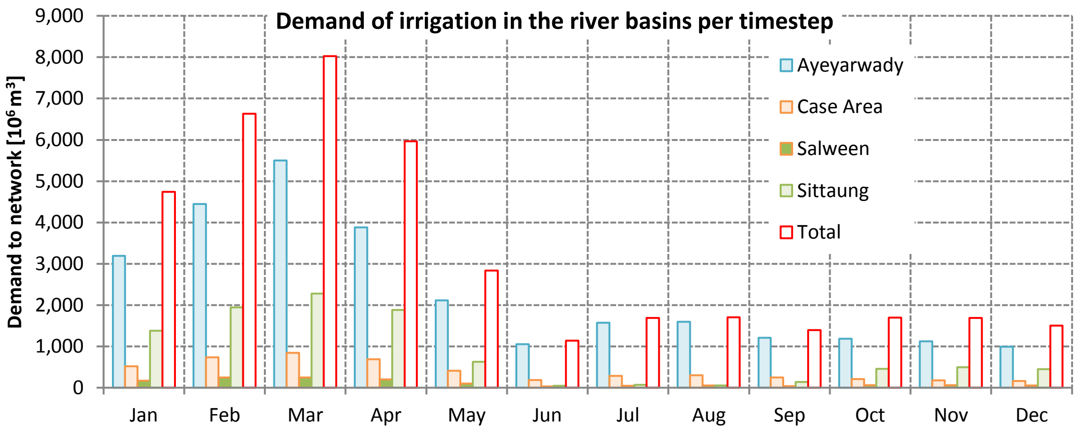


Figure 4.6.2 Demand from the irrigation sector to network per river basin (10^6 m^3/ time step) – Actual situation (current amount of irrigation area)

The water withdrawal and the irrigated area for the Salween according to (FAO, 2010) is shown in the last column of Table 4.6.3. A cross reference is made between this data and the simulated water withdrawal, indicated with the symbol #. . For the same area, the water withdrawal of the simulated output is higher than the data found in literature. There is difference of a factor 1.36.

Table 4.6.3 Withdrawal from irrigation for the major river basins – Salween literature: (FAO, AquaStat, 2011)[3]

Annual average water usage (km³)	*IRRIGATION _ Actual*				
(Author, year) - Description of resources (s) : simulated	Total Irrigation area (ha)	Area cultivated (ha/ year) - average	Demand to network (km³/ year)	Irrigation withdrawal (km³/ year) - average	Irrigation withdrawal total (km³/ year) #
Ayeyarwady	864,800	272,903	17.015	13.31	-
Sittaung, Bago and Myit Ma Hka	163,650	58,181	3.134	2.848	-
(Mying, 2008)	180,377	58,181	3.134	2.848	-
Salween (FAO)	200,000	-	-	2,100	2.861#
Salween (S)	53,057	16,680	0.908	0.759	0.557#
Total (s)	**1,081,507**	**294,764**	**21.057**	**16.917**	

4.6.5. Storage capacity of surface water reservoirs for irrigation

The ID, MoAI, had constructed a total storage capacity of 22,966 million m³ in 2013, (MoAI, 2013a). The total storage capacity for irrigation, including reservoirs serving multipurpose is 51,491 million m³. Almost all dams with a multipurpose have a hydropower station, with exception of NgaMoiYeik Reservoir (Yangon Division), which has the main purpose to supply the drinking water for Yangon City, but also has a large irrigation area downstream. The reservoirs store water during the monsoon season, to be release it during the dry season, when the winter and summer paddy are demanding lots of water.

Table 4.6.4 Storage capacity for irrigation purposes - including planned

River basin	*Full Storage Capacity (10^6 m^3)*	*Dead Storage Capacity (10^6 m^3)*	*Available Storage Capacity (10^6 m^3)*	*Ratio DS/ FS (-)*
Ayeyarwady	35,194	10,095	25,099	29
Case Area	5,784	1,822	3,962	32
Sittaung + Bago + Myit Ma Hka	9,662	5,615	4,046	58
Salween	851	636	214	39
Total	**51,491**	**18,168**	**33,321**	**35**

[3] *Total Actual Renewable Water Resources (TRWR_actual): The sum of internal renewable water resources (IRWR) and external actual renewable water resources (ERWR_actual). It corresponds to the maximum theoretical yearly amount of water actually available for a country at a given moment.*

4.6.6. Performance of the irrigation systems

The typical highly fragmented pattern of small coupled basins (0.08 to 0.125 ha) with irregular shape and at slightly different levels characterizing rice production under rain-fed conditions is widespread in the irrigated rice growing areas. Irrigation water is discharged from the plots nearest to the canal outlets to the lower plots in a plot-to plot water distribution and drainage system. The flows are controlled by upstream users by temporarily lowering and raising the earth bunds, see Figure 4.6.3. At present day, most of the farmers own still a small piece of land (1 – 4 ha), in an irrigated area. For the average irrigation area (~5,198 ha) this means there are over 1,750 farmers in one area. In the traditional method (Figure 4.6.3– left) the efficiency is much lower than the modern irrigation system. Cooperation and training of the farmers to share the water equally is a responsibility of ID, MoAI. Well trained farmers lead to an increase in the overall efficiency for the supplied water, both on-farm and off-farm practices. Farm groups, consisting of a number of farmers along a (water course or field ditch) irrigation canal, are responsible for the maintenance of the canals and inlet structures. ID, MoAI is responsible for the maintenance and operation of the reservoirs, main or first order, secondary canals and 3rd order or tertiary canals.

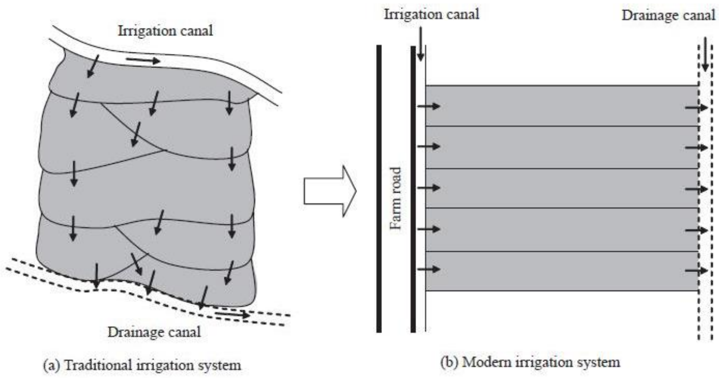


Figure 4.6.3 Traditional and modern irrigation – In the traditional system the downstream farmers largely depend on the maintenance done by order farmers. Modern irrigation systems have one shared irrigation and drainage canals where the maintenance of these benefits all farmers source: (Naing, 2005)

Cropping programmes are not well matched with existing hydraulic facilities, poor maintenance increases system losses, and much water delivery is non-productive. Current irrigation efficiency is very low with less than 5% in the Central Dry Zone of water abstracted actually transpired by crops, (McCartney et al., 2013). As a result, and even with the limited areas currently developed, many users at the lower end of distribution systems find water deliveries inadequate for programmed crops (UNDP, 2008). In the design of the canals losses of 30 – 35% are taken into account (Assistant Director Design Branch, 2013). These losses should be accounted for seepage of the earthen canals. In the sensitivity analyses, Appendix R, the overall field application efficiency is discussed. The simulated overall efficiency of the irrigation areas is estimated to be around 30%, based on the FAO documentation, (Brouwer et al., 1989a), with 37% during the dry season, and 27% for the rainy season. The term 'overall efficiency' is says how much supplied water (rainfall or irrigated), is actually used by the crops. Large farmers have the highest technical efficiency score followed by medium and small farmers, Library (2014). The drop in the monsoon season can be explained by the fact that during the rainy season, interception has a large contribution to the efficiency of the rainfall event. Also, a large part of the rainfall is drained from the irrigation fields to the main river downstream so most of the precipitation is not used by the crops. In the following figures the different factors influencing the overall irrigation efficiency is illustrated.

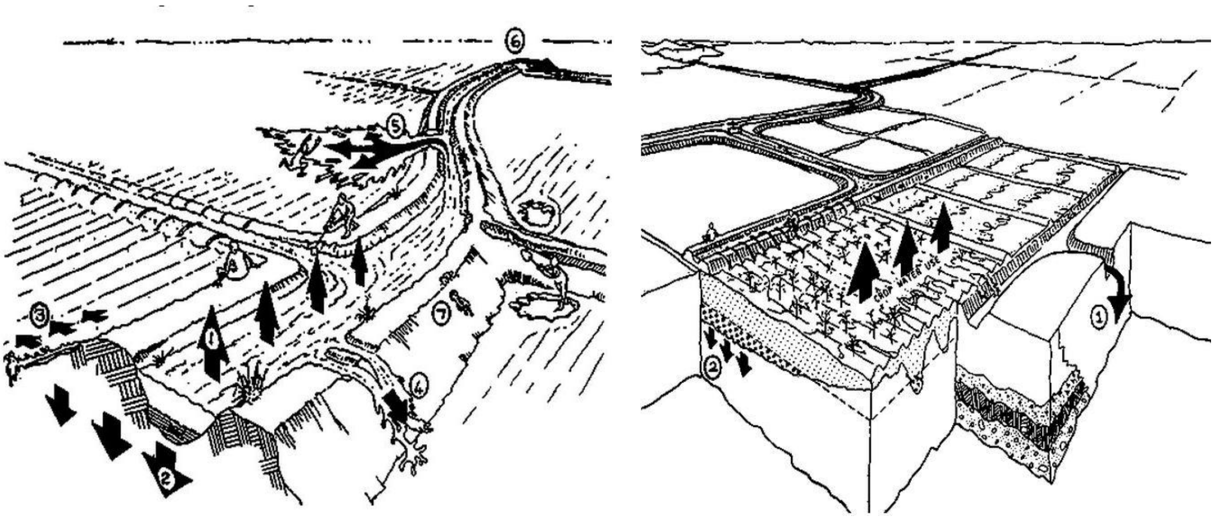


Figure 4.6.4 Efficiency of irrigation fields (left) canal losses, (right) field losses – Source: (Brouwer et al., 1989b)

4.6.7. Performance of the irrigation in the Central Dry Zone

Reported problems with irrigation projects in the Dry Zone include inappropriate design that prevents adjustment of water supply according to variations in demand over seasons, incomplete tertiary canals and onfarm networks, unlined canals with high seepage, inappropriate crop choice (paddy) and irrigation method (basin) for soil type, and lack of maintenance and monitoring (LIFT, 2011). Improved engineering, technical and extension support, changes to crop selection, and an increase in farmer involvement have been proposed as approaches to improve the performance of pumped irrigation projects, (McCartney et al., 2013).

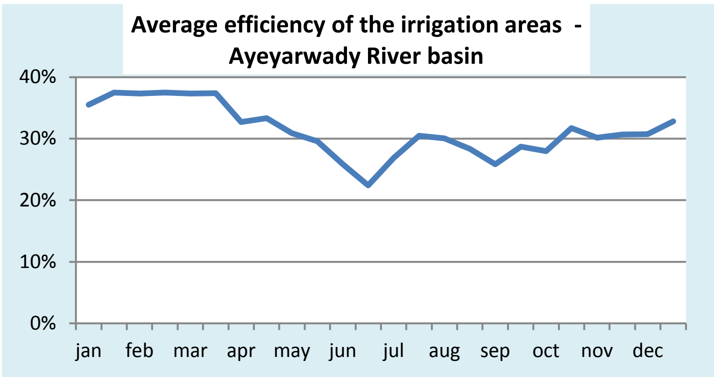


Figure 4.6.5 Simulated average overall irrigation efficiency for the current situation (*actual* irrigated area) – Ayeyarwady River basin. This efficiency factor consists of multiple other efficiency factors such as the normal and drought factors, surface and ground water conveyance factor, field application factor and the rainfall effectiveness

Table 3.8 Types of sources of irrigated water for agricultural land in Myanmar in hectare (ha): surface water reservoir, tube wells and river pumping

	Actual (ha)	*Year*	*Proposed (ha)*	*Potential (ha)*
Surface water irrigation (s)	953,451		1,858,458	
Tube wells#			36,000	
River pumping #			150,000	
River pumping (s)	30,018		316,269	
Total		2007	2,110,000	
(AQUASTAT, 2014)	2,083,000			10,500,000
(MoAI, 2013a)	1,372,000			
(s)	1,138,436	2011	2,249,055	

- (Ti & Facon, 2004), (s) assessed in simulation

The *actual* and *proposed* irrigation area for Myanmar has been collected from ID, MoAI as part of the IWRM project. This data has been merged with data from the hydropower dams, of which some include also irrigation areas, into one big data overview, called the 'Mastersheet'. This data sheet has been processed, and completed with data from the internet or assumptions. For a description of this process see Appendix P.

4.6.8. River pumps

For the present day simulation, about around 367 large scale pump irrigation schemes along the major river systems in Myanmar under the control of WRUD. The actual water supplied area which is simulated in the model, is 30,018 ha, which includes also some schemes under the control of ID, MoAI. The total beneficial area is expected to be the identified potential area that can be operational when the right sources (money, infrastructure) are available. A major limitation for the pumped irrigation is the costs of the diesel or electricity to pump the water to the field. This method is much more expansive than the surface water reservoirs that cover most of the irrigation areas in the country. When electricity or diesel becomes cheaper, this way of supplying irrigation fields, has a large potential area, over 10 times the area that is supplied these days. In the model, multiple pumps in the same region are lumped into one area, see also Appendix P. In Figure 4.6.6 a river pump installation of the main pump station in the Twingyi River pump irrigation project is shown.

Table 4.6.5 Potential irrigation area bye river pumping stations of WRUD in Myanmar in hectares (ha) and actual water supplied area (2011 – 2012). A large potential of river pumping projects are

Name of River	*Number of of installations*	*Beneficial Area (ha)*	*Water Supply Area (ha)*	*Current area supplied relative to potential area (%)*
Ayeyarwady	86	118,996	18,350	15.4
Chindwin	22	39,425	5,834	14.8
Salween	6	3,480	681	19.6
Sittaung	29	11,169	552	4.9
Mu	21	13,094	565	4.3
Dotehtawaddy	27	7,645	1975	25.8
Others	176	106,665	8426	7.9
Total	**367**	**300,474**	**36,383**	**12.1**

Figure 4.6.6 Main pump station of Twingyi river water pump irrigation project, in Myaung Township, Sagaing Region Source: WRUD

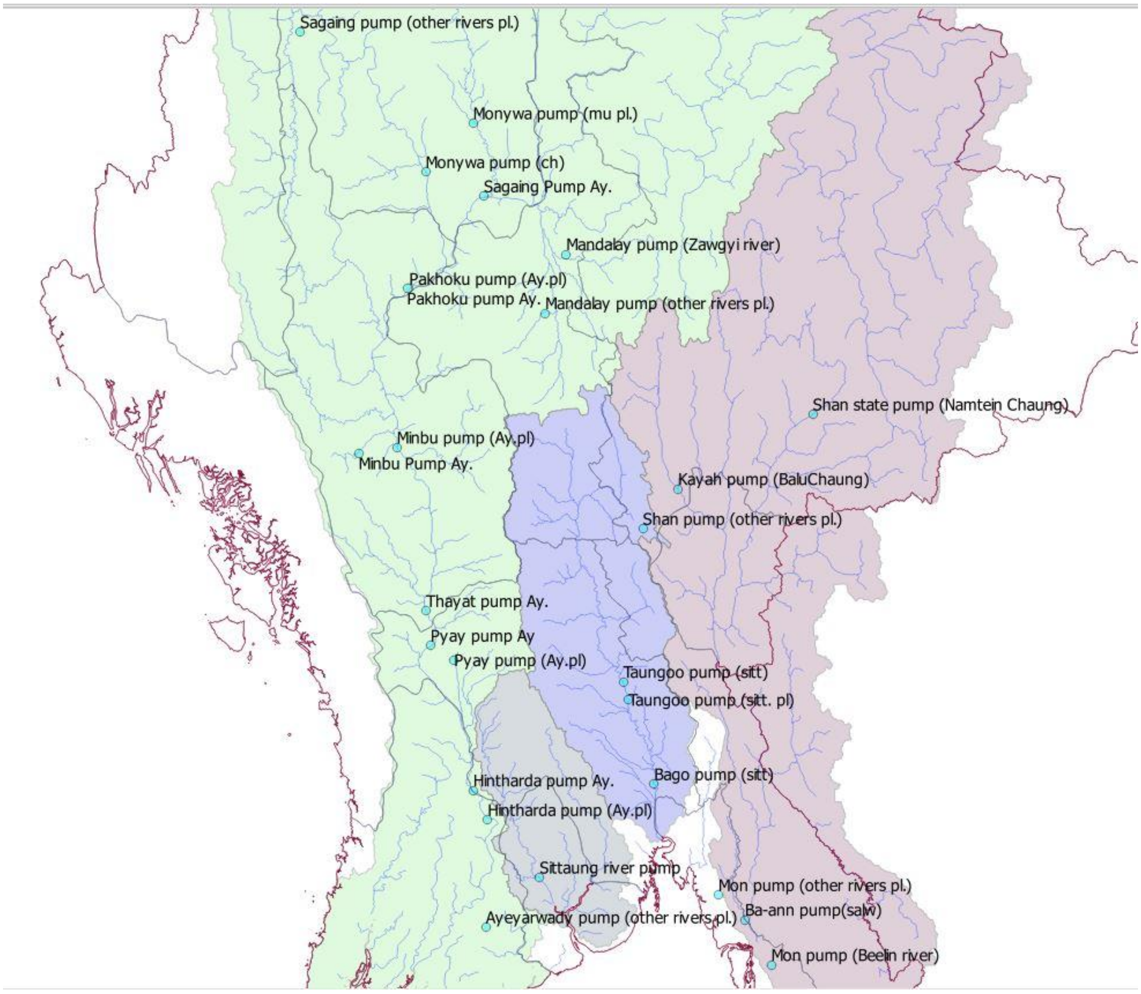


Figure 4.6.7 River pumping location in the - (pl) – planned river pump irrigation areas

4.6.9. Cropping pattern

An *advanced irrigation* node is used for the calculation of the irrigation demand, which is the node which the highest level of detail. The cropping patterns have been collected for many irrigation areas from the ID, MoAI, during a field trip in the beginning of 2014 on behalf of Deltares. These cropping patterns were ordered by State and Divisions and the most used cropping pattern for per State/ Division is been applied for all irrigation areas in the State/Division. An overview of the different cropping patterns, see Appendix 0. Only the irrigated crops are included in the model, so the agricultural land which is rain-fed during the monsoon season is not part of this assessment. An example of the Palin, Magway Division is shown below. The total water demand per time step is shown in the Figure 4.6.8 below the cropping pattern.

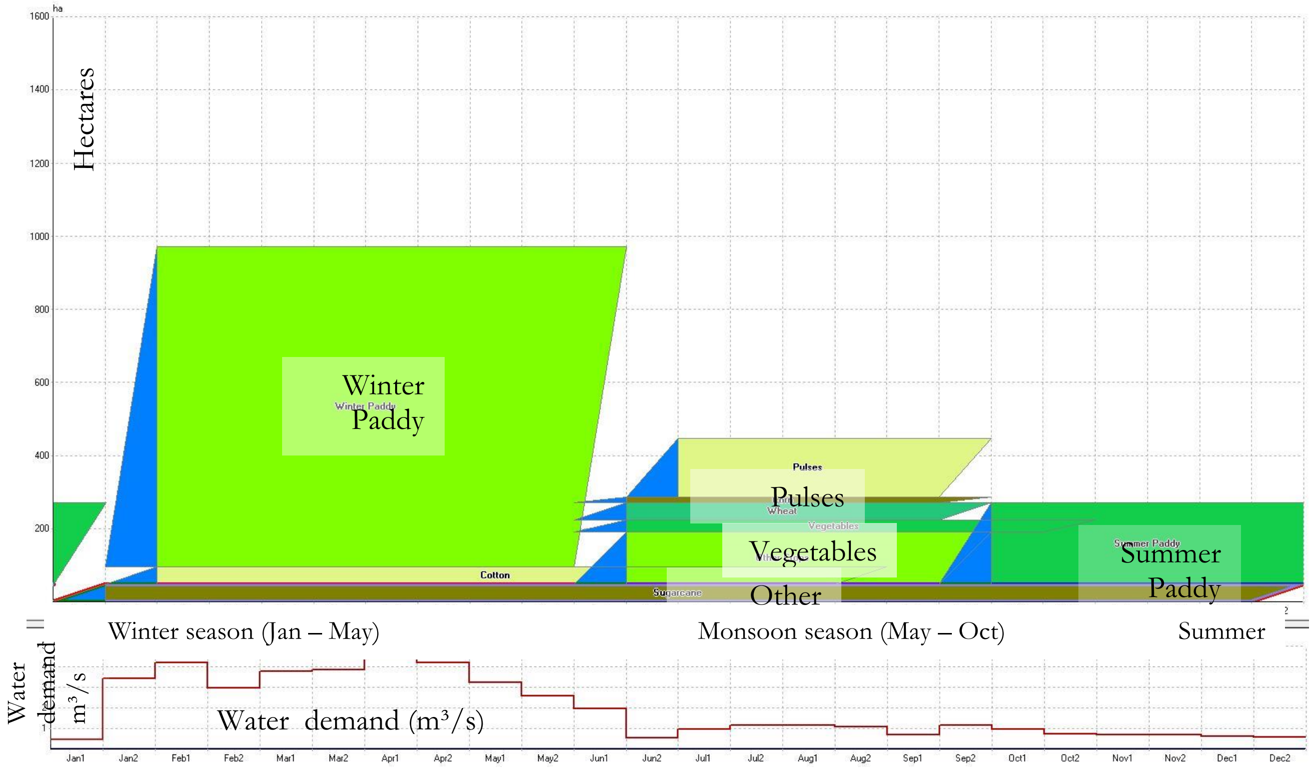


Figure 4.6.8 Cropping pattern of irrigated area at Pinle North, Magway Division. The cropping patterns used in the simulated ara averaged per State/ Divison. On the vertical axis is the area of the crop is presented. On the graph below the cropping partn, the water demand (m^3/s) is shown. This cropping pattern is for the irrigated cropos, and thus not include the rain-fed paddy. Winter paddy is the dominant crop in Magway Region.

The cropping characteristics are used from the available literature from the FAO, such as root-zone depth, percolation etc. The efficiency factors are factors that are characteristics of the irrigation area(s) and are found in literature and by discussions in the field. They represent the ratio of the supplied water, and the water that actually ended up in the root-zone to be used by the crop. The impact of the changing all these input parameters are studied in the sensitivity analysis. An overview of the outcome is shown in Section 6.3.

4.7. **Domestic water consumption**

The country is home to 59.13 million people (est), and 51.42 million people according to the official 2014 Census , spread across 12 States and Divisions and 135 different ethnic groups (officially acknowledged by the government), (Wiki, 2014). The last census was performed in 1983 and the next census to be conducted in 2014 will soon provide new information on total population and population density and composition. Since 2005 the capital is Naypyidaw, which is located in between the two major urban areas of Yangon (~ 5,5 million inhabitants) and Mandalay (~ 1,4 million inhabitants). Both cities, together with areas along the coast (Mawlamyine and Rakhine State) are important drivers for Myanmar's economy. Myanmar is characterised as one of the poorest in the world, with a Human Development Index (HDI) of 0.524 (2013), listed 150 out of the 187 countries, with an annual growth of 1.67%. The people living below the poverty line were 26% in 2010. The annual population growth is 1.1% according to (ADB, 2012a), 1.5% and 1,75% by (FAO, 2010) as an average growth since 1990 (estimated), see. The growth rate (Figure 3.3 and Table 3.2) of rural population in years 2005 - 2010 is 0.1% whereas the growth rate of urban population in 2005 - 2010 is 2.9%. The urban population is thus growing considerably faster, however the country still being dominated by the rural population (MoAI, 2012). The major cities and their population is shown in Table 4.7.4.

Table 4.7.1 Population growth (in millions)

Year	*Annual population growth*		
	1.1 %	*1.5 %*	*2.0 %*
2014	51.42	51.42	51.42
2020	65.26	67.35	68.69
2030	72.80	78.17	81.70
2050	90.60	105.28	115.59
2100	131.74	185.02	282.32

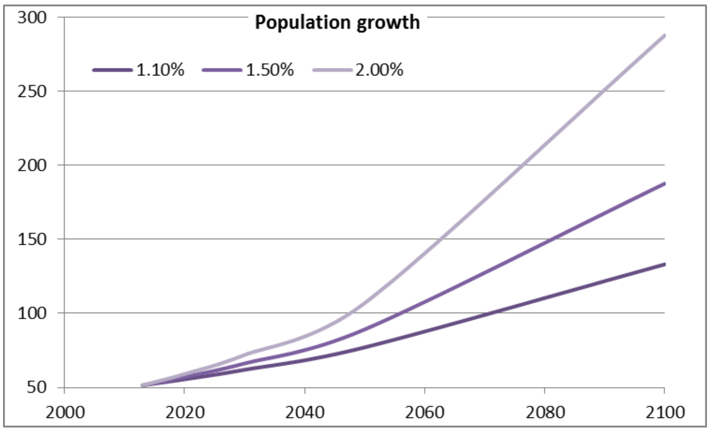


Figure 4.7.1 Expected population growth (in millions) in Myanmar for 3 different annual growth rates: 1.1, 1.5 and 2.0% -based on (ADB, 2009; CSO, 2011)

Source: Yangon (Sein, 2012), census: 2010; Source others: (CSO, 2011), census: 2011

The public water sector and industrial sector are separated in the model. The industrial water demand is constant over the year, where the public water sector has a higher water demand (from the network) during the dry season compared to the monsoon season. The public demand is schematised in nodes representing the people living a certain State/ Division. When the State/ Division is located in more than one basin, for each basin a node is added, with an estimated number of people based on the size of the region. The water demand for these nodes is calculated outside Ribasim, and has an explicit demand (m^3/s). For the demand of the cities, a unit demand is applied, where the population is an input parameter and the daily water consumption per capita. for the present situation, the *mean* daily water demand is used for the calculation, which is 45 litre/capita/day and 95 litre/capita/day for rural and urban respectively, see Table 4.7.3. The seasonal variation for the consumption is computed by assuming a larger demand during the dry season (x 1.25) and lower during the monsoon (x 0.75). Since then also rainwater harvesting is used for the daily consumption, and no demand from the network is required, see Figure 4.7.4.

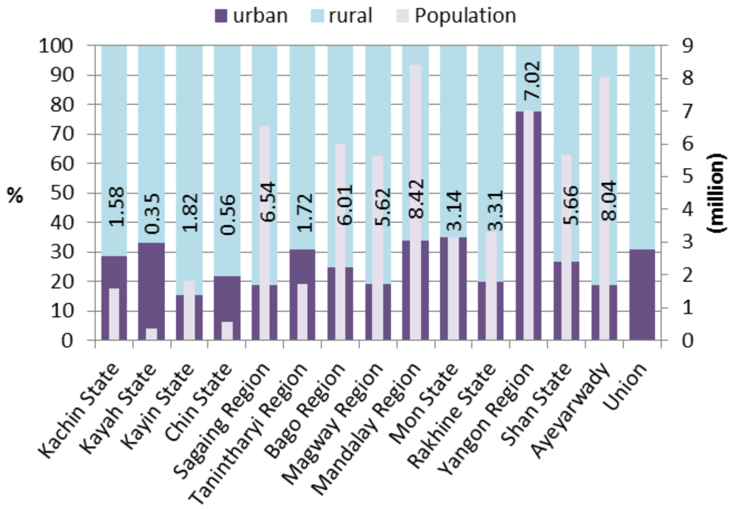


Figure 4.7.2 Urban & rural rate and total population (in million) per State / Division (2010) - Source: (CSO, 2011) - Department of Population – These numbers are used in the calculation of the public water demand – The recent census of 2014 is not used. Left vertical axis – ratio of urban and rural, right vertical axis the population in million

4.7.1. Rural population

The population living in the rural areas of Myanmar contributes to a large part of the share of the total community. In most developing countries rural economic growth is a critical precondition for overall economic growth and the products that will give economic yield are mainly natural resource-based goods (Tun Kyi, 2004). Those people are dependent of local and small farming and fishing activities for their livelihood. Most of those farmers have small to very small piece of land, smaller than 4 ha, of which half is irrigated and the other half is rain-fed. They often are tenants or sharecroppers, using irrigation water from the ID, MoAI. The rural poor are located in the greater ethnic minorities and in the central dry zone, and in the remote mountainous and hilly regions, where they really dependent on small, local resources. These communities are highly vulnerable to a change in the climate, lack of water availability or food pricing, sudden loss, and little possibilities for development and employment opportunities due to their financial condition.

The total population for the State/ Divisions as well as the major cities, are determined based on the estimated date from the (CSO, 2011) and extrapolated with the annual population growth rate found over the period 2000 to 2005.

4.7.2. Public water demand

Urban water supply, including for industrial use, is implemented by city development committees (CDC), notably in Yangon (YCDC) and Mandalay (MCDC). The total volume of water for domestic use is estimated to amount to 3.0 km3 /year and 1.5 km^3 /year for industrial use (Ti & Facon, 2004). For the city of Yangon, a daily water consumption of 95 l/day/capita for the demand. It assumed that this value is the averaged value for all urban areas in the country. For the rural demand, a much lower value of 45 l/s/capita is used in the assessment. This gives an average of 60 l/capita/day. In the future situation, a daily demand of 115 and 75 l/day/ capita is used for urban and rural respectively. During the dry season, an additional factor of 1.25 is applied for the public water demand for both urban and rural, and 0.75 during the rainy season, assuming that rain water is fetched by the people, and less water is demand from an external source.

4.7.3. Domestic water use

The minimal requirements for a person to fulfil his minimal daily requirements (drinking, human hygiene, sanitation, and most daily house hold needs), is 50 l/day (Gleick, 1996). In the poorest rural regions of the Ayeyarwady Division, the average water consumption is just about 28 l/capita/day, (ACF, 2008). Almost all domestic use in rural areas is from groundwater, mainly private bore holes and a pump, or domestic well (WFP, 2011).

Each year at the end of the dry season there are almost water shortages for regions with limited rainfall, capacity to get it supplied from a surface water reservoir and/ or the groundwater quality is insufficient due to a to high salinity level (Ayeyarwady and Sittaung Delta area). Villages will get their drinking water from trucks filled with water to make shure people have sufficient drinking water. Examples of last year's drought see the online news article from *Reliefweb* - May, 2013[4]. It is not clear what the scale of this water scarcity in Myanmar is: how many people are affected and the main reasons where that causes the water scarcity, like lack of infrastructure or regional water unavailability, poor water quality.

4.7.4. Industries and water consumption

The industrial activity and thus also the withdrawal of fresh water is very little in Myanmar, see Table 4.7.2. On a national scale the withdrawal by industrial will not have a great impact on the water balance, but locally it can be relevant, especially the water quality can have a big impact on the downstream users: pollution, water temperature, and other pollutants. It might end up in the drainage or outflow from these industrial installations. Large consuming industries such as sugar mills, paper mills and cement factories, normally depend on surface water, whereas most of the other industries rely on groundwater. Across the nation, groundwater supplies 22% of water, which is similar to that within the Dry Zone Division: 48.1 million m^3 / year for groundwater and 173.3 Mm^3 / year for surface water (McCartney et al., 2013). Bago River is the main fresh water resources for improvement of Thilawar industrial zone, a big industrial area below Yangon City (DWIR, 2013). Assumed is that the most significant industrial activities are located around 7 industrial regions have been schematised in the model, where the most important ones are around Mandalay and Yangon, see Figure 4.7.3. Myanmar has 18 different designated industrial zones, but some are really small and stil under development, see appendix O.

Table 4.7.2 Withdrawal of freshwater in the year 2000 - (FAO, 2010)

Sector	*Surface water (km^3)*	*Surface water (%)*
Industry	**0,22**	**1**

[4] *News article example – 17 May 2010 http://reliefweb.int/report/myanmar/myanmar-drinking-water-supplied-people-sagaing-mandalay-bago-yangon-and-ayeyawady*

Agriculture	27,98	89
Domestic	3,26	10
Total	28,60	100

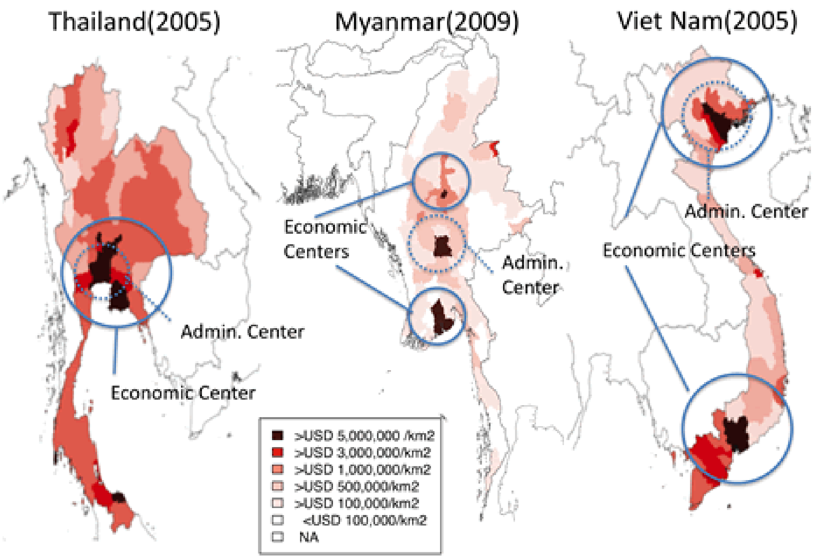


Figure 4.7.3 Economic important zones for Thailand, Viet Nam and Myanmar. The zones with the largest economic activity are assumed to be the regions with industrial activities, excluding NayPyiTaw, which is the administrative capital of Myanmar. - Source: (Kudo & Kumagai, 2013)

Table 4.7.3 Public consumption - liter/capita/ day – for minimum, average, and maxium scenario's

	min	*mean*	*max*
Rural	20	40	75
Urban	70	95	115

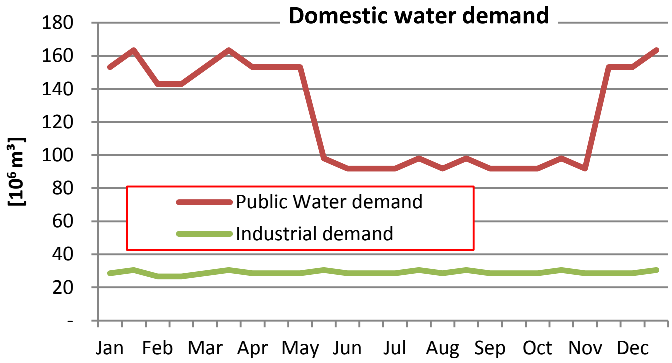


Figure 4.7.4 Public and industrial demand per season – present situation

Table 4.7.4 Major cities in Myanmar (located in the major river basins 2011), according to the statistical yearbook of 2011

City	*Population (2010)*	*Population (2014)*	*State/ Division*	*River Basin*
Yangon	5,110,000	5,442,563	Yangon Region	Myit Ma Hka, Bago
Mandalay	952,570	1,472,267	Mandalay Region	Ayeyarwady
Naypyidaw	924,608	1,117,782	Nay Pyi Taw	Sittaung
Mawlamyine	325,927	545,239	Mon State	Coast/ Salween
Pathein	241,624	280,888	Ayeyarwady Division	Ayeyarwady
Pyay	110,942	278,095	Bago Division	Ayeyarwady
Taunggyi	192,105	192,105	Shan State	Salween
Monywa	148,066	185,783	Mandalay Region	Ayeyarwady
Bago	175,922	185,047	Bago Division	Bago
Lashio	123,126	129,513	Shan State	Ayeyarwady
Myitkyina	62,936	66,201	Kachin State	Ayeyarwady

4.8. Energy demand and production

4.8.1. Demand for energy

Myanmar's per capita electricity consumption is the lowest among the ASEAN-10 countries, estimated at 100 kilowatt hours (KWh) in 2010 (approximately one-twentieth of that in Thailand), see Figure 4.8.2. The average annual GDP growth between years 2000 to 2005 was 5.5% in Bangladesh, 9.4% in China, 6.5% in India, 9.15% in Myanmar and 5.0% in Thailand (WRI 2009), explaining the rapid increase in energy demand in Myanmar and its neighbouring countries(Kattelus, 2009a). Data is sparse, but even the most optimistic estimate say that less than 25 percent of the country has access to electric power (Somani, 2013). Electricity consumption in Myanmar has doubled from 3,303 giga watt hours (GWh) in 2000, to 6,093 GWh in 2012(USEIA, 2013). The already low installed capacity of around 3500 megawatts (MW), only about 60 percent is reliably available. In Appendix O a more detailed description about the energy sector in Myanma is presented where the focus lies on the hydropower potential and development.

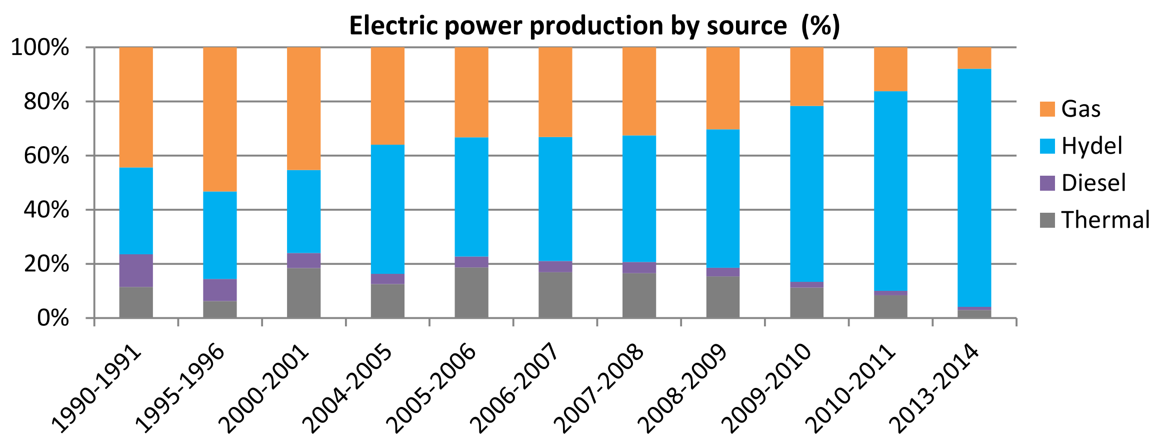


Figure 4.8.1 Electric Power Production by type, in percentage (%) – Source: (CSO, 2011)

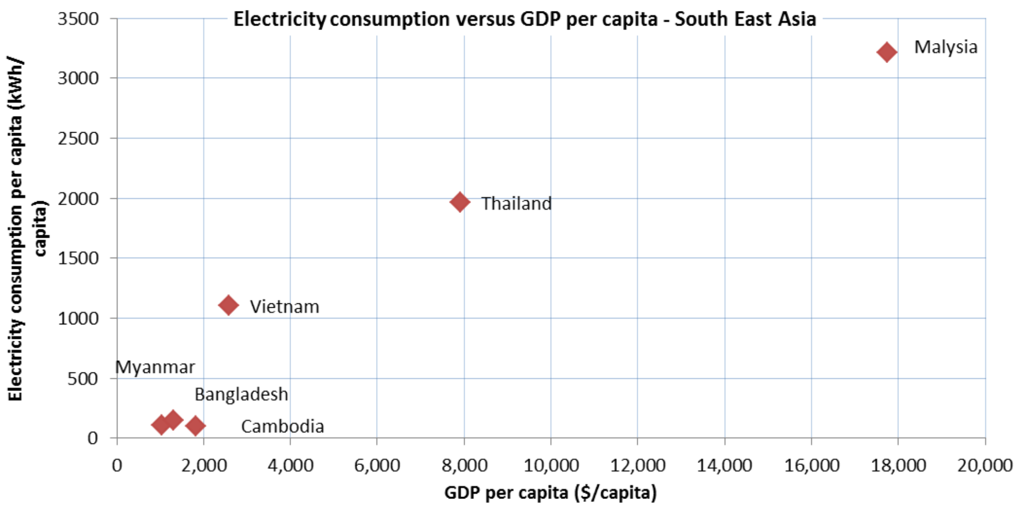


Figure 4.8.2 - Electric power consumption per capita (kWh) in SEA for 2012 and GDP per capita (2013) in South East Asia

4.8.2. Hydropower

According to different sources, there are at present 36 small to large hydropower stations located in Myanmar, Figure 4.8.3. The capacity ranges from 2 to 1050 MW, with an average of 129 MW. In Table 4.8.1 and the existing hydropower projects are given by river basin and by State / Division.

Table 4.8.1 Number existing hydropower projects by river basin

River basin	*Existing capacity (MW)*	*Number of projects (existing)*
Ayeyarwady	2,407	15
Salween	415	6
Bago	20	1
Sittaung	751	10
Other	0	
Total	3,603	32

Almost all hydropower stations present in Myanmar are constructed in a reservoir which also serves to supply irrigation water. The size of the dams and the power capacity are limited compared to large scale dams that are planned in the hilly regions, see Section 0. So far no hydropower project has been constructed in the main course of the major. In the upper part of the Ayeyarwady, some larger hydropower dams are already constructed in larger tributaries. Depending on the size of the reservoir, some of these stations can be considered as runoff- river stations due to the relative small reservoir compared to inflow during one time step in the simulation. For these the flow regime is not changed. For the multi-purpose reservoirs however, the main owner or operation rules are not known. E.g. the (lower) PaungLaung Dam in the Sittaung River basin has a big potential to generate energy (~280 MW) and also has a weir downstream which diverts the water to the irrigation areas (left and right) downstream. It is unknown which user has priority during the dry season. Since this station is one of the largest power production stations in the country, it is possible that power production has priority over the irrigation areas, or vice versa, since the irrigation areas are also rather big.

Table 4.8.2 Existing hydropower projects by State/ Division source: (Burma Library, 2012; DHPI, 2013)

State/ Division	*Existing Power capacity (MW)*
Shan State	1,015
Mon State	-
Sagaing Division	30
Mandalay Division	1,291
Ayeyarwady Division	5
Bago Division	411
Kayah State	144
Kachin State	380
Magway Division	149
Kayin State	168
Yangon Division	-
Other (Chin State, Rakhine State, Tanintharyi Division)	-
Total	**3,645**

Other important sources in the production of energy to the grid of Myanmar are Gas Turbine and coal. On local scale (rural areas) the use of animal dung and wood is the main source of energy for the daily supply. Also mini/ micro hydropower stations are increasingly more important in rural regions.

Table 4.8.3 Installed electricity production facilities. Total installed capacity per source

Installed capacity (MW)	*(ADB, 2012b)*	*(Burma Library, 2012; DHPI, 2013)*
Hydro	2,260	2792
Mini Hydro	33	33
Gas Turbine	550	768
Combine Cycle	120	120
Coal fired	120	120
Diesel	5	-
Wind, solar	-	-
Total	**3,087**	**3834**

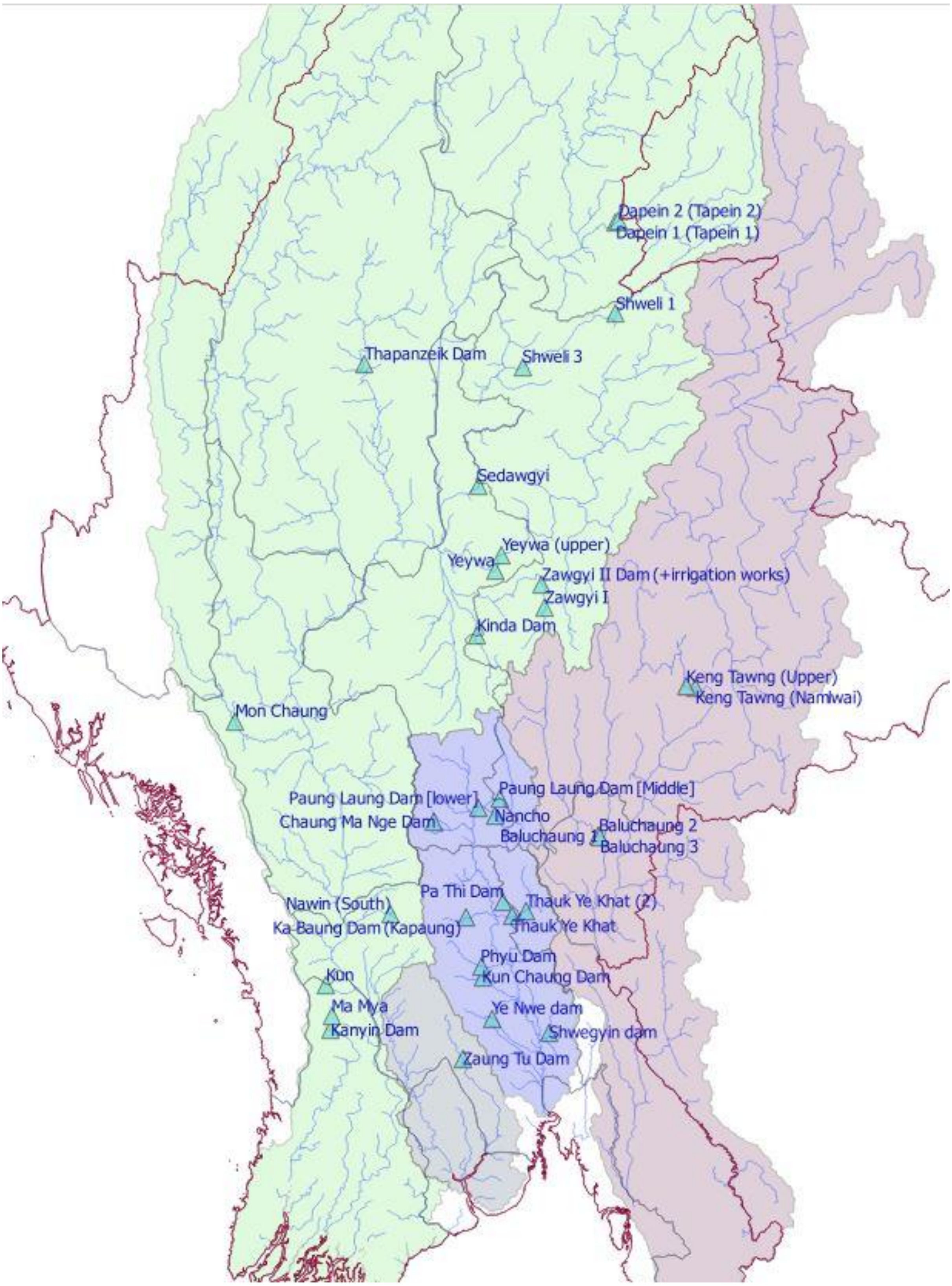


Figure 4.8.3 Existing hydropower stations in Myanmar (2014)

4.9. Other important stakeholders in the WRS

4.9.1. Navigation

Most of Myanmar Rivers and their tributaries are used for navigation and water. The most heavily used part of extensive waterways system is the Ayeyarwady River and its delta, (DWIR, 2013). The Ayeyewady and the Salween belong to the longest free flowing rivers in the world (>1,000 km), (WWF, 2006). As can be seen in Table 4.9.1 the Salween River is very limited due to many high differences and rapids

Table 4.9.1 Navigable length rivers in Myanmar (km)

Navigable Rivers in Myanmar	*Navigable Length (km)*	*Total length river (km)*
Ayeyarwady	1,534	1,200 (Confluence Mali Hka/ Mai Hka till Zalun
Chindwin	730	880 Confluence with Ayeyarwady till Tanai)
Ayeyarwady Delta	2,404	
Salween and Mon State Rivers	380	1,250 Chinese border till Gulf of Martaban
Rakhine State rivers	1,602	
Mekong (Myanmar territory)	265	
Total	6,915	

Figure 4.9.1 Free flowing rivers in Asia – source: (WWF, 2006)

4.9.2. Fisheries and aquaculture

Fishing is besides agricultural activity an important source of nutrition's, especially for the rural population in all (delta) regions of Myanmar. Approximately 75% of the rural population rely on agriculture, livestock and fisheries, (DeltaAlliance, 2014). It is also an important contributor to the nationals economy, 8.94% of Myanmar's GDP in 2005, compared to 54.6% for agriculture (est. 2005). In 2004, almost 800,000 people were involved in the primary fishing sector, and 2.5 million in the secondary sector, (FAO, 2006). In 2003 the production of fish was 1,397,439 tons (for human consumption) 252,208 tons (for animal feed and other purposes) = 1,649,647 tons. As a reference about the fish production in the Mekong River Basin is 1,162,350 tons, see (Ringles, 2001)

Table 4.9.2 Fish and aquaculture areas (ha) in Myanmar – source: (CSO, 2011)

2011 – 2012	*Area (ha)*	*1000 viss[5]*	*Multiplying factor from viss to tons*	*Tons (kg)*
Area of fish and prawn ponds (ha)	181,327			
Production		499,897	1.63293	816,296

There are two main threats for the fishing sector related to the water resources

Dams

Unnatural changes in the flow regime of a river will result in: riverbank destruction due to increased erosion; altered flood cycles and disruption to the replenishment of wetlands, floodplains and delta ecosystems. This results in a decline of fisheries and aquatic plants dependent on these nutrients rich ecosystems. In addition, water quality will be reduced resulting in a decline of fish species and knock on impacts to the abundance and diversity of bird populations within the basin.

Water quality

Due to salinisation of the waters due to climate change or a changed flow regime due to the dams upstream, the salinity level increases which affect the habitat of the fishes and shrimps. Also the use of fertilizer, waste water dumping in the river, may cause negative effect on the water quality in the river.

There is no data collected about the different locations of the fisheries in Myanmar. It is assumed that most of the fishing activities take place in the delta region of the Ayeyarwady, since this delta area is large compared to the Sittaung, Bago and Salween basin. During the field trip in the southern part of the Sittaung, flood plains were observed which are important for fishing activities during the monsoon season.

[5] *Burmese unit – traditionally known in old English - 'peittha' – 1,63293 kg*

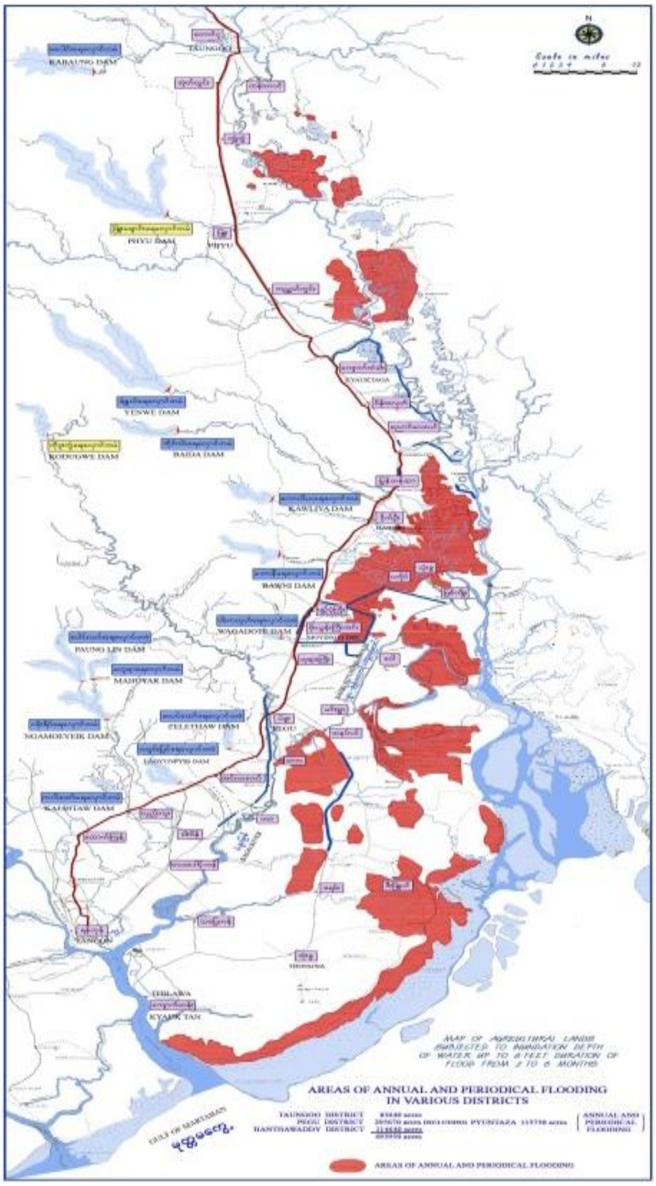


Figure 4.9.2 Areas with are regularly flooded during the monsoon season in the lower Bago and Sittaung Basin (Red)

4.9.3. Environment

Much of Myanmar's natural habitats and ecosystems still exist due to the country's slow rate of economic development. A recent report highlights that approximately 40% of the remaining forests in all of South-East Asia are presence within Myanmar, which 50% of its land covered by forests. The Ayeyarwady River basin is rich in biodiversity. Over 50% of basin area is forest and about 6% is wetlands (Kattelus, M et al., 2013; Sovacool, 2012).

The term 'Environmental Flow Requirement' (EFR) will be used to describe the requirements to maintain a 'good' or 'desired' state of the environment. In conclusion, the EFR, refers to a (minimum) quantity of flow, the quality of the water and temporal variation over the seasons in a river reach or a connected area. The change in flow regime can thus be used as an indicator for the environmental flow in the water demand and allocation simulation. A basic assumption in the integration of EFR in the water allocation model is that every change in the flow regime will have effect on the ecosystem. The question is how much alteration is accepted, or how much reduction in yield is accepted to restore the ecosystem. These are societal and thus political choices.

The objective of Myanmar's environmental policy issued in 1994 is ".. the integration of environmental considerations into the development process to enhance the quality of life of all its citizens… it is the responsibility of the State and every citizen to preserve its natural resources in the interest of present and future generations. Environmental protection should always be the primary objective in seeking development". Environmental sustainability refers to the maintenance of the ecosystem and the natural resource base. Environmental degradation signifies three forms: depletion of resources, pollution, or overuse of the waste absorbing capacity of the environment, and reduction in biodiversity, a loss of some types of resources (M.O.F., 2009).

Note

A more detailed explained and discussion about the environmental flow conditions can be found in Appendix O - System Description. But for now, no indicators have been analysed for this stakeholder in the assessment since no data on the environmental conditions/ boundary conditions are known.

The importance of including the environment in the model is to assess the impact on the flow regime, which is an indicator for a well-balanced and untouched river ecology. Also in the delta area, where salt intrusion from the ocean, can damage ecosystems and ecosystem services, such as aquaculture farms. The low flow during the month of March, is the most vulnerable time in the year for the salt water to move in. The river flow than has less energy to push back the salty water.

Figure 4.9.3 MoYinGyi wetland area and floodplain used by local fisherman during the monsoon season – Sittaung River Basin – Rens Hasman

Water Resources System in Myanmar – Present Situation

Part 2 - River Basins Water Resources

In part 2 of chapter 4 describes the present day situation for the water resources system (WRS) in the major river basins in Myanmar, which are the Ayeyarwady, Salween, Sittaung, Bago and Myit Ma Hka River basins, see for an overview map Figure 4.3.1. In the next sections the water availability and basin description is explained for each major river basin in Myanmar. A comparison is made between the simulated and monitored inflow into the basins, or available literature. The most important sectors and their status within the basin are mentioned. For the Ayeyarwady River basin two sections are include, of which one is about the whole basin, and one about the Case Study area, which is located in the lower Central Dry Zone. With this case study, a more in depth analysis is done to better understand the importance of the input parameters and the functionality of the model.

ZaungTu Weir irrigation infrastructure (Bago – Sittaung Basin) – photo: Rens Hasman

4.10. Other river basins in Myanmar

The catchments area of Myanmar's eight principle river basins comprises about 737,800 km² and the average annual inflow of water is 1,081.89 km³, (Mying, 2008) . The annual inflow from other countries is about 128.186 km³: with 20 km³ (15.6%) coming from India, 68.74 (53.7%) km³ (Nu to Salween) and 31.3 km³ (2.4% - rivers in west Yunan Province) from China, and 8.156 km³ (6.4%) from Thailand. The Mekong River flows approximately 170 km along the border with Lao People's Democratic Republic on Myanmar Territory. The source of the river is in China, the total annual flow is 73.63 km³, half of which or 36.815 km³ can theoretically be considered as an additional external resource. The total natural renewable water resources (including flow from incoming or border rivers) are therefore an estimated 1,167.8 km³/year, (FAO, 2010).

Table 4.10.1 Available water resources in other river basins than the major river basins, based on (FAO, 2010)

River/rivulet	*Volume of inflow (km³/year)*	*Catchment area (km²)*
Bilin river and tributaries	31.17	8,400
Rivers/rivulets in Rakhine State	139.25	58,300
Rivers/rivulets in Taninthary Division	130.93	40,600
Mekong river (within Myanmar territory)	17.63	28,600
Total	318.98	135,900

4.10.1. Mekong River

As a reference of the volumes in the river basins of the largest rivers in Myanmar a brief comparisaon is made with the Mekong River, a well known river in Southeast Asia. The annual average flow in the Mekong between 1960 – 2050 the flow at Stung Treng, Cambodia, is 414 km³ , - Figure 4.10.1 - (MekongRiver, 2014), and 475 km³ at the mouth of the river into the South China Sea. (Botkosal, 2009). The Mekong River has an catchment area of 795.000 km², (FAO, 2010), compared to 413,710 km² for the Ayeyarwady River. The yearly average discharge of the Mekong is 13,100 m³/s at Stung Treng (90% of total), 16,000 m³/s at the mouth (Wiki, 2014), compared to 12,000 m³/s at Pyay (~85% of total) and 13,000 m³/s at the mouth. For the Salween River, the average river discharge is 11,085 m³/s with a corresponding catchment of 324,000 km², see . (Wiki, discharge time series received from the Department of Meteorology and Hydrology – DMH, MoT).

Table 4.10.2 Comparison of river discharges from the Ayeyarwady, Salween and Mekong River.

	Average river discharge (m³/s)	*Catchment area (km²)*
Mekong River		
Stung Treng	13,000	
River mouth	16,000	795,000
Ayeyarwady River		
Pyay	12,000	
River mouth	13,000	412,650
Salween		

River mouth	11,085	324,000

Figure 4.10.1 The lower Mekong River Basin

4.11. **Water Resources - Salween River Basin**

In the literature the Salween River is often called Thanlwin River and named Nu River in China. The source of the river is in the Tibetan Plateau and has its course for 1,000 km through Chinese territory.. The Salween River is the longest free-running river in mainland Southeast Asia, with a total length of 2800 km and the river basin has a total area of 324.000 km^2 of which 134400 km^2 is within the Myanmar borders. The remoteness and lack of infrastructure has resulted in the Salween River being the only major river in the region that still runs freely ("Damming the Salween River," 2009; Magee & Kelley, 2009). The river originates on the Tibetan Plateau in the Himalayas and runs south through Yunnan Province of China. After entering Burma, the Salween River flows through the Shan, Karenni, Karen, and Mon States in the eastern part of the country before reaching the Andaman Sea. s catchment for 53%in China, 5% in Thailand and 42% in Myanmar. The yearly average flow over the period 1966 and 2010 is 5204 m^3/s, obtained by data received from DMH, MoT. The average simulated flow is 8343 m^3/s over the period 1998 – 2009; 5454 m^3/s for the monitored flow. The forests of the lower Salween basin form an expanse of deciduous forests with large stands of teak, (WWF, 2006).

More than 10 million people, representing at least 13 different ethnic groups, depend on the Salween river basin for their livelihoods: fisheries are a major source of dietary protein, and the river's nutrients nourish vegetable gardens in the dry season and fertilize farmland (Wolf A.T. & Netwon J.T., 2007).

In Figure 6.8.7 the total yearly available runoff available as fresh water resource shows the difference in the monitored and simulated situation. The yearly average available water is presented in Table 3.6. The variation of volumes fresh water between the different sources is large. In the literature it is not explained how they came to these values. According information about the Salween basin by FAO, AquaStat (2011) The total area equipped for irrigation in the Salween river basin is estimated to be around 400,000 ha, of which Myanmar accounts for approximately 5%, China 42%and Thailand 8%. The area actually irrigated is estimated at 380,000 ha (FAO, 2010). The irrigation area according to the received data of ID, MoAI is 51,145 ha. The equipped area irrigated by surface water and groundwater account for 97% and 3%respectively. The development of irrigated agricultural land is very low, especially compared to the amount of land developed in the other river basins. The demand of the irrigation fields is still the largest consumer of water in the basin, but only accounts for 0.34% of the total yearly inflow, see .

Table 4.11.1 Cumulative inflow into the Salween River Basin and cumulative demand of the irrigation areas

Salween River Basin	*Cumulative inflow (km³)*	*Cumulative demand (km³)*	*Demand during dry season (km³)*	*Demand of total (%)*
Actual_Case 2	265,394.45	908.06	744.55	0.34

Table 4.11.2 Annual average available water resources – Salween River basin

Source	*Annual average water resources (km³)*			
(Author, year) - Description of resources	Years	Salween (Myanmar territory)	Salween (China territory)	Salween
Than Zaw (2009), adopted from (Thet, 2012) – (2)	1980 - 1993	107.7	24.40*	132.2*
FAO, AquaStat (2011) – (3)	Unknown	141.3	68.74.	210.0
DMH (from average flow)	1998 - 2010	-	-	172.0
Salween (simulated)	1998 – 2009	216.4	49.00	265.4
Share (%)		81.5	18.5	100

* - these values are computed by looking at the ratio china/ Myanmar territory for the simulated data. 2) annual average water resources potential; 3) volume of inflow

The yearly averaged flow at Hpa-An of the Salween is 11,058 km³/s, which an average low of just under 2000 km³/s. the variation in the inflow is large at the end of the monsoon season.

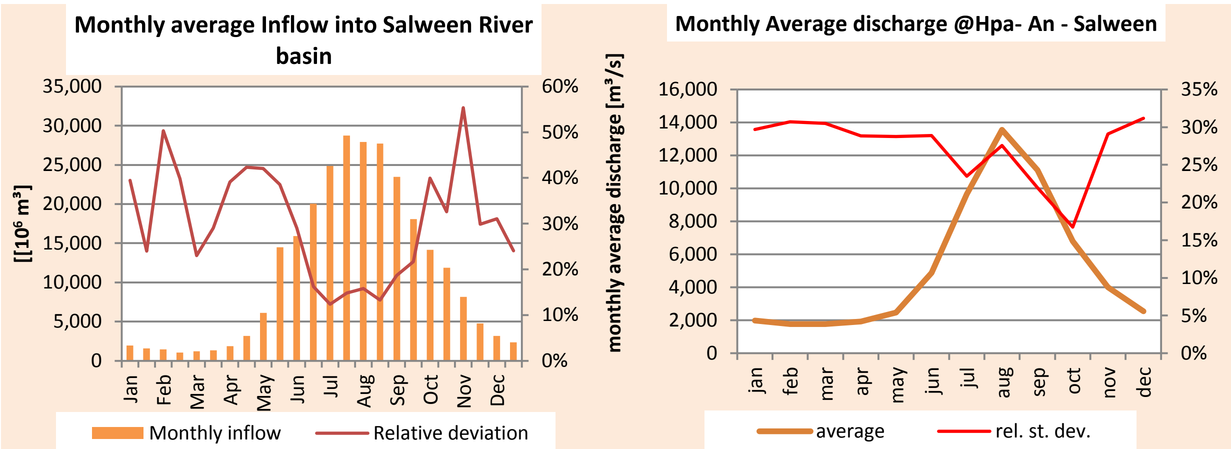


Figure 3.11 Average inflow into Salween River Basin (runoff Variable inflow nodes) – The red line is the relative standard deviation per time step (%)

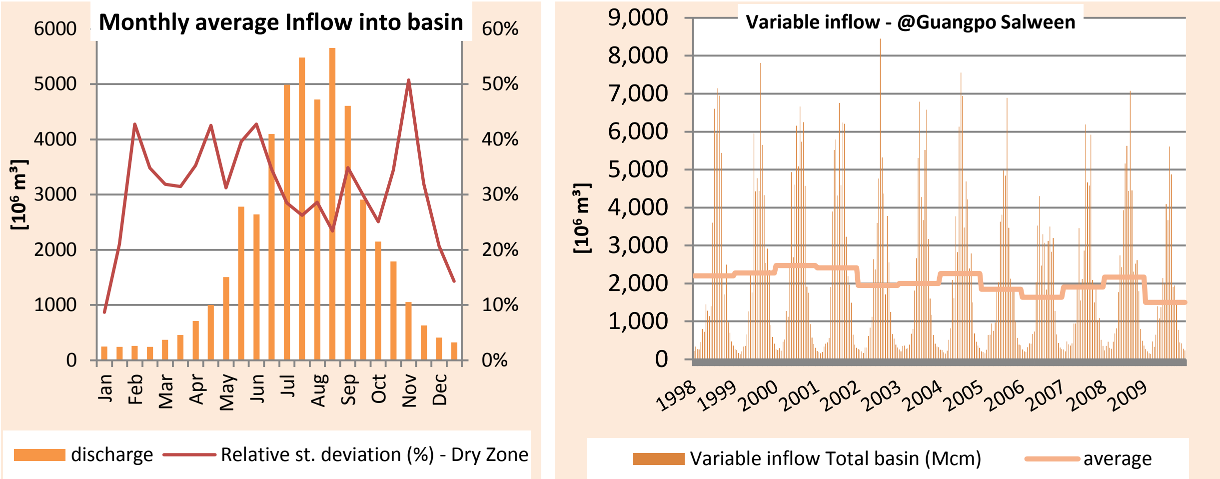


Figure 4.11.1 Monthly average inflow into the Salween River at the Chinese border (at Guangpo) and the yearly variation over the simulation period 1998-2009

The inflow from the Nu River (Salween River on Chinese territory) has still a natural variation, as can be seen in Figure 4.11.1. When the planned hydropower stations (see Section 0) are constructed, the flow will differ. The base flow is likely to increase, as well as the reduction of the peak flows during monsoon season. Also the deviation at the end of the monsoon season is large. This indicates the offset of the monsoon varies larger than the onset.

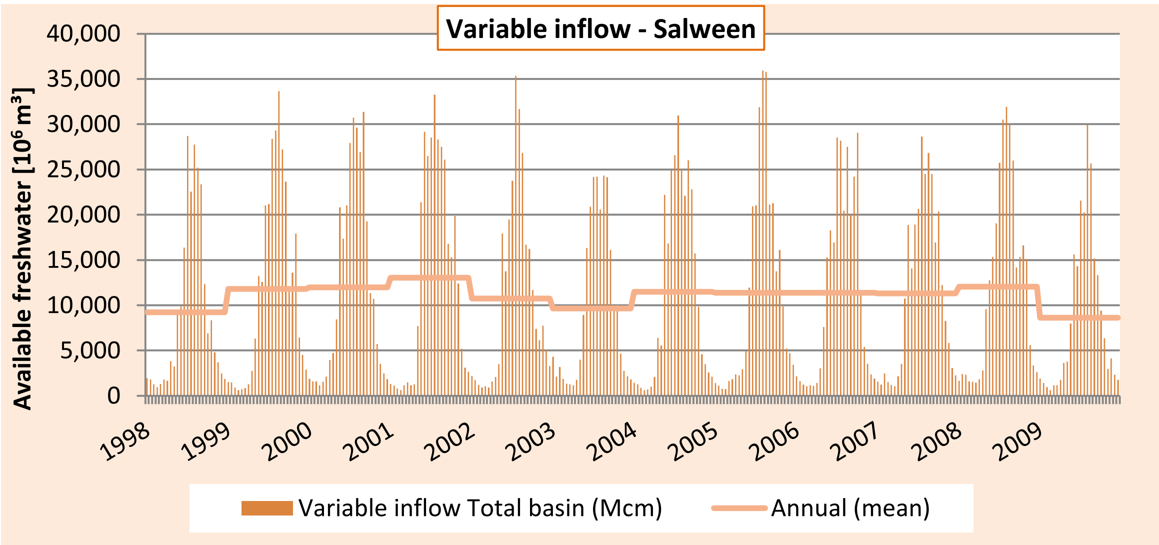


Figure 3.12 Variable inflow into Salween River Basin for simulation period 1998 to 2009 (runoff Variable inflow nodes) – the horizontal line indicates the yearly averaged flow

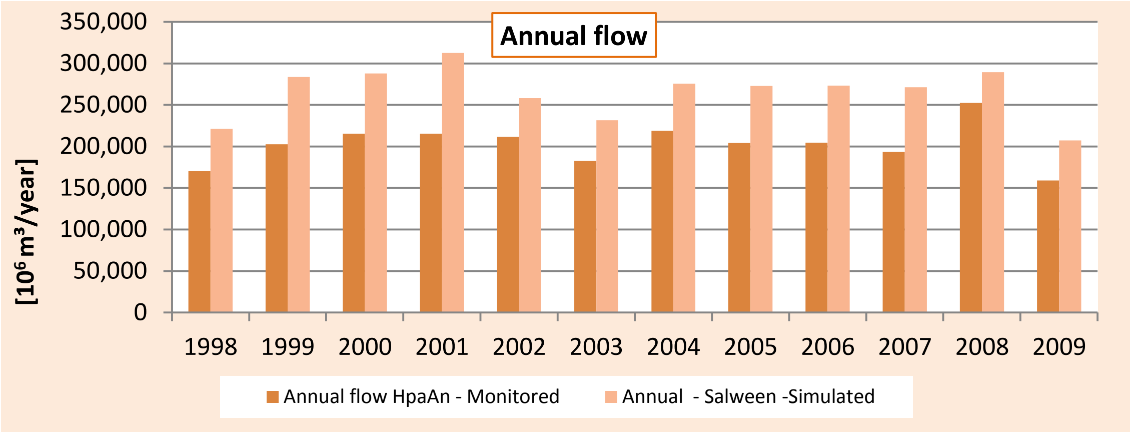


Figure 3.13 Annual flow in the Salween River basin – Monitored vs Simulate –

For the monitored flow downstream of Hpa-an is completed with time series of the simulated runoff from the variable inflow NodeID60, which represents the runoff from a catchment with an surface area of 8,279 km². Without this additional runoff the annual flows of the monitored series are just under the simulated flow. Now the annual simulated and monitored flows are very much alike. The simulated available volume of water per year in the Salween river basin is assumed to be a perfect match. The distribution over the seasons however, has not been calibrated yet with the WFlow model.

Figure 4.11.2 Watershed of the lower Salween River Basin (Myanmar territory)

4.11.1. Hydropower

A series of 17 dams on the Salween (Nu) River in Burma and China will force the resettlement of numerous ethnic minority communities, Figure 3.18. The dams are being developed by companies from Thailand, China and Burma. The pursuit by the Chinese of Myanmar's natural resources has become all the more important to China as its rapid industrialization and urbanization require an increasing amount of energy and raw materials. In particular, as China is now one of the world's top energy consumers[6]. The energy consumption per capita is the highest in the region: 3,298 kWh/ capita and increasing fast. This fast increasing of the energy demand in China and the unexploited, highly potential for hydropower development in the mountainous areas, results in a large number of proposed on the Salween/ Nu river. In Table 3.10 all dams in the Nu River are presented. It all are large scale dams which are likely to have a big impact on the flow conditions. An overview of all hydropower projects including the salient data in the Salween see Appendix T – the overview table of the surface water reservoirs.

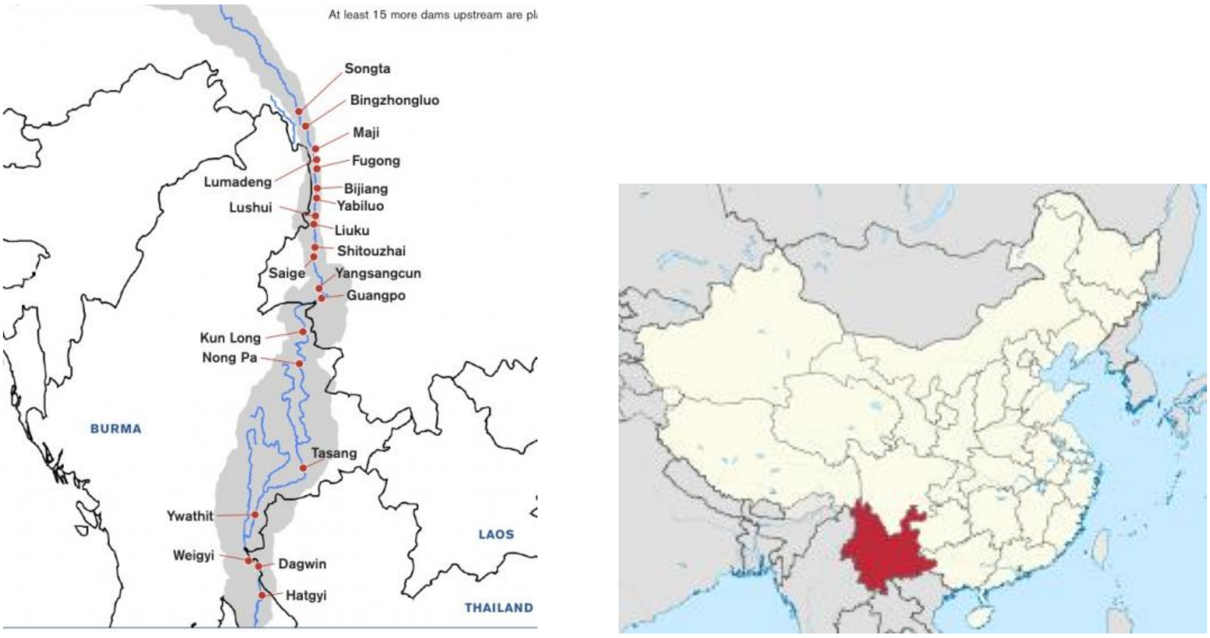


Figure 4.11.3 (left) Proposed dams on the mainstream of the Salween/ Nu River – (Right) - Yunnan State, PR of China

There are a lot of public discussions and protests concerning the transparency and public involvement for these dam development projects. A lot of NGO's and expert question the assessments done and are afraid that a lot people will be forced to move and that the environmental impacts are poorly assessed. It is therefore not known what the status of the of dam projects and if they are going to be build or not. For example the Weigyi dam would be a dam with a large inundation area was found in older documents, but no recent articles were found. It is also not included in the data list received by DHPI, MoE during the data collection project in 2013. It is questioned whether this dam will be build or not. In the model all dams mentioned in older and recent articles are included. The produced energy by the dams in the Salween will benefit the regions

[6] From *http://www.nationmaster.com/cat/ene-energy*

of Yunnan (P.R. of China - Figure 3.21) and Thailand. Yunnan is one of the major production bases of copper, lead, zinc, tin and aluminium in China. The electricity industry is another important economic pillar of Yunnan, which plays a key role in the "West-East Electricity Transmission Project", (Wiki, 2014).

Table 3.10 Planned Dams on the Nu River – (Salween River on Chinese territory)

Dam name	*Height (m)*	*Capacity (MW)*	*Status**
Songta	307	4,200	Active site preparation
Bingzohngluo	55	1,600	Planned
Maji	300	1,600	Active site preparation
Lumadeng	165	2,000	Site preparation halted
Fugong	118	400	Planned
Bijiang	118	1,500	Planned
Yabiluo	133	1,800	Site preparation halted
Lushui	175	2,400	Planned
Liuku	36	180	Site preparation halted
Shitouzai	59	440	Planned
Saige	79	1,000	Site preparation halted
Yansangshu	84	1,000	Planned
Guangpo	58	600	Planned
Total in China		21,320	

* - International Rivers, China Global Dam Database – Accessed by (InternationalRivers, 2012) May 2012

4.12. **Sittaung, Bago and Myit Ma Hka River Basin**

In the coastal area of Myanmar there are a lot of agricultural and industrial activities present. The Sittaung river has a length of 420 km and a catchment area of 48100 km^2, which is about 7,5% of the total catchment areas of major river basin in Myanmar. Around 6 million people are living in the Sittaung River basin, which around 10% of Myanmar's total. In the Ribasim software, the three rivers are combined into one model, since at the boundaries and/or confluences of the rivers, water resources users are located which benefit from both systems. For the boundary between the Sittaung and Bago River, the Moyingyi Wetland area and agricultural land is located. This fresh water lake receives also its water from a reservoir (Wagadok Reservoir) in the Bago River basin. The two are also connected via the Zaungtu Weir and the Bago- Sittaung canal, which plays an important role in flood control and regional irrigation water supply. The confluence of Bago and Myit Ma Hka Rivers, is at the city of Yangon. The fresh water supply for public water consumption is relying on these two sources. In APPENDIX it is explained that in the future this will be more dominant. The interaction between the Ayeyarwady Basin and the Myit Ma Hka River is an unknown in this study. In this analysis it is assumed that these systems are independent of each other, but which is most likely not the case in reality. In the extreme northern most part of the basin, average annual rainfall is 889mm while in the south, rainfall range from about 2540 mm to 3810 mm. Average annual rainfall of the whole basin is about 2540 mm, (Mying, 2008). Most of the irrigation projects in the Sittaung Basin (29/ 32), surface water reservoir, weirs and irrigation areas, are constructed after the year 2000. In the region around Yangon there are a lot of cultivation areas which are supplied with fresh water from different sources. Yangon city, with a population of around 5,5 million and industrial activities, is located close to the coast and is an important region for Myanmar's economy. (See also Appendix O). The Sittaung River basin is home to many irrigation projects with surface water reservoirs and other irrigation supporting structures like weirs and pumps. The ground water potential of the basin is estimated to be 28.4 km3, (Mying, 2008), which is around 35% of the available freshwater potential.

Table 3.7 Annual average available (surface) water resources – Sittaung

Source	*Annual average water resources – (km^3/year)*				
(Author, year) - Description of resources (s) - simulated	Years	Bago	Sittaung	Myit Ma Hka	Total
Than Zaw (2009), adopted from (Thet, 2012) (2)	1980 - 1993	-	52.75	-	
FAO, AquaStat (2011) (3)		8.02	41.96	-	49.98
Naing (2005)			81.15		
(Mying, 2008)			81.15		
Sittaung, Bago & Myit Ma Hka (s)	**1998 to 2009**	**5.00**	**44.49**	**20.46**	**62**

* - these values are computed by looking at the ratio china/ Myanmar territory for the simulated data. 2) annual average water resources potential; 3) volume of inflow

During the monsoon season the agricultural land turns into a swamp were fishing turns to be the most important activity. A total of 72 996 hectares is irrigated paddy (9%) in the Sittaung basin, 714 614 hectares (91%) is monsoon – rain fed, which gives a total 787 609 hectare of paddy fields. This is equal to 9,8 % of the paddy fields of Myanmar, the production in the Sittaung basin as a percentage of the total of Myanmar is 10,6 % (Mying, 2008).

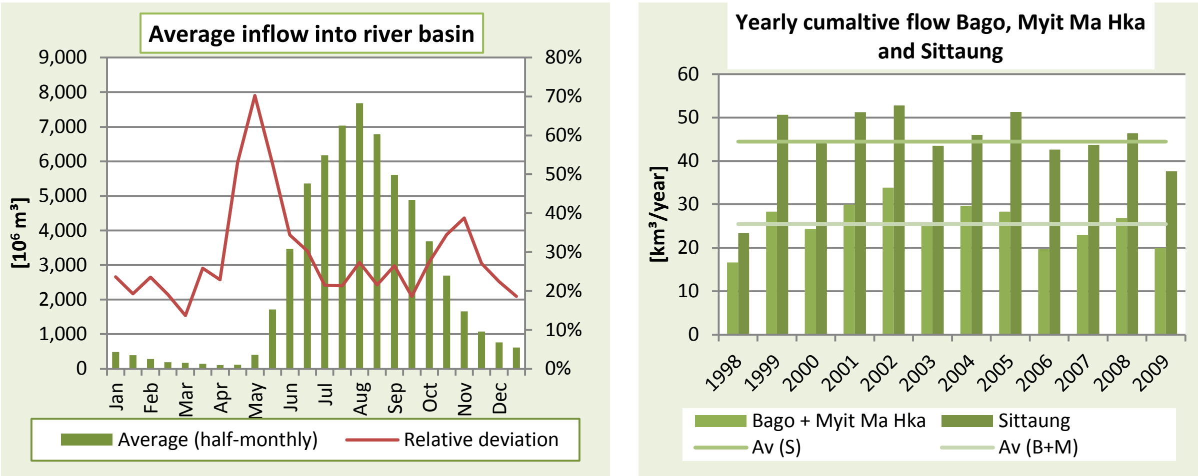


Figure 4.12.1 (left) Average inflow into Sittaung, Bago and Myit Mha Hka River Basin (runoff Variable inflow nodes) – The red line is the relative standard deviation per time step (%) – (Right) Simulated yearly flow at the river mouths (all users at non-active)

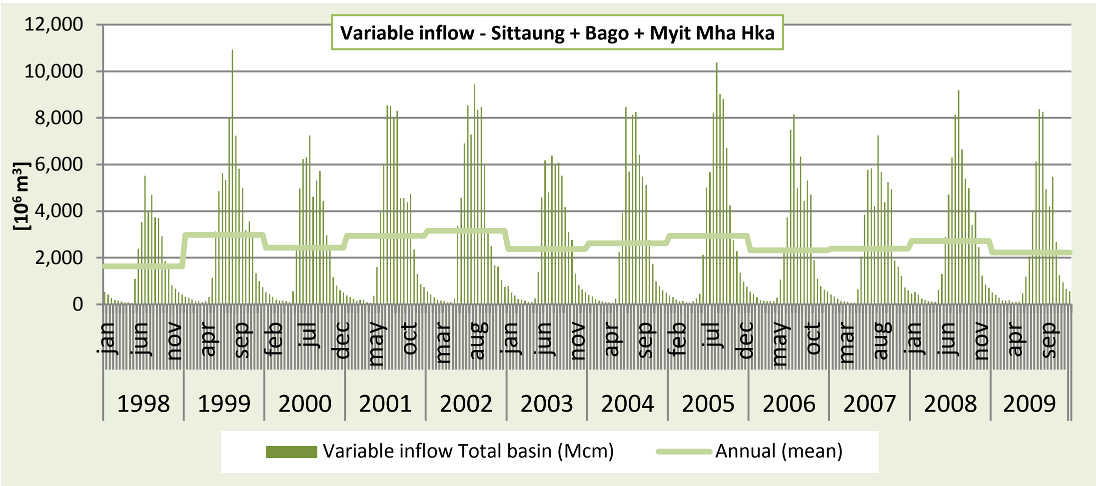


Figure 3.17 Variable inflow into Sittaung, Bago and Myit Mha Hka River Basin for simulation period 1998 to 2009 (runoff Variable inflow nodes) – the horizontal line indicates the yearly averaged flow

4.12.1. Importance of the Sittaung River

- Transportation of goods (food products and timber)
- Surface water reservoirs and pump irrigation from the river for development of the agricultural productivity by irrigation practices
- Generating hydropower at the dams

Table 4.12.1 Cumulative inflow into the Sittaung, Bago and myit Ma HkaRiver Basin and cumulative demand of the irrigation areas in

Sittaung, Bago and Myit Ma Hka River Basin	*Cumulative inflow*	*Cumulative demand*	*Demand during dry season*	*Demand of total (%)*
Actual_Case 2	61,502.59	2,754.90	2511.39	4.48

For the Sittaung, Bago and Myit Ma Hka River Basin, on average, the demand in the dry season is approximately 92% of the total annual demand, where the inflow into the basin during this season is only 7.7% of the annual inflow, see Table 4.2.2. The remaining 92.7% enters the system in during the monsoon season. The cumulative demand of the irrigation fields account for 4.48% of the total available water in the basin.

Figure 4.12.2 Sittaung, Bago and Myit Ma Hka River Basins – In blue: Rivers; in Green: major cities.

4.13. **Water Resources - Ayeyarwady River Basin**

The 2170 km long Ayeyarwady River has an catchment area of 413,710 km² which is 55% of the countries area. Headwaters of the river are Nmai (H'ka) and Mali (H'ka) rivers that join about 50 km north of Myitkyinā.. The town of Bhamo, about 240 km south of the Mali and N'Mai river confluence, is the northernmost city reachable by boat all the year round although during the monsoons most of the river cannot be used by boats. The city of Myitkyina however lies 50 km south of the confluence and can be reached during the dry season. Limit for year round navigation is Bhamo, situated 240 km south from headwaters confluence point. The headwaters of both rivers originate in the south-eastern Himalayas, Figure 3.3. Downstream, the river empties into the Andaman Sea through a nine-armed delta. The delta of the river begins about 93 km north from Hinthada and is boarded by Pegu (Bago) and Arakan mountains.

The available water resources for the Ayeyarwady River basin and the basins characteristics in the present situation are described in this section. In most literature the river basin is cut into three regions: Chindwin River, Upper Ayeyarwady and Lower Ayeyarwady. For this research when talking about the Ayeyarwady River Basin, there is referred to all these separate regions together. To say something about the distribution of the water resources available in the river basin, the distribution between the separate regions are used. The lowest discharge is observed in March where salinity problems might occur if the salty water is inland for a long period of time. The vulnerability of the Ayeyarwady Delta is high according to (NAPA, 2012) since 30% of the total rice production of Myanmar, is in the Ayeyarwady Region. Very limited irrigation work present here. Increase of salinity intrusion in the coastal areas is making existing water supply sources (domestic and agricultural) and freshwater ecosystem vulnerable. Also the urban and industrial development in and around Yangon will put extra pressure on water availability. The local existence of arsenic contamination of the ground water often hampers the use of shallow tube wells (around 30 m depth), (DeltaAlliance, 2014).

Table 4.13.1 Annual average available water resources, simulated and from in literature – Ayeyarwady. The first row has the unit of annual average water resources potential; the second row the volume of inflow; the simulated series is the total yearly inflow in the river basin.

Source	*Annual average water resources (km³)*				
(Author, year) - (s) - simulated	Years	Chindwin	Upper Ayeyarwady	Lower Ayeyarwady	**Ayeyarwady**
Than Zaw (2009), adopted from (Thet, 2012)	1980 - 1993	107.7	172.0	229.9	**509.6**
(FAO, 2010)		141.3	227.9	85.8	**455.0**
Ayeyarwady (s)	1998 to 2009	-	-	-	**412.24**

For According to, the annual average water resources for the Ayeyarwady River Basin, is 107,720 10^6 m^3 (Chindwin River), 171,969 10^6 m^3 (Upper Ayeyarwady), 229,873 10^6 m^3 (Lower Ayeyarwady) which summed up, gives a total of 509,562 10^6 – or 510 km³. The transition between Upper and Lower Ayeyarwady is at the confluence with the Chindwin.

As can be seen from the difference in the monitored and simulated flow for the Ayeyarwady River, there is a little variation between the two. The simulated flow is on average 7% higher than the monitored flow. The base flow of the simulated series is lower than the monitored ones; the peak in the simulated flow occurs approximately one month earlier than the monitored flow. The fall of the peak flow at the end of the monsoon season is more or less the same for the monitored and simulated flows. On average there is a larger river discharge in the simulated series, which might indicate to an overestimating of the water availability in the basin simulation. The seasonal variations over the simulated period of the simulated inflow into the sub catchments is the largest for the dry season, and lower for the monsoon season. This variation on full basin scale looks different for regions across the basin. The variation of the southern part of the Dry Zone is shown in the next section for the Case Area.

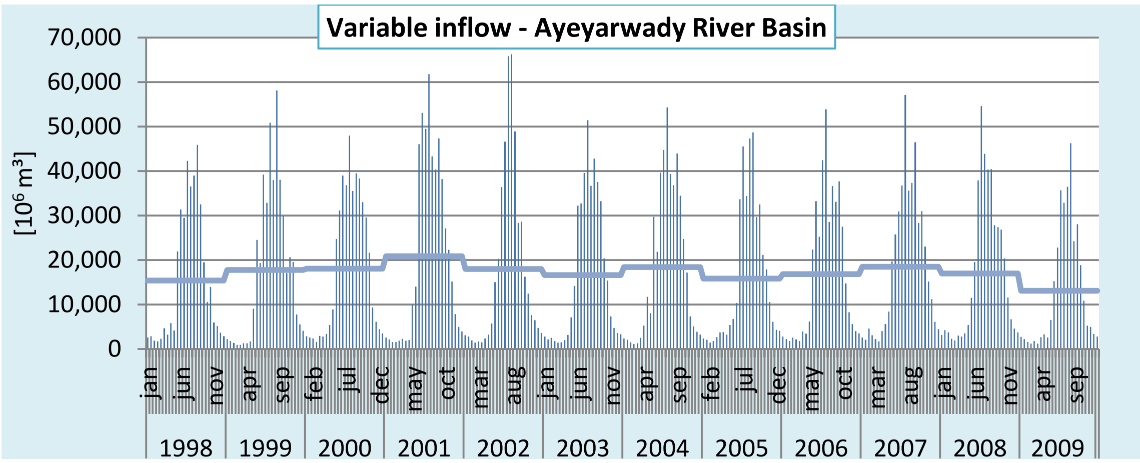


Figure 4.13.1 Variable inflow into Ayeyarwady River Basin for simulation period 1998 to 2009 (runoff variable inflow nodes) – the horizontal line indicates the yearly averaged flow

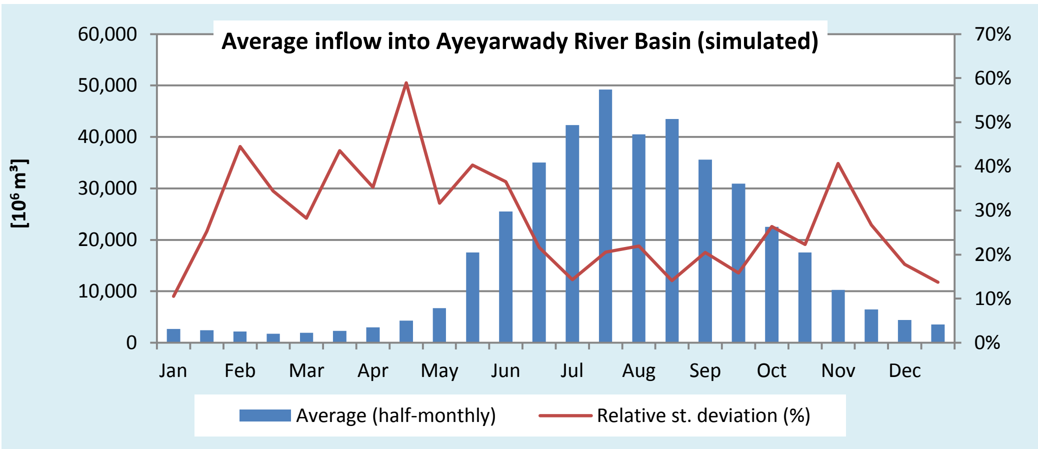


Figure 4.13.2 Average inflow into Ayeyarwady River Basin (runoff Variable inflow nodes) – The red line is the relative standard deviation per time step (%)

The water availability is thus affected by this variation of seasonal differences. A 20% variation of inflow in the rainy season is large, especially when the water demand is increasing for the development of the stakeholders in the WRS.

The season variation for the inflow in the most northern part of the Ayeyarwady, up till the confluence of the May Hka and Mali Hka Rivers, is large for the dry season, see Figure 4.13.3. This has an impact on the available variation of the hydropower projects at the reservoirs/ run-off stations. Since the base flow is low, the power production during the dry season large depends on the storage capacity of the reservoir, or firm demand by the user.

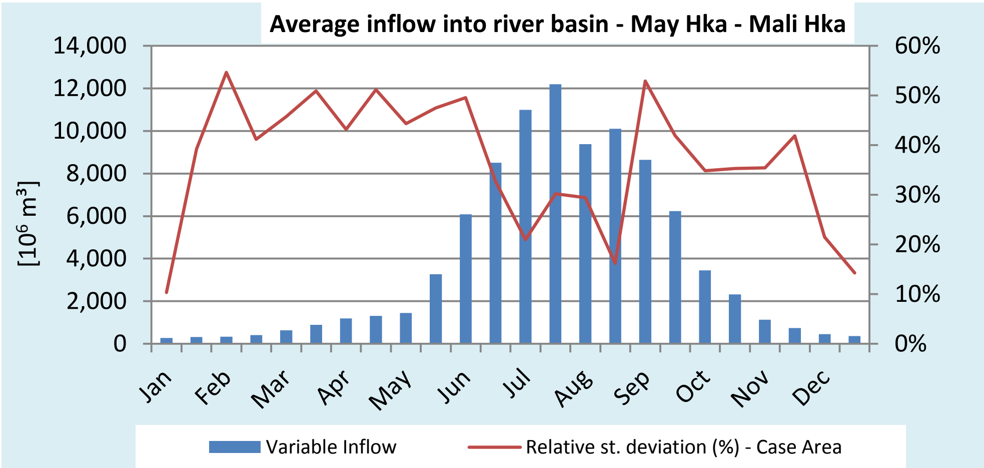


Figure 4.13.3 Average inflow into May Hka + Mali Hka Rivers (upstream of Myitkyina) and into the Case Area (runoff Variable inflow nodes) – The red line is the relative standard deviation per time step (%)

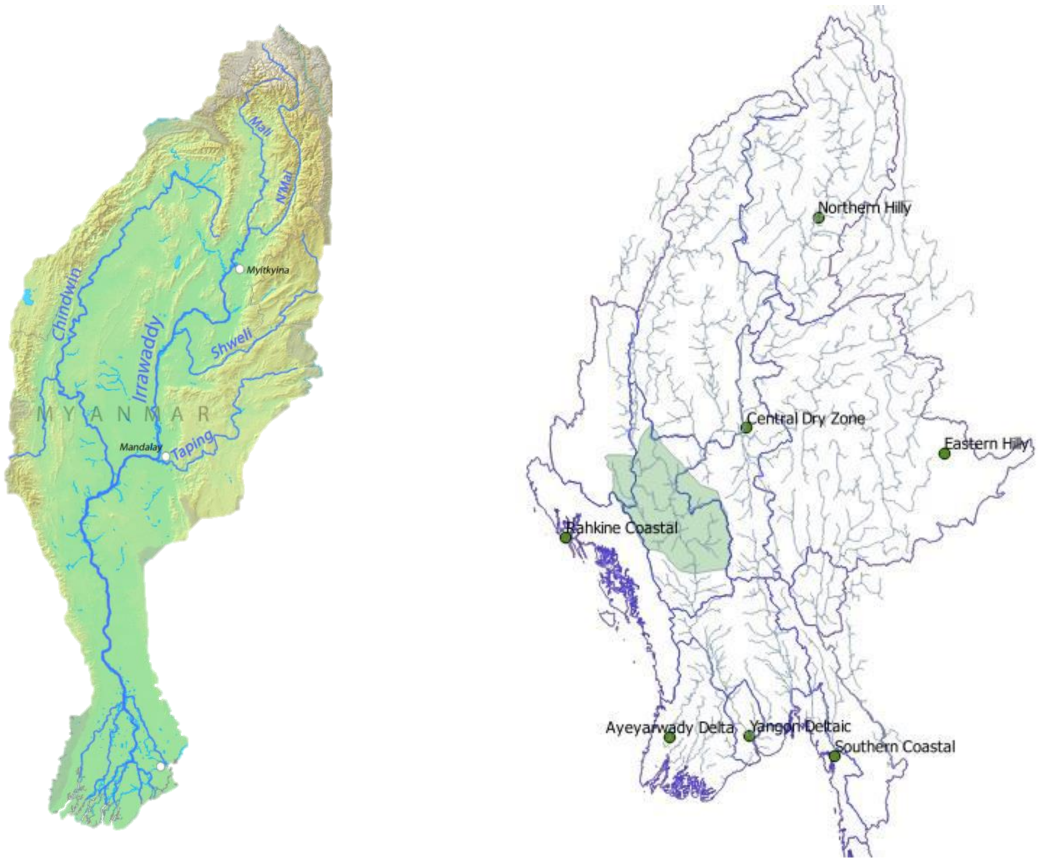


Figure 4.13.4 Ayeyarwady River catchment area (left) and the Case Area (right, in green) in the river network of Myanmar

Table 4.13.2 Cumulative inflow into the Ayeyarwady River Basin and cumulative demand of the irrigation areas (km^3)

Ayeyarwady River Basin	*Cumulative inflow*	*Cumulative demand*	*Demand during dry season*	*Demand of total (%)*
Actual_Case 2	412,241	22,656.18	17,345.24	5.5

For the Ayeyarwady River Basin, on average, the demand in the dry season is approximately 76% of the total annual demand, where the inflow into the basin during this season is only 10% of the annual inflow, see Table 4.2.2. The remaining 90% enters the system in during the monsoon season. The cumulative demand of the irrigation fields account for 5.5% of the total available water in the basin.

4.14. In conclusion

The seasonal variation for each basin is observed. For all basins, the average relative standard deviation is 10%. The standard deviation for all basins is the largest at the end of dry season or onset of the monsoon season. The standard deviation is based on the simulation period of 12 years, which scientifically speaking too short to really come to statistical conclusions. A 30 year observation is statistically supported to draw conclusions about the weather. However, it was understood during the field visit that the onset of the monsoon varies over the last. This has been observed since the 1970's (Lwin, 2002). The onset is important for the start of the cultivation of the summer paddy. The variation for the Magway and Minbu Case area is larger compared with the full basin. In the dry season relative standard deviations are observed between the 50% and 60% which is significant for the water availability. The variations between the dry and wet years are larger compared with the bigger system, on the river basin scale.

5. Water Resources System in Magway and Minbu Region - present situation

Since the calibration and validation for the models could not be done due to a lack of data, the impact of the input parameters on the model behavior, water demand and availability, is tested in a smaller area: the Case Area, located in the southern part of the Central Dry Zone. This region is particular interesting to analyse in more depth, since it is located in the Central Dry Zone, the most vulnerable region of the country when it comes down to water availability. In this region, less precipitation is present during the monsoon relative to the other regions in the country. Also a more regional assessment on the water scarcity is done for this area, where roughly two regions are loated: Magway (left side of the Ayeyarwady River bank) and Minbu (right side of the bank), see Figure 5.1.2. For the overall assessment of the WRS in Myanmar, the findings and outcome from the analyses in the case study are used to understand the interactions of the stakeholders and the model behavior.

5.1. **Case Area Magway and Minbu**

The assessment and performance of the WRS in the present and future situation is done by analysing the modelling output, and the sensitivity analysis for a single node and case study area, named 'Case Area'. In Appendix Q the Case Study area and other potential case study areas are described. For the analyses of the different regions in Myanmar, three distinct regions were identified based on the areas of interests in the development of the country. These regions were part of the discussion in an IWRM workshop under the MoU with the Dutch Government and the The Republic of the Union of Myanmar, (UNESCO-IHE & MandalayTechnology, 2014):

- ❖ Hilly region (upper Myanmar) – Hydropower development
- ❖ Central Dry Zone (Central Myanmar)
- ❖ Delta/ Coastal Region

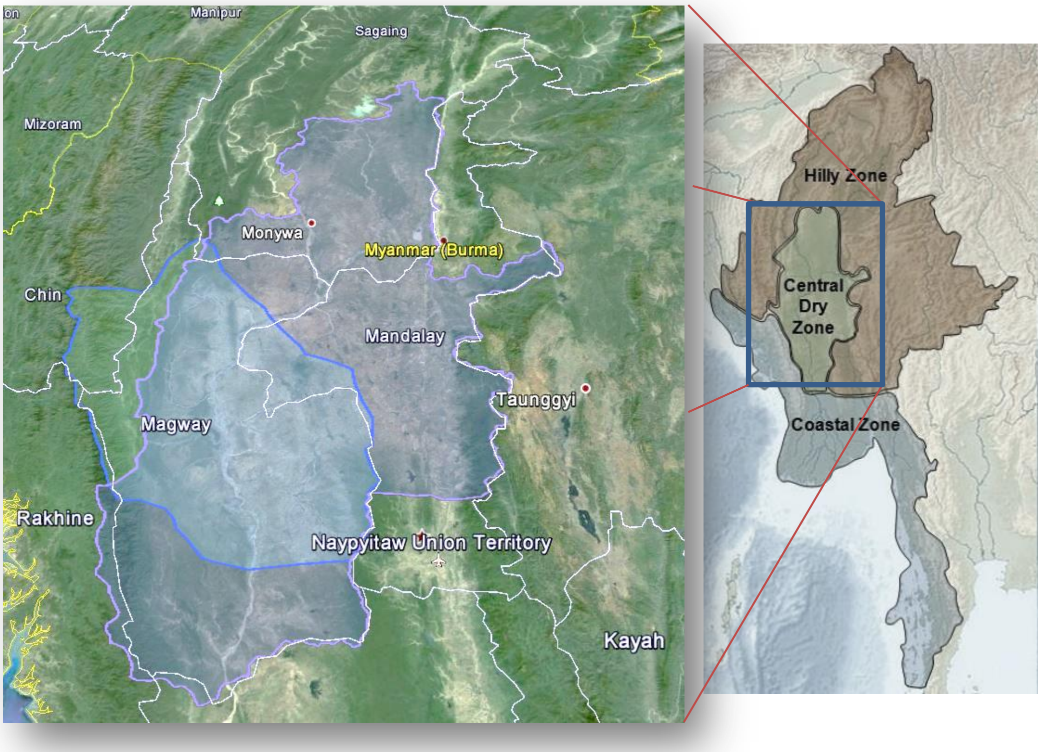


Figure 5.1.1 Case Study area (blue) Case Area – (purple) Central Dry Zone

From these regions, the Central Dry Zone is the most vulnerable region, based on the water scarcity that occurs at the end of the dry zone, and the scale of region with many people living there. Besides Yangon, the area around Mandalay is an important economic region and corridor. The great interests of development in this region, made the decision to make the case study area in this region, a logical decision. The problem however, the model schematisation of the Central Dry Zone and build up, as it was during this assessment, appeared to be not convenient for using it as a whole as a case study. The blue lined area in Figure 5.1.1 resembles the Case Area. As can be seen, it is located mostly in the Central Dry Zone (purple), but not in the most vulnerable part (around Meiktila, an area of interested by the Asian Development Bank with a high priority of development). It covers the Minbu and Magway area and two different climates: dry region at the left bank of the Ayeyarwady, and a wetter region on the right side of the river. The case study includes some hydropower dams, pumping stations and domestic water consumption. So all key stakeholders are represented, as it resembles the stakeholders involved in national level. Also the biggest irrigation areas of the country is located here, downstream of the Mone Dam and Mezali Weir (354,015 ha) and Linzin Weir, even bigger than Thapanzeik (202,350 ha) according to (MoAI, 2013a).

5.1.1. Assessment description

The performance of the water resources system, and in particular the irrigation areas were analysed with models in Ribasim on basin, and regional scale, for which the Case Area is been used. The insight in the behaviour of the modelling result in the single irrigation area and case study are used to give recommendations about the performance local scale, where for a few input parameters, the changes were analysed on river basin scale. In the discussion of the sensitivity analysis, see section 6.3, the impact of the input parameters on the model output is discussed. With this knowledge, the performance of the infrastructure is discussed and recommendations are formulated. Also in the outcome of the sensitivity analyses, three different *cases* are formulated which represent different representations of possible development possibilities, related to the operation of the irrigation fields: the overall efficiency factor.

The availability of water used for irrigation and domestic water consumption is mostly crucial at the after the monsoon season. The sources of water can either be a aquifer, the river or a surface water reservoir. For the availability of water on a local scale, the available runoff, storage capacity of the reservoir and the available discharge in the river is compared with the actual demand of the stakeholders.

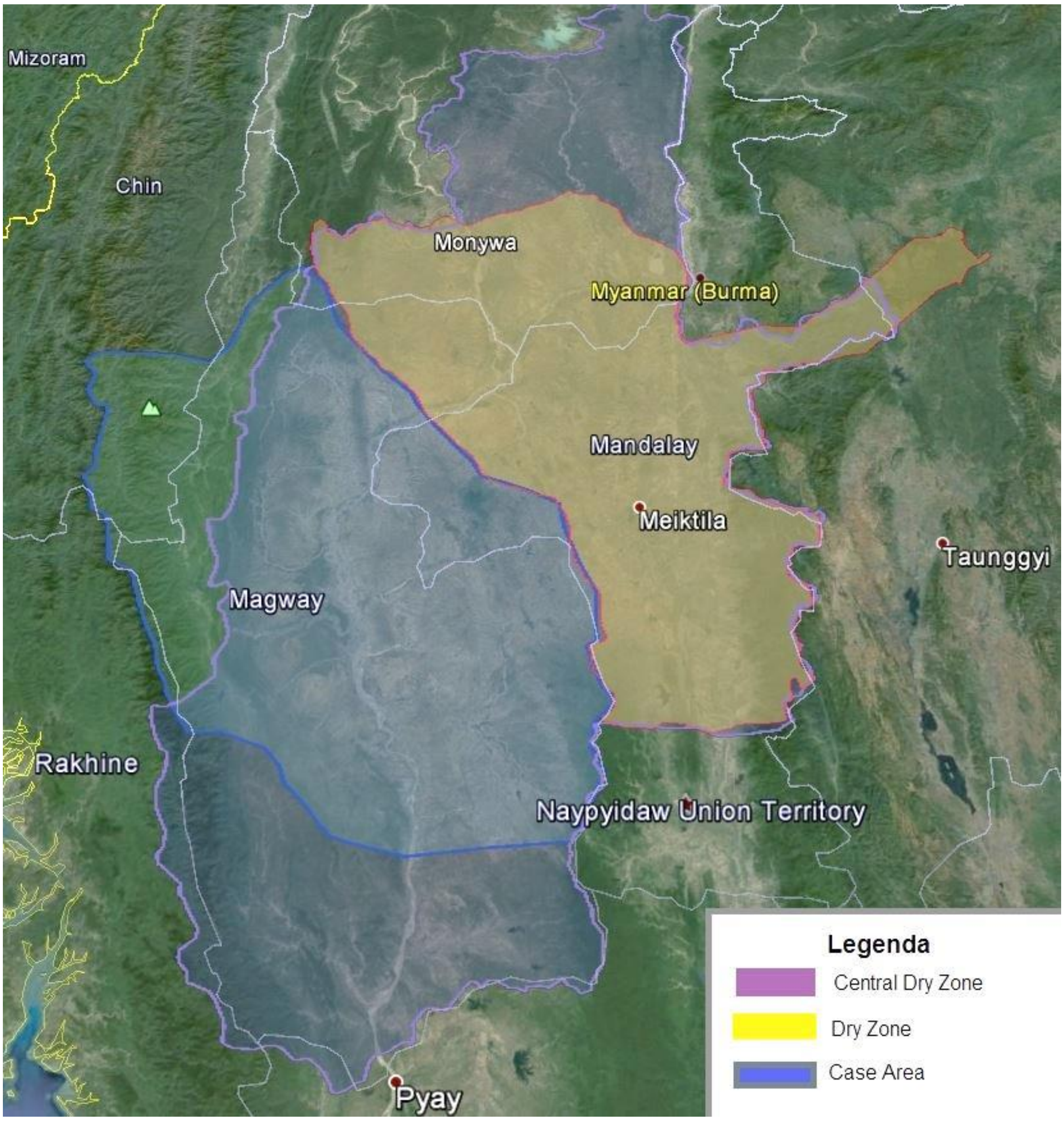


Figure 5.1.2 Dry Zone (Purple), Central Dry Zone (yellow) and Case area (Blue). Here, the Central Dry Zone is referred to be the whole central part of Myanmar which significantly receives less water than the countries average. The Case Area (Magway and Minbu Region) is the area which simulated in the model. The Minbu (right side of the Ayeyarwady River) is relative wetter than the other river bank. The Dry Zone as referred here, as the region outside the Case Area, which is the most vulnerable region in the Central Dry Zone

The average runoff in the Central Dry Zone and the Case Area over the period 1998 to 2009 is presented in Figure 5.1.3 and shows that limited water is available for the local users, compared to Case Area. The peak in the runoff during the monsoon season occurs later, where the base flow is of similar quantity. In Table 5.1.1 the annual runoff and deviation over the simulation period is presented. The variation in the dry period is larger for the Dry Zone than for the central part of the Central Dry Zone, where the Case Area is located. The location of the Magway and Minbu case area relative in the country is shown in Figure 4.13.4.

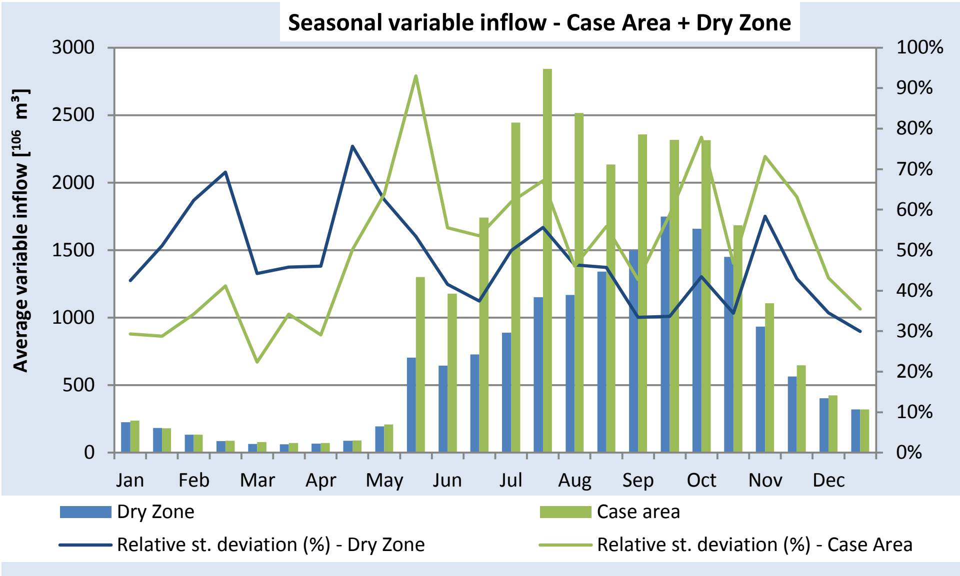


Figure 5.1.3 Water availability from runoff in Dry Zone and Case area – Averaged over the simulation period 1998 -2009 and the relative standard deviation for each time step

Table 5.1.1 Runoff for the major river basins (km^3/year) Central Dry Zone – Averaged over the simulation period 1998 – 2009

River basin	*Yearly (10^6 m^3)*	*Standard Deviation (σ)*	*Relative St. Dev. (%)*	*Lowest discharge (ts)*	*Lowest water availability (10^6 m^3)*
Case Area	26,495	8,561	32	1st half April	72
Dry Zone	16,310	4,553	28	2nd half March	62.2

The seasonal variation in the inflow in to the Case Area sub-catchments is shown in Figure 4.13.3. the relative standard deviation shows the deviation during that time step for the simulation period 1998 – 2009. As can be seen, the deviation is large at the onset of the monsoon season, and at the end of the monsoon. This variation for the whole simulation period is shown in Figure 5.1.4, where clearly wetter and dryer years can be observed.

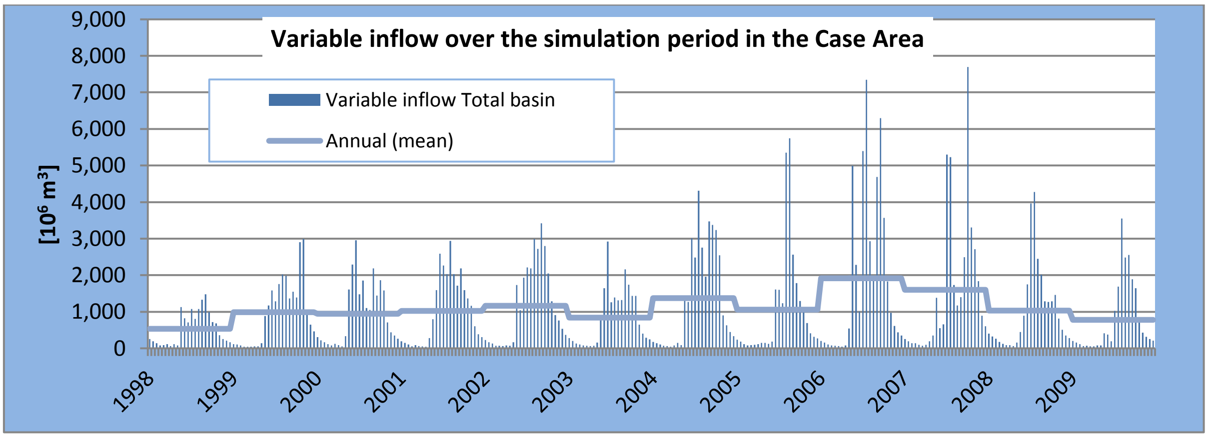


Figure 5.1.4 Variable inflow into Case Area for simulation period 1998 to 2009 (runoff Variable inflow nodes) – the horizontal line indicates the yearly averaged flow

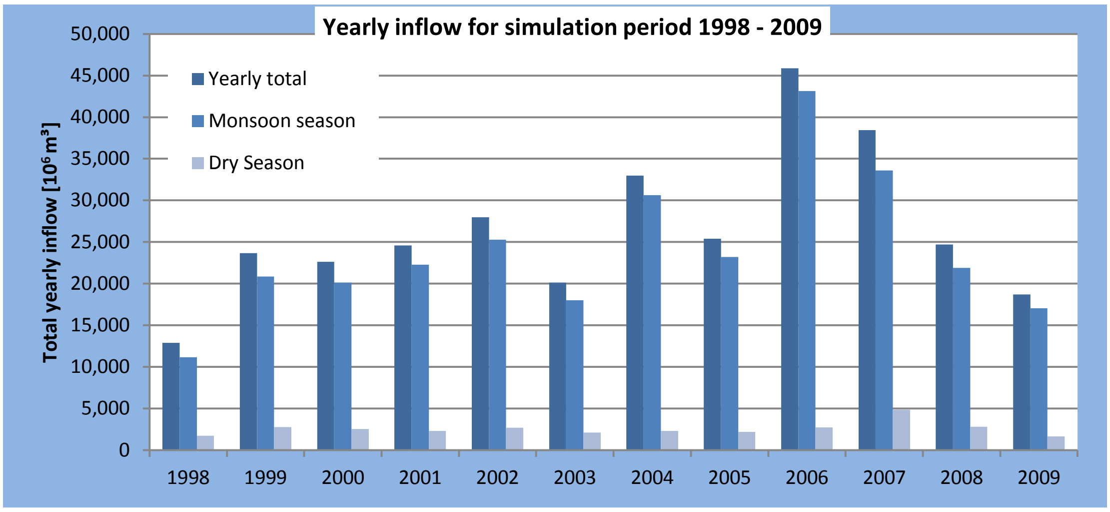


Figure 5.1.5 Total yearly inflow for the simulation period 1998 to 2009 – Case Study area – and the inflow during the monsoon and dry season.

The volumes of runoff in the Case Area per season vary largely. The difference between the monsoon and dry season is presented in Figure 5.1.5 and Table 5.1.2. The monsoon season is here chosen from half May till half November, and the dry season from the second half of November till the first half of May. The filling of the reservoirs depend on the available runoff during the monsoon.

Table 5.1.2 Average yearly inflow, standard deviation and relative standard deviation for the simulation period 1998 to 2009 – Case Study area – also for the inflow during the monsoon and dry season.

	Average (10^6 m^3)	*Standard Deviation (10^6 m^3)*	*Relative st. deviation (%)*
Yearly	26,495	8,560	32.3
Monsoon Season	23.937	8,091	33.8
Dry Season	2.558	785	30.7

The research objective (RO1 and RQ1) of this research is to analyse the present situation of the water resources of the major river basins of Myanmar. As explained in the section on the development process, the model of the basins in the Ribasim environment is used as a representation of reality. With the knowledge gained by preparing the input data, analysing the modelling output, the calibration of some parts of the model, and analysing the output, the status of the present WRS in Myanmar situation is discussed below. The most important stakeholders and their impact on the WRS, are discussed in the sections before. The output from the model is discussed in relation to the available literature about Myanmar's water resources.

5.2. **Water Scarcity**

The seasonal variation in water availability and the demand of water especially from the irrigation sector, leads to seasonal water shortage, particularly in the Central Dry Zone, Figure 5.2.1. For the Case Area the scarcity is calculated, by taken the ratio of from the yearly inflow or 'supply' from watershed into the reservoirs and the demand of the irrigation area downstream. The available water in the Ayeyarwady River has not been included in this assessment. In Table 5.2.1 the scarcity levels for actual irrigated areas in Minbu and Magway are 5.5% and 4.5% respectively with the simulated variable inflow, and 12.1% and 11.8% respectively for the available storage (full storage – dead storage capacity). This means that water scarcity levels for the available runoff in Minbu and Magway Region in the present are insignificant, whereas considering the available actual storage capacity, the water scarcity number increase to a *moderate* level. Socioeconomic

Table 5.2.1 Water Scarcity factors according to the UN and IWMI. Four different scarcity levels can be identified: severe, medium, moderate and little (n). - (NAPA, 2012)

	UN	*IWMI*
Scarcity level	L_{un}= withdrawal as & of water supply	L_{iwmi1} = withdrawal as a % of water supply L_{iwimi2} = future withdrawal as a % of current withdrawals
Severe	L_{un} > 40%	L_{un} > 50%
Medium to severe	20 % L_{un} < 40 %	L_{un} < 50 % and L_{iwmi1} > 200%
Moderate	10 % L_{un} < 20 %	Lun < 50% and 125%< L_{un} < 200 %
Little or none	L_{un} < 10 %	L_{iwmi1} < 50 % and L_{un} < 125%

$$L_{un-iwmi} = \frac{Withdrawal}{Water\ \mathrm{supply}}$$

Equation 1 Water scarcity factor according to the United Nations (UN) and the International Water Management Institute (IWMI)

Table 5.2.2 Scarcity level for the Minbu and Magway area. – The scarcity levels (%) are for the simulated inflow (left) and for the available storage capacity (full storage – dead storage capacity)

Region	*Yearly inflow (km^3/year)*	*Storage capacity (10^6 m3)*	*Demand from network (km^3/yr) - actual*	*Scarcity level (%) – actual Runoff*	*Scarcity level (%) – actual storage capacity*
Minbu	7.576	3.199	0.387	5.5	12.1
Magway	1.474	0.500	0.059	4.0	11.8

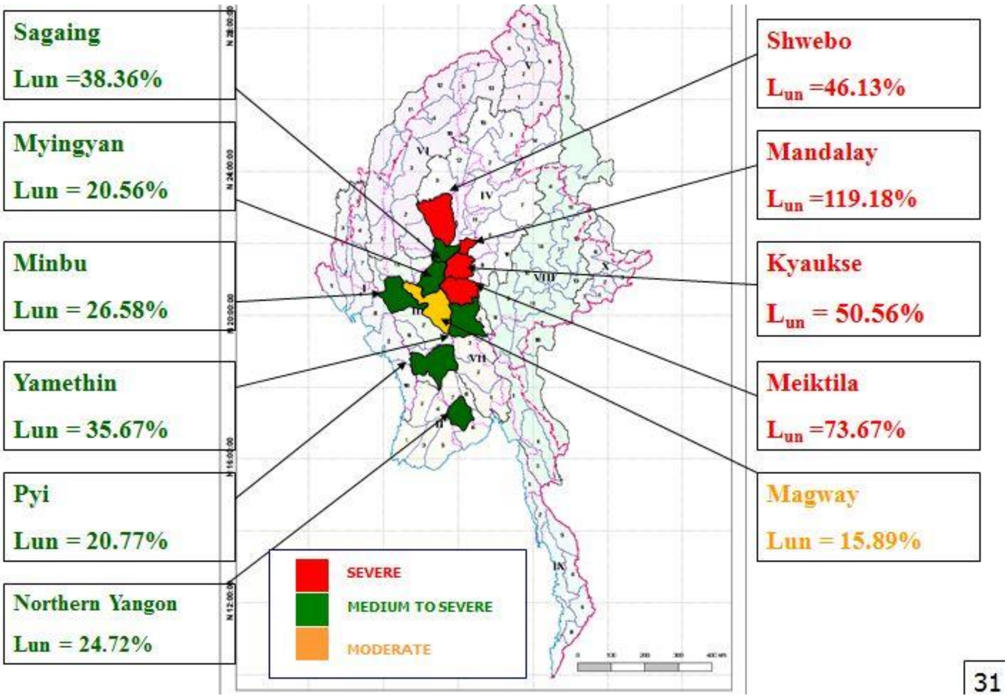


Figure 5.2.1 Surface water withdrawal level in water scarce areas in Central Myanmar. L_{un} = water withdrawals as a percentage of the total water resources — These numbers are not the outcome of the simulation but are calculated by (NAPA, 2012)

The scarcity levels in Table 5.2.1 are may be determined by the available inflow in the total area in the area plus all the irrigation in the area. In the simulation only the bigger reservoirs and irrigation areas are included. Therefore, the scarcity levels are a little bit lower than the ones from the UNEP report. However, the available water in the Ayeyarwady, also during the dry zone, is assumed to be sufficient to fulfil the remaining demand. The average low-flow at Magway, is around 2,800 m^3/s, where the lowest recording discharge is 2,140 m^3/s, which occurred in 1995. The water scarcity in thus more of a local problem, where the lack of proper infrastructure is unable to supply the water, than it is of the lack of overall water availability due to physical conditions. The accessibility of ground water resources was not included in this quick analysis. It may be concluded that in the present water scarcity, for both regions, no severe water scarcity is observed, but when all developed irrigation areas are operational, the storage capacity can be of a limiting factor for both regions.

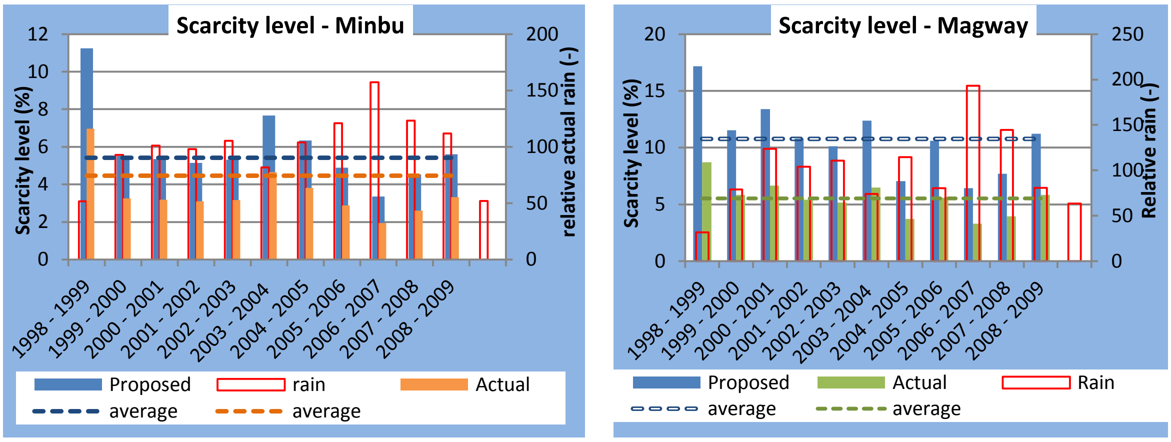


Figure 5.2.2 Scarcity levels for the simulation period 1998 to 2009 – Minbu and Magway area – On the left vertical axis the scarcity levels (%) are presented – on the right the relative inflow (yearly inflow/average inflow over the simulated period*100%)

5.2.1. Domestic water scarcity

Water scarcity is not only for agriculture, but also for domestic use, is a key constraint to livelihoods and people's wellbeing. The water scarcity level in the Dry Zone is high for the domestic sector. 73% of the 630 household (McCartney et al., 2013) has surveyed, 73% had access to improved water supply, where 77% of the households had access year round to fresh water.

In Figure 5.2.1 the scarcity levels are illustrated for the regions in the Central Dry Zone, calculated by the National Adaptation Programme of Action, (NAPA, 2012).

When the domestic water demand will be included in the water scarcity assessment, the levels will become higher. For the total amount of water demand in these regions, 10% is the total demand is assumed to be for the domestic sector. The following scarcity levels are found, and show in .

Table 5.2.3 Scarcity level for the Minbu and Magway area, including the domestic water consumption. – The scarcity levels (%) are for the simulated inflow (left) and for the available storage capacity (full storage – dead storage capacity)

Region	*Yearly inflow (km^3/year)*	*Storage capacity (10^6 m3)*	*Demand from network (km^3/yr) - actual*	*Scarcity level (%) – actual Runoff*	*Scarcity level (%) – actual storage capacity*
Minbu	7.576	3.199	0.426	5.6	13.3
Magway	1.474	0.500	0.065	4.4	13.0

6. Relevant parameters for the Water Resources System in Myanmar

Part 1 – input data

and scenario development which has to be considered in whole process of the modelling process. According to (EPA, 2009; Refsgaard et al., 2007) it is of great importance that the uncertainty assessment should be seen as a red thread throughout the modelling study starting from the very beginning. Traditionally, this step is only carried out at the end of the modelling study when the model has been calibrated and validated. For integration of the model results into the broader IWRM context and increase the capacity building of the local partners it is recommended by Refsgaard et al. (2007) that making an uncertainty assessment is an on-going process that from the beginning till the end of the project where it meets both the water management and model objectives. Understanding of the input parameters and the available data increases the understanding of the system, which may benefit the development and operation of the WRS.

Daw (Ms). Khin Aye Mu - Library of the Irrigation Department, MoAI office in Yangon- photo: Rens Hasman

6.1. Model input data

The model development process of both the hydrological model WFlow and Ribasim included many uncertainties in the input parameters. In Ribasim most input data is data that can be obtained from the stakeholders, which concerns the operation of the infrastructure and agricultural/ irrigation characteristics.

6.1.1. Runoff

For the runoff time series from the catchments that are needed as input for the Ribasim the hydrological model WFlow[7] has been used. WFLOW is a distributed hydrological rainfall-runoff model, based on the PCRaster Python framework. The model uses a combination of meteorological input data (precipitation, evapotranspiration, temperature) and information on land use and soil parameters for the (sub-) catchments. Via hydrological routing the kinematic wave is modelled for the runoff. The available precipitation series is from the year 1979 till 2009. For the current model, the WFlow has generated time series for the simulation period 1998 – 2009.

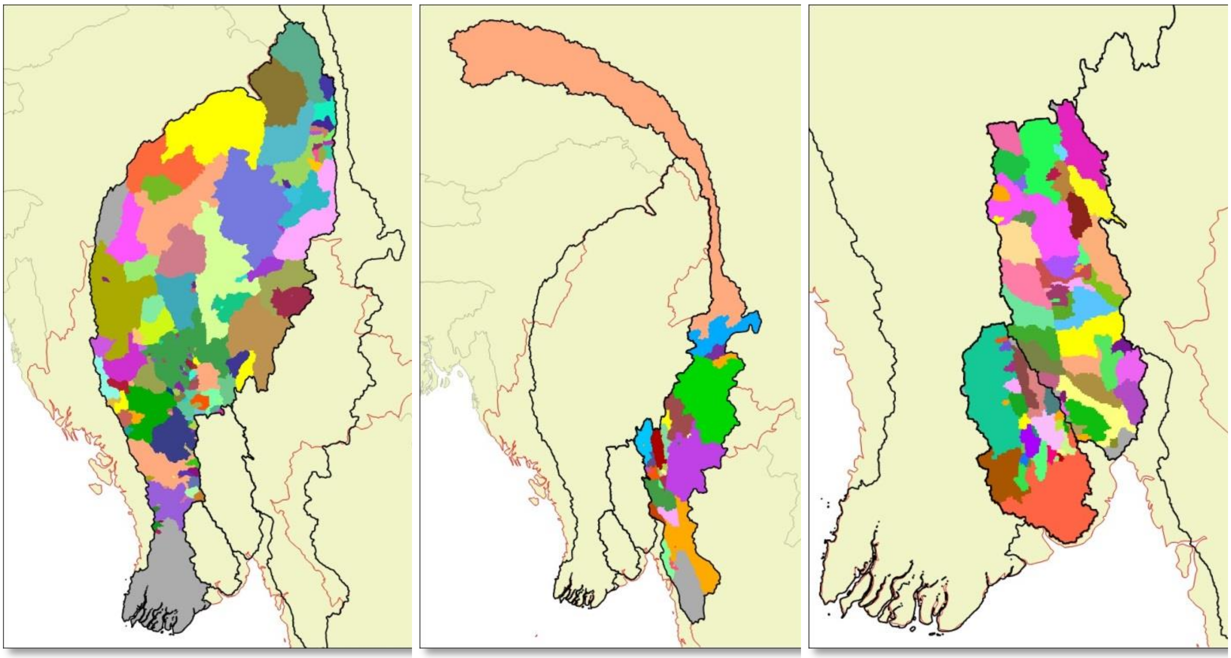


Figure 6.1.1 Sub- catchments of the modelled river basins in WFlow. From left to right: Ayeyarwady, Salween and Bago, Sittaung and Myit Ma Hka River basin.

[7] *Deltares Software - version 1.0RC2*

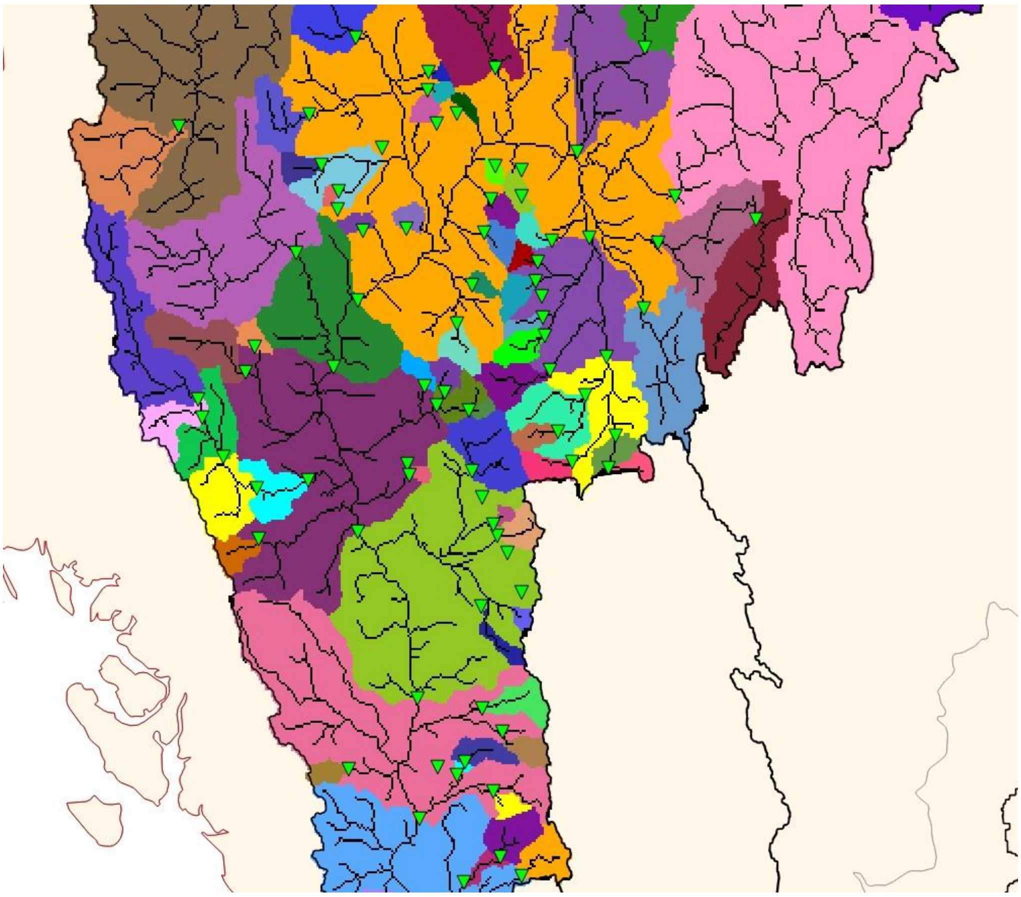


Figure 6.1.2 A close-up of a part of the Ayeyarwady catchment, including sub-catchments, the dam / weir / irrigation locations used to generate these (green triangles) and the course of the river

Having mentioned that, the data requirements (satellite data) for WFLOW are not trivial. The following data products have been used for modelling the Rainfall-runoff relationship for catchments in Myanmar.

Table 6.1.1 Sources of Data for Wflow Model input

Data type	*Data product*	*Resolution (arcsec if nothing is mentioned)*
Digital Elevation Map (DEM)	Hydrosheds	15 (90*90 m)
Precipitation	Watch Forcing Data (WFD)	3 hourly/ daily
Evapotranspiration	FAO	Monthly
Land Use	*FAO* - Globcover V2.2	10
Soil Type	FAO - HWSD	30

The EU-WATCH Forcing Data (WFD) is a reanalysis product which provides spatio temporal global precipitation maps at a daily resolution. The Spatial resolution for these maps is 30 minutes. The dataset is available for the whole 20th century making it really valuable for time series analysis of long durations return periods.

From internal report of Deltares for the development of the Ribasim and WFlow models (July, 2014).

The soil type use data of the FAO's Harmonized World Soil Database (HWSD)(Fischer, 2008) and Globcover V2.2 for land cover. The different classes shown in the tables below.

Table 6.1.2 Land cover classes in the study area, based on a reclassification of the ESA GlobCover V2.2 dataset

Land cover class	*(%) of total study area*
Forest	33.2%
Crops	35.3%
Shrubland	22.9%
Grassland	5.1%
Bare	0.2%
Flooded (salt)	0.3%
Water	1.0%
Ice	2.0%
Urban	< 0.1%

Table 6.1.3 The main soil types in the study area, based on the Harmonized World Soil Database V1.2

Main soil types	*(%) of total study area*
Acrisols	45.0%
Cambisols	12.5%
Fluvisols	0.8%
Gleysols	12.0%
Leptosols	12.5%
Luvisols	6.0%
Nitisols	6.2%
Non-soils[8]	0.3%
Total main soil types	95.4%
Other soil types	4.6%

Each soil type has its pre-set or default parameters, which can be adjusted in the model. For this modelling phase, no extensive

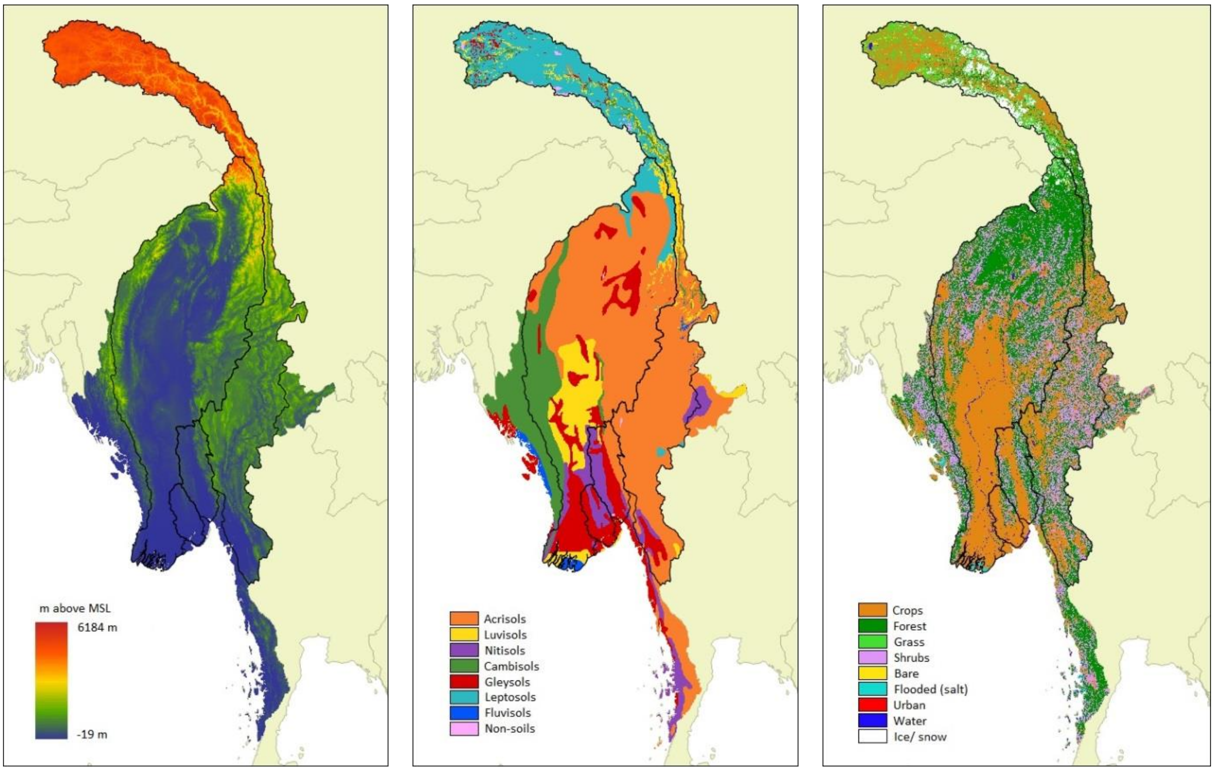


Figure 6.1.3 Input maps on DEM, soil and land cover. From left to right: Ayeyarwady, Salween and Bago, Sittaung and Myit Ma Hka River basin.

[8] *Non-soils can be, for example: rock outcrop, sand dunes, water bodies, glaciers, etc.*

The Ribasim and WFlow development process has been done parallel since the input requirements of Ribasim should be verified with the WFlow output. The variable inflow are coordinated in a sub-catchment were the runoff is needed. The coordinates for the inflow points are or the inflow into a reservoir, or a control/ measuring station (discharge). The coordinates of the dams were provided by ID, MoAI, and are pin pointed at the outlet of the reservoir. The time series generated for the inflow nodes represent all the runoff at that particular point. For a measuring station in the main river, little errors are possible, since it is the lowest point in the region. For the reservoirs however, as can be seen in the next example, the modeller should be judging each point if it matches the physical reality. In Figure 6.1.4 the case of Pyaungpya is displayed. As can be seen, the two pictures on the left is the modelled situation, and on the right side, the actual situation. The catchment of the dam is too small, which can be seen in the model, that the outflow (demand from the irrigation area), is larger than the inflow.

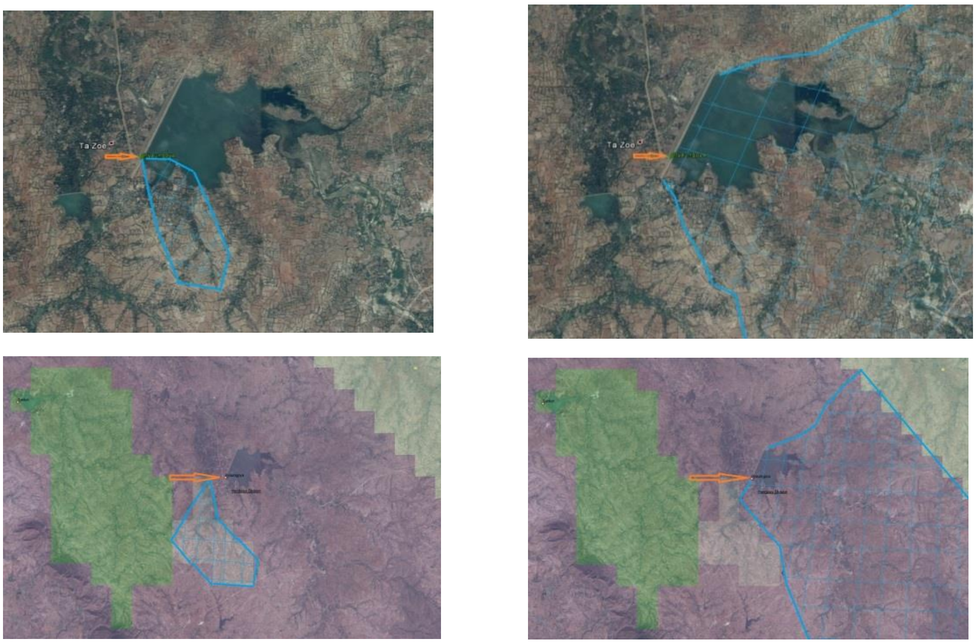


Figure 6.1.4 Example incorrect sub catchment WFlow Pyaungpya in the Central Dry Zone, Mandalay Division

Depending on the grid size of the hydrological modelling tool, with a DEM map as input, the stream of the rivers is produced. Depending on the stream order, the chosen coordinate for runoff time series, should be checked if it is located on the wished stream. In really mountainous and hilly regions the above described issue is of less concern, since often the inflow point is close to the mainstream. The hydrological model snaps the required point to the stream with the highest stream order which often is the location where the dam is located. The corresponding watershed is practically correct for these medium to large dams. The watershed of the smaller reservoirs and tanks in less hilly regions, mostly located in the Central Dry Zone, were more difficult to model with the present WFlow models, since the vertical resolution might be too low.

Sometimes, the dam has a large length, and gets its inflow from more than one watershed, see Pyaungpya example above. In the model only one is simulated. For these cases, it is recommended to compare the modelled sub-catchment with the real situation. Especially since in this region is known to experience water scarcity at the end of the dry season. With a smaller catchment, the inflow is therefore underestimated, and it is more likely that shortages occur in the irrigation areas downstream, on local scale. The overall inflow in that region (Dry Zone) can be assessed easily.

Also the lumping process may result in an underestimating of the inflow into the reservoir. Especially in the Dry Zone, the smaller reservoirs/ tanks, are lumped with a bigger one, in the region. The inflow into the modelled (lumped) reservoir originates from a smaller watershed compared to the situation when the reservoirs are not lumped. This results in an underestimation of the water availability for the lumped irrigation area. it is recommended that for the assessment of the Dry Zone area on a courser scale, is done with a higher density of reservoirs than in the present model is been schematised. The assessment of the water availability versus the water demand from the irrigation as better done on regional scale, so for the whole Dry Zone.

6.1.2. Reservoirs

The storage balance (S) of the reservoir shows all the fluxes per time step of the simulation.

$$\frac{dS}{dt} = Q_g + Q_r + Q_p - Q_e - Q_{extr} - Q_s - Q_{spill}$$

Equation 2 Storage balance of surface water reservoirs

Q_g	Runoff from the groundwater
Q_{gr}	Surface runoff
Q_p	Precipitation on the reservoir
Q_e	Open water evaporation
Q_s	Extraction from downstream demand: $Q_s = (Q_I + Q_{HP} + Q_{dmc})$
Q_I	Extraction for irrigation purposes
Q_{HP}	Extraction for hydropower production
Q_{dmc}	Extraction for irrigation purposes
Q_s	Losses from the reservoir due to seepage/ infiltration
Q_{spill}	Overflow from the dam spillway

In the simulation of the storage balance the inflow, runoff from ground- and surface water, precipitation and open water evaporation have been computed with the WFlow model for all the location of the reservoirs. Compared to the rainfall and evaporation fluxes, the seepage flux is negligible and is not taken into the simulation of the water balance. The outflow from the reservoir is driven by the downstream demand in the model. The outflow is driven by the demand of an irrigation area, domestic water node, or a target for production hydroelectric power. The outflow for irrigation and/or domestic water consumption can be combined by the outflow through a turbine to generate the energy. When the water level has reached to full storage level, the excessive water is spilled. In the model there is no limitation set in the outflow, meaning that discharge through the main gate is infinity. In the simulation this results in that all the excessive water is not spilled, but discharged through the main gate. For the downstream flow/ demand this makes no difference.

6.1.3. Field water requirements - irrigation areas

Gross crop requirements - For the gross irrigation planning, the demand of the irrigation is given in. As can be seen from that equation, the field demand depends on both physical as on irrigation operation and management factors. The demand of are fixed annual series which is different from irrigation area to another.

$$D_{gross} = \{(P_{sat} + K_c * ET_0 + P) - \mathrm{R_e}\} * 100 / OvAlEf$$

$$\mathrm{R_e} = R_{dep} * \mathrm{R_{eff}} / 100$$

$$OvAlEf = E_{fa} * E_{nr} * E_{cv} / 10000$$

Equation 3 Field water requirements for irrigation nodes

D_{gross}	Gross irrigation water requirements	(mm/day) or (l/s/ha)
P_{sat}	Pre-saturation requirements	
K_c	Crop factor (K_c)	(-)
ET_0	Reference crop evapotranspiration	(mm/day)
P	Percolation	(mm/day)
R_e	Effective rainfall	(mm/day)
R_{dep}	Dependable rainfall	(mm/day)
R_{eff}	Rainfall effectiveness	(%)
OvAlEf	Overall irrigation efficiency	(%)
E_{fa}	Field application efficiency	(%)
E_{nr}	Normal period irrigation efficiency	(%)
E_{cv}	Surface water conveyance efficiency	(%)

The spatial distribution of the ET_0 values for 34 stations of the FAO can be found in Appendix R adopted form FAO Methodology for crop water requirements, (Brouwer et al., 1989a; FAO, 1977). An example of the spatial distribution for the month of April is in Figure 6.1.6. As can be seen, in April, the Central Dry Zone has a high value compared to the other regions of the country. This means, the demand for the same cropping patterns differs spatially over the regions. Although for each local region, at township level, they have their specific cropping patterns for that area, the cropping patterns in the simulated are equal per State or Division. The cropping patterns used in the assessment of the water resources system represent the 'old' approach by the government, in which rice was the main crop to be cultivated with the water from irrigation works from the government.

Crop specific parameters that are important for the water demand of the irrigation are – start of planting period, cultivated area (%), wilting point (% of Root Zone - RZ), field capacity (% RZ), saturation capacity (% of RZ) and initial moisture (% of RZ).

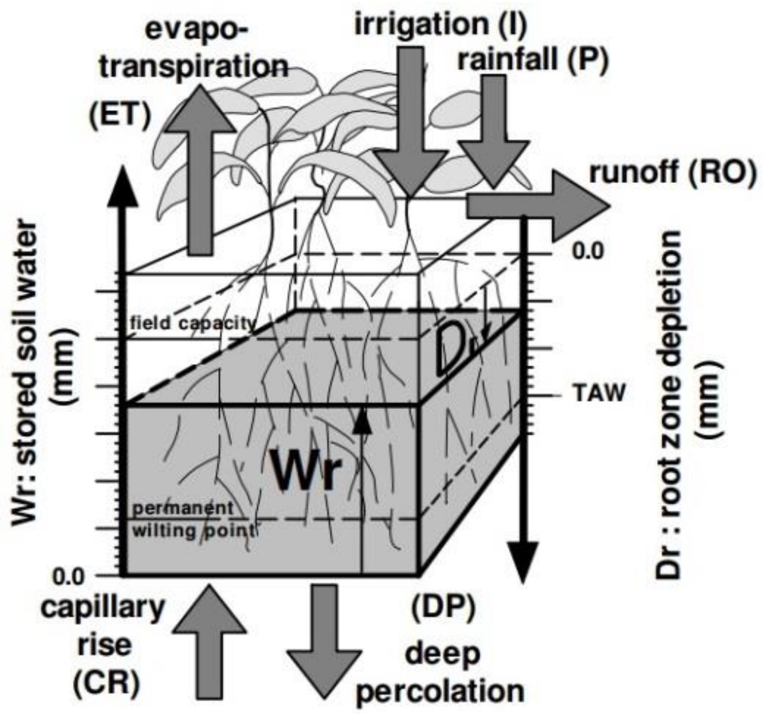


Figure 6.1.5 Root zone schematisation (Brouwer et al., 1989a)

The method used to calculate the reference evapotranspiration from the actual evapotranspiration originates from the FAO publication No 54, (FAO, 1998). Reference evapotranspiration was calculated with the Penman-Monteith method in mm/day for the 34 stations using FAO's CLIMWAT 2.0 database which provides long-term monthly mean values of seven main climatic parameters: temperature (min and max), relative humidity, wind speed, sunshine hours, solar radiation, rainfall and effective rainfall. With the 34 points, for all irrigation area locations the ET_0 was assigned.

6.1.4. Feedback on field status

The demand of the irrigation area to a water supplying source upstream can be set in two settings related to the feedback on the field status. When this option is 'Active', before every time step the actual available moisture is checked and then the remaining water required is set as a demand for the next time step. When the setting is 'Inactive', the demand from the irrigation area is the same for since every time step the field status is neglected. This option represents the 'demand' and 'supply' driven water supplying operation option. During the field visit to irrigation areas in the Bago and Sittaung region, all areas were operated 'supply' driven: a fixed amount of water, design flow, was released from the reservoir for a particular area of farm land.

Hydrology: Actual rainfall > dependable rainfall : the actual water level in the field above target level (storage of water in the soil) which means that in the next time step the demand will be lower.

Actual rainfall < dependable rainfall : the actual water level in the field drops below target level which means that in next time step the demand will be higher.

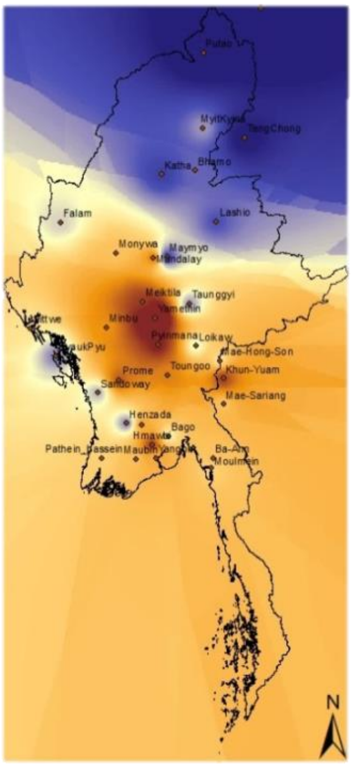


Figure 6.1.6 Interpolated long-term average ET_0 values for April (ranging from low: 2,4 – blue, to high – 7,8)

6.1.5. Hydrology

Besides supply from the network, inflow from a source upstream like a reservoir or the main river, the irrigation area receives also water from the rain during the monsoon season. In the advanced irrigation nodes, the supply from rainfall to the irrigation area is calculated according the following equation, which include many different input parameters that can be changed by the modeller.

$$R_{zs2} = R_{zs1} - R_{eff} * ActRan / 100 - Q_{instIn} + Q_{net} + ActEvp + ActPrc$$

$$ActEvp = K_c * ET_0$$

If

$$Rzs2 > AimLvl + FbStor$$

$$Outflw = InDrUt + (1.0 - R_{eff} / 100) * ActRan + R_{zs2} - AimLvl - FbStor$$

$$Rzs2 = AimLvl + FbStor$$

Other

$$Outflw = InDrUt + \left(1.0 - R_{ef} f \;/\; 100.\right) * ActRan$$

Equation 4 Hydrology equation – for the soil moisture field water level

With

Rzs2	Soil moisture level or field water level at end of time step
Qnet	Net field water supply
AimLvl	Soil moisture target level or field water level (mm)
Rzs1	Soil moisture level or field water level at beginning of time step
Reff	Rainfall effectiveness (%)
ActRan	Actual rainfall
QinstIn	Instantaneous flow from upper field
QinstOut	Instantaneous flow to lower field
P	Potential percolation = ActPrc
AimLvl	Soil moisture target level or field water level (mm)
ActEvp	Actual crop evapotranspiration
ActPrc	Actual percolation

The time series for the actual rainfall and actual evaporation are based on the historical data, produced by the WFlow model. The source of the data is the EU-Watch packages. The dependable rainfall is used for the calculation of the crop requirements. In this assessment the dependable time series represent for every time step the 80% probability of the exceedence for the date 1979 to 2009. See chapter 7.9 – recommendations, for a elaboration and discussion about this input parameter.

6.2. **Modelling results: Irrigation areas**

The irrigation areas are the most sophisticated nodes in the model. They have the most important parameters, either default or to be filled in by the modeler. For the Case Area the behavior of the different input parameters have been tested and analysed. Based in these tests, one case (Case 2) has been chosen to be representing the current status of Myanmar irrigation schemes. To show the operation of the irrigation areas in one region, in Figure 6.2.1 the biggest fluxes are shown for the proposed (planned irrigation) areas. This graph looks similar for the present situation (actual) except for the magnitude. As can be seen, the overall efficiency (effective water used/ gross water supplied) is relative low, where a large part is drained or evaporated. The evaporation rate is almost as high as the effective supply. The actual evaporation is obtained from the hydrological model, but has not been validated on large scale yet with ground data. For two dam locations, the open water evaporation is validated, see the graphs in Appendix R. The data is aquired by the Operation and Maintenance Branch, ID, and collected from the Hydrological Branch, ID, which is the overall branch within the ID responsible for the monitoring of this data. Two conclusions can be drawn from comparing the simulated with the model parameters:

- For the Nawin South Reservoir the actual evaporation is a factor 5 larger than the simulated. This seems to be too high.
- The Baingda Dam looks to match with the simulated data. However, the data set is not complete and shows strange shifts in time. An incorrect method or bad observation could be a cause

It is recommended for the improvement of the model and to improve the validation with the hydrological model, that the (reference) evaporation should be part of the quick wins in the future data monitoring collection programmes.

Large part of the supplied water is drained, due to the inefficiency of the irrigation fields (canals, ditches, skills of the farmers, cooperation between farmers). The impacts of individual parameters are tested in sensitivity analysis, which is described in Appendix R. In that appendix the meaning of the parameters are discussed. In section 6.3 outcome is presented in an illustrative way.

6.2.1. Shortages

The supply-demand ratio for both the *actual* and *proposed* situation has a drop during the dry season, with the lowest value found approximately around 45%. This means that there is a shortages of water and the demand cannot be met, Figure 6.2.2. The reason of these shortages can have different causes, which can be explained either by the representation of reality, model artefact, wrong assumptions/ simplification, or there are actually shortages in reality:

- ❖ Limited available runoff into the reservoirs;
- ❖ Limited storage capacity available;
- ❖ Limited pump capacity for river pump installations (not modelled in the simulations)
- ❖ Irrigation efficiency is low, with a drainage rate as a consequence;
- ❖ Other losses (percolation, evaporation)

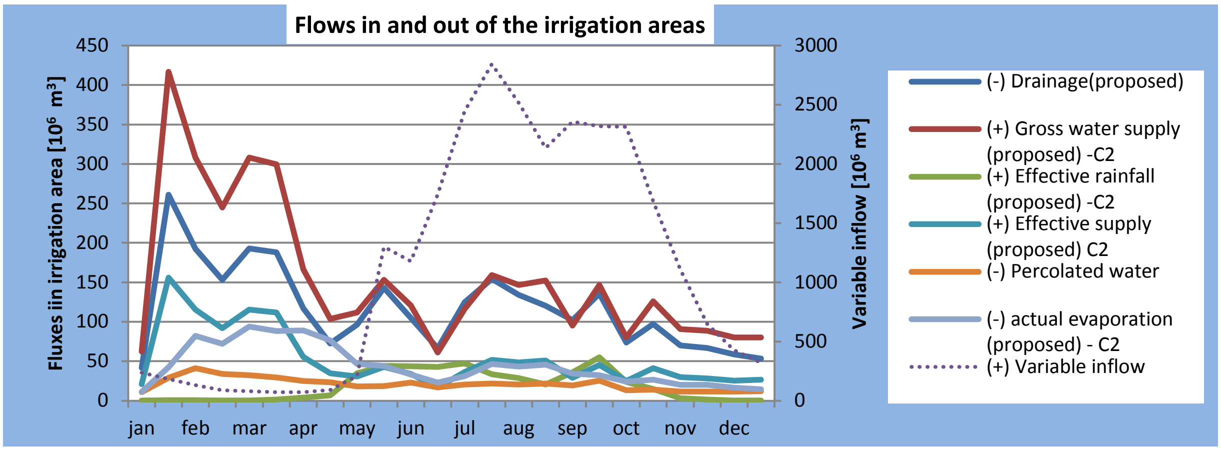


Figure 6.2.1 Flows in and out of the irrigation areas of the Case Area for the developed situation – *proposed C2*

As can be seen in Figure 6.2.1 the fluxes of the water from the irrigation areas are varying largely over the seasons. The effective supplied water to irrigation area is relative small to the gross supplied water, resulting from the overall efficiency of 31%. Large part of the water is drained or evaporated. Percolation is important input parameter, affection the effective supplied water. On basin scale, the percolation will have a significant on the water demand. In the Figure 6.2.2 the effective supplied water to the irrigation areas and the overall efficiency is shown where can be seen, that when improving the field application efficiency with 25, the overall efficiency direct is positively affected.

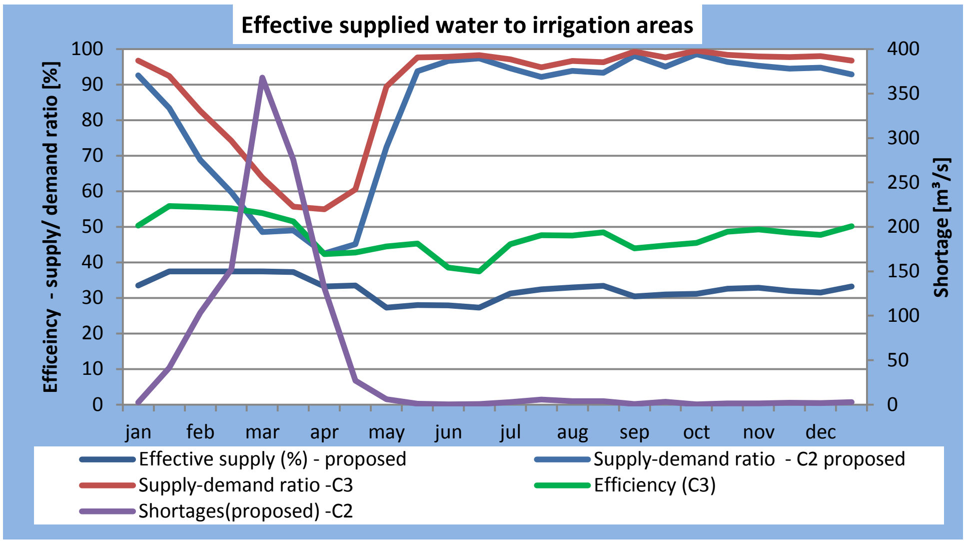


Figure 6.2.2 Effective supplied water to irrigation areas versus the overall efficiency for the proposed situation (*proposed C2*) and proposed improved situation (*proposed C3*)

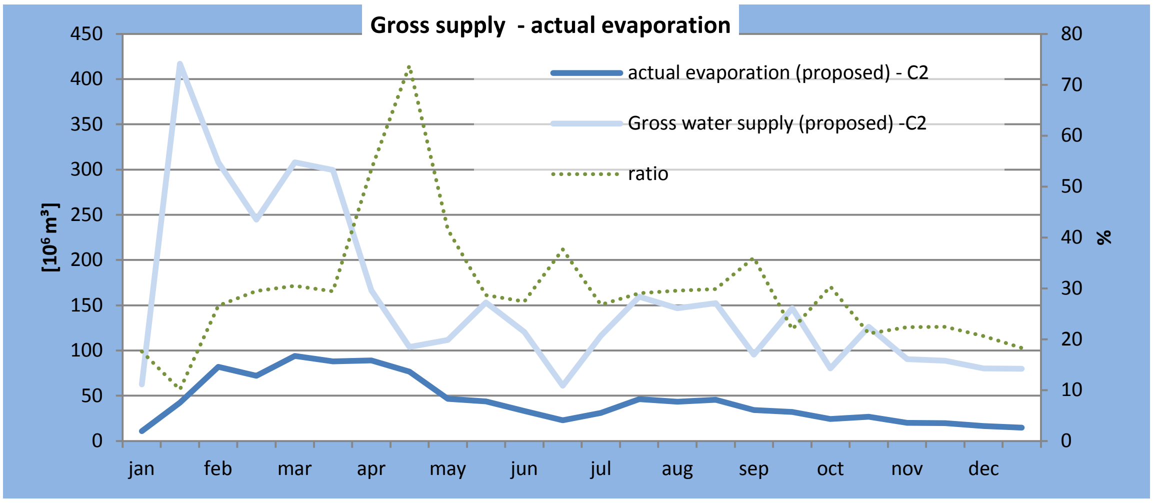


Figure 6.2.3 Importance of evaporation at the field compared to the gross water supply in the Case Area – (1999) – *proposed C2* irrigation – at the end of the dry season, large part of the gross supplied water to the fields is evaporated. The number is even up to over 70%

6.3. Sensitivity analysis

The impact of changing the input parameters on the output, are analysed in the sensitivity analysis. All parameters are discussed more in depth in the Appendix R. The physical meaning is explained in this appendix based on literature of the FAO: (Brouwer et al., 1989a) and personal communication with local expert during the field visit, (NEPS, 2013a). The case area has been used for this assessment for the regional scale. One dam is used for the individual scale

There are three types of input parameters that can be identified:

- Irrigation practices – these parameters describe how crops are cultivated or the water is distributed over the farm land by the farmers.
- Physical factors – these parameters are fixed input parameters since they are related to the climatological conditions or characteristics of the crops, soil or atmospheric
- Infrastructure – are related to the constructed infrastructure to supply/ release and distribute water of the irrigation network system

The operation of the irrigation project, so irrigation fields + the infrastructure like reservoirs and canals, can be modelled pretty good, if validation data is available. Since for this assessment no validation data has been used, parameters are assumed based on literature and knowledge from the field. The outcome of the sensitivity analysis describes which parameters are important to collecting of input data, to improve the representation of reality. Also the parameters are discussed which have a high impact on the overall water balance, and are related to the operation of the irrigation schemes.

The parameters are sorted by:

- Impact they have on the overall water demand/ supply and ;
- Uncertainty/ availability of the parameters.

In Table 6.3.1 the relevance of each of these parameters are graphically explained. On the vertical axis the high or low impact indicates what the relative importance of the parameter is on the water balance of the WRS. The vertical axis represents the availability or uncertainty of the data in Myanmar, based on the field experience of the available data sets or the online available data sets.

Table 6.3.1 Impact versus uncertainty of parameters

High uncertainty/ availability	No priority in data collection – medium term objectives	- Recommended to collect / obtain the data in the field - adaptation
Low uncertainty/ availability	Data is available – no priority in data collection for model improvement	- Quick wins - Data available – should be included in next phase modelling
	Low impact	*High impact*

In Figure 6.3.1 the parameters that influence the water demand form the irrigation sector is presented. The three colours, and colour combinations refer to the origin of the parameter.

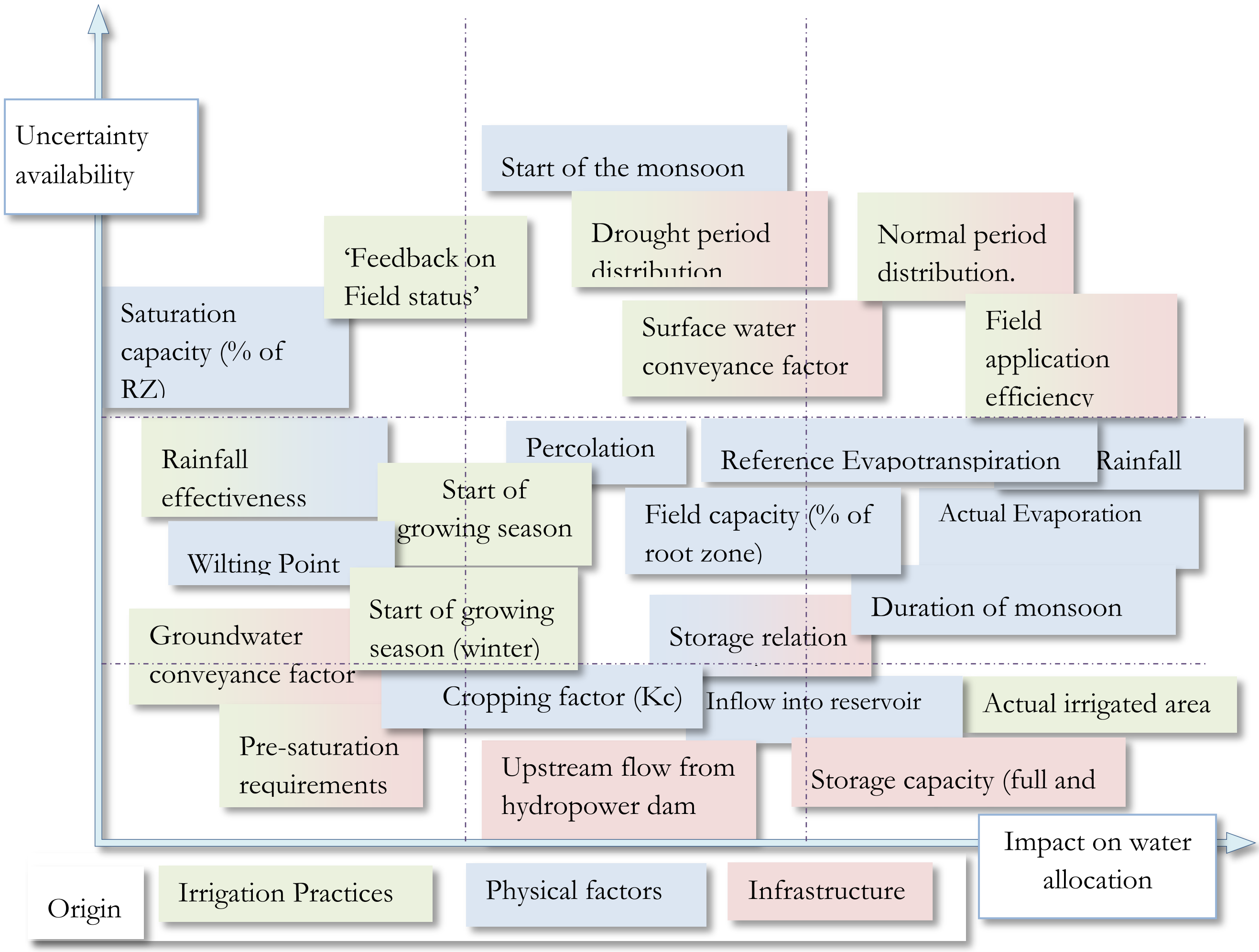


Figure 6.3.1 Overview of the outcome of the sensitivity analysis. The parameters are characterised in three groups: irrigation practices, physical factors and infrastructure. The groups refer to the origin of the parameter and how these data sets can be obtained. The vertical axis shows the importance for the water allocation in the system or the rate of impact. The vertical axis represents the availability or uncertainty of the parameter

The parameters mentioned in the above sensitivity analysis could be collected or obtained according different methods.

- Irrigation practices – These parameters can be obtained from the literature or by measuring the fluxes in the irrigation fields
- Physical factors – these factors can be observed by monitoring the physical system and environment. For the crops, these parameters can be looked up in available literature of the FAO.
- Infrastructure – The infrastructure parameters are related to the design and operation of the structures in the system. These are often readily available at the design office of the owner of the infrastructure but are also linked to maintenance of the object.

The quick wins in the model improvement: **storage capacities, storage relations, cropping patterns and crops characteristics, inflow (validation of hydrological model)**

For the water resources system in general the following model parameters are important to validate with the actual local parameters: **actual rainfall, irrigation efficiency (to be obtained by monitoring the irrigated to and drained water from the field), actual evaporation, operation of the release of the water for multi-purpose dams (hydropower and irrigation)**

Relevant parameters for the Water Resources System in Myanmar *Part 2 – Validation of data*

The simulation of the water resources for the present day situation includes data both collected from some stakeholders and from available literature. Datasets received related to the operation of reservoirs and river discharge tiIme series, could be used to validate the model outcome. In the following section the validation data sets are discussed. The simulated versus the monitored series are compared, and for the difference between the two an explanation will be given. It is possible that the quality of the monitored is questioned, but this has to objective to improve the overall understanding of WRS to improve the existing data and data measuring techniques. With good data, a more detailed assessment can be carried out without making too many assumptions.

View from the Bago- Sittaung Canal to a sluice from the MoYinGyi Lake (October 2013) – Photo: Rens Hasman

6.4. **Official Statistics**

Most government agencies produce their own statistics and only relatively small proportion of official statistics is produced by the Central Statistical Organisation (CSO) in Myanmar. The CSO produces a yearbook which includes data on forestry statistics, livestock and fisheries statistics, profiles of children and women, and monthly economic indicators. Every ministry also has its own statistical department who is responsible for collecting the data within the ministry. Statistics and administration for the agricultural and irrigation sector is collected by Settlement and Land Records Department (SLRD), under the MoAI. Capacity in the CSO is limited, reflecting both a lack of resources and the decentralized nature of Myanmar's statistical system, (OECD, 2014). The new population census of May, 2014 provided much of the raw data required to improve the statistical infrastructure of the country. The population in Myanmar according to this census is 1,850,000 lower than the estimated number by the Myanmar government before the census, Table 6.4.1. While the individual agencies involved in collecting data make basic data entry and data quality checks, there is no system wide process for ensuring data quality. One result of this situation is that there are inconsistencies in statistics produced by different government ministries based on the slightly different administrative needs of different agencies, (OECD, 2014).

Implementing any development strategy as well as ensuring an effective design, adoption and monitoring of policies will require a crucial governance tool: an appropriate statistical system. Structuring of the statistical system adheres to the UN principles of official statistics an important driver of the overall quality and reliability of official statistics, (OECD, 2014).

A second institutional issue in Myanmar relates to the process for the release of official statistics. After the data are collected and compiled from the departments and the analysis has been completed by the CSO, statistics are submitted to the minister before release. Official statistics are made publicly available only after approval is received from the minister. As the economy of Myanmar grows in complexity and its people come to expect that the Government will be a key player in the provision of social services, it is vital to strengthen data and information management systems to contribute to effective policymaking. In particular, an urgent need exists to upgrade the system of national accounts, conduct the population and agricultural censuses, and improve the MDG data set, as well as invest in improving the overall statistical capacity of the country.

6.4.1. Census 2014

The simulation for the public drinking water demand is based on the estimation of the CSO (2011) and extrapolated with the population growth over the period 2006 to 2011. The last census before 2014 was performed in 1983. The official census has counted 7,710,580 less people than the estimation. In the official census of Myanmar, 2014 (UNFPA, 2014), the immigrants in other countries such as Thailand and other people living abroad are not included. An estimation of 130,000 people abroad is thus not included in the official census.

Table 6.4.1 Population of the official 2014 census versus the estimation from the Myanmar government in 2013 and ADB

	(CSO, 2011)	*Myanmar government (est)*	*(ADB, 2009)*	*(UNFPA, 2014)*
Total population	59,130,000	60,980,000	61,650,000	51,419,420
Urban population (%)	27.2			29.6

For the public drinking water this means with an average water usage of 88 l/capita/day, a difference of 0.247 km^3 per year should be kept in mind. That is 8% of the total public water demand (2.952 km^3/year).

6.5. Groundwater

Groundwater is an important source for the public water consumption, especially in the rural areas. Most people pump up the water during the dry season from a well or a drill hole. There is a wide spread belief that groundwater is abundant, but also worries that this may not be the case and that ground water resources are depleting. However, data to support either view is not available. Systematic monitoring is hardly done, (Hulsman & Rutten, 2013). The accessibility of the groundwater at the end of the dry season is crucial for the daily use for many people. Data about the availability, recharge and accessibility of groundwater are important parameters to be included in the water allocation assessment.

6.6. Validation data - irrigated area

In addition the Settlement and Land Records Department under the Ministry of Agriculture and Irrigation is taking responsibility not only for the crops statistics but also for the statistics on the land use and land management. In order to get the complete and reliable statistics, SLRD always keep the close relation and collaboration with the relevant departments and ministries (APCAS, 2011). The simulation of the irrigation areas for the current situation of the WRS is done with the *actual* water supplied area, has been documented for the year 2011. This is the latest year available for which data of all irrigation areas is merged. For the development of the irrigation areas, the *proposed* area is provided by the ID, MoAI. If the proposed area was not given, the potential area is used. In the next analysis, the gross water supplied area and cultivated area is assessed. Data about the actual cultivated area or the amount of crops produces has not been collected for but could be a good data set to be used as a validation.

Settlement and Land Records Department (SLRD) is sole government department taking responsibility for collecting, compiling and disseminating agricultural statistics, particularly for production statistics, such as planted area, harvested area, yield and production of crops, in Myanmar. In addition the SLRD under the Ministry of Agriculture and Irrigation is taking responsibility not only for the crops statistics but also for the statistics on the land use and land management. The regional offices of the Agricultural Department (AD) keep track of the operation and crops used by each individual farmer. After each year they make a strategy plan how to produce the different crops based on the lessons learned in the previous year(s) and the trend in rainfall. During a visit to the local office of the Agricultural Department (AD) at the office in Bago City, it was observed that all data available is written down in Burmese and very little information is digitised. For every township (7 in total) in the region they have keep track of the cultivated area, net cultivated area and type of crops. Each year they make a cropping calendar for each township which indicates different possible combinations of crops, dependent on the location in the region, (Agricultue, 2013).

In the model development phase irrigation areas were lumped or excluded from the simulation if they would have a negligible effect on the overall water balance, Table 6.1.1. See Appendix P for the full model process. For the Salween, a large part is excluded since most of those irrigation projects where small at the moment and the location could not be identified or be having an impact on the water in the Salween Basin. Most of the largest are located along the coast, not influencing the main stream.

Table 6.6.1 Excluded irrigation area from the simulation – actual and proposed

	Actual	*Proposed*	*Proposed over total proposed in simulation (%)*
Ayeyarwady	5,664	38,027	2.5
Salween	638	10,606	12.2
Sittaung, Bago, Myit Ma Hka	708	7,329	1.2
Total	7,010	55,962	2.5

6.6.1. Thapanzeik irrigation area

It is assumed that tracking the actual irrigation area is not a fully representation of the real situation since for a lot of irrigation areas the surveyed area for some years in a row are exactly the same, equals 10,000 acre (4,047 ha), or is larger than the proposed irrigation area. As an example, the actual irrigation area, representing the surveyed area in the year 2011, for the Central Dry Zone our data sheet sums up the irrigation areas belonging to a reservoir to 721,365 ha, and 25,145 to river pumps (total: 746,510 ha), where in the literature a smaller value is found: a total of 256.578 ha (McCartney et al., 2013). This difference might be partly explained by the biggest fresh reservoir of the country.

The Thapanzeik reservoir is the largest fresh water reservoir in the country, and has the largest irrigated area: two weirs, distributing the water over 4 main canals (Kin That en Ye-U) to 487.133 ha, according to the input data sheet ''RibasimMastersheet', see Table 3.9 (Appendix T). According to the FAO it is 274,964 and 53,825 ha by (MoAI, 2013a) and 192.124ha by JICA. McCartney et al. (2013) mentions that it may include multiple cropping cycles, so multiple crops per year, and thus double the area is calculated. It is unclear however, which total area actually belongs to the Thapanzeik reservoir. Another check can be done visually by estimating the surface area of the irrigated land from a satellite image, see Figure 3.15 (a) + (b). Extracting the Thapanzeik irrigation area leaves us 234232 ha for the Central Dry Zone, The green area in Figure 3.15 (b) has an area of 317,492 ha. (McCartney et al., 2013) - Figure 3.15 (c) suggests that only the right main canal is functioning. Table 6.6.2 shows the different areas corresponding to the irrigation field downstream of the Thapanzeik Dam.

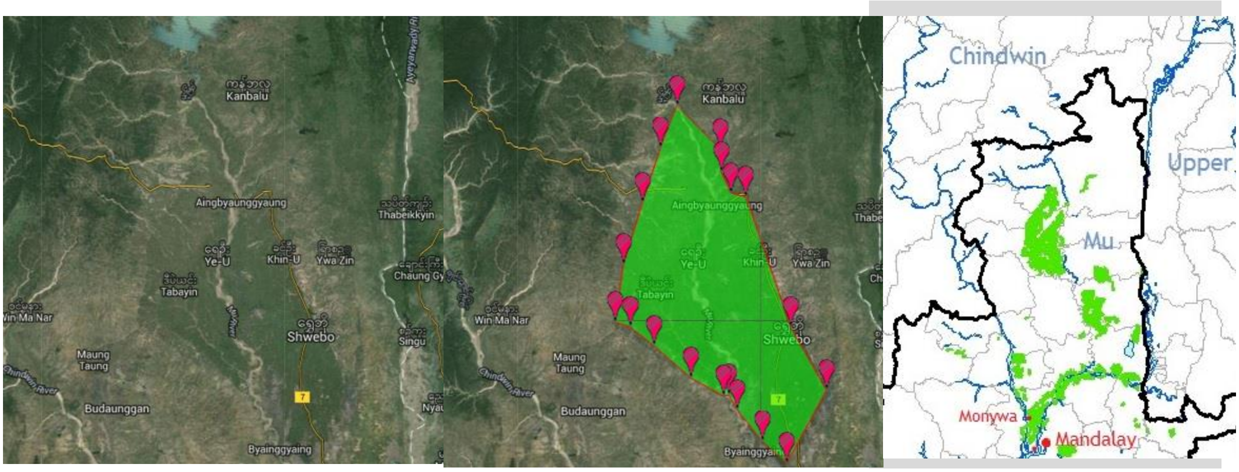


Figure 6.6.1 Thapanzeik irrigation area visually estimation (left two images) (a) + (b) – (c) – (right) Thapanzeik irrigation area according to (McCartney et al., 2013)

From this example can be seen that the actual irrigation area is just a rough indication of the real irrigation area, present in the field. For the calculations, the data received from ID, MoAI is used. The surveyed areas for 2011 – 2012 are used for the actual area for all simulation years. The suggested/ proposed area for the future situation is the situation when the full potential of the area is operational. The difference between actual and proposed tells us how efficient an area operates.

Table 6.6.2 Thapanzeik Project – Irrigation area – from 'Mastersheet' – Received from: ID, MoAI (2014)

OID[9]	*Name*	*operational since*	*Name*	*Irrigation area (ha)*	
				Proposed	*Actual*
430	Shwebo Canal (Kabo Weir)	Colonial period	Shwe Bo Canal (Kar Bo Weir) (thapanseik)	222,516	205,804
433	Thapanzeik Dam	2001	Thapanseik	187,150	165,807
427	Rehabilitation of Ye-U canals	2005	Yae U Canal (Kar Bo Weir) (Thapanseik)	116,224	115,522
433	**Thapanzeik total**	**simulation input**		**525,890**	**487,133**

It can be concluded from this example that the actual amount of irrigated area differs to the water supplied area, which is used as input for the simulation. The overall efficiency of the irrigation area might be compensating this: that just a portion of the irrigation area received sufficient water to grow crops.

[9] OID – the number in the master sheet as input for the Ribasim model

6.6.2. Excluded irrigation areas from simulation

During the modelling process all the collected irrigation areas were analysed and put into the schematisation of the river network. Since the density of the irrigation network is way to high to include in the model simulations, irrigation areas were lumped into one node, or deleted when the location was unknown, the area not substantial (<200 ha) or the location was not relevant for the water resources assessment. The latter was mostly the case in the Salween River basin where most planned irrigation areas are located in the mouth of the river and along the coast, which actually is outside the river basin. At least these areas are expected to be influenced by, or influence the water allocation in the river network. In total only, 0.62% for the actual and 2,5% of the total *actual* and *proposed* respectively is excluded, most influenced by the Salween basin. See for the full modelling development processP.

Table 6.6.3 The excluded irrigation areas that were left out of the simulation. During the modelling process it was decided that these locations are either to small (<200ha) or the location unknown or unimportant

	Total irrigation area – actual	*Total irrigation area - proposed*	*Excluded irrigation area (ha) – actual*	*Excluded irrigation area (ha) - proposed*
Ayeyarwady	923,866	1,535,973	5,664	38,027
Sittaung, Bago & Myit Ma Hka	1,666,997	612,975	786	7856
Salween	51,145	86,836	638	10,606
Total	1,142,008	2,255,096	7,088	56,488
		Excluded compared to total (%)	**0.62**	**2.5**

S

6.6.3. Validation with irrigation data: Nawin South and Baingda

The validation with the monitored data for the irrigation projects is done with data collected from ID, MoAI. For approximately 30 dams the monthly and yearly fluxes in and out a reservoir were collected.

Figure 6.6.2 Nawin South (Ayeyarwady Basin) and Baingda Reservoir (Sittaung Basin) – Southern Myanmar

For the years 2006 to 2014 the fluxes are storage digitally and include data on monthly basis and in inch and acre feet:

- Inflow into the reservoir For an example see Appendix R of a data sheet for Baingda Dam project. (ac-ft/ month)
- Water supply for irrigation (ac-ft/ month)
- Water supply for other purposes, e.g. public water usage or industry(ac-ft/ month)
- Hydropower outflow (ac-ft/ month)
- Actual evaporation (inch/ month)
- Actual rainfall (inch/ month)
- Spilled (ac-ft/ month)
- Storage balance (ac-ft)

This information is available for all dams and reservoir operated by ID. From the day the construction starts, data on rainfall and evaporation is present. Data from before 2006 is not digitized and is still in Burmese language.

The following can be concludes from this validation process:

- For Nawin South – during the monsoon season, the supplied water for irrigation is larger than for the dry season. This means the cropping pattern differs largely from the simulated one. The peak in gross supplied water is half-way the monsoon season. During the dry season, the supplied water is much larger than the *actual* irrigation, but smaller than the *proposed* irrigated area;
- The same relation is found in the storage balance of the reservoir. The monitored storage balance is between the *actual* and *proposed* output.
- The evaporation losses from the reservoir are over 5 times higher than the simulation series (5 million m^3 during the peak of the simulation versus 25 million m^3 for the monitored ones). This seem to be very high. The water spread area could be underestimated in the simulation, but this difference is large. The observation technique of the evaporation could be incorrect.
- For the Baingda reservoir, the inflow during the dry season, so the base flow, is not included in the monitored data sheet, where in the simulation, there is a base flow.
- The monitored inflow has a clear peak at the onset of the monsoon season, which is not visible in the simulated output. It is possible that the peaks cannot be modelled correctly.
- The storage balances matches for the *proposed* irrigated area.
- However, the gross water supply is over 2 times larger than for the *proposed* situation, and way larger for the *actual* situation.

For the Thapanzeik Reservoir, the same observations are made for the inflow except for that here clearly a base flow is observed.

The simulated storage balances for most reservoir show that in the first few years the reservoir is filled up, after which the demand is too little to drop the water level till the dead storage level. For the proposed area, this looks much better, but individual validation or calibration for the outflow can be necessary.

6.7. **Hydropower**

For all hydropower dams the power capacity was able to collected from both literature as well as from the data collection phase in the field. The designed energy production is found in only literature, see Table 6.7.1. The following table shows the validation between the expected yearly produced energy and the simulated energy. The total designed energy production for the example hydropower projects below is 225,660 GWh of which 129,724 GWh has been simulated (57%) in the water demand and allocation model. The hydropower dams were simulated without inserting a firm demand per time step. This production is purely a result of the natural flow conditions. Since for most large scale hydropower dams, the exact location, full and dead storage capacity has not been provided during the field trip, these parameters were determined based on reference projects in the region for which this data was known. The firm demand or electricity production demand over the seasons is a factor that depends on the available storage capacity and the inflow into the reservoir. More details about the reservoir and the turbine is required for the validation of the hydropower dams.

As can be seen, most dams produce approximately half of the designed energy, were others are not even close to that number. Remarkable is that for a few dams, the simulated power production is higher than designed value.

Table 6.7.1 Validation of produced hydropower – Planned and simulated. – The designed production is found in (ADB, 2009; Burma Library, 2012) – The numbers is red represent the power capacities which were not provided by (DHPI, 2013)

Name	***River-Basin***	***Power Capacity [MW]***	***Designed energy production capacity (GWh/year)***	***Simulated energy production (GWh/year)***	***Simulated energy production (%)***
Chibwe (Chipwi)	Ayeyarwady	3,400	17,770	10,829	61
Chipwi Nge	Ayeyarwady	99	599	372	62
Dapein 1 (Tapein 1)	Ayeyarwady	240	1,070	336	31
Dapein 2 (Tapein 2)	Ayeyarwady	140	775	312	40
Gaw Lan (Kulant)	Ayeyarwady	100	552	122	22
Hkankwan (Khamkawn)	Ayeyarwady	140	769	8	1
Htamanthi (Tamanti)	Ayeyarwady	1,200	6,685	0	0
Khaunglanphu	Ayeyarwady	2,700	14,730	-	-
Kun	Ayeyarwady	60	236	78	33
Laikzar (Laza)	Ayeyarwady	3,000	10,440	12872	123
Lawngdin (Laungdin)	Ayeyarwady	570	3,131	0	0
Mawlaik	Ayeyarwady	800	3,310	2157	65
Myitsone	Ayeyarwady	6,000	30,860	15683	51
Nam Tabak 1	Ayeyarwady	141	920	479	52
Pisa (Phizaw)	Ayeyarwady	2,000	11,080	126	1
Sedawgyi (upper)	Ayeyarwady	60	134	0	0
Shweli 2	Ayeyarwady	520	2,814	2343	83
Shweli 3	Ayeyarwady	1,050	3,500	3260	93
Shwezaye	Ayeyarwady	660	2,908	4836	166
Tongxingiao	Ayeyarwady	340	1,746	916	52
Wutsok (Wusauk)	Ayeyarwady	1,800	10,140	422	4
Wuzhongze (Htonshin)	Ayeyarwady	320	1,757	0	0
Yenam	Ayeyarwady	1,200	6,650	200	3

Yeywa (upper)	Ayeyarwady	280	1,330	487	37
Dagwin (Mae Sariang 2)	Salween	792	5,422	0	0
Hutgyi (Hat Gyi)	Salween	1,360	7,325	9670	132
Kun Long (upper Salween)	Salween	1,400	7,338	4654	63
Mai Tong (Tasang)	Salween	7,000	35,446	29414	83
Mantong (Man Taung)	Salween	225	924	140	15
Nam Hka	Salween	210	937	719	77
Nam Pawn (Hseng Na)	Salween	45	234	226	97
Nam Pawn (Htu Kyan)	Salween	105	551	568	103
Nam Pawn (Pa Laung)	Salween	105	536	576	107
Nam Pawn (Tha Hkwa)	Salween	150	776	-	-
Wei Gyi (Mae Sariang 1)	Salween	4,500	29,217	26922	92
Bawgata	Sittaung	168	500	52	10
Nancho (RoR)	Sittaung	40	156	108	69
Pa Thi Dam	Sittaung	2.2	8	3	38
Middle Paung Laung Dam	Sittaung	100	267	322	121
Phyu Dam	Sittaung	40	1,512	132	9
Thauk Ye Khat (2)	Sittaung	120	605	380	63

6.8. Validation data – river discharges

The validation of the simulated river flows and water availability is done with discharge series collected from the Department of Meteorology and Hydrology (DMH), MoT. The location of the measuring stations are shown in Figure 6.8.2 and Table 6.8.1. In this figure, the watersheds of the major rivers are shown, relative to the country borders. The water level (WL) measuring stations are from ID, MoAI, but no time series were collected during the field trip. They can in a later stage of the modelling process be used to see differences in flow pattern variation. First the reservoirs and irrigation areas should be validated. For the validation, the simulated flows are extracted from the present day situation

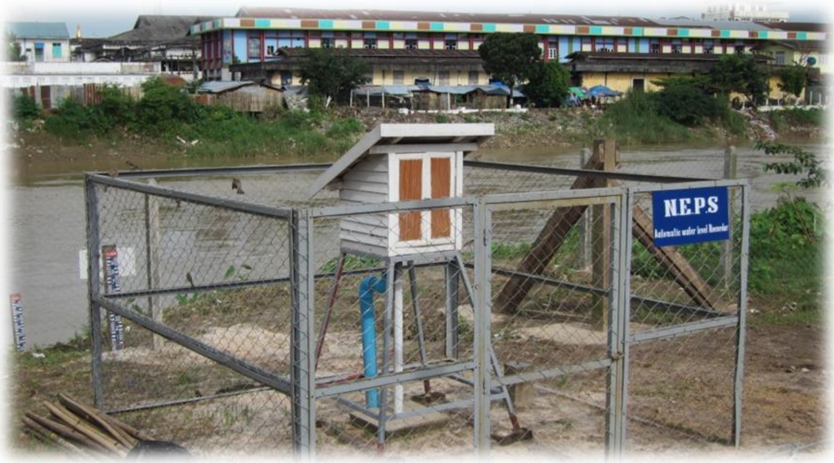


Figure 6.8.1 Automatic water level gauge station – Bago City – Bago River – Owner: Japanese researcher – This is not a station of DMH. - Photo: Rens Hasman

In Appendix S the monitored time series are shown from the first year they were operational up till 2010.

Figure 6.8.2 Monitoring Stations in the major rivers – River Basin boundaries – States& Divisions

Table 6.8.1 Discharge and water level measuring stations main rivers by DMH and ID – Discharge (Q) and Water Level (WL)

Name of station	*River basin*	*Latitude (N)*	*Longitude (E)*	*WL/ Q*	*Drainage area (km²)*
Myohla	Sittaung	19.417	96.283	WL	
Ohnpin	Sittaung	18.817	96.433	WL	
Byetkale	Sittaung	18.683	96.450	WL	
Zalokegyi	Sittaung	18.600	96.517	WL	
Taungpu	Sittaung	18.517	96.583	WL	
Kwinchaungwa	Sittaung	18.233	96.683	WL	
Innpalwe	Sittaung	17.917	96.850	WL	
Thuyethamein	Sittaung	17.767	96.883	WL	
Zalun	Ayeyarwady	??	95.217	Q	348,061
Pyay	Ayeyarwady	18.8	95.217	Q	346,225
Aunglan	Ayeyarwady	19.367	95.217	Q	340,390
Magwe	Ayeyarwady	20.133	94.917	Q	335,567
Chauk	Ayeyarwady	20.9	94.833	Q	323,630
Katha	Ayeyarwady	24.167	96.333	Q	77,942
Myitkyina	Ayeyarwady	25.367	97.35	Q	41,803
Nyang-U	Ayeyarwady	21.2	94.917	Q	39,248
Sagaing	Chindwin	21.867	95.983	Q	120,193
Monywa	Chindwin	22.1	95.133	Q	110,350
Kalewa	Chindwin	23.2	94.3	Q	72,848
Mawlaik	Chindwin	23.633	94.417	Q	69,339
Homalin	Chindwin	24.867	94.9	Q	43,124
Hkamti	Chindwin	26	95.370	Q	27,420
Hsipaw	Dokehtawady	22.6	97.3	Q	11,798
Hpa-an	Salween	16.8412	97.617	Q	295,270
Maudauk	Sittaung	17.917	95.85	Q	26,758
Toungoo	Sittaung	19.417	96.283	Q	14,660
Shwegyin	Sittaung	17.917	96.533	Q	1,747

In the delta area, around five measuring stations are located under the control of DMH, which are not included in the schematisations of the river basins since they are not relevant for the calibration and validation of the model since the lowest point in the model is upstream of the delta area. The reason for this is that the model settings and the digital elevation model are to course for the little elevation in this region to define clear sub catchments. Stations in the Ayeyarwady Delta: Henzeda, Maubin, MyaungMya, Ngawin.

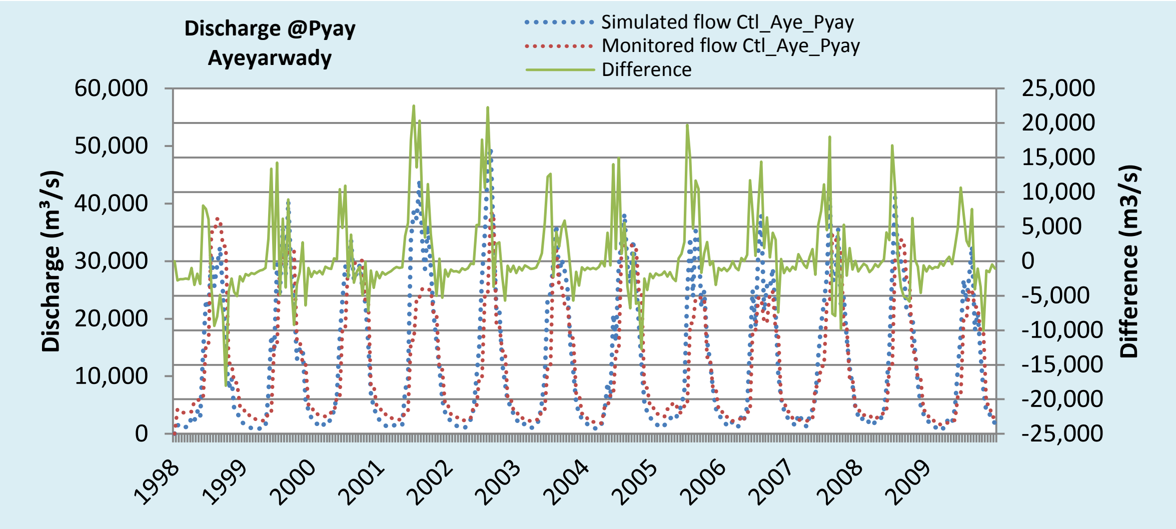


Figure 6.8.3 Simulated versus monitored flow at Pyay – Ayeyarwady River, most downstream control node in the model. The green line shows the difference between the monitored and the simulated flow

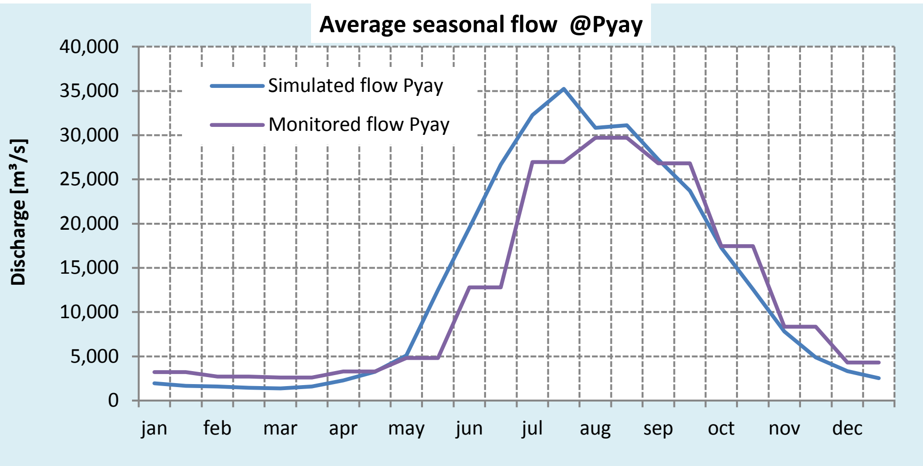


Figure 6.8.4 Average simulated versus monitored flow over the simulation period 1998 – 2009.

The seasonal variation of the fresh water resources for the Salween river basin is computed for the simulated data set. The base flow during the dry season is much smaller than the flow in the monsoon season, Figure 3.10. The red line in the figure represents the relative standard deviation for each time step. As can be seen, during the monsoon the variation over the years is less than during the dry season and start of the monsoon. This analysis is done for the simulation period, 1998 – 2009, which gives the available fresh water over the seasons as in Figure 3.11.

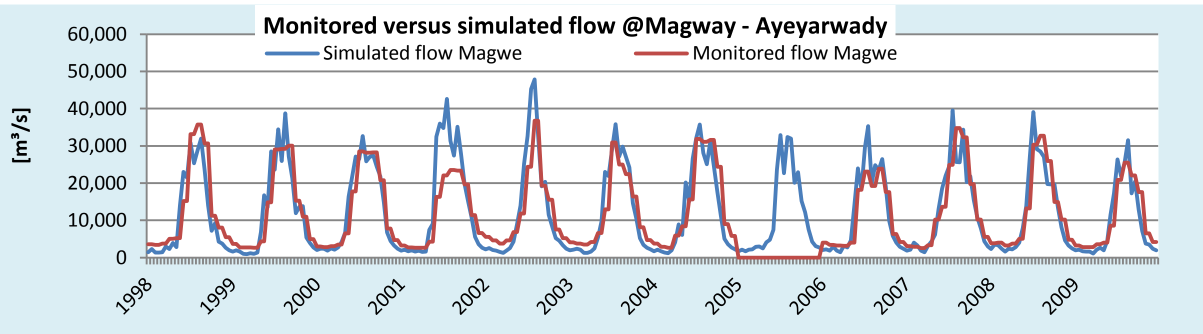


Figure 6.8.5 Monitored versus simulated flow @Magway – Ayeyarwady – for period 1998 -2009

6.8.1. Rating curves - Myitkyina

The monitored flow (source: Department of Meteorlogy and Hydrology (DMH), Ministry of Transport (MoT)) at the city of Myitkyina looks odd when comparing with the downstream flow at Sagaing. The discharges at Sagaing, and in particular the base flow, have been compared with the discharge series of Nyaung U, Magway and Pyay and this seem to be correct. As can be seen in Figure 6.8.6, the base flow at Myitkyina is higher than the base flow at Sagaing. Sagaing is located approximately 500 km downstream of Myitkyina.

- A possible explanation for a higher base flow upstream is the inflow into the river banks from the river, so called influent river. This occurs when the water table is lower than the water level of the river, and the soil of the banks are permeable enough. However, the differences (green line in Figure 6.8.6) indicates difference of up to 2000 m^3/s, which is unlikely to happen. The station of Myitkyina is important for the assessment of the flow, since it is located just downstream of a region where large scale hydropower dams are planned.
- The time- lag between the flow between Myitkyina and Sagaing is approximately 5 days, so a little shift in the series of Sagaing should be added.
- The actual evaporation during the dry season is high (~5 mm/day) is to be expected (~20 m^3/s). However, this is not significant to explain the difference.
- Another explanation which is also found during the development of a Sobek model for the Ayeyarwady River Basin, that the rating curves used for the determination of the discharges have not been updated with the changing bed profile of the river, and thus another relation between Q (discharge) and h (water depth at location x).

Another example is the cumulative flows monitored at Sagaing (Ayeyarwady) and Monywa (downstream of the Chindwin) here larger than the flow at Nyaung-U, just downstream of the confluence with the Ayeyarwady and the Chindwin. See also Appendix S.

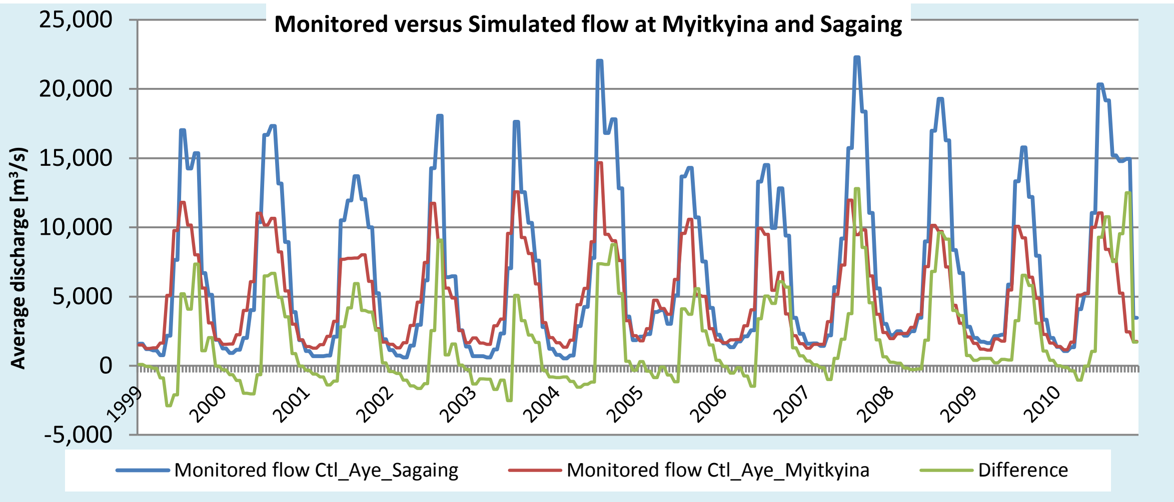


Figure 6.8.6 Average discharges at Myitkyina and Sagaing – Monitored 1999 -2010

The average simulated and monitored flows at Magway are as good as the same, but the base flow of the monitored series is slightly higher than the simulated flow.

Table 6.8.2 Monitored versus simulated average flow at Magway station – averaged over the simulated period 1998 to 2009 – Ayeyarwady River . There is little deviation between to two average discharges

Simulated flow Magwe (m³/s)	*Monitored flow Magwe (m³/s)*
12,761	12,579

6.8.2. Salween river discharge series

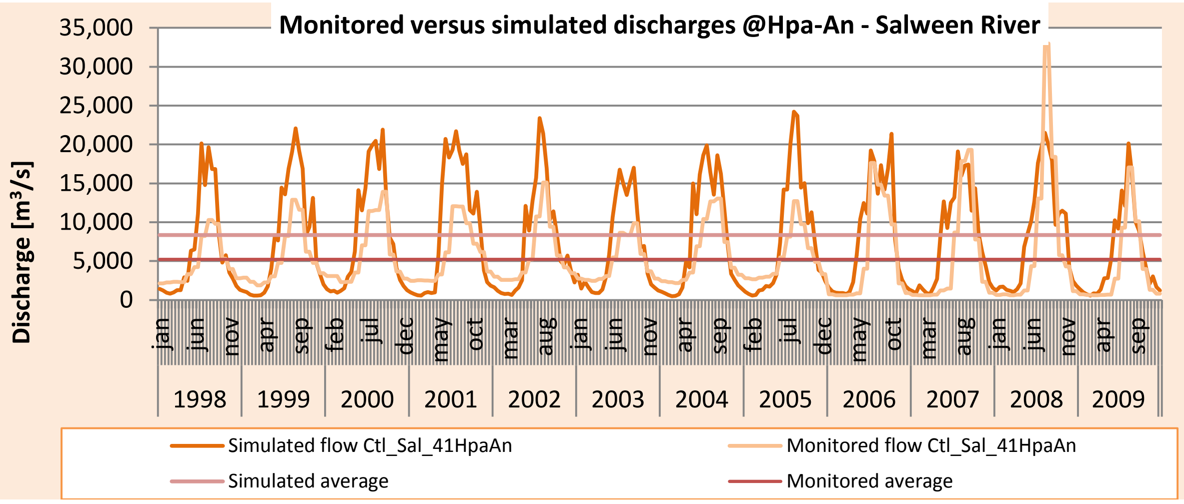


Figure 6.8.7 Monitored and simulated discharge Salween @Hpa-an 1998 – 2009

The monitored discharge at Hpa-an has a remarkable drop in the base in the year 2006. From the start of observation in 1966, the base flow looks to be overestimated, when the data from 2006 and on are compared with the simulated data, assuming the simulated data is more accurate. Since the difference in base flow for the Ayeyarwady River between the simulated and monitored flows, Figure 6.8.3, it is assumed that the used model is a good representation of reality, and the monitored/ observed flow till 2006, is incorrect. In Figure 6.8.8 the difference between monitored and simulated is shown, were from 2006 (end 2005), the difference becomes smaller. The used rating curves at the gauging station is possibly adjusted in 2006. It assumed that the simulated series better represent the flow in the Salween, since the base flow looks reliable.

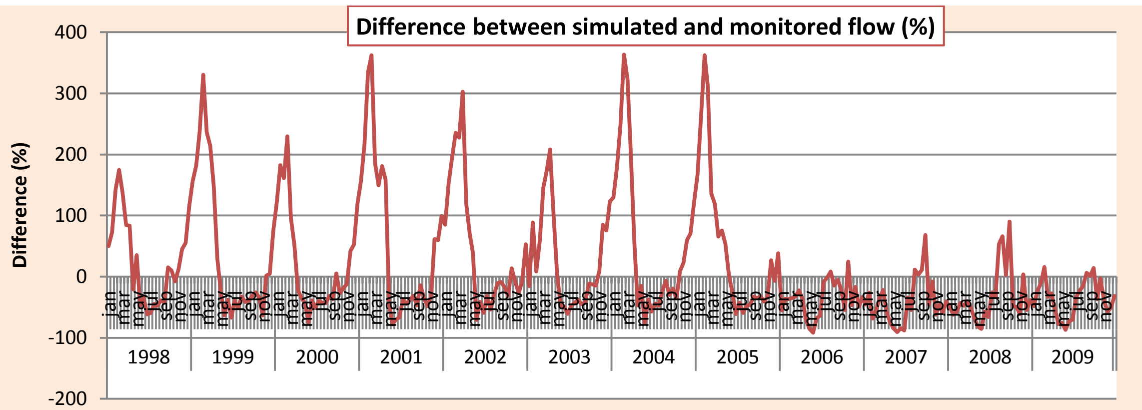


Figure 6.8.8 Difference in discharge between simulated and monitored flow (%) (Monitored/ Simulated ratio)– 1998 to 2009

6.8.3. Sittaung

The simulated versus the monitored data for two locations in the Sittaung River (Toungoo and Madauk) are shown in the figures below. The big differences with the monitored are observed at the base flow for Toungoo and Madauk station. The difference between simulated and monitored becomes larger till the end of the simulation period for Madauk station, which might be explained by a changing bathymetry and a non-adjusted rating curve. The match between monitored and simulated high water levels at Madauk is larger than for Toungoo. It is assumed that Toungoo station matches with the monitored flow.

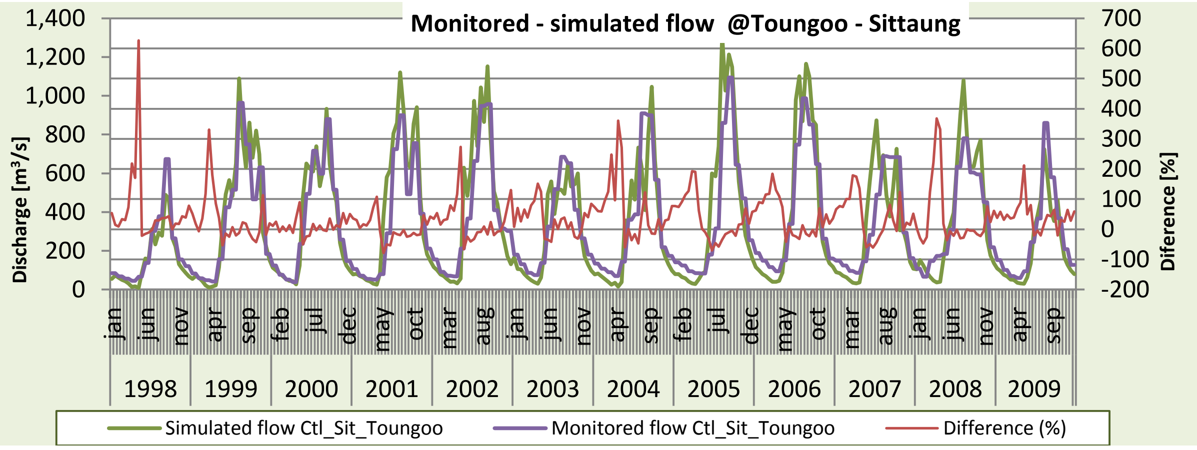


Figure 6.8.9 Monitored and simulated discharge @Toungoo, Sittaung – 1998 -2009

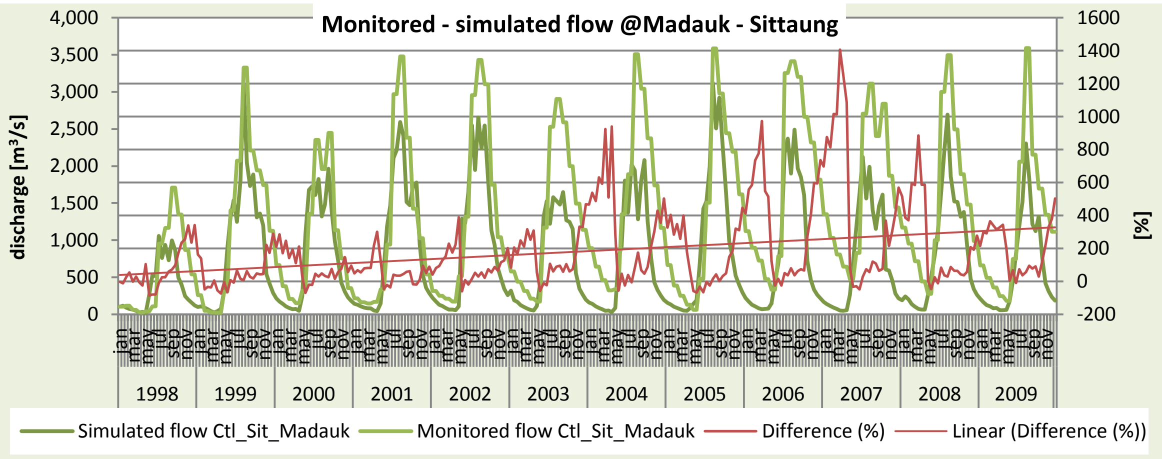


Figure 6.8.10 Discharge @Madauk, Sittaung – simulated and monitored – 1998 -2009

The cumulative yearly flow at Madauk and Toungoo varies largely. The annual flows for the simulated flow at Toungoo look to match with the monitored ones, where for Madauk the monitored flow is much larger than the simulated flow, see Figure 6.8.11. The water released from the reservoirs in the Sittaung Basin might explain some shift in the base flow, but the relative difference is pretty big compared to the storage capacity available to increase complete base flow. The difference however in the cumulative yearly flow is much larger for the monitored flow than the simulated flow, where the Toungo series are better alike.

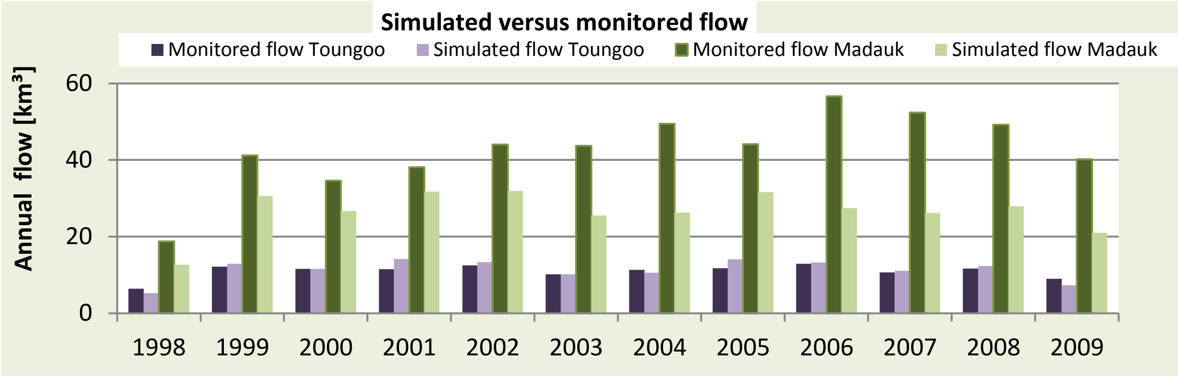


Figure 6.8.11 Monitored and simulated annual discharges @Toungoo and Madauk – for the simulation period 1998 -2009

6.8.4. Bago River

The first three years of the simulation the simulated flow and monitored flow do not differ much compared to the last 7 years. Remarkable is the base flow that increases suddenly in the monitored flow, where the simulated flows remain constant. This can be explained that the ZaungTu dam, including hydropower, upstream has been completed in 2000 and the hydropower has been operation only after a few years. The model input for the energy demand for the ZaungTu dam is not known, so the firm demand during the dry season is an important parameter for determining the downstream flow.

Calibration of the individual hydropower reservoirs is necessary for the analyses of the of water balance per season. The extra water released during the dry season compared to the situation when no dam has been constructed will have effect downstream, positive or negative.

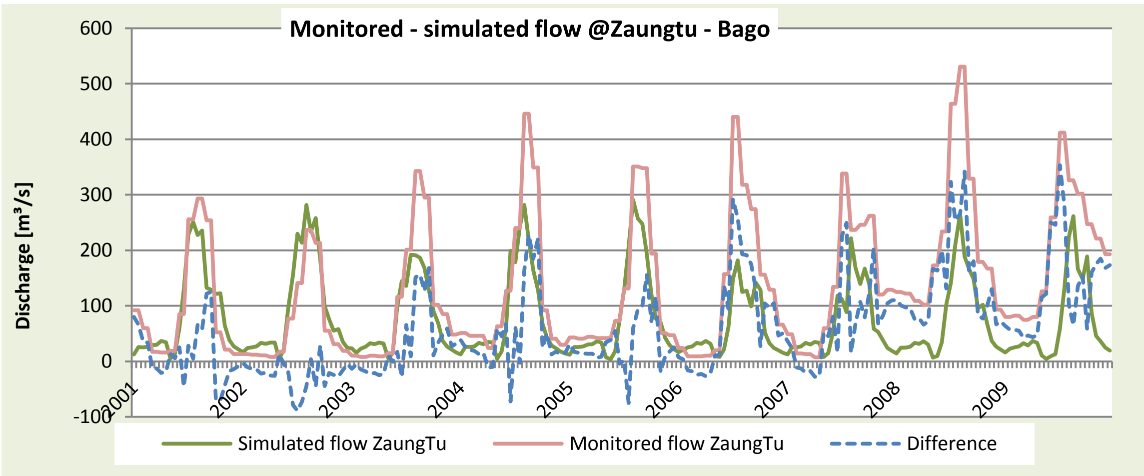


Figure 6.8.12 Monitored versus simulated flow @ZaungTu – Bago

6.9. **In conclusion**

Understanding the way how the monitored data is obtained is part of model (validation) process. The modeler should have a critical eye to all the data that is used for the model assignment. Assuming that all monitored data is useful is not possible. The quality of the discharges, both simulated and monitored, is discussed in the previous sections. What can be concluded is that it is likely that not all measuring stations are operating well. It is possible that still the old rating curve is used and never has been updated. This is a common phenomenon in the monitoring of river engineering practices. It is therefore not possible to validate the simulated time series, especially in the monsoon season, the differences are the biggest.

In Table 6.9.1 an overview is given of the important parameters and the availability, impact and quality. The abbrivations used in the source column, refer to in which department, branch or organisation they can be found/ is responsible for this data.

Source:

- AD – Agricultural Department, MoAI
- ID – Irrigation Department, MoAI
- DMH – Department of Meteorology and Hydrology, MoT
- HB – Hydrology Branch, ID, MoAI
- OpenS – Open Source data, online available
- FAO – Food and Agricultural Organisation
- DHPI, Department of Hydropower, Planning and Implementation, MoE
- *Other* – it is likely that the information of a certain parameter is there, but not identified by the author in which organisation

Each parameter is described by three criteria on the importance of the parameter. Not for every parameter it will be described what actually the status is. This overview is purely to see the variation of the parameters to each other.

Availability	How relative accessible the data is. If it is shared with other stakeholders, freely available online, need to pay for it etc.
Quality	the quality of the data can refer to the completeness, reliability, digitally availability of the data sets. During the field visit, it was concluded that much local that is still in hardcopy and in Burmese langue
Impact	The importance of the parameter on the overall water balance and water allocation assessment

Table 6.9.1 Data availability overview of the parameters in Myanmar needed for an water resources assessment. The availability, quality and the impact or the data is described, relative to the other parameters

Data type	*Source*	*Availability*	*Quality*	*Impact*
	Very Low/ bad (--) ; Neutral(0) ; Very high/ good (++)			
River discharges	DMH	-	+	+
Variable inflow	HB, OpenS	++		
Percolation	AD, FAO, OpenS	+	0	+
Storage capacity	DHPI, ID	+	+	++
Dead storage capacity	DHPI, ID	+	+	++
Actual rainfall	OpenS, AD, ID, DMH, other?	+	+	++
Actual evaporation	OpenS, AD, ID, DMH, other?	+	+	++
ET0	FAO, AD, ID	+	++	++
Area-capacity water level relation	ID, DHPI	0	0	+
Cropping factors	FAO, AD	++	++	+
Drainage	*unknown*	??	??	++
Irrigation efficiency	ID	--	--	++
Pre-saturation requirements	FAO, AD, ID	+	+	0
Start of growing season	AD, ID	0	0	++
Wilting point	AD, FAO	+	+	0
Field capacity	FAO, AD	+	+	+
Cropping patterns	AD, ID	0	+	++
Cross section reservoir (outlet)	ID, DHPI	-	0	+
Expected rainfall	DMH, HB, OpenS	+	0	++
Aquifers	*Unknown*	??	??	+
Soil characteristics	OpenS, AD, *other*	0	+	+
Electricity production demand	DPHI	-	0	+
Seepage (other losses)	ID	0	0	0

7. Socioeconomic development in the Water Resources System in Myanmar *- Future situation*

In the following sections, the future situation of Myanmar's WRS will assessed, and will result in answering RQ3: *How will the water resources system change based on the expected socioeconomic development?* In the first section the development of scenario's are described, which consist of the trends of the development of the socioeconomics and the change of the external factors, such as the climate.

Construction works of a saddle dam at KoDuKwe Resrvoir (November 2013) Photo: Rens Hasman

Since the rapid development of the country will have (a large) impact on the environment and the water resources, the planning for the short, medium and long term is crucial to do this a sustainable way to not destroy the environment or create conflicts between sectors and threaten the food and drinking water security. Predicting the future is impossible, but looking at the possible extremes in the future scenarios, allows planners to adjust to different possible futures. Looking at the extremes of the development trends and possible scenarios, the real future is most likely to within those extremes. Together with knowledge of the behaviour of the present day situation and the impact of the input parameters on the (simulated) WRS, the different future scenarios can be assessed. In the assessment of the future situation of the WRS the development trends are investigated for the different sectors involved. This will give insight in how the water balance on basin scale will change, and what impacts are to be expected on the system or other sectors. In the system description, Appendix O, the development of Myanmar is described.

7.1. Scenarios

The assessment of future situation on a country and regional scale can be done by simulating different scenarios. Each scenario represent an extreme of a future situation that is a combination of both internal and/or external factors. The use of scenarios is often used to show the involved policy makers what the impact is of extreme changes in the system, e.g. sea level rise or industrialisation. The extremes affecting the system are related to both the external (climate) and internal (socioeconomic) factors, where those factors are based in trends or predictions for the long- term, say 50 to 100 years. The external factors influencing the WRS can e.g. be the change in duration of the monsoon, increase of the evaporation etc. For this assessment the changing climate has not been included in scenarios and included in an assessment. The motivation of not including these factors is that the model as it is now has not been validated enough on the local scale. The changing climate is likely to impact the sub-systems and sub-users rather than the full basin. Only the possible effects it would have on the system is discussion section in the last sections. The focus in the assessment of the future WRS are the observed trends in the development of the socioeconomic. So only the horizontal axis is assessed with the models of the river basins. With the outcome of the simulations the impact on the WRS are assessed and discussed. .

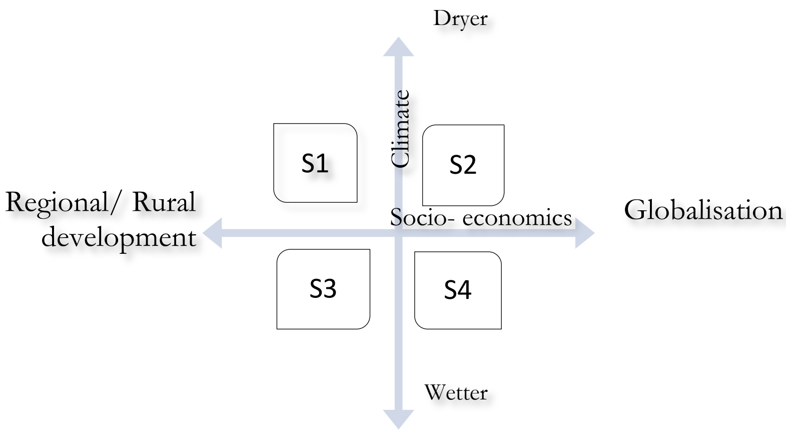


Figure 7.1.1 Scenario development for sketching different extremes in the future of the WRS

7.2. **Climate change**

Despite the fact that the changing climatological conditions are ot included in the scenario development, in the following section the expected change in the climate in Myanmar is described. From NAPA (2012) report, the observed climate variability and change in Myanmar over the last six decades includes the following:

- a general increase in temperatures across the whole country (~08°C per decade), most notably in the northern and central regions;
- a general increase in total rainfall over most regions. Hhowever, with notable decreases occurring in certain areas (e.g. Bago Region), an average increase of 29 mm per decade for whole Myanmar. For Bago region has a decrease of 81mm per decade. The regions of Taninthayi, Yangon, Rakhine, Ayeyarwady and Mon State are longer exposed to the south west monsoon flow and will therefore experience more rain;
- a decrease in the duration of the southwest monsoon season as a result of a late onset and early departure times. Also the onset has become later in the year, and withdrawal earlier this year. The droughts will especially affect the Central Dry Zone – Sagaing, Mandalay and Magway Regions, particular the agricultural land located there(NCEA, 2012); and
- increases in the occurrence and severity of extreme weather events, including; cyclones/strong winds, flood/storm surges, intense rains, extreme high temperatures and drought.

The National Commission on Environmental Affairs is the agency in Myanmar that is responsible for the adaptation framework for climate change in the country. The commission together with the DMH, MoT and United Nations Environment Programme (UNEP) the National Adaptation Programmes of Actions is made which describes the way Myanmar will be affected by climate change and how it can adopt himself (UNEP, 2006).

7.2.1. Projections

Future changes of temperature and precipitation have been estimated for Myanmar using a number of global and regional climate models. For the purpose of the (NAPA, 2012), the predictions from the model "Providing Regional Climates for Impacts Studies" (PRECIS) are reported. The model was conducted using 20 km by 20 km resolution, and operated by the South East Asia System Analysis Research and Training Regional Centre (SEA START RC) using the A2 emissions scenario. The baseline information uses modelled data for the period 1971-2000. The model used data collected at seven stations, assumed to be representative of seven physiographic regions in Myanmar. The projections show an increase in both average temperatures and annual rainfall. Predictions up to 2100 show an increase of 2.8° to 3.5 ° C for all regions and an increase of 1582 mm and 209 mm for the Rakhine coastal region and Eastern Hilly region respectively, see Figure 7.2.1. For the central regions no increase in temperature is expected, but it will experience longer dry periods. (The values for the increase in rainfall are standard deviation values from the respective base years.)

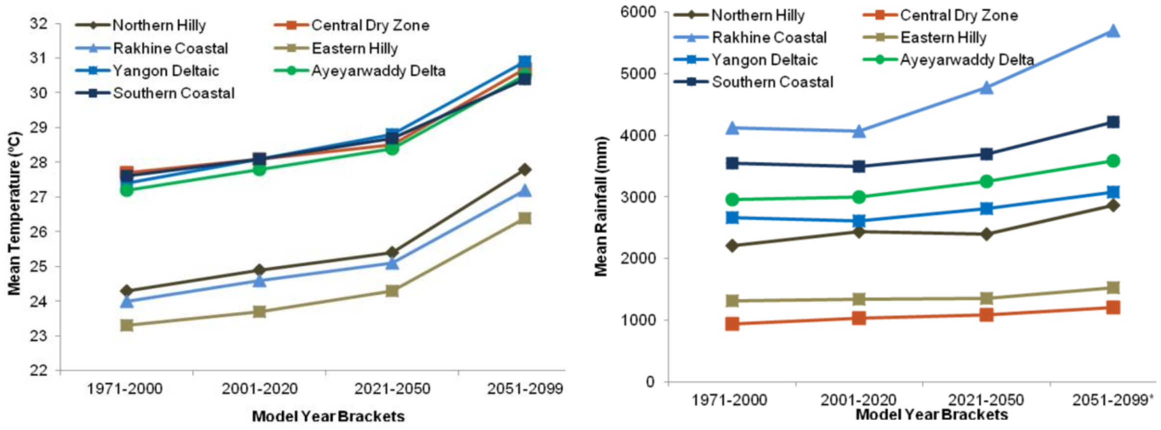


Figure 7.2.1 Climate Change projections of Myanmar, the mean Temperature (2000 - 2100) and average Rainfall (2000 - 2100)

The effect for an increase in rainfall and its intensity is the increase in runoff which leads to an increase in erosion, soil degradation and loss of fertile soils. Also it can damage vulnerable crop and can create flash floods in the lowland areas. From July to October in 2011, heavy rain and flooding in the Ayeyarwady, Bago, Mon and Rakhine Regions/States resulted in losses of ~1.7 million tons of rice(NECC, 2012). The intensity of the rainfall is enhanced during La Niña (opposite phenomena of El Niño), when large areas in the world experience an increase in precipitation. During an increase of the discharges and water levels in the water level, in combination with the increase in development of the area along the rivers and coastal areas, the probability of flooding increases if no proper flood control and protection measures in place. With the help of retention reservoirs in the hilly region and constructions like weirs and good embankments (dikes) can prevent the high discharges from causing damage and possible loss of lifes in the vulnerable areas.

7.2.1. Changing climate

A statistically significant reduction in rainfall amounts in June in recent years, combined with the very high variability in the onset date of the wet season, is likely to impede agricultural production by increasing the risk of drought at the beginning of the rain fed crop cycle. This vulnerability is particularly high in the central part of the Dry Zone including the townships of Natmauk, Kyaukpadaung, Meiktila, Kyaukpadaung, Chauk, Nyaung-U, Taungtha and Mahlaing (McCartney et al.. 2013).

For this assessment the change in water availability or the water resources due to climate change is not analysed quantitatively. Only the changes and the possible impacts on the WRS due to the changes in the climate conditions are discussed. This thus will not include numbers on which the conclusions are drawn.

7.3. **Trends**

For the development of Myanmar's socioeconomic the available online literature, news articles, trends and discussions with stakeholders are used to identify the extremes and impact on the system. The most important sectors to be developed, as explained in the introduction of this report, are the irrigation and energy sector. For an illustration of the planned developed see also (Hasman, 2013; Hulsman & Rutten, 2013) and Appendix O and Q. Two different pathways are defined for the development of the socioeconomics: rural development which focusses on the food security for the own people and rural development; internally oriented to stimulate the country's economy by increasing the collaboration with foreign investments.

Rural development

Myanmar is ranged 149 among 189 on the Human Development Index in 2012. and despite improvement over the last years, still many people suffer from malnutrition and (water born) diseases. Number one priorities on the adaptation priority list are agriculture, early warning systems and forest. Second in the list are public health and water resources. Increase the quality of life by increasing the water availability to the rural people. and increase their health condition, which include the access to safe water and sanitation. are important strategies for the Myanmar government. The Red Cross Myanmar (2013). in Myanmar and the National Adaptation Programme. (NAPA, 2012). has adapted the SPHERE standards handbook on to respond to the humanitarian standards in the country. which includes minimal requirements for water availability and access to safe water. (Red Cross Myanmar, 2013). it also includes access to water during emergencies and natural disasters like (severe) droughts. cyclones. landslides etc. Energy and Industry are listed number 4 on the priority adaptation list.

'Trend 1' – Drinking water security and WASH

One of the main objectives in the rural development and the fight of poverty is to increase to food production on local scale. By this way, the government aims for to employ more people and reduce the poverty rate in rural areas. One of the objectives of NAPA (2012) and FAO, 2010Red Cross Myanmar (2013) is to increase the connections for drinking water and improve the drinking water and sanitation conditions. An increase in the daily use together with a growth in population leads to an increase in water demand for daily use. The ratio between urban and rural population increases, which results to an overall larger domestic demand. The population growth in the rural areas is here assumed to be going faster than the urbanisation rate.

'Trend 2' – Agricultural development

The MoAI has the objective of achieving a surplus in rice production. Other objectives are to achieve self-sufficiency in edible oil and to set up the production of exportable pulses and industrial crops. Irrigation will have to play a major role in the development of Myanmar's agriculture sector (Naing, 2005). One of the main objectives is to increase the agricultural and irrigation productivity to create a surplus in rice and other crops. At the present status, only 20% of the potential irrigated land is exploited, so a lot of land can be used to achieve these goals. The production of food is increasingly more (international) market orientated and a freedom of choice for agricultural production rather than prescribed cropping patterns by the government, (ARCD, 2011). A changing in cropping pattern for different regions and a change in the demand of water is a result of this. The crops cultivated during the summer and winter season are mainly paddy and pulses, but the variation in crops is increasing. The main objectives of the government in the agricultural sector are to produce surplus of paddy for domestic food security and for promotion of exports; to achieve self-sufficiency in edible oils; and to expand production of beans and pulses and industrial crops for exports (ID, 2007; MoAI, 2006). The focus within this assessment is the development of the identified *potential* irrigated area, which means almost the doubling of the current or *actual* irrigated area in the major river basins. The remaining potential (10,2 million in total) has not been identified. It is assumed that the increase of the overall efficiency of the irrigation areas will be increased on the long term for a sustainable use of the irrigation waters. This can either mean the change of irrigation method or the optimisation of the current, irrigation and drainage canal systems.

Globalisation

'Trend 3' – Industrial development

The involvement of foregin investors, exploiting Myanmar's natural resources and the increase of exporting products may result in the number of industrial land. Most development is planned along the coast, Yangon and Mandalay. This increase includes an extra demand of water from the river system. The annual growth is expected to be large, and assumed to be 5% (scenario 1) and 10% (scenario 2) for the long term. The most critical impact of the industrial activities is expected to be the water quality from the drained water of the industrial sides. Water quality calculations are important in the IWRM context but is not included in this assessment. The model however, is capable to also include the water quality. Since the industrial areas are developed near urban areas, the urban population and the daily water consumption is expected to increase. The urban growth rate is higher than the rural growth rate.

'Trend 4' – Energy demand increase

The population growth, development of the economy where foreign investors become more and more important, results in an increase in the demand of electricity production. The economic development is going rapidly in South and Southeast Asia (IEA, 2012b). The neighbouring countries Thailand, Bangladesh and China have a high demand of electricity production, and are willing to develop the huge hydropower potential present in Myanmar. Attracting foreign capital is an important motivation for the government to develop the hydropower dams. At the same time, many of Myanmar's neighbours have very ambitious targets on electrification of their countries (Srivastava L. & Misra, 2007). The export of energy, together with the national increase of electricity demand, results in many planned (large) hydropower dams in the mountainous area of Myanmar. Depending on the storage capacity, most electricity will be produced during the monsoon season, where during the dry season, other sources like gas and coal should be able to meet the demand.

7.4. **Trend 1 – 'Rural development'**

'Trend 1' – Food security and WASH focusses on the increase of the rural development and the drinking water and food security. An increase of the daily water consumption is to be expected in this scenario. The annual growth for both rural and urban areas are variables that are translated into 4 different *realities*. The base case is defined as the public water demand for the current situation where the others each represent the

Table 7.4.1 Cases for the public water demand, including the distribution over urban and rural population, the daily demand per capita, and the expected population growth.

	Water consumption (rural)	*Water consumption (urban)*	*Urban population growth*	*Rural population growth*	*Population growth*
Base	45	95	-		-
Reality 1	75	115	1.5	2	
Reality 2	75	115	2	-	1.5
Reality 3	75	150	2	2	1.5
Reality 4	95	115	-	2	2

Table 7.4.2 Simulated - Public water consumption in the major river basins

River Basin	*Public Consumption Annual average water usage (km³)*				
	Base	Sc1	Sc2	Sc3	Sc4
Ayeyarwady	0.589	268	2.251	1.5765	1.5765
Sittaung, Bago and Myit Ma Hka	0.443	0.631	0.705	0.6266	0.6266
Salween	0958	0.274	0.298	0.2554	0.2554
Myanmar Total	1.1278	308	3.292	2.480	2.480

7.5. **'Trend 3' – industrialisation**

The data about the existing industries and its water consumption is very limited. The planned industrial activities are unknown besides the planned 'economical zones' in Myanmar, see Appendix O. Yangon, Mandalay, Dawai and other coastal regions are still the focus of the development for industrial activities. The water withdrawal at the river mouth does not have in impact on the WRS. It is therefore assumed that the following change in demand for this sector does not impact the WRS for other sectors significantly. The annual increase is therefore assumed to be high for both 'scenarios': annual increase of 5% and 10%. In the table below the increase of the water demand is shown. The two sources below indicate the (FAO, 2010) (source 1) and (UNEP& NCEA, 2006) (source 2). These sources mentioned different numbers of the share of the industrial withdrawal.

Table 7.5.1 Simulated - Public water consumption in the major river basins

River Basin	*Industrial Consumption* *Annual average water usage (km3)*		
	Base	Sc1 (5 %)	Sc2 (10%)
Ayeyarwady	0.212	0.672	3.616
Sittaung, Bago and Myit Ma Hka	006	020	0.106
Salween	002	005	0.027
Myanmar Total			
Source1	0.220	0.545	2.940
Source2	0.284	0.697	3.750

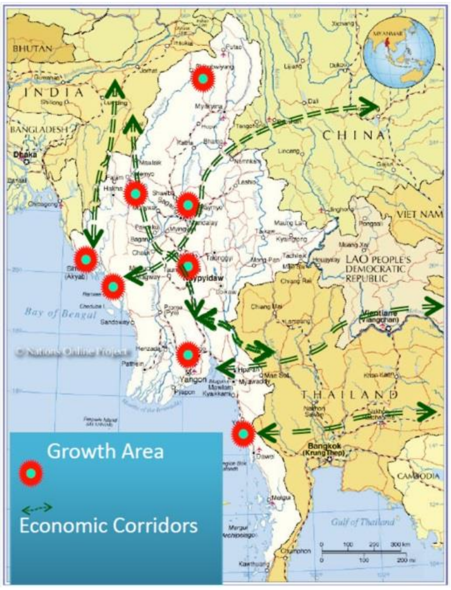


Figure 7.5.1 Economic corridors and zones in Myanmar – Source: (Kudo & Kumagai, 2013)

7.5.1. Domestic water sector

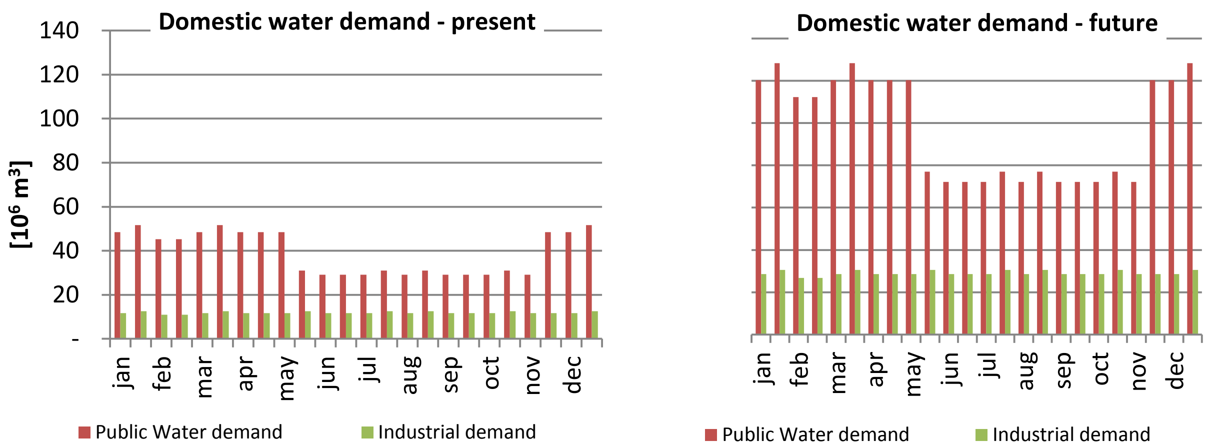


Figure 7.5.2 Demand of the domestic sector – (left) present situation (Base Case) for all major river basins - (right) – Reality 4 for the public water sector and Scenario 2 for the industrial sector

As can be seen, not remarkable increase is to be expected in the overall domestic water in the future situation of the WRS. The overall water utilisation in Myanmar will increase from 4.05% to 4.47%. The increase of the utilisation in the Ayeyarwady Basin is the largest: from 5.98% to 6.83%

Table 7.5.2 Total water use per sector in the major river basins of Myanmar for the full developed irrigation situation

River Basin	*ANNUAL AVERAGE WATER USAGE (km³/year)*					
	Availability fresh water (inflow)	Irrigation demand	**Industrial demand (SC 2)**	Public demand	Total water consumption (km³/year)	Withdrawal total share of availability (%)
Ayeyarwady	412.241	22.656	3.616	1.903	28.175	6.83
Sittaung, Bago and Myit Ma Hka	61.503	2.755	0.106	0.761	3.622	5.89
Salween	265.394	0.908	0.027	0.287	1.222	0.46
Total	**739.138**	**26,319**	3.**75**	**2.976**	33.045	4.47
Withdrawal total (%)		80%	11%	9%	100	

7.6. ‘Trend 4: irrigation development’

For the development of the irrigation areas as are defines as ‘proposed’ irrigation areas, the modelled irrigation area is increased from *actual* to *proposed* and have the characteristics simulated as Case 2 (C2)

- *Actual* – The irrigation areas as they are surveyed in the year 2011 – Total area: <u>1,138,436 ha</u>
- *Proposed* – The irrigation areas as they are planned or proposed to be developed in the future. proposed – full use of the available irrigable areas in the country. These number were either proved by the ID, MoAI, or found in the online data bases of news articles: (Burma Library, 2012). – <u>Total proposed area: 2,249,055 ha</u>. See Table 7.6.1 for the increase of area in procentages.

Table 7.6.1 Increased irrigation area from *actual* to *proposed for the river basins in Myanmar*

	Increased irrigation area (%)
Ayeyarwady	75
Sittaung, Bago, Myit Ma Hka	278
Salween	55
Myanmar	98

Within this strategy there are different cases possible:

- Continue with the current practices – no development of the operation practices – Case 2 - same settings as for the present *actual* situation – the overall efficiency is 38%
- Increase the efficiency of all irrigation schemes (Case 3) – for *actual* or *proposed* situation – Case 3 where the overall efficiency is increased with 25%. The following actions are part of the efficient use of the irrigation schemes
    - by upgrading the irrigation systems to another supply system/ irrigation method. From canals to sprinklers or dripping. With this method the overall efficiency increases drastically. From a field application efficiency of 50% to 80% - 90%. The overall efficiency than is over 80%.
    - increase the skill level of the farmers by capacity building; This will improve the surface water conveyance efficiency factor

- maintain the irrigation (inlet) structures and distribution canals – this will also improve the surface water conveyance efficiency factor
- monitor the actual field status - by monitor the actual field requirements by real time monitoring water used by the crops, and water drained from the irrigation fields

These different measures have been merged into different *cases* that were tested with the models. The numbers of these case do not correspond with the cases used in the sensitivity analysis. They number reference refers to the sequence that these cases were tested and do not have a specific meaning.

- ❖ Base Case – Here, the Default values as used in Ribasim are unadjusted. This is the starting point from the assessment. It more or less describes the ideal situation, where limited losses occur since the overall efficiency is high (~75%). For an irrigation system with open channels, this is a high value, which cannot perform better. The overall efficiency range between 75% - 99% is for fields which used closed, piped, distribution systems: e.g. dripping or sprinkling. This case is not used in the assessment of the water resources, but it used as reference case in the sensitivity analysis
- ❖ Case 1 (C1) – for an open canal system, an efficiency of around 50% is assumed; the 'Feedback on field status' is on ('Yes'), representing a supply driven situation. This case is not used in the assessment, but only shown to shown the starting point of the development of the cases
- ❖ Case 2 (C2) – 'Feedback on field status' is off ('No'), but here the surface water (SW) and groundwater (GW) conveyance factor are decreased to 75% and 90% respectively. Here the overall irrigation efficiency is around 38% during the dry season, and 27% during the rainy season.
- ❖ Case 3 (C3) – Based on C2 where the field application efficiency is increased to 75%. For the overall increase in efficiency see Figure 7.6.1
- ❖ Case 4 (C4) – Base on C2, but here the 'Feedback on field status' is switched on ('Yes')

Table 7.6.2 Different cases for the efficiency statuses of the irrigation areas – These so called 'cases' are applied to all irrigation areas within the river basins. No local variation is applied. Eff = efficiency. *Actual* is for the current irrigation area; *proposed* is for the developed/ increased irrigation areas

	Cases used for the following irrigation areas	*Field application eff. (%)*	*irrigation eff. (dry season) (%)*	*irrigation eff. (monsoon season) (%)*	*Overall irrigation eff. (%)*	*Feedback on field status*
Case 2	Actual_C2 – Proposed C2	50	33	29	31	Off
Case 3	Actual_C3 – Proposed C3	75	50	45	48	Off
Case 4	Proposed C4	75	33	29	31	On

Note about Case4 - The addition in the water and allocation model to select the 'check on field status' one would expect that a more efficient water management is applied. The option suggests that it is the difference between *supply driven* and *demand driven* supply management. The Case 4 has a higher demand at the start of the growing season of the winter paddy, at the end of January. Here the soil moisture is simulated to be lower compared to the other cases. It however is questioned if this large increase in demand from C2 to C4 is realistic, see

Table 7.8.2. Here the demand in the dry season is 3.131 km^3 (C2) and 4,654 (C4) in the Magway and Minbu case area, which is substantial. Since this function is questioned, it is left out from the following assessments.

See Appendix R – Sensitivity analyses for a more detailed description of the cases and parameters influencing the performance of an irrigation area. The results on basin scale are shown in Table 9.4.2, Table 9.4.3 and Table 9.4.4

Table 7.6.3 Change in overall efficiency for the development from C2 to C3 (increase of field application from 50% to 75%)

	Increased efficiency	*Overall efficiency*
Actual/Proposed_C2		32.30
Actual/Proposed_C3	Field application efficiency +25	47.52
Difference (-)		15.22

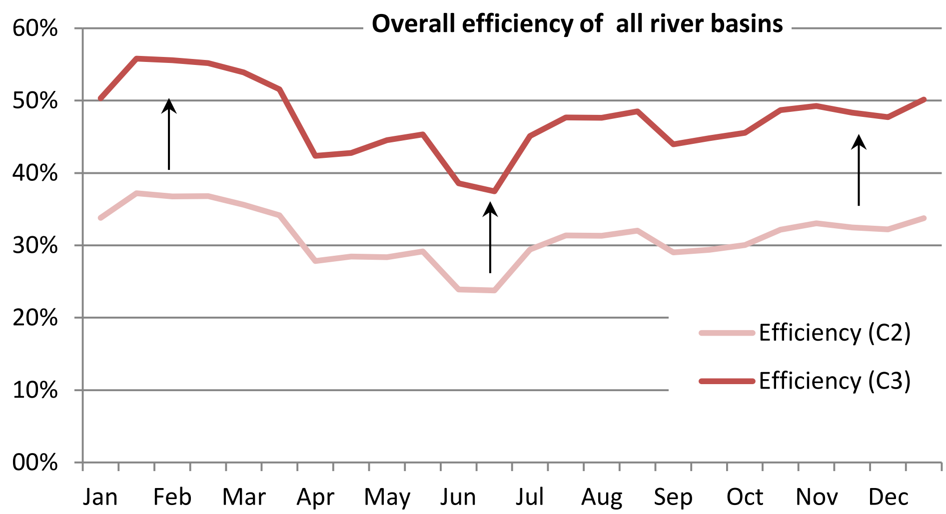


Figure 7.6.1 Seasonal variation of the overall efficiency for the Case Area. This represents the efficiency of all irrigation areas in all major river basins in Myanmar

7.6.1. Simulation outcome of the irrigation cases

It was found that there is a difference between the supplied and water demand. This be explained that the irrigated crops during the monsoon receive their water from the rain, see Figure 7.6.7. In the cropping patterns used, no non-irrigated crops are used. The cropping patterns were provided by ID, MoAI with the note that these were the irrigated crops. For the calculations, the total demand is used, and the actual supplied water. With the water saved more agricultural land can be cultivated. The average cultivated area is calculated to see the benefits for extra cultivated land.

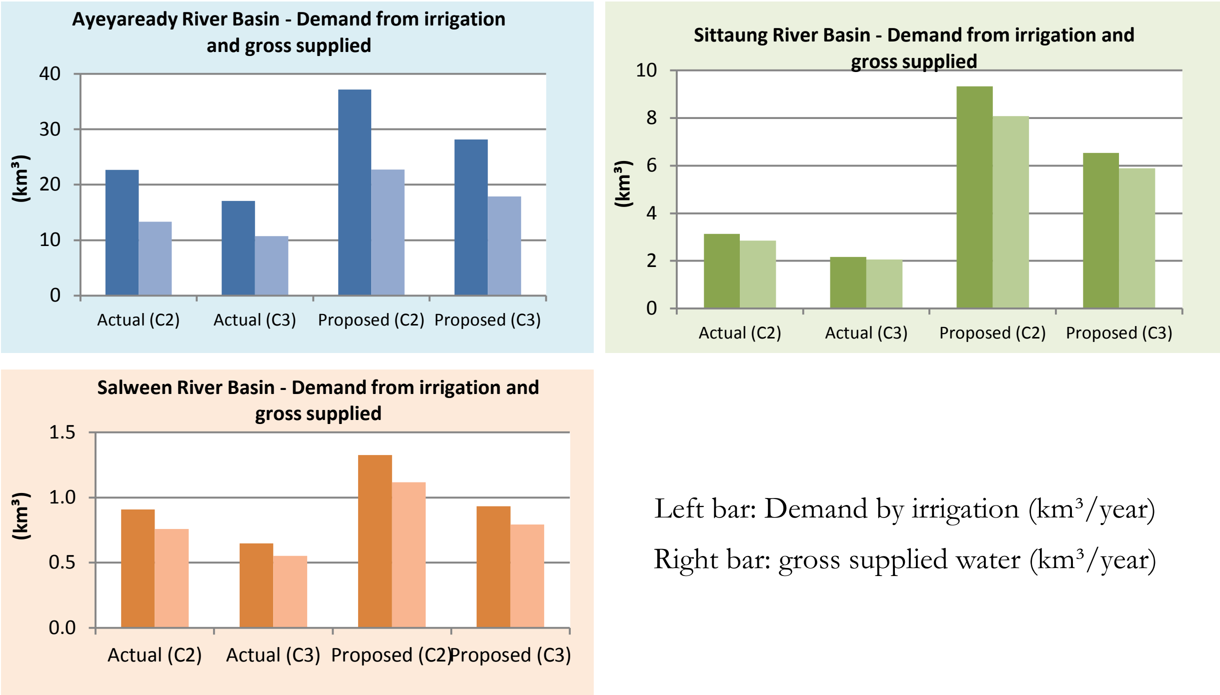


Figure 7.6.2 Demand of irrigation versus gross supplied water for all cases - *actual* and *proposed* - Ayeyarwady River

For the different cases mentioned above, the following overall demand for the irrigation sector is found in the simulations. The reduction per river basin is around the 25%, which is linear with the improvement of the overall irrigation efficiency.

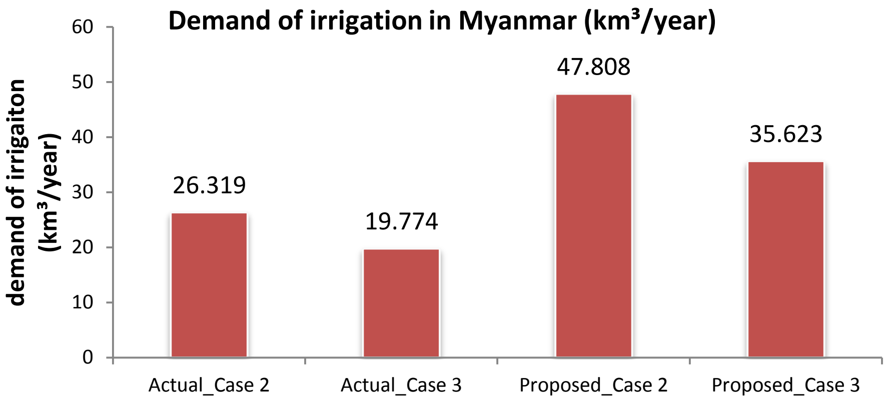


Figure 7.6.3 Water demand of irrigation in Myanmar for the developed situation – for actual_C2, actual_C3, proposed_C2 and proposed_C3

Table 7.6.4 Change in demand (%) for the different development in the irrigation sector for all major river basins – C2 – current management practices (overall efficiency of 32.2%) – C3 (improved irrigation practises (overall efficiency of 47.52)

Development	*Change in overall demand (km³)*	*Water saved (km³)*	*Water saved (%)*	*Decrease in demand (%)*	*Decrease in withdrawal*
Actual_C2 → Actual_C3	26.319 → 19.774	3.58	13.6	24.4	21.2
Proposed_C2 → Proposed_C3	47.808 → 35.623	9.47	19.8	25.5	27.8

Table 7.6.5 Change in demand (%) for the different development in the irrigation sector for all major river basins – C2 – current management practices (overall efficiency of 32.2%) – C3 (improved irrigation practises (overall efficiency of 47.52)

	Change in overall demand (km³)	*Increase in water (km³)*	*Increase in demand (%)*	*Increase in withdrawal (%)*
Actual_C2 → Proposed_C2	20.671 → 47.807	27.136	131	101

Table 7.6.6 Reduction of the demand by increasing the efficiency of the irrigation areas

River Basin	*Decrease of water demand for actual (%) - C2 → C3*	*Decrease of water demand for proposed (%) - C2 → C3*
Ayeyarwady River Basin	25	24
Sittaung. Bago and Myit Ma Hka River Basin	29	30
Salween River Basin	26	30
Myanmar total	**26**	**25**

For the assessment of the available water in the river basins. the available water during the required period is the indicator if the demand can be met. The Case Area is used to see how the present and future system performs for the supply of irrigation waters. The irrigation areas have been split up between river pumps and reservoirs. In the Ayeyarwady River basin river pump schemes are more dominant than in the other river basins. The simulated demand in the dry season for the Ayeyarwady Basin of the irrigation schemes with a surface water reservoir. can be met according to the available storage capacity. For the Salween Basin however. the available storage is too little compared to demand, as can be seen in

Table 7.8.2 at an overestimation of the dead storage. In looks also to be the case for the Sittaung river basin. With the knowledge gained during the model development process. The dead storage in the Sittaung Basin is agreed on to be too high. The new ratio of the dead storage over the full storage with the required demand is 38%, compared with the used 58%).

7.6.2. Utilisation for irrigation demand

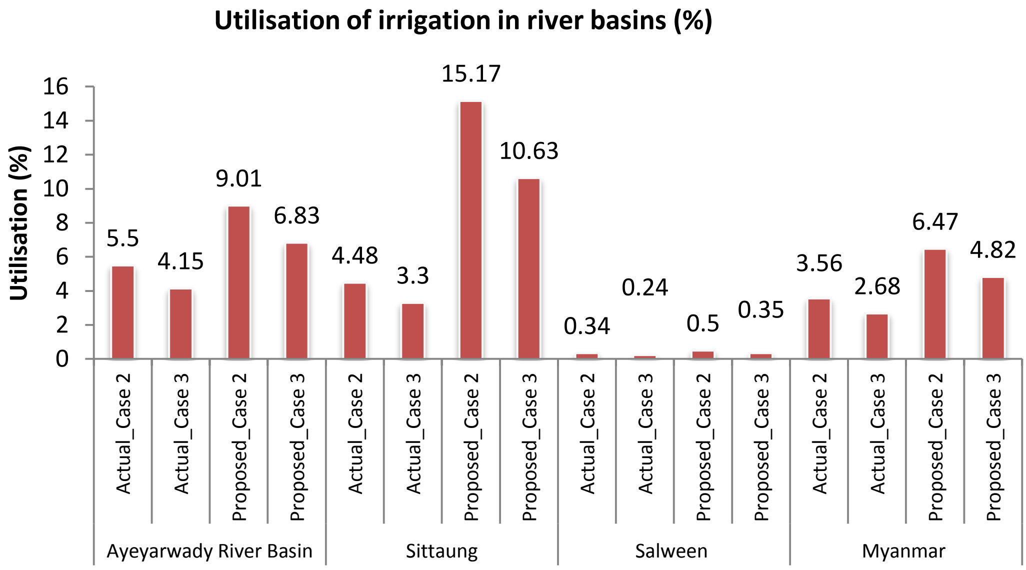


Figure 7.6.4 Utilisation of the irrigation demand in the developed situation – for actual_C2, actual_C3, proposed_C2 and proposed_C3 – Where Sittaung basin includes also the Bago and Myit Ma Hka Basin

The utilisation per river basin for all different irrigation development cases are summarised in Figure 7.6.4. The Sittaung, Bago and Myit Ma Hka Basin have the largest utilisation of the whole country in the *proposed* situations, both Case 2 and Case 3. In none of the situations the utilisation of the irrigation becomes larger than the threshold of 20%, resulting in a limitation for economic development (UN, 1997; UNESCAP, 1998).

Total irrigated area is the full capacity of irrigation field. However not all area is in use, depending on the cropping pattern – the area cultivated is the amount of land that received sufficient water to cultivate the crops. In the graph below the cultivated area for Myanmar total and per river basin is shown.

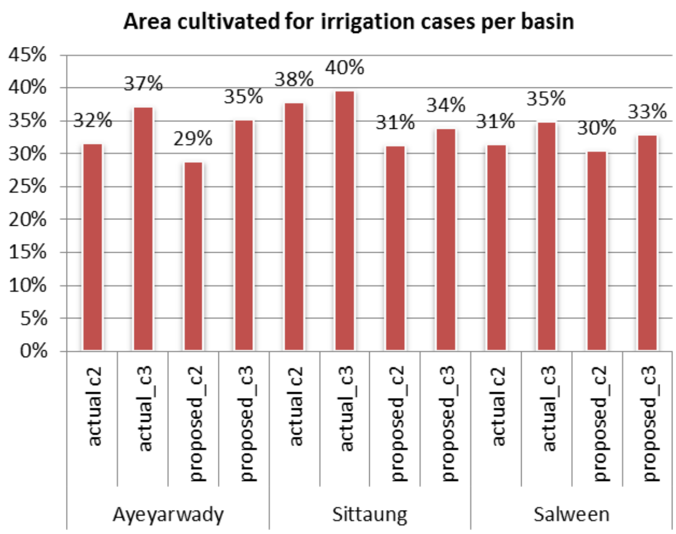


Figure 7.6.5 Area cultivated total per river basins – for actual_C2, actual_C3, proposed_C2 and proposed_C3

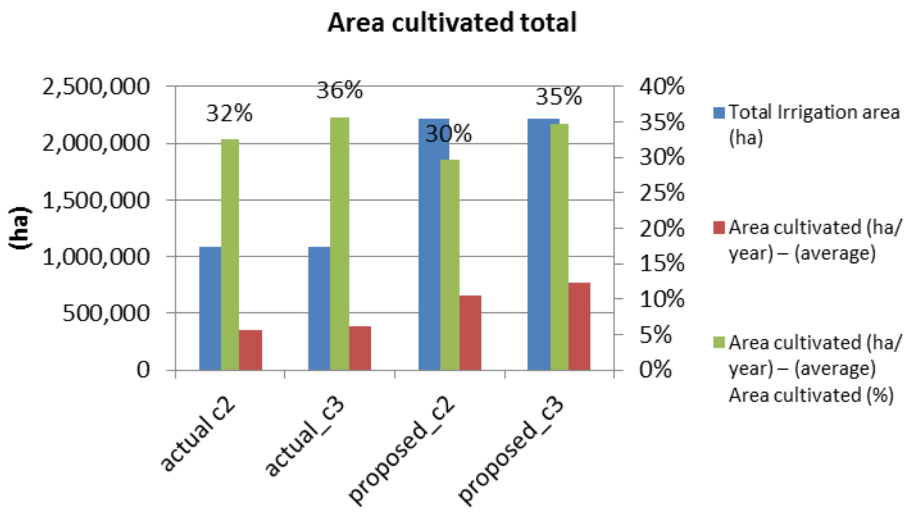


Figure 7.6.6 Area cultivated total for all river basins – Total irrigated area is the full capacity of field. But not all area is in use, depending on the cropping pattern – the area cultivated is the amount of land that received sufficient water to cultivate the crops

Table 7.6.7 Improvement of the (average) cultivated areas per river basin

	Ayeyarwady (%)	*Sittaung. Bago. Myit Ma Hka (%)*	*Salween (%)*
Actual C2 → Actual C3	15.00	3.50	9.6
Actual C2 → Proposed C2	37.70	680	33.62
Proposed C2 → Proposed C3	17.96	7.70	7.5

Table 7.6.8 Decrease of demand for the *actual* and proposed *irrigated* area per river basins. C2 – current management practices (overall efficiency of 32.2%) – C3 (improved irrigation practises (overall efficiency of 47.52)

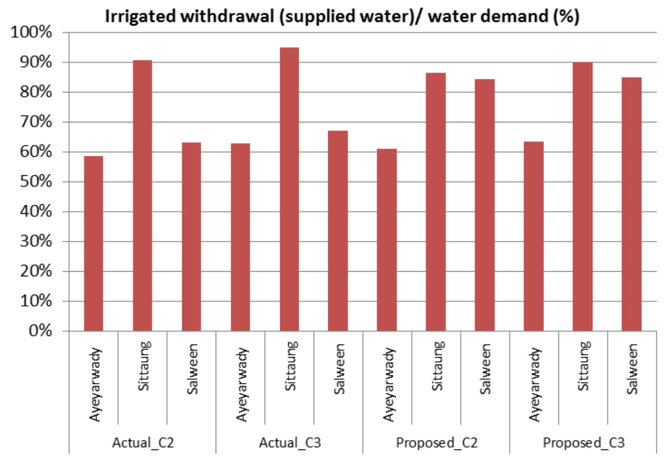


Figure 7.6.7 Irrigated withdrawal (supplied water)/ water demand (%) for the major river basins. There is little variation observed with the ratio's for every river basin

Table 7.6.9 Reduction of gross water supplied water to irrigation areas for different cases

Case Area	*Gross supply*	*Increase/ Reduction (%)- compared to 1) actual 2) C2*	*Cultivated land (ha)*	*Increase cultivated land %*
C2_actual	5348.4	-	1.226.473	
C2_proposed	7438.2	+ 39.1 (1)	1.765.637	44
C3	6123	- 17.7 (2)	1.923.256	8.9
C4	6903	- 7.2 (2)	1.784.073	1

7.7. Water Scarcity

See for the water scarcity levels Table 5.2.1. For the proposed irrigation the scarcity levels are 9.9% and 5.4% for the yearly inflow, and 23.5% and 15.8% for the available storage.

Table 7.7.1 Scarcity level for the Minbu and Magway area. – The scarcity levels (%) are for the simulated inflow (left) and for the available storage capacity (full storage – dead storage capacity)

Region	*Yearly inflow (km3)*	*Storage capacity (km3)*	*Demand from network (km^3)*		*Scarcity level (%) – proposed*		*Scarcity level (%) – actual*	
			proposed	*actual*	*Inflow -*	*Storage*	*Inflow -*	*Storage*
Minbu	7.576	3.199	0.753	0.387	9.9	23.5	5.5	12.1
Magway	1.474	0.500	0.079	059	5.4	15.8	4.5	11.8

The scarcity levels in Table 5.2.1 are may be determined by the available inflow in the total area in the area plus all the irrigation in the area. In the simulation only the bigger reservoirs and irrigation areas are included. Therefore. the scarcity levels are a little bit lower than the ones from the UNEP report. However. the available water in the Ayeyarwady. also during the dry zone. is assumed to be sufficient to fulfil the remaining demand. The average monitored low-flow at Magway. is around 2800 m^3/s. where the lowest recording discharge is 2140 m^3/s. which occurred in 1995. The water scarcity in thus more of a local problem. where the lack of proper infrastructure is unable to supply the water. than it is of the lack of overall water availability due to physical conditions. The accessibility of ground water resources was not included in this quick analysis. It may be concluded that in the present water scarcity. for both regions. no severe water scarcity is observed. but when all developed irrigation areas are operational. the storage capacity can be of a limiting factor for both regions.

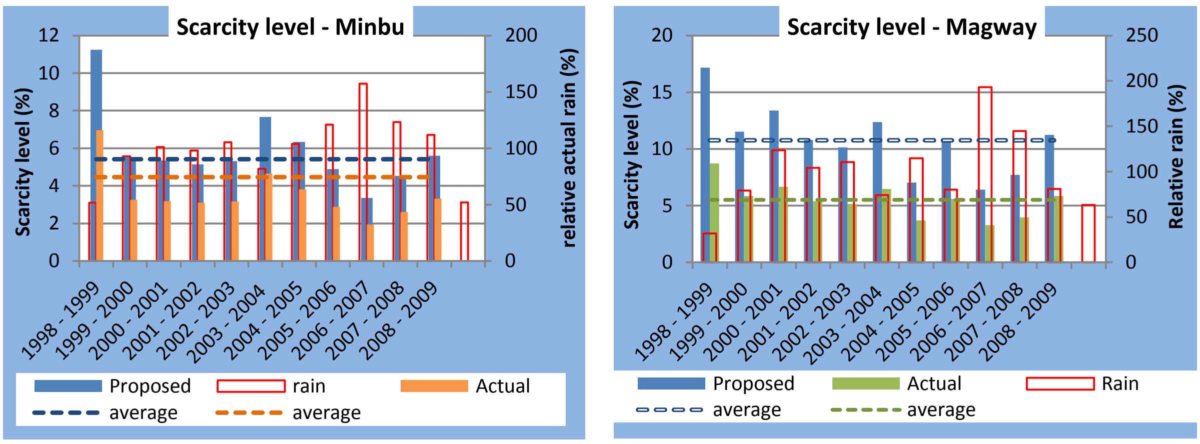


Figure 7.7.1 Scarcity levels for the simulation period 1998 to 2009 – Minbu and Magway area

The water scarcity level for the *proposed* situation is critical for the available storage in both Minbu and Magway region. They can be marked as moderate water scarcity. The available inflow downstream of a reservoir is not included in this calculation. This flow however is assumed to be insignificantly small; only the inflow into the reservoirs.

The shortage during the dry-season for the Case Area (C2_proposed) is 1,431.9 million m³ and 526.8 million m³ for C3_proposed. That is reduction of 905.1 million m³.

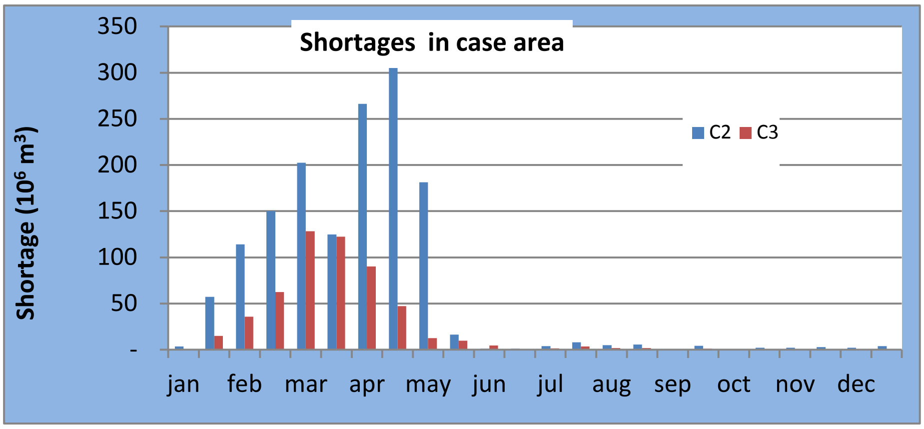


Figure 7.7.2 Total Shortages per time step – C2_proposed and C3_proposed

7.7.1. Water scarcity and domestic water consumption

The domestic water consumption is assumed to be 10% of the total water withdrawal in the region. When this is added up to the demand of the irrigation sector, the following water scarcity levels are found, see Table 7.7.2 .

Table 7.7.2 Scarcity level for the Minbu and Magway area. including the domestic water sector – The scarcity levels (%) are for the simulated inflow (left) and for the available storage capacity (full storage – dead storage capacity)

Region	*Yearly inflow (km³)*	*Storage capacity (km³)*	*Demand from network (km³)* <u>*proposed*</u>	<u>*actual*</u>	*Scarcity level (%) –* <u>*proposed*</u> *Inflow -*	*Storage*	*Scarcity level (%) –* <u>*actual*</u> *Inflow -*	*Storage*
Minbu	7.576	3.199	0.753	0.387	10.9	25.9	5.6	13.3
Magway	1.474	0.500	0.079	0.059	5.9	17.4	4.4	13.0

7.7.2. River pumping station

For the assessment of the river pump irrigation areas the simulated flow at Magway is used as a reference for the available river flow. Namely most river irrigation schemes are located in the Central Dry Zone and along the Chindwin and Nu, Ayeyarwady and other tributaries. Magway is the lowest point for the clustered of rivers pumps in schematisation for the Dry Zone region. The water demand of the current river irrigation stations are low compared to the available river discharge, see Figure 7.7.3, with tops a ratio of 7% at the end of the dry season. However, when all proposed irrigation is developed and the current irrigation practises are still applicable (*Proposed_C2*), than the ratio even becomes 17% at the end of April. which is not lowest part of the flow. see Figure 7.7.3. For the C3 the peak is dropped to 11%.

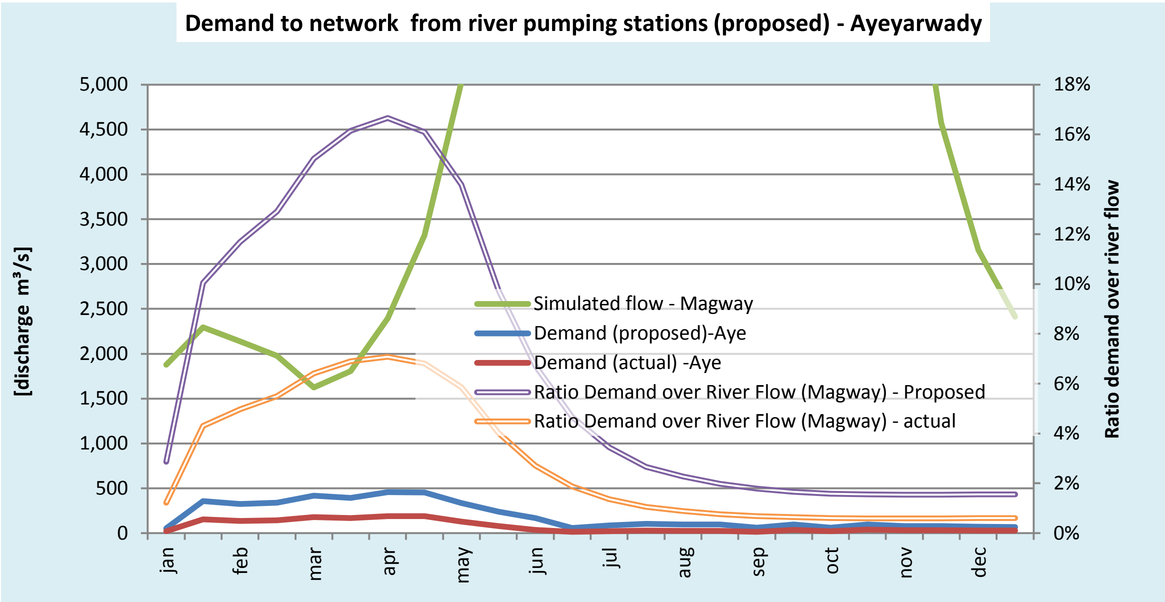


Figure 7.7.3 Demand to network from river pump stations in the Ayeyarwady River Basin

The critical point is observed at the beginning of April, were for the proposed irrigation areas, the river discharges is the lowest. The ration of river irrigation demand over river flow is than 17%. This however, will be noticeable when indeed all irrigation areas are in use. Especially when the overall efficiency of all irrigation increases of the irrigation schemes, so less drainage flows are to be expected. This will have a consequence for the base flow in the river. See also section 7.9.

7.8. Future WRS

In Appendix L the water demand for all water resources is shown. For the domestic water sector, both public and industrial, the maximum withdrawal or demand is used to assess the maximum water utilisation in the future situation of Myanmar. For the irrigation sector, both developed (C2) and developed + improved (C3) are included. For the major river basins, the largest utilisation that can be expect is 7.4%, see .The total

Table 7.8.1 Total water demand of all important stakeholders in the major river basins of Myanmar (km^3/year) and the overall utilisation of the water resources

	Total water demand (km^3)	*Withdrawal total share of availability (%)*
Ayeyarwady		
Developed (proposed_C2)	42.719	10.363
Developed + improved (proposed_C3)	33.717	8.179
Sittaung. Bago and Myit Ma Hka		
Developed (proposed_C2)	10.14	16.487
Developed + improved (proposed_C3)	7.348	11.948
Salween		
Developed (proposed_C2)	1.651	0.622
Developed + improved (proposed_C3)	1.260	0.475
Total		
Developed (proposed_C2)	54.849	7.421
Developed + improved (proposed_C3)	42.664	5.772

The distribution of the total water demand per sector is shown in the figure blow. As can be seen, the industrial demand is larger than the public demand. In the current case, the share of the industries is small.

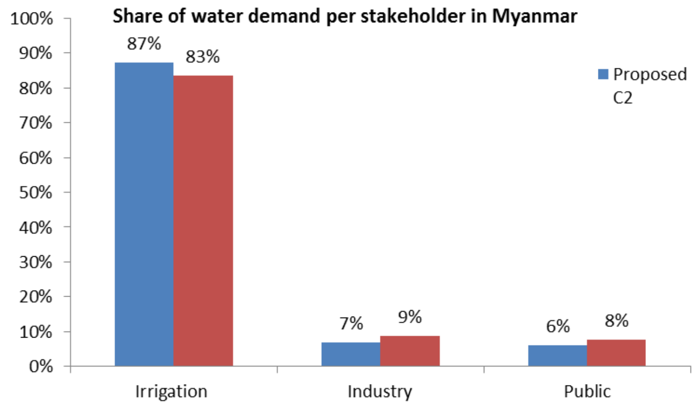


Figure 7.8.1 Water withdrawal per sector relative to the total withdrawal for the major river basins

Table 7.8.2 Available storage capacity versus demand of irrigation during the dry season – Proposed C2 – the available storage (including planned dams) has capacity to increase the irrigation area in the Ayeyarwady basin, but is

	Demand in dry season (million m^3)	*Full storage (million m^3)*	*Available storage (million m^3)*
Ayeyarwady	17,345		
River pumps	9,560		
Reservoirs	7,785	35,194	25,099
Case Area		5,784	3,962
Proposed C2	3,131		
Proposed C3	2,853		
Proposed C4	4,654		
Sittaung. Bago and Myit Ma Hka		9,962	4,046
Actual	2,511		
Proposed	6,214		
River pumps	438		
Salween	481	851	214
Proposed C2	1,016		
Myanmar irrigation reservoirs total		46.,07	29,359

In the same Appendix the share of the water users per basin are described but they are similar to the overall distribution. The cumulative demand for all the basins and future irrigation scenarios are graphically represented in Figure 7.8.2. As can be seen, the demand of the irrigation areas relative to the available water at that time of year is substantial. Especially for the Sittaung,. Bago and Myit Ma Hka basin, where for the proposed or developed situation under the current irrigation practices is even up to 80% (including the domestic demand). The available storage capacity then is crucial to meet all the demand in the basin. For the Ayeyarwady river basin, with a water demand of up to approximately 50% of the water available water up till that point of year, is not as critical as it is in the Sittaung, Bago and Myit Ma Hka basin, but still rather substantial.

To meet the demand in the Sittaung, Bago and Myit Ma Basin, the ratio of dead storage/ full storage should be at least 37% to be able to supply the demand in the dry season of the current cropping patterns, mainly dominated by winter paddy.

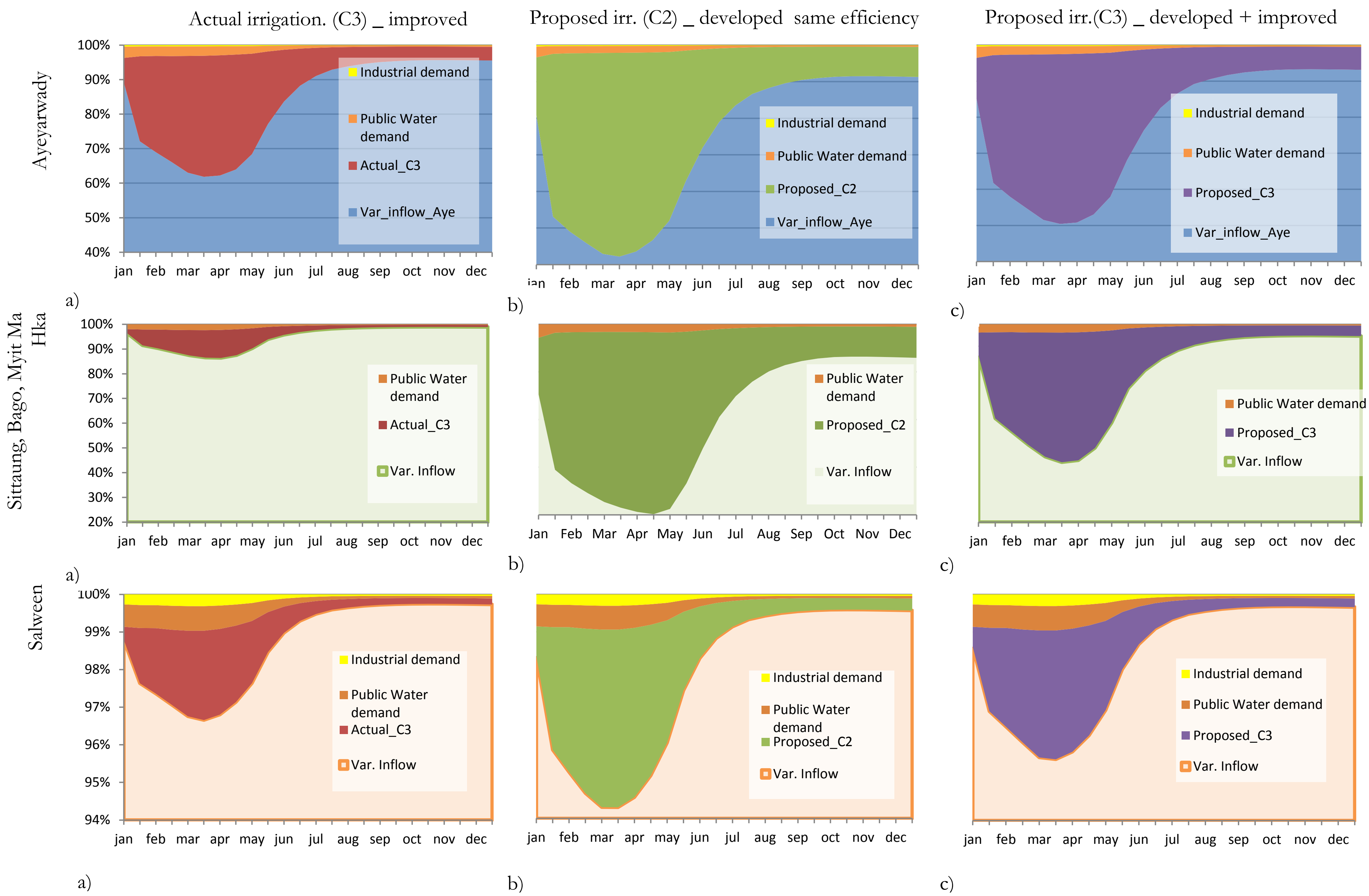


Figure 7.8.2 Cumulative demand per sector versus inflow into the river basin (10^6 m^3) – future situation

7.9. Impact of the changing environment on the WRS

Combining the different trends into the possible extremes with the future development of the water resources system based on the socioeconomical development trends the following overall conclusions can be drawn for the WRS. For both the *Global* and *Rural* trends a *low* and

Table 7.9.1 Total water use versus availability (2011) – Source water availability and withdrawal for other countries: (AQUASTAT, 2014)

Country	*Population (2013)*	*Freshwater availability (km³/year)*	*Total water withdrawal (km³/year)*	*Availability m³/cap/year*	*Withdrawal share of availability (%)*	*Withdrawal m³/cap/year*
Present day situation	55.69	739.14	29.970	13,272	4.05	538
Global						
Low	85.02	"	23.762	8,694	3.2	279
High	121.87	"	26.815	6,067	3.6	220
Rural						
Low	85.02	"	50.509	8,694	6.8	594
High	121.87	"	38.321	6,067	5.2	314

7.10. **Irrigation development impact on downstream water flow**

The water consumption of the irrigation water by the summer and winter crops have affect on the water outflow of the basin. For the example of the developed and improved cases (C2 and C3), the change in river outflow is shown in the figures below. The Ayeyarwady and Sittaung, Bago, Myit Ma Hka River basins have the largest fraction of planned irrigation areas relative to the available water resources. The irrigation areas in Salween Basin are very small compared to the available river flow, and are therefore left out of this analysis. In the figures a delay is observed in the present day situation (with *actual C2* as irrigation) between the variable inflow into the basin, and the outflow. This is the water stored in the surface water reservoirs. When the irrigation areas are extended to proposed (*proposed C2)*, a higher demand of water is to be expected, resulting also in a higher consumption. This can be observed during the winter season (half- January till beginning of May), especially during the period end of February till May. For both basins, the increase of irrigation areas results initially to a higher base flow. For the Sittaung River Basin this change can be better observed since the increase from actual to proposed irrigation area is large (ration actual/ proposed ~ 27%).

When the overall efficiency will be improved, less water is drained from the irrigation fields, but is consumed by the crops. In Figure 7.10.5 clearly the variation in base flow can be observed for the different irrigation cases for the Sittaung Basin. For the *proposed C3* (developed and improved) the flow is even lower than the natural flow. For

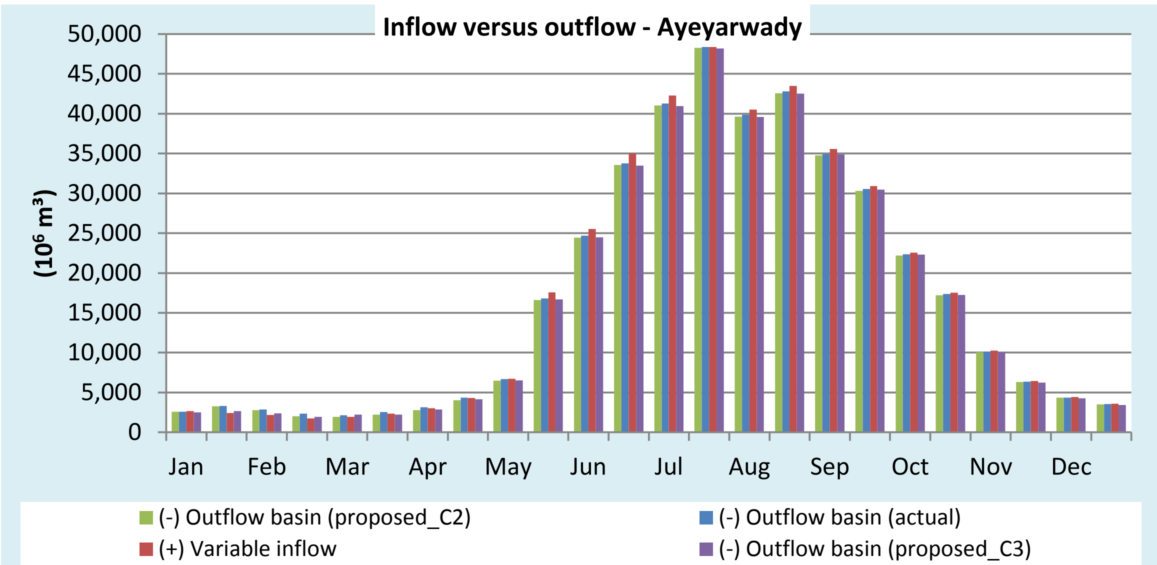


Figure 7.10.1 Half-monthly inflow versus outflow of the Ayeyarwady Basin for the actual (C2), proposed (C2) and proposed improved (C3)

The decrease in the base flow can have huge negative effects for the water quality as a result of salinisation in the delta area. The mass flow of fresh water from the river is in balance of the salt water from the sea somewhere within the delta. When the river discharge becomes lower, this boundary between salt and fresh water is expected to move more upstream, affecting the water quality for the users along the river e.g. farmers, drinking water and industries. Salinity intrusion already affects the water quality for farmers in the delta region, which is an important region for rice production in the country. This analysis is done for the average situation, so for a dryer year, this affect will be more crucial, since also the upstream users will try to store more water to use. So less drainage water and base flow is then to be expected.

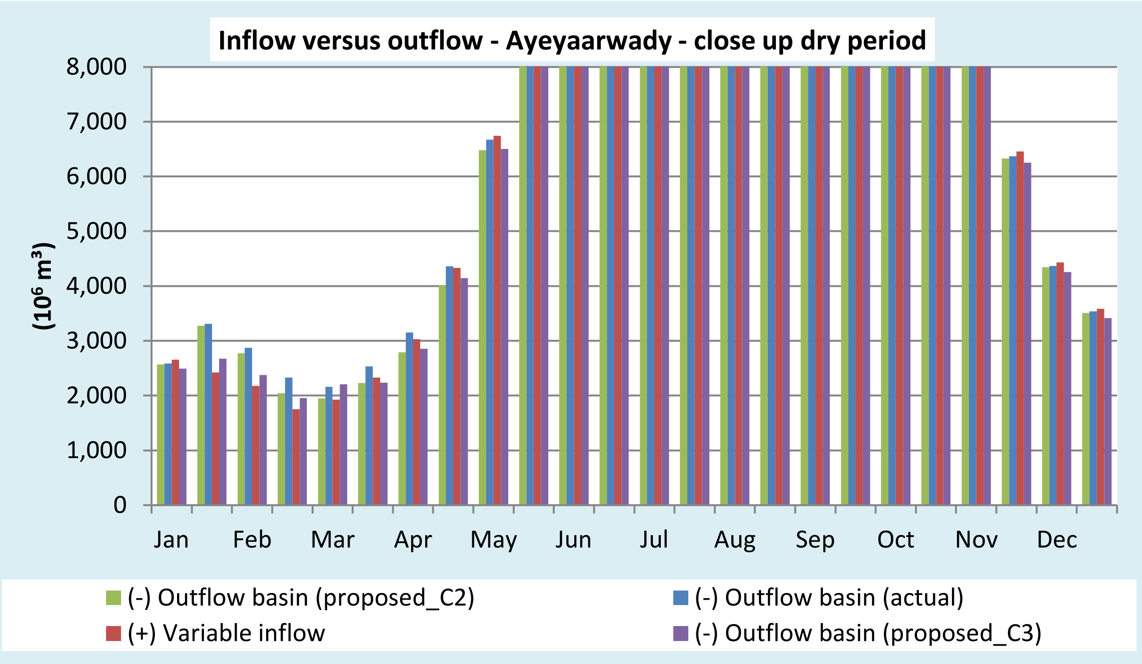


Figure 7.10.2 Half-monthly inflow versus outflow of the Ayeyarwady Basin for the actual (C2), proposed (C2) and proposed improved (C3) – Close up of the dry season. It can be observed that the base flow decrease when irrigation efficiency are improved

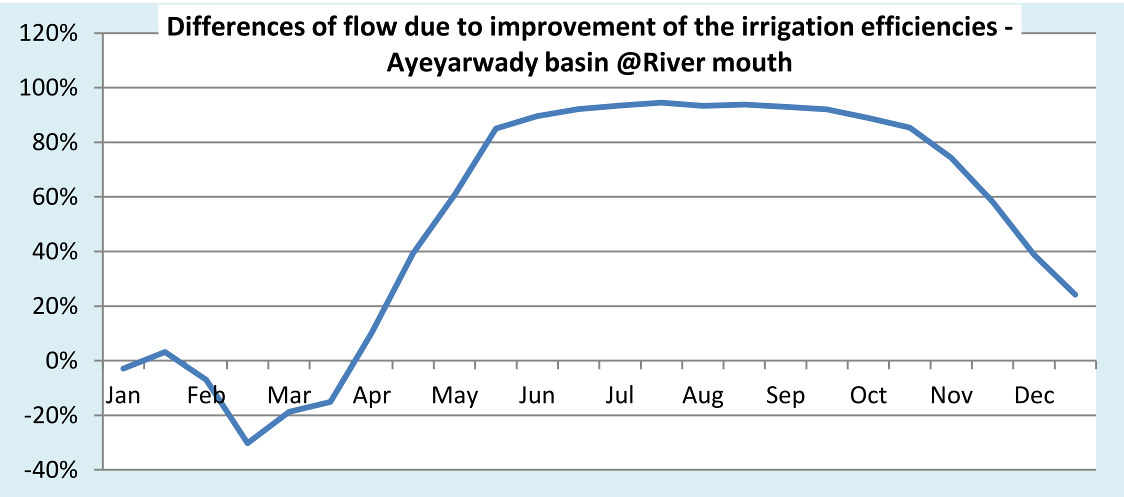


Figure 7.10.3 The differences in the outflow at the river mouth of the Ayeyarwady River between the *Proposed* C2 and improved irrigation efficiencies *proposed C3* – At the base flow in the dry season the largest difference is a reduction of 30% at end of February

The decrease in flow during the dry season might also have in impact on the water level and thus on the navigability of the rivers. The changes in drainage should be translated to discharges to see if the effects are noticeable.

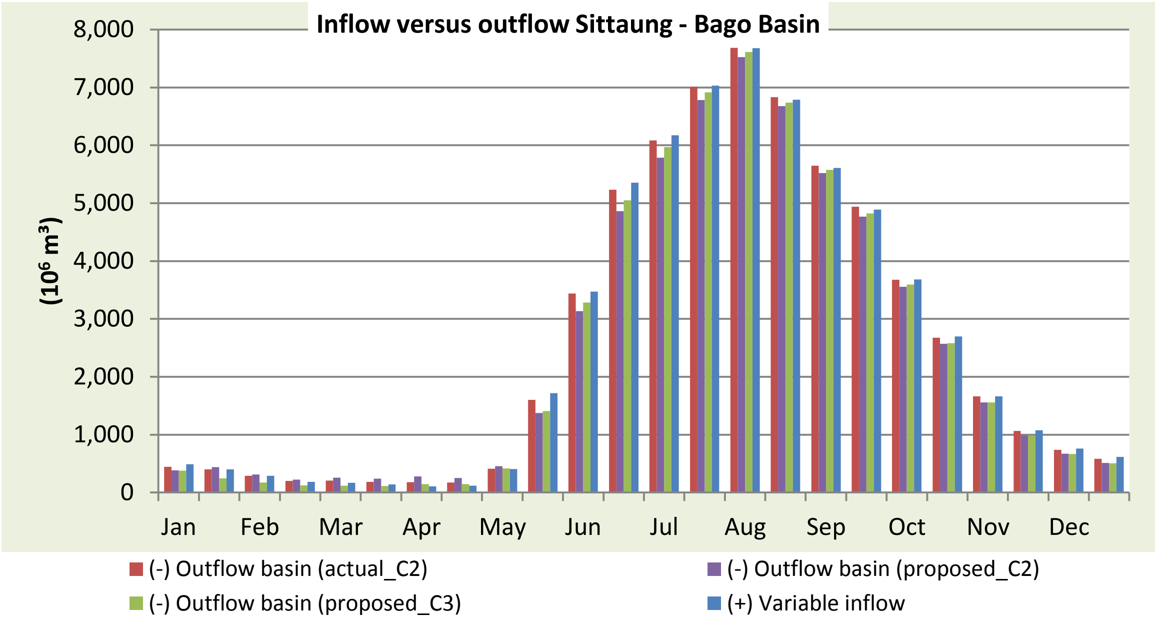


Figure 7.10.4 Half-monthly inflow versus outflow of the Sittaung, Bago and Myit Ma Hka Basins for the actual (C2), proposed (C2) and proposed improved (C3)

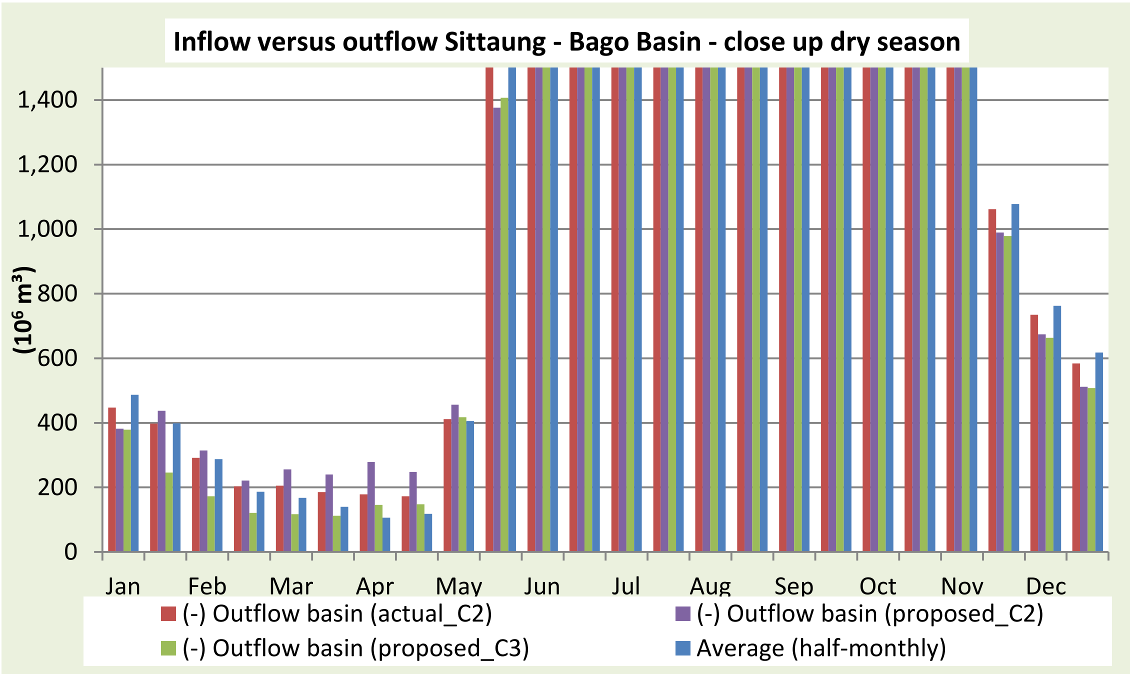


Figure 7.10.5 Half-monthly inflow versus outflow of the Sittaung, Bago and Myit Ma Hka Basins for the actual (C2), proposed (C2) and proposed improved (C3) – Close up of the dry season. It can be observed that the base flow decrease when irrigation efficiency are improved

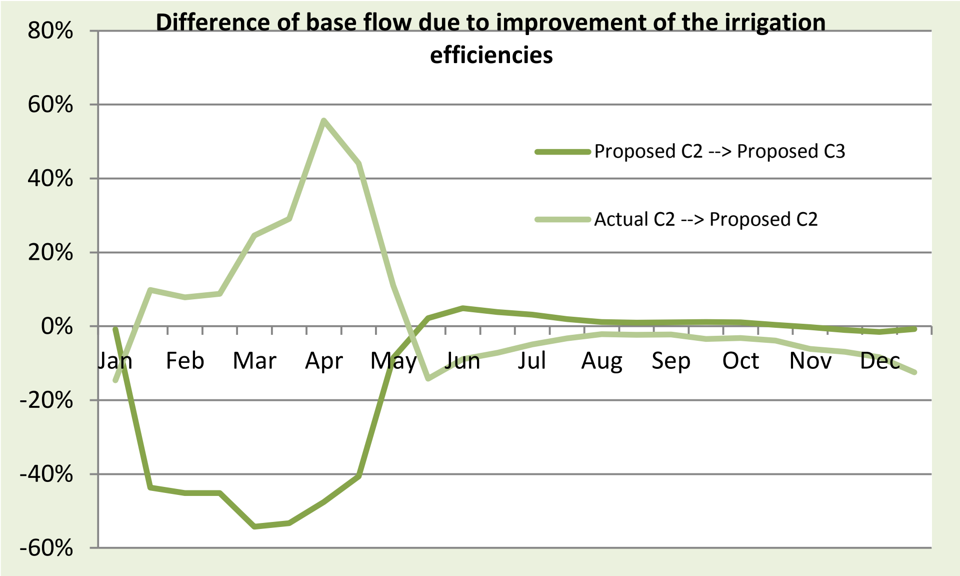


Figure 7.10.6 The differences in the outflow at the river mouth of the Sittaung, Bago, Myit Ma Hka River between the *Actual* C2 and improved irrigation efficiencies *proposed C2*. The increase in irrigation area, also results in more release from the reservoirs in the dry season, with an increase base flow as a consequence. The differences in the outflow at the river mouth of the Sittaung, Bago, Myit Ma Hka River between the *Proposed* C2 and improved irrigation efficiencies *proposed C3* – At the base flow in the dry season the largest difference is a reduction of 54% beginning of March.

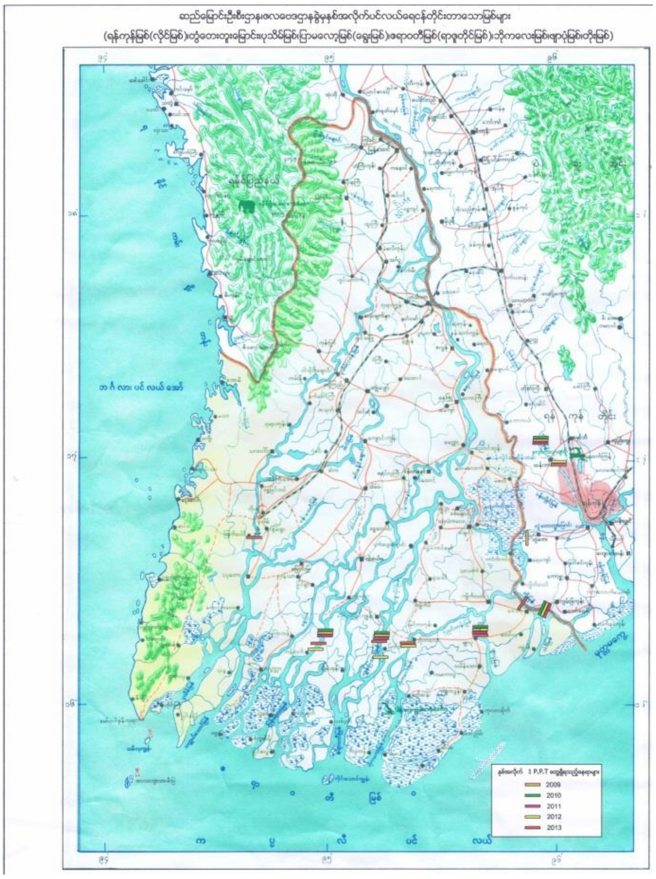


Figure 7.10.7 Salinity map of the Ayeyarwady Delta – produced by Hydrology Branch, ID, MoAI. The coloured bars indicate the salinity threshold value of 1ppt during the lowest discharge of the Ayeyarwady (end of May during spring tide) for the years 2009 to 2013

7.11. **Development of Myanmar**

Its strategic geographic location provides Myanmar the potential to become a land bridge between South and Southeast Asia. and linking the People's Republic of China (PRC) to these markets (ADB, 2012b). Electricity consumption in Myanmar has doubled from 3.303 giga watt hours (GWh) in 2000. to 693 GWh in 2012 (USEIA, 2013). Total generation of electric power during the last fiscal year was 1348 billion kwh. up from 10.964 billion kwh in the 2012-13 fiscal year and 8.625 billion kwh in 2011 to 2012, according to the state-run Central Statistical Organization (CSO). Private consultant, Thoung Win, who sits on the government's energy development committee, said that by 2030. Burma may generate about 30%of its power from gas and coal fired plants. 30 percent from renewable sources like wind and solar, and 40% from hydro (Ferrie, 2014). Investment in the energy sector is expected to be an important driver of the economy. Four main goals form the basis of Myanmar's energy policy framework:

(i) maintaining energy independence;
(ii) promoting the wider use of new and renewable sources of energy (see the projecting of these sources Table 7.11.1 and Figure 7.11.1and Figure 7.11.2) ;
(iii) promoting energy efficiency and conservation; and
(iv) promoting household use of alternative fuels.

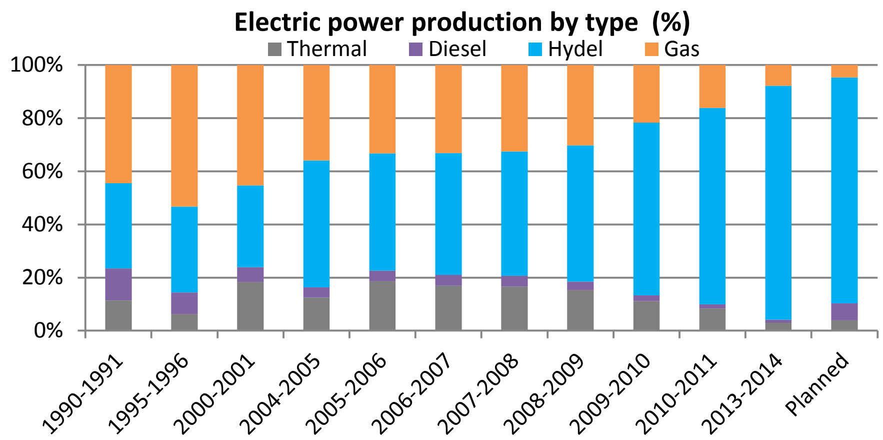


Figure 7.11.1 Electric Power Production by type. in percentage (%)[10]

Table 7.11.1 Existing and planned power production sources

Installed capacity (MW)	*Year: 2012*	*in own report (2014)*	*Planned*
Hydro	2260	2792	56.308
Mini Hydro	33	33	231
Gas Turbine	550	7685	2086
Combine Cycle	120	120	
Coal fired	120	120	1752
Diesel	4.54	unknown	unknown
Wind and solar	-	-	2930
Total	**3087**	**3834**	**63.306**

[10] *Source: (CSO, 2011) – adopted from the Ministry of National Planning and Economic Development – from Ministry of Electric power*

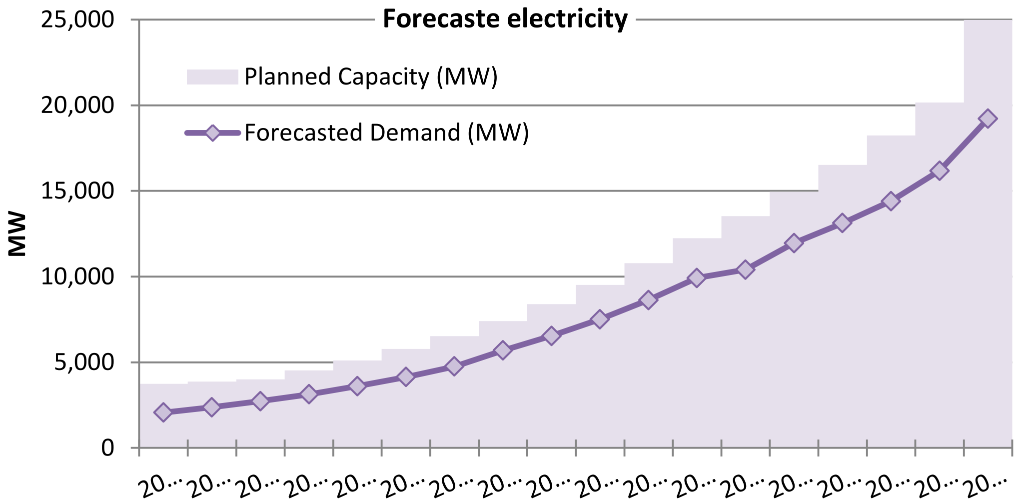


Figure 7.11.2 Forecasted demand and planned energy production capacity for Myanmar by all sources of energy
Source: (MoEP, 2013)

7.12. Hydropower. a large potential for energy production

Hydropower is the largest source of renewable electricity today in the world. It plays an important role in today's electricity mix, contributing to more than 16% of electricity generation worldwide and about 85% of global renewable electricity. (IEA, 2012a). Since the hydropower development has started to gain momentum the water management activities shifted to more from the agricultural to the energy sector, (Hoff, 2011). It has a particular advantage in that it can adjust quickly and flexibly to sudden load changes. Hydro reservoirs serve as a means of storage in power systems and therefore play an important role in helping to cover peak loads and sudden losses of power from other sources. Depending on the country, the cut-off point between small and large systems and somewhere around 10MW and 50MW. In in this report no distinction is made between the two. Large scale dams are controversial since they affect the water availability downstream and can cause damage of the environment and relocation of people due to their water spread area. Depending on the concern of people to not proceed the hydropower development. It is a good alternative to compensate CO_2 emissions.

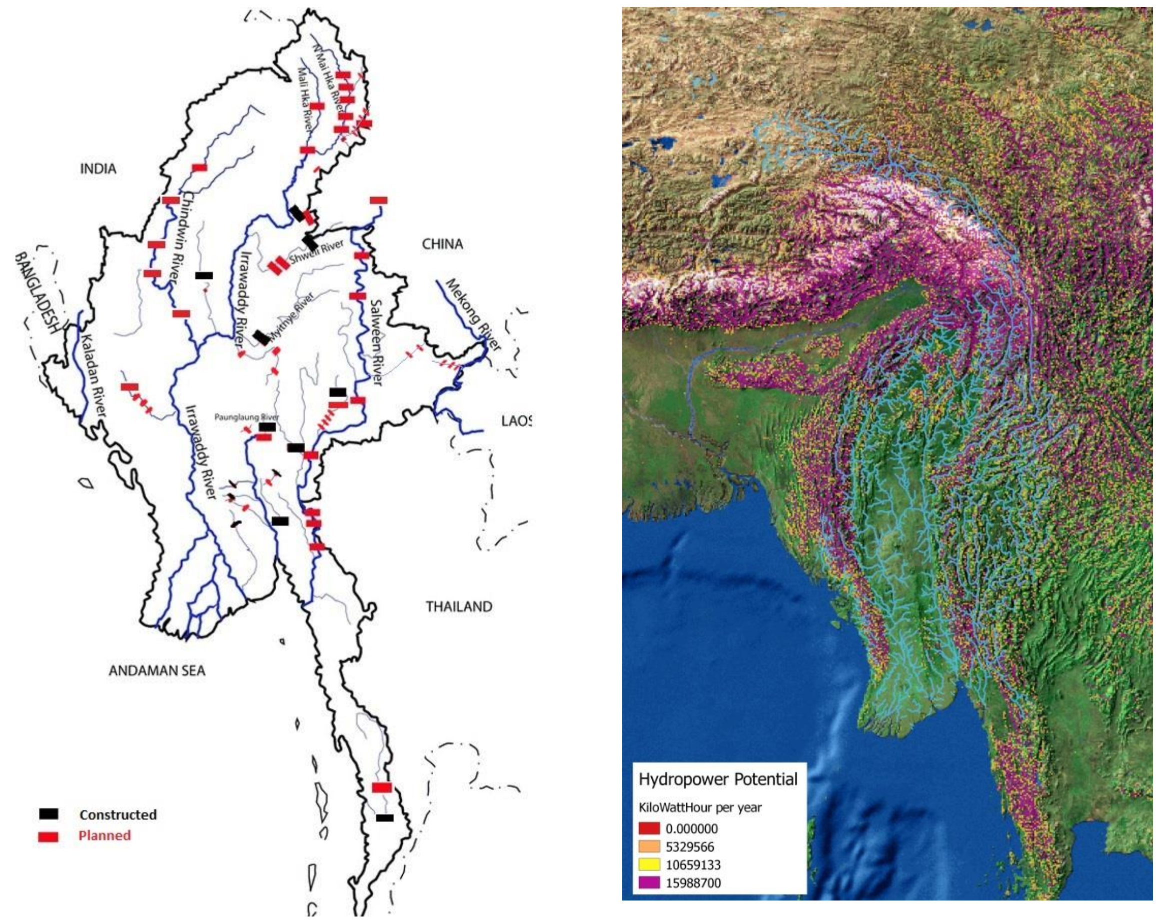


Figure 7.12.1 Large Hydropower projects (planned and existing) in Myanmar (left) – And the hydropower potential for the region (Meijer, 2012). As can be seen, Myanmar has a lot of (large scale) potential to be developed (Meijer, 2012)

After the economic liberalization in 1988 the energy sector has also been intensifying its activities. The energy sector has set a target to increase the hydropower development in order to meet the domestic energy demand and to gain the much needed foreign capital from electricity exports (Kattelus, 2009a). The hydropower potential of Myanmar is estimated to be as much as 10000 MW, and looks like in Figure 7.12.1 (right), (Meijer, 2012). according to (ADB, 2012c; MOEP, 2012) the potential large hydropower projects have a total installed capacity of 46.101 MW (ADB, 2012b); 49.220 (MOEP, 2012) and 56.110 MW (Burma Library, 2012; DHPI, 2013) The installed capacity of hydropower in 2012 was 2770 MW (ADB, 2012b) and currently the hydropower capacity is good for 3.833 MW (est.) in 2014 (DHPI, 2013) of which 60% is reliably available (Somani, 2013), see Table 7.12.1 for the existing and planned hydropower stations per basin and Table 7.12.2 for the existing and planned stations per State/ Division. Myanmar is undertaking ventures to exploit these energy resources, both as a basis for accelerated overall economic development and for direct social benefit to residents—especially through greater electricity supply to rural areas where the electrification rate is much lower than in the urban areas respectively. The energy demand in Myanmar is increasing fast due to the development of the country and involvement of foreign investors. The hydropower potential in all major river basins will be exploited on large, medium, small and micro- scale. According to different sources, there are at present 36 small to large hydropower stations located in Myanmar. The capacity ranges from 2 to 1050 MW, with an average of 129 MW. In Table 4.8.1 and the existing and planned hydropower projects are given by river basin and by state / division.

Table 7.12.1 Existing and planned hydropower projects by river basin

River basin	*Existing capacity (MW)*	*Planned Capacity (MW)*	*Number of projects - existing*	*Number of projects (planned + existing)*
Source:	(ADB, 2012b; DHPI, 2013)	(Burma Library, 2012; DHPI, 2013)		
Ayeyarwady	2,407	32,656	17	47
Salween	415	22,875	5	25
Bago	20	20	1	1
Sittaung	751	159	11	13
Other	0	1,754	-	11
Total	3,603	58.367	35	95

Myanmar's per capita electricity consumption is the lowest among the ASEAN-10 countries. estimated at 100 kilowatt hours (KWh) in 2010 (approximately one-twentieth of that in Thailand). The average annual GDP growth between years 2000- 2005 was 5.5% in Bangladesh. 9.4% in China. 6.5% in India, 9.15% in Myanmar and 5% in Thailand (WRI 2009). explaining the rapid increase in energy demand in Myanmar and its neighbouring countries (Kattelus, 2009a). Data is sparse. but even the most optimistic estimate say that less than 25% of the country has access to electric power(Somani, 2013). Electricity consumption in Myanmar has doubled from 3.303 giga watt hours (GWh) in 2000, to 693 GWh in 2012 (USEIA, 2013). Of the already low installed capacity of around 3,500 megawatts (MW), only about 60% is reliably available.

Table 7.12.2 Existing and planned hydropower projects by State/ Division

State/ Division	*Existing Power capacity (MW)*	*Planned Power Capacity (MW)*		*Number of projects*
In major river basins	(Burma Library, 2012; DHPI, 2013)	(Burma Library, 2012)	(ADB, 2012b; MoEP, 2013)	
Shan State	115	12.950	13.414	23
Mon State	-	355	303	1
Sagaing Division	30	3.220	2.848	6
Mandalay Division	1.291	1.846	1.424	9
Ayeyarwady Division	5	5	-	2
Bago Division	411	581	543	11
Kayah State	144	6.603	775	10
Kachin State	380	25.546	20.788	20
Magway Division	149	381	370	6
Kayin State	168	5.309	954	3
Yangon Division	-	-	-	-
Total	**3.645**	**56.796**	**47.709**	**85**
Other*	-	1.754	1.511	10
Total	**3.645**	**58.550**	**49.220**	**95**

*Other: Chin State. Rakhine State. Tanintharyi Division

7.12.1. Energy produced by hydropower dams

For the different river basins the simulated energy generated is displayed here. Since the individual reservoirs and hydropower stations have not been validated and the outcome do not correspond with the expected production, this section is just a brief indication of the possible order of magnitude and variation of the energy generated. See for the figures of the generated per time step per river basin Appendix M.

Table 7.12.3 Energy produced by the existing and planned hydropower dams in all river basins of Myanmar. This is an outcome of the simulation and is assumed to be low, since little validation efforts have taken place

	Produced energy (GWh)	*Produced energy (GWh) – incl runoff river*	*Reference to Appendix M*
Ayeyarwady	80,466	80,5800	Figure 9.4.2 - Figure 9.4.6
Upper Ayeyarwady	59,629	59,629	Figure 9.4.5
Chindwin	8,169	8,169	Figure 9.4.7 - Figure 9.4.8
Sittaung/ Bago	2,220	2,328	Figure 9.4.4
Salween	69,773	71,132	Figure 9.4.3
Total	**152,459**	**154,040**	

7.13. Multi- purpose reservoir: hydropower and irrigation

For the multi-purpose dams (Buywa and Kyeeon Kyeewa) in the Magway and Minbu case area the release of water through the turbine as a result of the water demand of the irrigation area downstream. It can be concluded that the for the future situation the reservoirs are emptied at the end of the dry season, so no energy can be produced. When increasing the efficiency of the irrigation area, water can be saved over a longer period of time to be released. This results consequently in a power production over a longer period of time as well and a net annual increase of produced energy, see Table 7.13.1.

The same result can be achieved when the undeveloped situation (*actual*) is maintained. As can be seen in the figure, for this situation the available water in the reservoir can be used for even a longer period of time. So when improving this irrigation efficiency, this will benefit the water management of the reservoir and has the benefit to generate more electricity. The distribution of the release of the water results in a peak in the electricity production at the start of the dry season. The question need to be asked for the operation of the electricity generation, is what the required temporal distribution will be for the supply to the national grid.

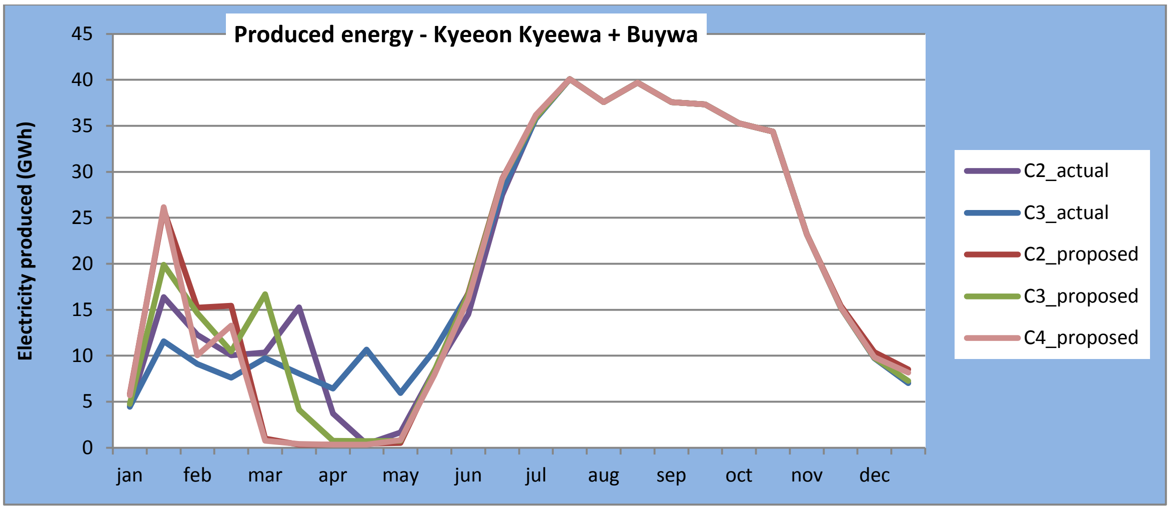


Figure 7.13.1 Produced energy for Kyeeon Kyeewa and Buywa hydropower dams under different cases for irrigation development

Table 7.13.1 Averaged Generated energy for cases C2 (actual + proposed irrigation), C3, C4 for the Buywa + Kyeoon Kyeewa Hydropower dams in Minbu Region – for the simulation period 1998 to 2009

	Averaged Energy produced (GWh/year)	*Percent of annual target (%)*
Actual_C2	478.1	86.0
Actual_C3	481.8	86.7
Proposed_C2	474.7	85.4
Proposed_C3	487.8	87.7
Proposed_C4	472.1	84.9
Design	556.0	100.0

8. Discussion

After the water allocation assessment in the major river basins of Myanmar using a modelling tool and different data as input, the meaning of the outcome should be discussed to understand the true meaning of the outcome and conclusions. Based on the experience with the model and the validation of the data, in the next section most important findings are discussed which also describe the recommendations for the model developing process. A critical note to this study is necessary, since very little verification and discussions were held with the local experts about the river basin schematisation and the model outcome.

MoYinGyi Wetland Area – Sittaung River Basin Photo: Rens Hasman – date: beginning November 2013

8.1. **Water allocation assessment**

The objective of this research was to assess the water allocation in the WRS of the major river basins in Myanmar in the present and future situation. It assessed the water availability, demand, allocation and utilization for the simulation period 1998 to 2009, 12 years in total, on basin and regional scale. For the regional scale a case area was used: the Magway and Minbu region. Here a more detailed assessment is carried out to see if the model developed, could be used for assessing the water allocation on this scale. In comparison with the literature found on water scarcity, the results do like to match. For this scale in particular, a good validation phase is necessary to study the water allocation and availability more accurate to assess the water scarcity and vulnerability. For ideal modelling purposes, sub-divisions or regions should be identified in the model. As the network schemitisation is now, not for all regions a local scale assessment can be executed. For the irrigation fields and reservoirs, all necessary data is available, but the information was not stored at one location but spread across different offices. This information is present at the MoAI.

The water availability on local scale, the input data for the actual reservoir capacity should be improved. The dead storage is likely to be high for many reservoirs as it is now. For the Sittaung, Bago and Myit Ma Sittaung, Bago and Myit Ma basin the average dead storage to full storage ratio is 58%, which is assumed to be too high. The cumulative demand of the proposed irrigation areas are up to 20% at the end of March relative to the available water in the basins. A dead storage over full storage ratio of at least 37% should be applied to meet the demand of the proposed irrigation under the current irrigation efficiency.

Also the overall irrigation demand is assumed to be an overestimation of the real situation, where paddy is becoming less dominant. The marked orientated approach for the cultivation of crops is not included. The winter paddy dominates the Bago District (large part of the Sittaung, Bago and Myit Ma Hka basins), which is a high demand crop. The cropping patterns as they are now in the model, do not include the change from a paddy dominated (prescribed patterns by the government) to a more free market orientated strategy, dominated by winter paddy. The crops included in the cropping pattern as they are now, include a relative small part in the monsoon season. The cropping patterns collected from the ID, MoAI supposed to only include irrigation crops. However also crops are cultivated in the monsoon season where they receive sufficient water from the rain. The total demand as calculated includes these monsoon irrigated crops. The actual demand or withdrawal is thus lower as it is concluded from the assessment. But since it is named 'irrigated crops' by ID, the monsoon irrigated crop are included in the total demand of the irrigation sector.

For the future situation, it is likely that there will be a change in some regions to less demand crops. As it is now, for some regions this create a very high demand, which cannot be met with the available stored water in the reservoirs. It is recommended to update the cropping pattern corresponding with the future situation, suitable for the available fresh water in the reservoirs and rivers during the dry season.

The irrigation areas included in the simulation are all collected from the ID. MoAI and thus are all government owned irrigation systems. It is unknown what part of the irrigation systems in Myanmar belong to the government, and which are privately owned. Assumed is that for the present situation, these private schemes can be neglected.

The available literature found on water allocation assessments more mostly focusing on sub-catchments or regions, where more in detail, the individual stakeholders were identified. This research focusses on three whole river basins located in one country, where the overall available water and allocation is the objective. The tool can be used to quickly assess the impact of national strategies, and the impact of the large scale dams planned in the upper basins. The water availability for agriculture, irrigation and domestic water use however, needs to have more detail, e.g. about the cropping patterns, and more validation is necessary with available data to create a better representation of reality such that water scarcity levels are more reliable.

Parallel to the water demand and allocation modelling development process, the hydrological model should also be continued to be improved by validating the river discharges or inflow into the reservoirs. This is crucial for the whole water allocation assessment since it represents the water availability in the basin. Temporal and spatial variation should also be validation to improve the assessment on local scale. However, the present outcome of the hydrological model looks to be match sufficient on basin scale to compare these with available literature, since for many control stations in the main rivers; little deviation is visible between the simulated versus monitored time series. On local scale, the inflow into the surface water reservoirs during the dry season of the monitored series (data from ID, MoAI) is not monitored, where the simulated ones do show a base flow.

The water quality aspect is left of this water allocation assessment. For most stakeholders this aspect is also crucial to include in the assessment of the WRS. The drainage water of irrigation for example may contain pesticides and affect the downstream water quality. For the industrial sector the water quality could be more of a critical factor than the water quantity aspect. The environment, ecosystems and fisheries are dependent of good water quality. These sectors (in stream uses) are not included in the current assessment, but are crucial for Myanmar's national and local economy since many rural people depend on fisheries. Due to limited data about these sectors, no boundaries could be identified yet to include in the model simulations, Introducing the term ecosystem services might support a good representation in the water allocation assessment. Ecosystem services refer to the economic benefits related to these sectors.

The groundwater aspect in the WRS is left out in this assessment since almost zero data is available about the status of the water availability and accessibility in the aquifers. Most urban and rural people rely on groundwater in the dry season. On a yearly scale and basin level, plenty of freshwater is available in the country, of which part of is included in the (subsurface) runoff. Mostly the accessibility can be limited when the water table drops and is difficult to be reached at the end of the dry season. The groundwater analysis should therefore be done on local scale and on seasonal basis.

The water allocation assessment now only focusses on the operation of the system, and the effect of the expected development. It is assumed that an increase with 25% of the overall irrigation efficiency may be very costly. Despite the critical importance of economic variables in water resource allocation and management, water resources studies have generally been dominated by hydrologic analyses for flood control management and water resources planning from an engineering point of view (Sulis & Sechi, 2013). For the decision makers the financial and economic aspects play an import role, or maybe the most important role in the decision making process, especially in developing countries. The investments of the developments versus the economic benefits or profits should be assessed as well in economic analysis to see what measures or strategic investments will create the most profit.

Ideally there should also be also integration in the IWRM process between the hydrological engineering and socioeconomic activities in the region. (Ringles, 2001).

The impact of the socioeconomic development on the system is now seen with the present climatological conditions, so no change in the climate is included in this research. Therefore the developed scenario's in the chapter about the future situation includes only the expected socioeconomic development. However, for the long-term planning, the impact of the expected change in rainfall patterns, duration of seasons, the onset of seasons etc., is likely to have impact on the entire system. During the field visit, experts mentioned that already on local see, the onset of monsoon have effect on the agricultural practices. At the start of the monsoon, many farmers produce rice, which has a peak in the water demand at the start of the growing cycle. The aspect of the variation in water availability over the seasons with a changing climate is crucial for short-medium and especially long- term planning.

8.2. **Ownership of the water demand and allocation model**

The involved stakeholders in the WRS should be able to identify themselves in the model representation and to clarify the input data. The involved in the model development process creates the feeling of ownership (Louks & Van Beek, 2005). Working closely with the involved stakeholders stimulates the mutual understanding of the system and the interests of other parties. The future users of the model should be aware of the quality of the output data, which consists of a simplification of reality. The NWRC or an independent organisation, could be the potential owner of the model. Since the relevant stakeholders of the WRS are involved in the NWRC, all of them should be able to understand the functionalities of the model. Not only one ministry should have the responsible for the calculations of the WRS. In this modelling phase, little validation has been done with local experts. Since little knowledge about this kind of modelling is present in Myanmar, capacity building of using these tools would be recommended. This will create an understanding and awareness of the functionalities of the model as a decision support tool.

The importance of water resources modelling has increased over the last decades since the society is getting more aware that for a sustainable development of a country or region,. the use and allocation of the natural resources should be assessed in an integral approach in which all relevant stakeholders are involved. The integrated and cooperative modelling development process is important in the debate about the hydrological. ecological. social and economic impacts of water resource development. In the hydrological domain. a comprehensive set of models has been effective in building understanding of the system. and in identifying and describing the issues and trade-offs involved in basin-scale water planning. Gaining inside and understanding of the interactions of the stakeholders and the trade-offs that have to be made in the water resources network. a water demand and allocation can be an effective and supportive tool in this process.

Additional options to be included in the water allocation assessment when the system is better understood and more historical data is available about the performance / non- performance of the system. An example is shown below

8.4. **Back casting – tipping point analysis**

When the simulated system is better understood and validated the performance of historic events can be analysed to learn from moments when the system was not operating well and to be proactive in the future. This *back casting* method could be method to define boundary conditions for the operation of the system. Events that have taken place in the past. Where (parts of) the system failed. these conditions are indicators for the boundary conditions of the system. These indicators can be applied to see if and when similar events occur in the future. When the system is being developed and experiences changes from the environment. At the moment. these events from the past were not part of this water resources assessment. It is recommended to analyse the past to plan for a sustainable development..

Adaptation tipping points are defined as points where the magnitude of change due to climate change or sea level rise is such that the current strategy will no longer be able to meet the objectives (Deltares, 2010). Another way to look what possible extremes are in the WRS is to use the top- down approach and look at events in the past where the system was not able to function well (*impact*): failed harvest due to water unavailability. energy shortages. flooding issues due to high run-offs etc. The conditions of these events are indicators within the scenarios to see. when and how often they are likely to happen in the future. given the return interval of the given events. The *state* at which these events occur. are then the boundary conditions within the system. and the climate characteristics are then the *pressure* on the system.

Table 8.4.1 Example of past events when the system operated not

Event	*Year*	*Frequency*	*Pressure*	*Indicators*	*Impact*
Event 1 (Drougth)	Example year 1	1/6 year	Extra long dry season	Extra long dry season	Local water shortages in region XX
Event 2 (Bad havest)	Example year 2	½ year	infrastructure	limited storage capacity – less inflow. wrong operation management of water release; efficiency is low of irrigation field	Lower part of the irrigation field has bad harvest
Event 3 Etc.	Etc.			Etc.	Etc.

When the events have a (high) frequency of occurrence. a list like Table 8.4.2 can be made. to see which events have the highest impact on the system. and which one can be mitigated by investing in the development of the system to reduce the (unacceptable) impacts. From this overview. a priority list can be made. to invest in certain parts of the system first to minimise the damage. Also quick wins or no regret measures can be identified by this way: measures that easily can be implemented on the short term. without a too big investment.

Table 8.4.2 Adaptive tipping points - examples

Event // Impact	*Acceptable*	*Moderate*	*unacceptable*
'Event 1'			Water scarcity in the public sector
'Event 2' Low discharges due to low run off	No year round navigation possibilities		
'Event 3'		Low irrigation efficiency due to untrained labour	

Table 8.4.3 Adaptive tipping points – action measures to avoid negative effects in the future - examples

Event // Impact	*Actions to be taken*	*Investment*	*Benefits/ gains*
'Event 1'			
'Event 2' Low discharges due to low run off			
'Event 3'			

9. Conclusions & Recommendations

The water allocation assessment has been an exploratory study on basin and local scale to the status of the water resources system in Myanmar, now and in the future. The data used for this study is collected in the field and in already available literature. A water demand and allocation model has been used to analyse the water availability, demand and allocation in the major river basins of Myanmar. This assessment can be seen as the inception phase in the IWRM process of Myanmar. An understanding of the WRS will support the decision makers develop plans and strategies which develop the country in a sustainable and integrated way. The temporal scale for water resource planners differs to those of an economist and politicians, approximately 20 years or more, few years, 4 to 5 years (political term) respectively. The importance of long term planning is crucial in sustainable planning of (water) resources should try to be included in the IWRM policies.

Irrigation area near Waw Township –Bago District – Sittaung Basin – Photo: Rens Hasman

9.1. Integrated Water Resources Management in Myanmar

The government of Myanmar is changing its national policy from a sectorial to a more integrated approach, where the water resources will play an important role in the country's socioeconomic development. The recently formed National Water Resources Committee (NWRC) has to objective to draw up a national Integrated Water Resources (IWRM) Strategy Plan which will include the strategies and policies of the involved stakeholders in the water resources system. This study support the inception phase of the IWRM process to draw up this long term planning report. The overall objective was to assess the WRS on basin and local scale for the present and future situation for which the following indicators are used to give recommendations about the system to support the IWRM process:

- Water allocation
- Water availability
- Water demand
- Water utilisation
- Interlinkages between sectors
- Validation of data

A water demand and allocation model (Ribasim) has been used to assess the above mentioned indicators. The assessment is done for the major river basins in the country: Ayeyarwady, Salween, Sittaung, Bago and Myit Ma Hka Rivers. The coastal regions are more local scale study areas and are likely to have little problem in water allocation between stakeholders. This assessment focussed only on the water allocation and not on the water quality aspects.

9.2. Water availability, demand, allocation and utilisation

Availability - On a yearly basis and on river basin scale it can be concluded that sufficient water is current as well in the planned developed situation for all sectors to fulfil the planned socioeconomic development. The variation of the water availability and demand over the seasons and regionally can be a more limiting. From the simulation output, a hydrological model, the annual availably water for basins was found:

Table 9.2.1 Available and full storage capacity for all major river basins (km^3) – from Section 4.1

	Available water resources (km^3/year)	*Variation (St. deviation) (%)*
Ayeyarwady Basin	412	10
Magway and Minbu Sub-basin	26	32
Sittaung, Bago and Myit ma Hka Basin	62	16
Salween Basin	265	11
Total	**739**	**10**

The seasonal variation of the available water is large in Myanmar. Roughly 90% of the rain enters the system in the monsoon season, i.e. half May and half November, whereas an increase in demand during the dry season puts pressure in the resources. Water availability for drinking water and food security is vulnerable at the end of this season. The annual available internal renewable water resources per capita are 13,272 m^3/capita/year which is the largest in the region. In comparison Thailand's internal water resources are 3,350 m^3/capita/year. The available water in surface water can is the main irrigation source in Myanmar. The total full storage capacity for irrigation purposes is 51.5 km^3, and an available storage of 33.4 km^3, see Table 9.2.2. In the Sittaung, Bago and Myit Ma Hka Basin the water demand during the dry season is approximately 50% of the available water at that time. Good management of surface water resources is crucial and efficiency water management for the reservoirs is advised.

Table 9.2.2 Available and full storage capacity for all major river basins (km³)

	Available storage capacity (km³)	*Full storage capacity (km³)*
Ayeyarwady Basin	25.099	35.194
Magway and Minbu Sub-basin	3.962	5.784
Sittaung, Bago and Myit ma Hka Basin	4.046	9.962
Salween Basin	0.214	0.851
Total	**33.359**	**46.007**

Demand - (Present) The total water demand for all dominant stakeholders in the present situation is 29.97 km³/year. The most dominant stakeholders are irrigation (good for 88% of the total demand), public water sector (10%) and the industries (2%). With around 70% of the employed population directly or indirectly working in relation to these sectors the agricultural activities are important for the country's economy. The demand of the irrigation sector is calculated based on the water supplied area of 1,142,008 ha with a cropping pattern prescribed by the government. Winter paddy is the most dominant crop, and accountable for gross of the demand in the dry season. This area is 10% of the potential irrigation area in the country. The assumed overall efficiency of the irrigation area of 37% during the dry season, and 27% for the monsoon season, is used for all irrigation areas in the country (*actual C2*).

The domestic water consumption is low, with an average water consumption of an estimated 60 l/capita/day, or 3.0 km³/year for a population a little under the 60 million, which is not the outcome of the recent census in the country. Industrial activities are still very limited, which are modelled in Mandalay and Yangon Region. The yearly water consumption is only 0.7 km³. In reality public water scarcity is observed in the Central Dry Region and the coastal area. This is because of the lack of good infrastructure to transport the water, since in the simulation these shortages are not found on basin scale. The accessibility of groundwater resources has not been part of this study.

Demand - (Future) The focus of the agricultural development is on increasing the irrigation areas to the planned and proposed area of 2,249,055 ha, which is thus double the current area. This results in the increase of demand by the irrigation sector 131% For the domestic sector, an maximum annual population growth 2.0% is assumed. The upper boundary for the annual increase of the industrial water demand is assumed to be 10%/year. When the average daily water demand increases to 96 l/capita/day, the maximum total water demand by the domestic sector becomes 7.0 km³/year.

Table 9.2.3 Increased irrigation area from *actual* to *proposed for the river basins in Myanmar*

	Increased irrigation area (%)
Ayeyarwady	75
Sittaung, Bago, Myit Ma Hka	278
Salween	55
Myanmar	98

Without improving the irrigation efficiencies (*proposed C2*), the total water demand for the irrigation is 47.8 km³/year. With this increase, an extra of 44% of land is cultivated relative to the actual situation. Than the total demand accounts for 95% of the total withdrawal

A second option for development is to increase the overall irrigation efficiency. The drop in utilisation is a result of a more efficient water supply. Less water is needed to supply the cultivated crops. The improvement of the overall efficiency of the irrigation areas can be accomplished by implementing the following structural and non-structural measures:

- The increase in maintenance;
- Operation practices of more skilled labour: training and capacity building;
- More efficient irrigation methods e.g. closed piped systems; and
- Upgrading the irrigation network, e.g. by constructing improved drainage canals that can re-use the water.

By increasing the overall efficiency from the current yearly averaged 32% to 48%, the annual demand increases for the current (*actual_C2)* to the more efficient situation (*actual C3*) with a demand of 19.8 km³/year. For the developed area (*proposed_C2 → proposed_C3)* the demand becomes 35.623 km³/year. This reduction in demand of 24.4% and 25.2% is assumed to be more or less linear with the change in overall efficiency of the irrigation areas.

The improvement of the overall irrigation efficiency with 25% results in an overall water utilisation of 5.8% in the major river basins. This improvement of the supplied water, results in the decrease of the drained water. For developed irrigation areas in the Sittaung, Bago, Myit Ma Hka and the Ayeyarwady Basins this can become critical. Here a decrease in base flow is observed of 54% and 30% respectively around March, the month were salinity intrusion is maximum.

*Regional scale – (*case area) The Magway and Minbu Region where analysed as a case area to see the behaviour of the WRS on local scale. This area is situated at the lower part of the Central Dry Zone, in the middle of the country. This zone is known to experience limited water availability compared to other parts of the country, especially at the end of the dry season. Magway is located at the left bank of the river, and has a dryer climate than the Minbu Region, located on the right bank. The term water scarcity is defined as the ration of demand over available water resources. In this analysis, the domestic water is included, and is assumed to be 10% of the total demand. For the Magway and Minbu case area the relative standard deviation of the annual inflow into the basin is large (32%) compared to the Ayeyarwady average deviation. Especially in the dry season the deviation of the inflow is between 50% and 60%. Since the base flow is relative low and has thus little contribution to the filling of the storage, it is assumed that this has little impact on the local water availability for the irrigation. The water scarcity level varies therefore largely over the simulation period. For the Minbu region, the highest level is twice the average level for the yearly inflow into the region.

Table 9.2.4 Water Scarcity levels for Magway and Minbu region – Case Area – for *actual* and *proposed situation (C2) where the water demand is the largest*

Region	*Scarcity level (%) – actual irrigation*		*Scarcity level (%) – proposed irrigation*	
	Inflow -	*Storage*	*Inflow -*	*Storage*
Minbu	5.6	13.3	10.9	25.9
Magway	4.4	13.0	5.9	17.4

For the inflow into the reservoirs in the actual situation, the water scarcity is marked as moderate according to the UN. The scarcity level for the developed situation and the available storage, the water scarcity level over 20% is considered to be severe. The above numbers do not include the domestic water demand. So the water scarcity levels level will even be a little higher. By including these, the numbers for the proposed irrigation are close the ones found in literature for this region: 26.6% for Minbu 15.9% for Magway. In the present situation the scarcity levels are not critical.

The storage capacity is thus the limiting factor for water availability in the case area. Sustainable water management of the reservoirs can benefit multiple users. When the irrigation efficiency is improved, the saved water can be used to supply the public water sector and generate electricity from hydropower plants (Buywa, Kyeoon Kyeewa Reservoirs). A more efficient use of the water from the reservoirs can benefit the irrigation as well as the hydropower sector. In the example of the Buywa and Kyeeon Kyeewa Reservoirs, the increase in efficiency of the irrigation area resulted in that the available water could be released through the turbine over a longer period of time, resulting in a higher energy production, a simulated increase of 2%. .

Utilisation (present and future) – The overall water utilisation is defined as the ratio water demand/water availability and is low in comparison with other countries in Southeast Asia. With an utilisation in the present day of only 4.1% it can be concluded that this is low. It is not even close to the utilisation factor of 20%, which is a threshold value for the restriction of the economic development of a country, according to the UN. In the driest year of the simulation (2009) the utilisation is 5.2%. For the future situation the observed trends in the agriculture, irrigation, energy, socioeconomics, food and foreign involved were translated to different scenarios. These scenarios do not include the climatological conditions, or climate change. When combining all trends a maximum overall water demand of 54.8 km^3/year, with an utilisation of 7.4%. The actual utilisation will be equal or less than this value. This is still low in comparison. In the Sittaung, Bago and Myit Ma Hka Basins, the withdrawal for the developed irrigation practices, is 16.5% of the yearly inflow, which can be assumed to become critical. See table below.

Table 9.2.5 Utilisation in the major river basins of Myanmar

	Utilisation of the water sources - current (%)	*Utilisation of the water sources – future (%)*	*Variation (St. deviation) (%)*
Ayeyarwady Basin	6.0	10.4	10
Sittaung, Bago and Myit ma Hka Basin	5.7	16.5	16
Salween Basin	0.5	0.6	11
Total	**4.1**	**7.4**	**10**

In conclusion, for both the current and most extreme development in the socioeconomics, the water utilisation on river basin level is low and is not restricting for the development of the country's economy. On a local scale, especially in the dryer regions of the country, the available storage capacity and other infrastructure are the critical factors and not the yearly inflow. For these regions, less water demanding crops can limited the water scarcity. Focussing on the efficient and sustainable development, sufficient drinking water is available for all people in the country. Improvement and development of infrastructure can supply water at the end of the dry season, the most critical time for all sectors.

9.2.1. Important parameters for water allocation assessment in Myanmar

For the improvement of water allocation in Myanmar, the outcome of the sensitivity analysis together with the validation of the modelled outcome in comparison with the data collected in the field, the following parameters are recommended to include in the data collection programme in the next phase of the modelling process: **storage capacities, storage relations, cropping patterns and crops characteristics, inflow (validation of hydrological model).** By monitoring of the WRS the system will be better understood. This may result in an increase in the increase of awareness by the involved stakeholders about the stakes, interests and synergies in the system.

For the water resources system in general the following model parameters are important to validate with the actual local parameters and to improve the understanding of the status of the WRS and to stimulate the integration of stakeholders in the IWRM process: **actual rainfall, irrigation efficiency (to be obtained by monitoring the irrigated to and drained water from the field), actual evaporation, operation of the release of the water for multi-purpose dams (hydropower and irrigation)**

9.3. Recommendations for the IWRM process

It can be concluded, that the looking at the available water resources in Myanmar and the expected developments of the socioeconomic, on annual basis the availability will not limit the development of the country's economic development. The variability of the water availability over the season results in some regions to sever water scarcity. More efficient water management is advised, since the availability is not the limiting factor. The allocation and distribution of the water via the network is the critical factor in the system.

- ❖ Agriculture is the most consuming activity in the country. The irrigation waters used for cultivation of paddy is dominant according the ID, MoAI. The vulnerable dryer regions for the water availability are likely not to be suitable to cultivate paddy in the winter season. Less water demanding crops such as garlic or beans will result in efficient water management where the saved water can be used for other purposes, such as public water supply. Large quantities of the supplied water are drained from the irrigation field due to the inefficiency of the network.

- ❖ In the Sittaung Basin the developed irrigation resulted in an increase in base flow, since more water is released during the dry season. This can has a beneficial impact on pushing back the salty sea water in the region where water quality issues are important for the farm land and public water withdrawal from the aquifers. The improvement of the irrigation scheme efficiency results a higher utilisation of the irrigation consumption. For the improvement of the irrigation scheme efficiencies, the amount of drained water from the field decreases, resulting in an observed lower base flow in the river. Since larger areas of crops can be cultivated in the dry season since the stored water can be used more efficiently. The base flow in the main river decreases, resulting in less water available for downstream users such as fisheries, or to counterbalance the saltwater. The most critical month for the salinity intrusion is the end of May, beginning of April. The water quality in the delta area can decrease when the salt water is moving more upstream. Fisheries and agricultural activities, and in particular paddy fields, may be affected by this decrease in water quality.

- Efficiency rates of the irrigation schemes have a largely effect on the water demand in the WRS. Improving the efficiency rate can be achieved by drawing up maintenance plans and capacity building of sustainable farmer. These are examples of no-regret measures to be undertaken on the short to medium long term, which increase the sustainable water demand.

- In the present situation due to the low efficiency parts of the irrigation area do not receive sufficient water. These crops wilt and die, resulting in no income for these farmers. The rural community largely depend on these local scale activities. Increasing the efficiency results in an increase in cultivated area. For the actual situation the cultivated area increases from 32% to 36%, and for the proposed it is 30% to 35%. The most important development Myanmar is the focus on the improvement of the main drainage system of the irrigation system. Gaining insight in the actual water used by the crops at the irrigation fields, by monitoring the inflow and drained water, will give insight in the efficiency rate of the system. The construction of new structures and drainage canals will allow to re-use the drained water and to increase the overall irrigation efficiency. By knowing the actual demand, the supply from the reservoirs can be adjusted to the demand and optimised water use can be achieved.

- The cropping patterns used for this assessment are purely the irrigated crops only, and are averaged per State/ Division. The simulated demand is for over 75% in the dry season. These cropping patterns are the pre-described ones by the government, dominated by winter paddy. Applying flexible cropping patterns to fully exploit the water resources.

- Due to a lack of affordable power source, the river pump irrigation areas are still very limited, with only 30,000 ha along the major rivers. In the future the proposed area is 316,269 ha, which is good for 14% of the proposed area in the major river basins. When the energy is going to develop and energy prices are affordable, the planned river pump schemes will not be hampered by the river flows in the main streams, since the largest ratio of demand over the available water in river is 17% in the Ayeyarwady Basin for the month April.. Depending on the irrigation efficiency, a large part of this will be drained into the river again. No limitations are to be expected here.

- As far as the author is aware, most of the irrigation reservoirs have only the purpose of irrigation supply, with exception of the Sittaung Basin, where many do include a turbine to generate hydroelectric power. In the Ayeyarwady River basin more and more multi-purpose reservoirs are developed. Since the domestic water consumption is low compared to irrigation demand, it is recommended to connect the surface water reservoirs with the public water supply network to improve the water availability for the rural population. The water demand of the public sector is low compared to the irrigation demand. The development of micro- or small scale hydropower stations is able to stimulate the rural development as well, by supplying them with electricity. Myanmar has much potential in the hilly and mountainous regions to exploit this source of electricity production.

- The large scale hydropower dams planned in the upper part of the Ayeyarwady, Chindwin and Salween Rivers have an extra power capacity of 54,764 MW, above the already 3,603MW in other parts of the country, but these are mainly small to medium scale projects. The data received from the Ministry of Electricity was not complete enough to validate the operation of dams. The average simulated electricity per year is 154,040 GWh, which is assumed to be low compared to the design power production. For many of the dams, the storage capacity and details about the turbine and turbine inlet are lacking so no validation could be done here. The time lag in release of the water through the turbines during the dry season instead of the monsoon season, will result in the increase of the base flow in the river during this season. This may affect the livelihood on the floodplains, who cultivate crops here after the monsoon. The increase of outflow may benefit the water depth for navigation purposes and also can counter balance the salt water intrusion in the coastal region. No simulations have been performed to support these statements. It is recommended to look at the possible operational strategies of these dams to see what the effect will be on the flow regime. In this assessment no boundary conditions have been formulated for the fisheries, navigation, ecosystems or salinity intrusion.

- The important parameters mentioned in the previous section are crucial for the understanding of the WRS. It is recommended that these parameters should be monitored properly in the field and be shared with all involved stakeholders in the IWRM process

- Data sharing of the data about the WRS will increase awareness and understanding of the system amongst the involved stakeholders of the IWRM process and the possible synergies there can be found.

- As stated in the Dublin principles, water should be seen as an economic good. Following the analyse done by Ringles (2001) on the allocation of the water resources over the riparian countries of the Mekong River basin, where an integrated economic- hydrologic tool is used to assess the impact of river basin development. Including the costs and benefits of the different actions in the WRS would create a feeling of viability. Often the economic benefits are in developing countries the first priority over sustainable development.

9.4. **Model Development**

For the Integrated Water Resources Strategic Master plan, it is recommended to increase the level of detail of the model for the irrigation schemes to test strategies on this local level. Also data about the operation of hydropower is key to assess the impact on the downstream users, which can or benefit: irrigation and navigation, or have large negative impacts: ecosystems, and fisheries. Good coordination and inside in the interlinkages of the different stakeholders involved, is crucial in the understanding of the impact of policies, strategies and projects on both the small, local scale, as well on the national, basin wide level. Also different pathways should be identified to be able to adapt the different uncertain factor which lay in the future.

Involvement of the local experts in the WRS are crucial for the IWRM process. The water demand and allocation tool is a decision support tool for assessing the WRs. The owner(s) of the model and all involved users, both related to water consumption as to vulnerable for water quality changes, should be comfortable with the schematisation of the system. Involvement in the model developed process is advised thus recommended.

By collecting data recommended based on the validation and sensitivity analyse will increase the accuracy of the model outcome. The more reliable the outcome, the more support it will get from the involved parties, which is the objective of the IWRM process. Good data management and sharing will improve this.

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A. Concept of IWRM

To achieve the water security in a country, during the Ministerial Declaration of The Hague strategies were formulated to meet these targets:

- Meeting basic needs: to recognise that access to safe and sufficient water and sanitation are basic human needs and are essential to health and well-being, and to empower people, especially women, through a participatory process of water management.
- Securing the food supply: to enhance food security, particularly of the poor and vulnerable, through the more efficient mobilisation and use, and the more equitable allocation of water for food production.
- Protecting ecosystems: to ensure the integrity of ecosystems through sustainable water resources management.
- Sharing water resources: to promote peaceful co-operation and develop synergies between different uses of water at all levels, whenever possible, within and, in the case of boundary and trans-boundary water resources, between states concerned, through sustainable river basin management or other appropriate approaches.
- Managing risks: to provide security from floods, droughts, pollution and other water-related hazards.
- Valuing water: to manage water in a way that reflects its economic, social, environmental and cultural values for all its uses, and to move towards pricing water services to reflect the cost of their provision. This approach should take account of the need for equity and the basic needs of the poor and the vulnerable.
- Governing water wisely: to ensure good governance, so that the involvement of the public and the interests of all stakeholders are included in the management of water resources.

The environment (wetlands, flood plains, forests, etc.) is also a stakeholder holder which has its minimum water requirements and increasing awareness of the environment and the potential of 'ecosystem services' for economic development. This stakeholders demands a certain flow regime or minimum/ maximum flow: so called environmental flow requirements. However, the priority in developing countries is mainly on economic development, by exploiting the resources needed for food security and to increase the GDP (export of goods and resource). Growing demand and non-sustainable management have increased man's ecological footprint and caused degradation of the natural resource base in many regions, including severe modification of ecosystems (Hoff, 2011). The availability of resources for food production such as water, land and a healthy production climate is competing with other land- and water users, where the focus for development of a countries economies and urban areas keep on increasing resulting an increase demand for food and energy production.

The importance of water as a resources on a basin scale

Every world citizen should have access to fresh water for primary (hygiene, drinking water and boiling food) consumption. Also food is a primary need for a human being. Water is essential for health and necessary for the production of food, economic growth and the support of the environment. Increased external pressure due to the increase of the population and urbanisation puts pressure on the availability and quality of the (water) resources. The term sustainable development and environmental awareness changes the focus on the integrated approach to maximise the benefits and to limit or mitigate negative effects to the environment. One of the challenges in the development of the water resources system (WRS) is to promote the synergies between different users of water at all levels within a river basin, between regions or countries to achieve sustainable river basin management. The water resources system includes all the natural, socioeconomic and administrative aspects related to the system.

Integrated water resources management depends on collaboration and partnerships at all levels, from individual citizens to international organisations, based on a political commitment to, and wider societal awareness of, the need for water security and the sustainable management of water resources. To achieve integrated water resources management, there is a need for coherent national and, where appropriate, regional and international policies to overcome fragmentation, and for transparent and accountable institutions at all levels, (Hague, 2000). The development of an IWRM in a countries national policy, different steps has to be undertaken where all the different aspects of administrative, natural and socioeconomic are analysed before drawing up the final plans, see Figure 2.2.1 for the different phases in an IWRM process. Assessment done on the WRS in relation to the implementation of the IWRM policy involves many layers of spatial and temporal detail. Understanding local scale systems cannot be seen separate from the big, basin wide, processes and interactions.

By the year 2050 the agricultural production would have to grow by another 70% (by 100% in developing countries) to meet the increasing demand (Hoff, 2011). Also the rapid increase in demand of energy in developing countries is demanding development of e.g. electricity production plants. Productivity and the availability of water, energy and land vary enormously between regions and production systems. There is a large potential to increase overall resource use efficiency and benefits in production and consumption, e.g. by addressing intensive agriculture (which often has higher water productivity but lower energy productivity than other forms of agriculture) or water- and energy-intensive meat products.

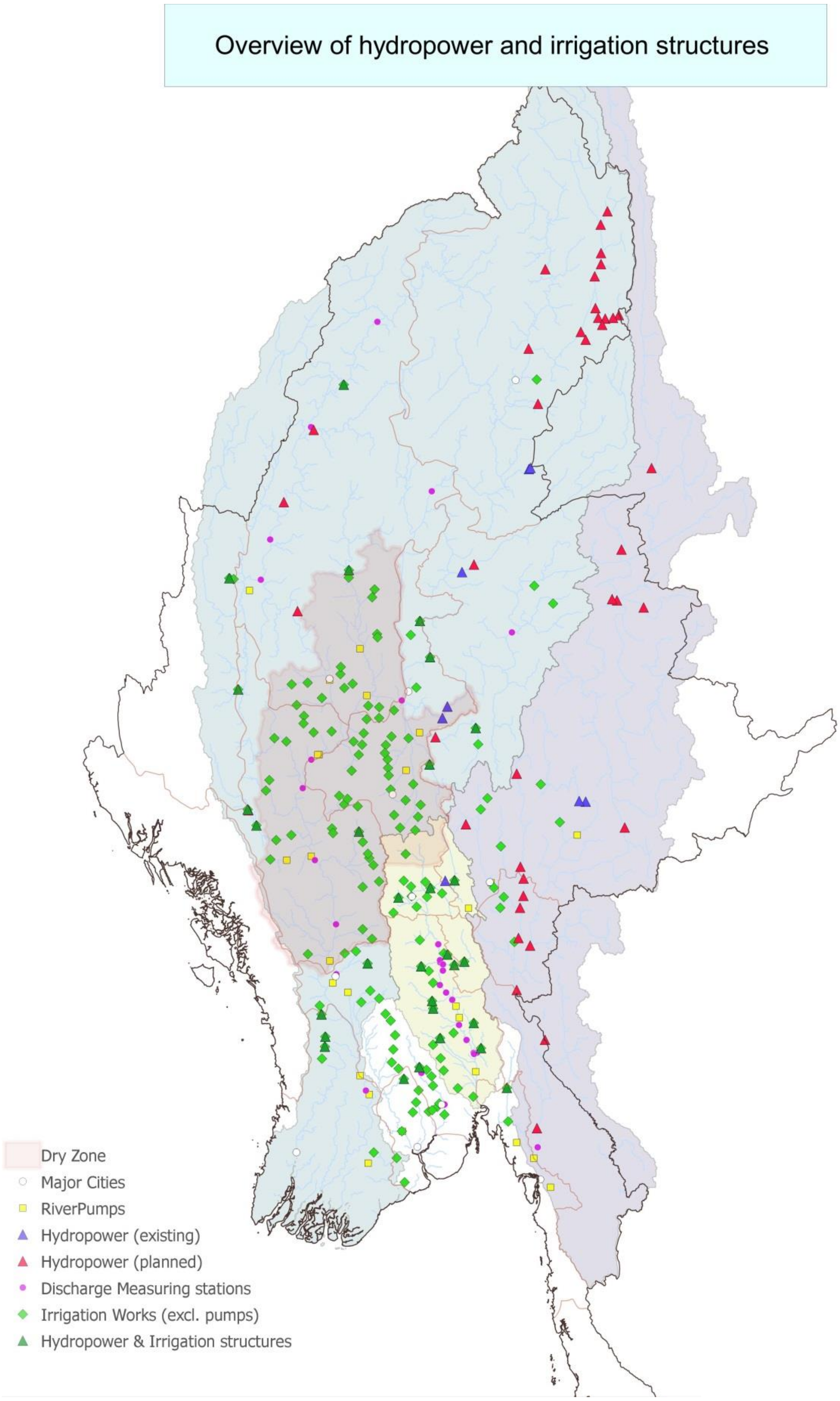
The nexus approach can boost this potential by addressing externalities across sectors (Hoff, 2011). The water resources of the basin contribute substantially to the economic development of a country as well as to local livelihoods and food security. The task of the responsible authorities of the WRS is to ensure good governance which involves policy making based on the involvement of all stakeholders and their interest, in which the understanding of the synergies between the different uses and the WRS itself is crucial.

Treating the water energy food nexus holistically would — in an ideal situation — lead to more optimal allocation of resources, improved economic efficiency, lower environmental and health impacts and better economic development conditions (Bazilian et al., 2011). It is important to not only strengthen institutional effectiveness, but to review the linkage and coordination mechanisms in and within the agencies related to rural development, agriculture, irrigation, hydropower and environmental protection, among others (James, 2005). Achieving appropriate management of natural resources depends on good governance, which should be built on equity, transparency, accountability, the rule of law and public participation (Myint, 2007). The numerous private actors introduced to the sectors further increase the level of complexity in the highly dynamic setting of Myanmar's natural resources governance (Kattelus, M et al., 2013).

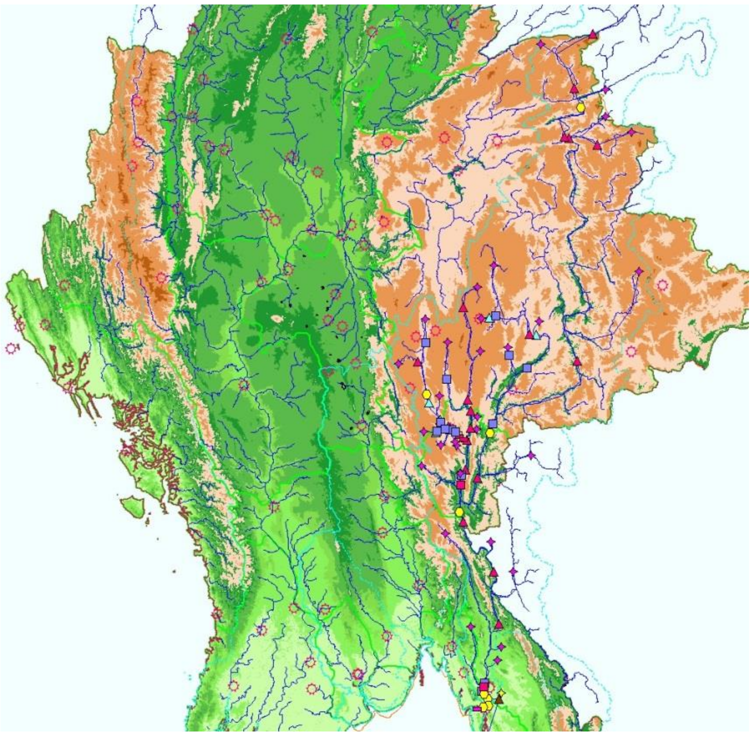
B. List of interviewees

Nr.		*Name of person*	*Institution*	*Function*	*Things discussed*
1	(Agricultue, 2013)	Unknown	Bago regional office, AD, MoAI	Director and staff officers	Cropping patterns, data availability of cropping details, rainfall agricultural practices
2	(Assistant Director Design Branch, 2013)	U Soe Htun Aung	Design Branch, ID, MoAI	Ass. Director Design Branch	Design of irrigation projects
3	(Hydrology Branch, 2013)	Ms. Khon Ra	Hydrology Branch, ID, MoAI	Director Hydrology Branch	Data collection at dam sides, statistics of irrigation projects
4	(Myint Soe, 2013)	U Myint Soe	Maintenance office Bago District, ID, MoAI	Assistent Director, ID, MoAI	Operation of irrigation fields, network discussion Sittaung and Bago Region
5	(NEPS, 2013a)	U Aye Mint, U Kyaw Thein	NEPS	Engineair – Pensioner, ID	Efficiency of irrigation fields, data availability, climatical variation, central dry zone challenges
6	(NEPS, 2013b)	U Aye Mint, U Kyaw Thein	NEPS	Engineair – Pensioner, ID	Efficiency of irrigation fields, data availability, climatical variation, central dry zone challenges

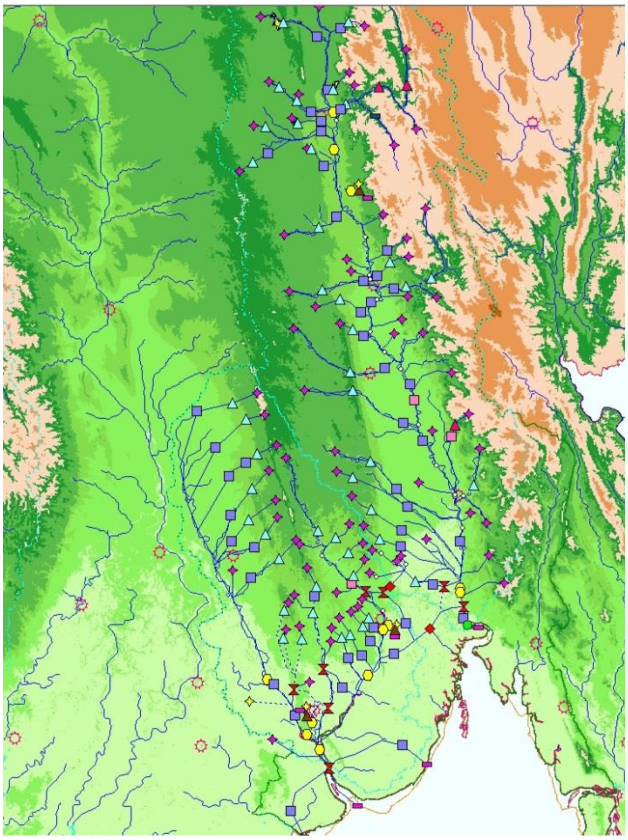
C. Overview reservoirs in Myanmar – hydropower and irrigation

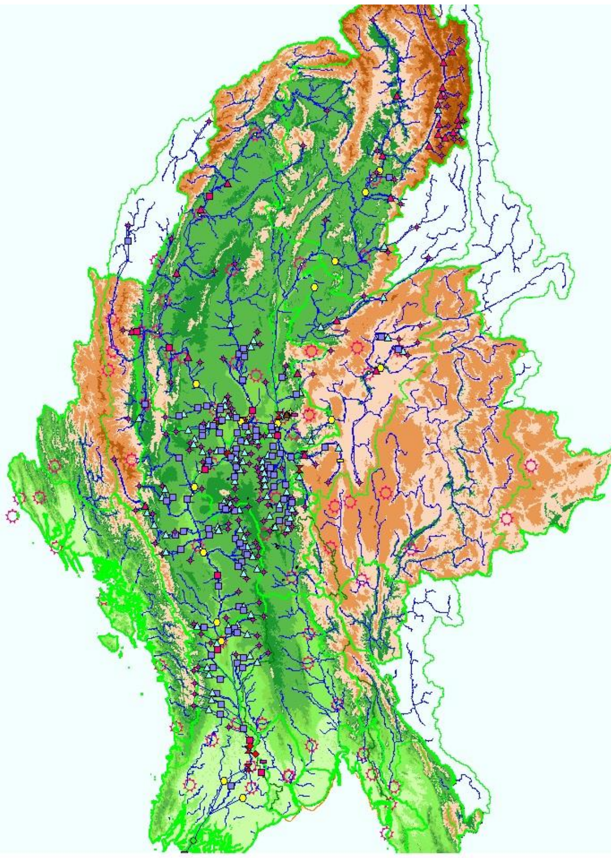


D. Model schematisations of river basins



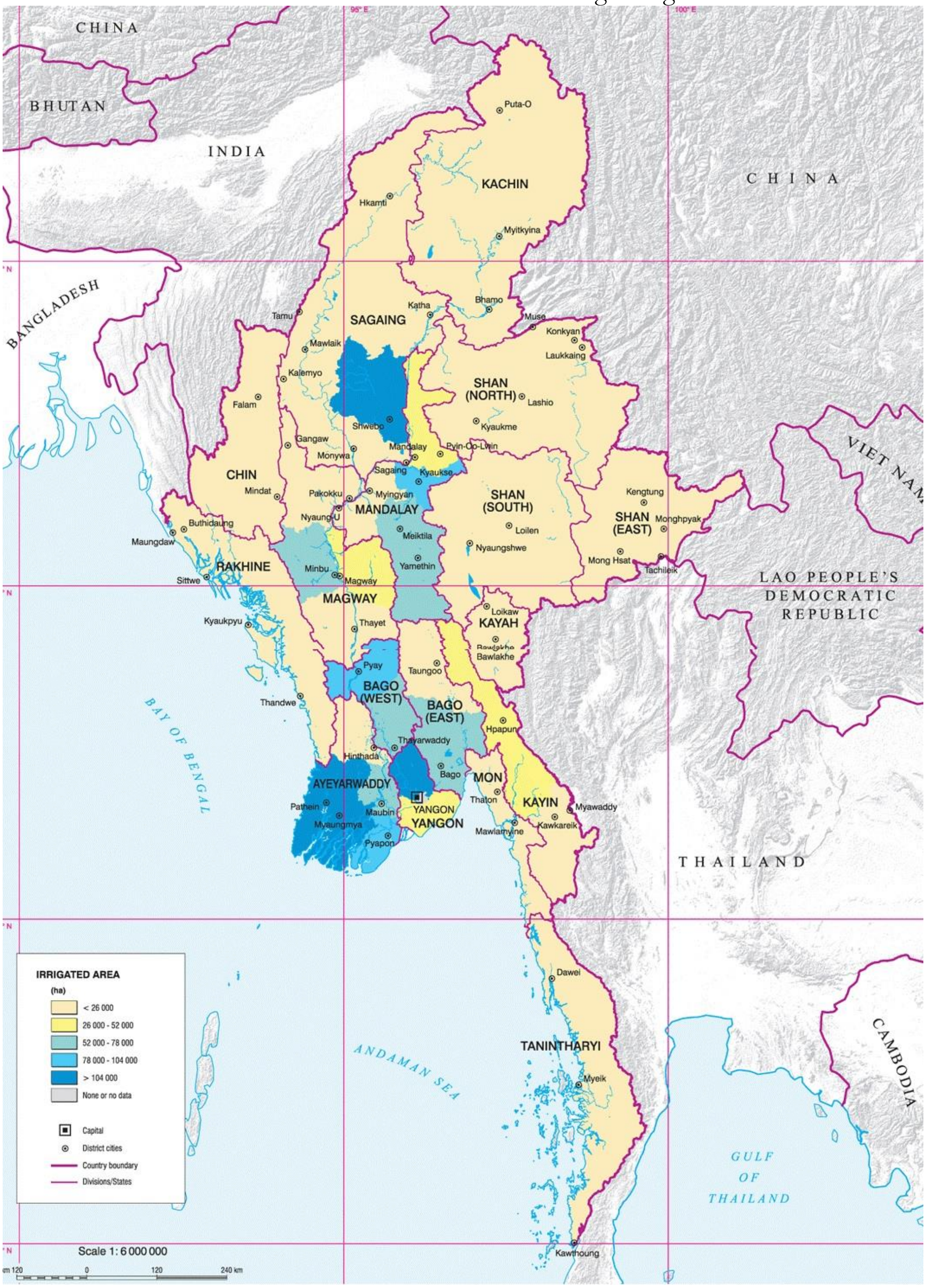
(top) Salweeen – (bottom left) Sittaung, Bago and Myit Ma Hka – (bottom right) Ayeyarwady





E.Irrigation Areas in Myanmar

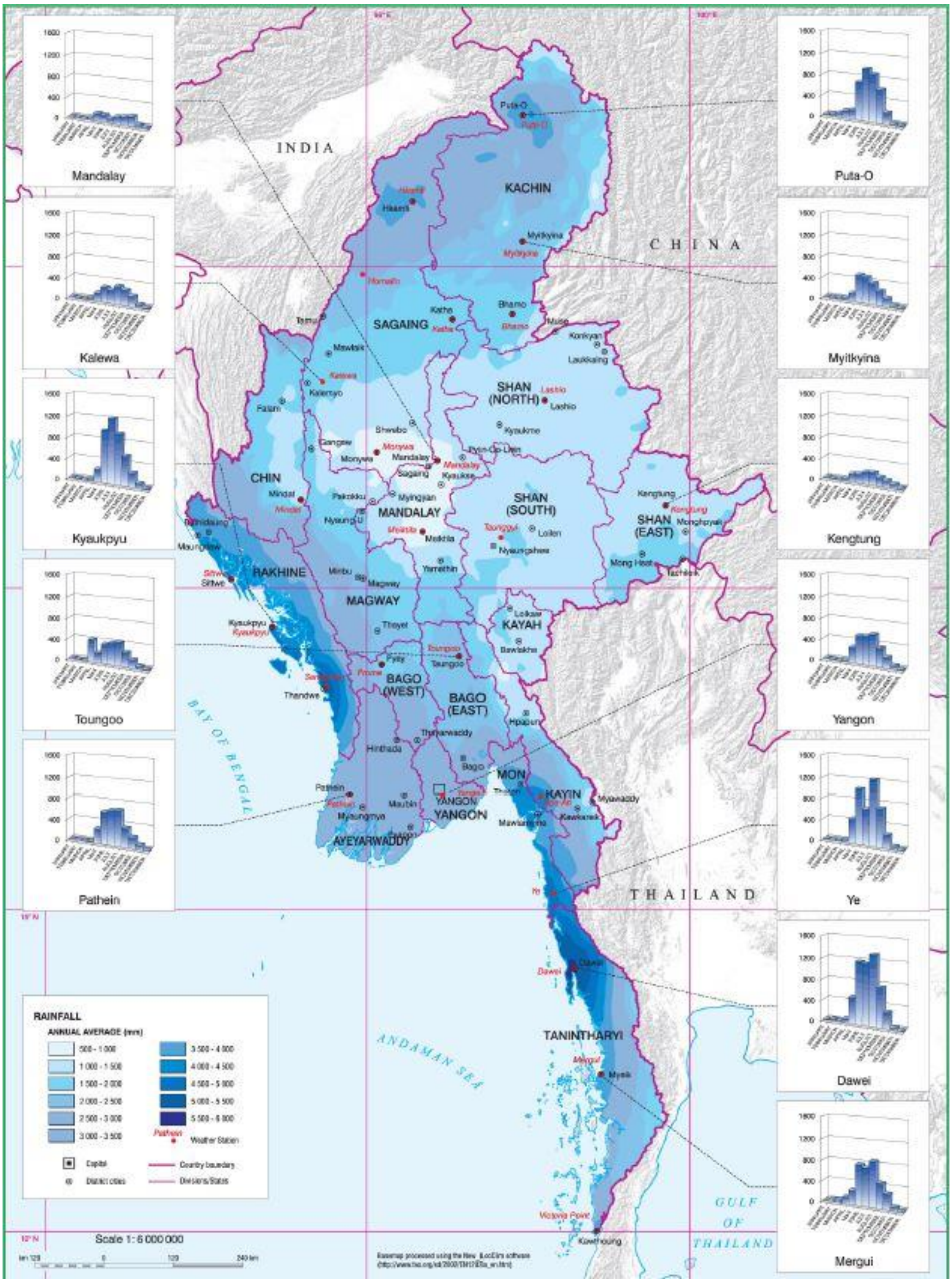
Source: Digital Agricultural Atlas – FAO[11]



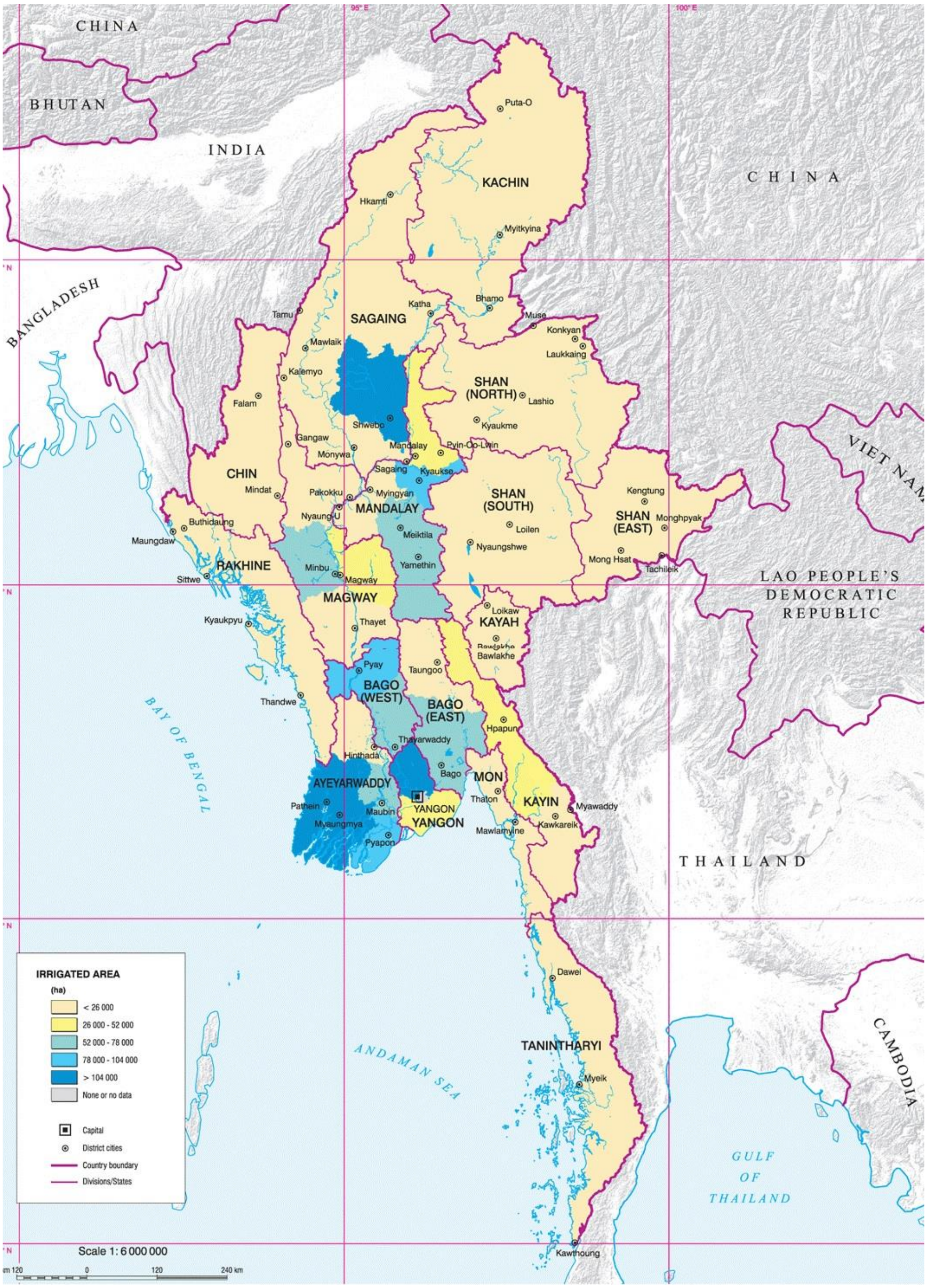
11 http://dwms.fao.org/atlases/myanmar/atlas_en.htm

F. Rainfall Map Myanmar

Source: Digital Agricultural Atlas – FAO



G. Irrigation Areas Myanmar



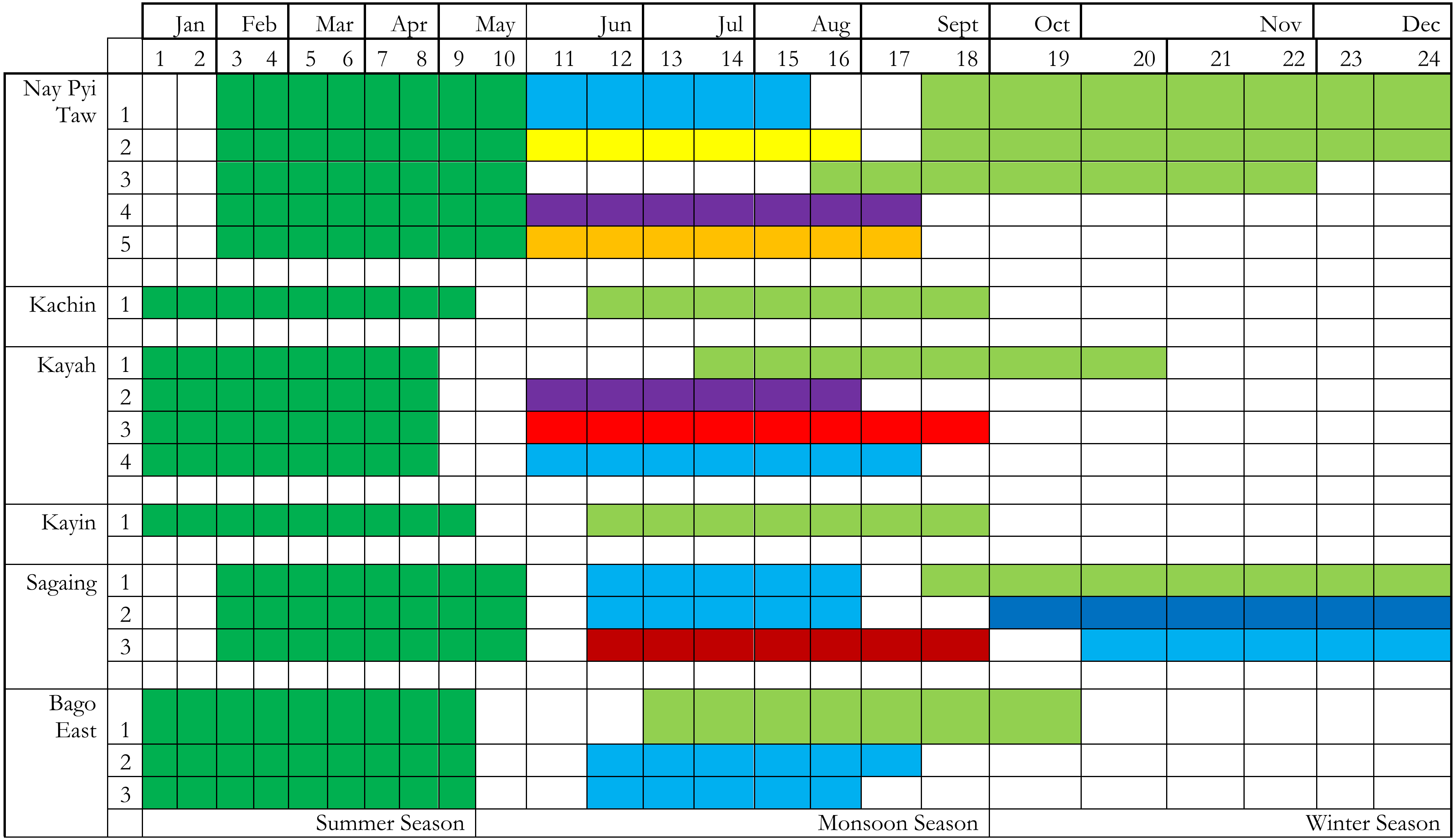
H. Bago River – Bago River discharges

Station under control of DMH

	Mean	Bago River	Bago City									
	Jan	feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1966	0	0	0	0	22	237	434	510	313	57	2	0
1967	0	0	0	0	57	0	246	634	0	0	0	0
1968	0	0	0	2	17	217	410	610	348	60	1	0
1969	0	0	0	0	34	330	366	561	392	60	3	0
1970	0	0	0	1	53	173	308	513	329	116	13	0
1971	1	0	2	0	3	237	470	438	133	66	18	0
1972	0	0	1	2	8	136	302	430	135	37	6	4
1973	0	0	1	0	69	218	340	386	289	118	4	0
1974	0	1	0	4	54	264	376	377	241	119	37	0
1975	0	0	1	1	67	247	335	428	204	139	9	0
1976	0	0	1	1	52	226	392	323	295	121	10	0
1977	0	0	0	1	20	115	336	354	283	26	3	0
1978	0	1	1	1	40	157	255	564	233	91	1	0
1979	0	0	2	8	30	160	207	427	136	45	0	0
1980	0	1	5	18	53	202	397	455	322	80	5	0
1981	0	0	0	7	57	286	318	426	239	157	28	1
1982	0	0	6	4	36	286	307	706	280	112	2	0
1983	0	0	3	0	20	152	200	336	227	140	45	0
1984	0	1	10	5	33	302	387	466	240	69	0	0
1985	0	0	0	1	46	249	416	570	250	104	95	2
1986	0	0	0	2	19	169	308	467	143	41	5	0
1987	0	0	0	5	19	166	361	265	297	64	34	0
1988	0	1	2	23	80	259	299	399	189	144	58	1
1989	0	0	0	0	32	209	232	400	320	107	5	0
1990	0	0	0	3	123	418	538	524	370	104	19	0
1991	0	0	0	0	4	131	371	606	176	70	13	0
1992	0	0	0	2	22	123	366	500	391	143	17	0
1993	0	0	1	1	17	272	293	443	278	49	3	0
1994	0	0	7	7	41	373	485	481	266	50	1	0
1995	0	0	1	11	69	269	497	374	426	105	14	0
1996	0	5	1	1	46	221	386	408	304	103	37	1
1997	0	1	1	10	60	288	573	689	327	107	1	0
1998	0	0	1	2	46	149	305	172	113	23	1	0
1999	0	0	0	1	72	318	384	527	328	75	16	0
2000	0	1	10	48	91	295	403	199	404	119	25	0
2001	2	2	3	5	20	224	522	427	233	110	17	2
2002	1	1	2	2	65	220	369	482	367	75	34	16
2003	0	0	1	1	16	168	213	548	339	57	10	1
2004	0	1	0	1	75	335	375	757	366	42	0	0
2005	1	2	4	5	5	127	305	595	411	91	38	0
2006	1	2	3	5	12	137	615	409	331	175	18	1
2007	N 5	9	1	1	121	156	580	378	263	226	60	8
2008	N 0	0	0	0	125	187	509	674	283	71	31	0
2009	N 0	1	3	3	23	156	380	338	217	112	20	0
2010	0	0	0	0	96	0	279	1223	0	79	0	0
2011	N 4	1	2	18	73	291	531	636	466	251	12	1

I. Cropping Patterns irrigation areas

Summer Paddy
Winter Paddy
Sesame
Sunflower
Pulses
Corn
Groundnut
Garlic
Wheat
Soy Bean
Cotton
Sugarcane
Vegetables
Other Crops


Jan
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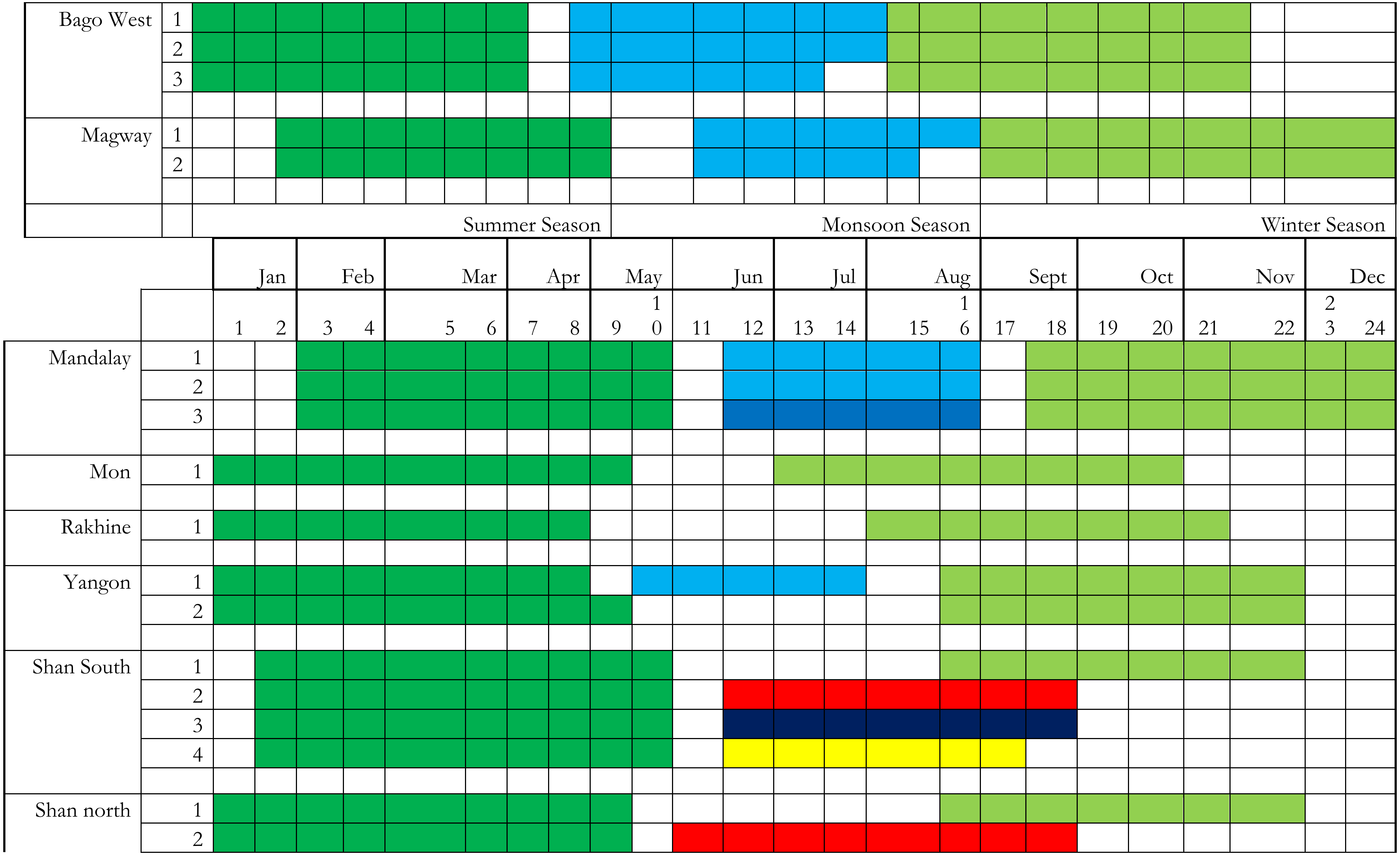
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Nay Pyi Taw
1
2
3
4
5
Kachin
1
Kayah
1
2
3
4
Kayin
1
Sagaing
1
2
3
Bago East
1
2
3
Summer Season
Monsoon Season
Winter Season


Bago West
Magway
Summer Season
Monsoon Season
Winter Season
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sept
Oct
Nov
Dec
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Mandalay
Mon
Rakhine
Yangon
Shan South
Shan north

	3			
	4			
Shan East	1			
	2			
	3			
	4			
Ayeyarwady	1			
	2			
	3			
		Winter Season	Monsoon Season	Winter

J. Reference evapotranspiration - table

Table 9.4.1 ETo long term averaged

Nr	Name	Latt	Long	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Ba-Ann	16.75	97.66	3.4	4.2	5	5.6	4.1	3	2.7	2.5	3.1	3.6	3.4	3.2
2	Bago	17.33	96.5	3	3.8	4.6	5.3	4	3	2.7	2.7	3	3.4	3.2	2.9
3	Bhamo	24.26	97.2	2	2.8	3.8	4.7	4.5	3.4	3.1	3.1	3.1	2.9	2.2	1.7
4	Deqen	28.5	98.9	1.5	1.6	1.9	2.4	2.7	2.9	2.7	2.6	2.3	1.9	1.6	1.5
5	Falam	22.91	93.68	2.3	3.5	4.6	5.1	4.7	3.7	3.3	3.1	3.2	2.9	2.3	2
6	Henzada	17.66	95.41	2.8	3.5	4.2	4.8	3.9	3	2.6	2.7	3	3.3	2.9	2.6
7	Hmawbi	17.1	966	3.4	4.5	5.4	6.4	4.6	3.1	2.8	2.8	3.1	3.4	3.2	3
8	Katha	24.16	96.33	2.1	2.8	3.8	4.4	4.4	3.7	3.5	3.4	3.2	2.9	2.3	1.9
9	Khun-Yuam	18.83	97.93	3.4	4.7	6	6.4	5.1	4.4	4.1	3.9	3.7	3.6	3.3	3.1
10	KyaukPyu	19.41	93.55	2.8	3.5	4.2	4.8	4.5	2.9	2.5	2.7	3	3.5	3.1	2.8
11	Lashio	22.93	97.75	2.2	3.2	3.2	4.6	4.3	3.6	3.1	3.1	3.2	2.8	2.3	1.9
12	Loikaw	19.68	97.21	2.8	3.8	4.6	5.2	4.5	4.1	4	3.8	3.7	3.4	3.1	2.6
13	Mae-Hong-Son	19.3	97.83	2.8	3.6	4.3	5.4	4.6	3.8	3.6	3.8	3.5	3.3	2.9	2.5
14	Mae-Sariang	18.16	97.93	2.9	3.8	4.8	5.6	4.4	3.6	3.5	3.4	3.4	3.4	3.1	2.7
15	Mandalay	21.98	96.1	2.7	3.8	5.1	6	5.5	4.7	4.3	3.7	3.6	3.1	2.6	2.2
16	Maubin	16.73	95.65	3.2	3.9	4.8	5.6	4.3	3.2	2.8	2.9	3.2	3.5	3.2	3
17	Maymyo	221	96.46	2.2	2.9	3.9	4.5	4	3.4	3.3	3	2.8	2.8	2.5	2
18	Meiktila	20.83	95.83	2.7	3.8	5.1	6.4	5.9	4.8	4.5	4.3	3.9	3.4	2.9	2.5
19	Minbu	20.16	94.88	3.1	4.1	5.1	5.9	5.7	4.7	4.6	4.2	4.1	3.6	3	2.8
20	Monywa	22.1	95.13	2.6	3.6	4.4	5.6	5.3	4.8	4.6	4.1	3.8	3.3	2.8	2.4
21	Moulmein	16.5	97.61	3.7	4.4	4.9	5.5	3.9	2.7	2.4	2.4	2.9	3.5	3.7	3.5
22	MyitKyina	25.36	97.4	2.2	3	4	4.9	4.5	3.3	3	3.3	3.3	2.9	2.3	2
23	Pathein_bassein	16.76	94.76	3.4	4.4	5	5.5	4.2	3	2.7	2.8	3.1	3.3	3.3	3
24	Prome	18.8	95.21	3.5	4.6	5.5	6.2	5.4	3.7	3.4	3.4	3.6	3.5	3.3	3.2
25	Putao	27.33	97.41	1.6	2.3	3	3.5	3.7	2.8	2.7	2.7	2.6	2.4	2.1	1.6
26	Pyinmana	19.71	96.21	3	4.2	5.3	6.6	5.5	3.9	3.6	3.3	3.7	3.6	3.1	2.7
27	Sandoway	18.46	94.65	2.8	3.8	4.4	5	4.5	3	2.7	2.7	3.2	3.6	3.2	2.6
28	Sittwe	20.13	92.88	3.2	3.9	4.2	5.4	4.2	3	2.8	2.9	3.4	3.6	3.2	3
29	Taunggyi	20.78	975	2.7	3.6	4.5	4.9	4.3	3.5	3.2	3	3.1	3	2.6	2.3
30	TengChong	25.11	98.48	2.1	2.7	3.6	3.8	3.5	2.9	2.4	2.7	2.9	2.4	2.2	1.9
31	Tharrawaddy	17.63	95.8	3.2	4.1	5.2	5.8	4.7	3.2	2.9	2.9	3.3	3.4	3.1	2.9
32	Toungoo	18.91	96.46	2.9	3.9	5	6	5.2	3.9	3.1	3.3	3.6	3.5	2.3	2.5
33	Yamethin	20.41	96.15	3.4	4.7	6.3	7.8	6.6	5.3	4.8	4.4	4.2	4	3.2	3
34	Yangon	16.76	96.16	3.5	4.5	5.1	5.7	4.2	3.1	2.8	2.8	3.2	3.5	3.4	3.3

K. Demand for future irrigation

76% of the total demand is in the dry season.

Table 9.4.2 Cumulative inflow into the Ayeyarwady River Basin and cumulative demand of the irrigation areas

Ayeyarwady River Basin	*Cumulative inflow*	*Cumulative demand*	*Demand during dry season*	*Demand of total (%)*
Actual_Case 2	412.241	22.656	17.345	5.5
Actual_Case 3	412.241	17.100	13.408	4.15
Proposed_Case 2	412.241	37.152	28.326	9.01
Proposed_Case 3	412.241	28.151	21.909	6.83

92% of the total demand is in the dry season.

Table 9.4.3 Cumulative inflow into the Sittaung. Bago and Myit Ma Hka River Basin and cumulative demand of the irrigation areas

Sittaung. Bago and Myit Ma Hka River Basin	*Cumulative inflow*	*Cumulative demand*	*Demand during dry season*	*Demand of total (%)*
Actual_Case 2	61.503	2.755	2.511	4.48
Actual_Case 3	61.503	227	1.993	3.30
Proposed_Case 2	61.503	9.329	8.615	15.17
Proposed_Case 3	61.503	6.537	653	10.63

82% of the total demand is in the dry season.

Table 9.4.4 Cumulative inflow into the Salween River Basin and cumulative demand of the irrigation areas

Salween River Basin	*Cumulative inflow*	*Cumulative demand*	*Demand during dry season*	*Demand of total (%)*
Actual_Case 2	265.394	0.908	0.745	0.34
Actual_Case 3	265.394	0.647	0.537	0.24
Proposed_Case 2	265.394	1.326	190	0.50
Proposed_Case 3	265.394	0.935	0.776	0.35

The overall decrease in demand of the *actual* and *proposed* in C3 compared to C2 is approximately 28%

Table 9.4.5 Cumulative inflow into the Salween River Basin and cumulative demand of the irrigation areas

Myanmar Total	*Cumulative inflow*	*Cumulative demand*	*Demand during dry season*	*Demand of total (%)*
Actual_Case 2	739.138	26.319	20.601	3.56
Actual_Case 3	739.138	19.774	15.938	2.68
Proposed_Case 2	739.138	47.808	3831	6.47
Proposed_Case 3	739.138	35.623	28.738	4.82

The overall decrease in demand of the *actual* and *proposed* in C3 compared to C2 is approximately 28%

11. Cultivated area from irrigation - future

(Author. year) - Description of resources (s) : simulated	*Total Irrigation area (ha)*	*Area cultivated (ha/ year) – (average)*	*Demand to network (km³/ year)*	*Irrigation withdrawal (km³/ year) - average*	*Irrigation withdrawal total (km3/ year)*
	IRRIGATION_Actual (C2)				
Ayeyarwady (s)	864,800	272,903	22.686	13.310	-
Sittaung. Bago and Myit Ma Hka (s)	163,650	61,855	3.134	2.848	-
Salween - (FAO. AquaStat. 2011)	200,000	-	-	2.100	2.861#
Salween (S)	53,057	16,680	0.908	0.759	0.557#
Total (s)	1,081,507	351,438	26.728	16.917	-
	IRRIGATION_Actual (C3)				
Ayeyarwady (s)	864,800	321.111	17.099	10.740	-
Sittaung. Bago and Myit Ma Hka (s)	163,650	6493	2.170	2.059	-
(FAO. AquaStat. 2011)	200,000				-
Salween (s)	53,057	18.461	0.647	0.551	-
Total (s)	1,081,507	114.665	19.916	13.350	-
	IRRIGATION_Proposed (C2)				
Ayeyarwady (s)	1,516,473	437,925	37.154	22.719	
Sittaung. Bago and Myit Ma Hka (s)	617,987	193,621	9.329	8.080	
(FAO. AquaStat. 2011)	200,000	-	-	2.100	2.79#
Salween (s)	82,394	25,129	1.326	1.118	0.840#
Simulated (incl. deleted)	93,000	28,363	1.497	1.262	
Total (s)	2,216,854	656,675	47.980	32.061	
	IRRIGATION_Proposed (C3)				
Ayeyarwady (s)	1,516,473	533,778	28.150	17.865	-
Sittaung. Bago and Myit Ma Hka (s)	617,987	209,698	6.537	5.890	-
(FAO. AquaStat. 2011)	200,000	-	-	-	-
Salween (s)	82,394	27,166	0.934	0.794	-
Simulated (incl. deleted)	93,000		1.054	0.896	-
Total (s)	2,216,854	770,642	35.621	24.549	-

L. Water users for future WRS

Table 9.4.6 Simulated - Public water consumption in the major river basins

River Basin	*ANNUAL AVERAGE WATER USAGE (km³)*					
Cases	Fresh Availability	Irrigation demand	Industry demand	Domestic demand	Total water demand (km³)	Withdrawal total share of availability (%)
Ayeyarwady	412.214		3.316	2.251		
Developed (proposed_C2)		37.152			42.719	10.363
Developed + improved (proposed_C3)		28.150			33.717	8.179
Sittaung. Bago and Myit Ma Hka	61.502		0.106	0.705		
Developed (proposed_C2)		9.329			10.14	16.487
Developed + improved (proposed_C3)		6.537			7.348	11.948
Salween	265.394		0.027	0.298		
Developed (proposed_C2)		1.326			1.651	0.622
Developed + improved (proposed_C3)		0.935			1.260	0.475
Total	739.138		3.750	3.292		
Developed (proposed_C2)		47.807			54.849	7.421
Developed + improved (proposed_C3)		35.622			42.664	5.772

Figure 9.4.1 Water withdrawal by the biggest users in the WRS of Myanmar's major river basins – Future – (%)

Source	*ANNUAL AVERAGE WATER DEMAND (%)*				
(Author. year) - Description of resources	Irrigation (proposed C3)	Irrigation (proposed + improved C3)	Domestic (urban max development)	Industry (full development)	Total
Ayeyarwady	87.0	83.5	5.3 – 6.7	*7.8 – 9.8*	100
Sittaung. Bago and Myit Ma Hka	92.0	89.0	7.0 – 9.6	1.0 – 1.4	100
Salween	80.3	74.2	6.0 – 7.7	1.6 – 2.1	100
Total	87.2	83.5	18 – 23.65	6.8 – 8.8	100

M. Hydropower production in the river basins

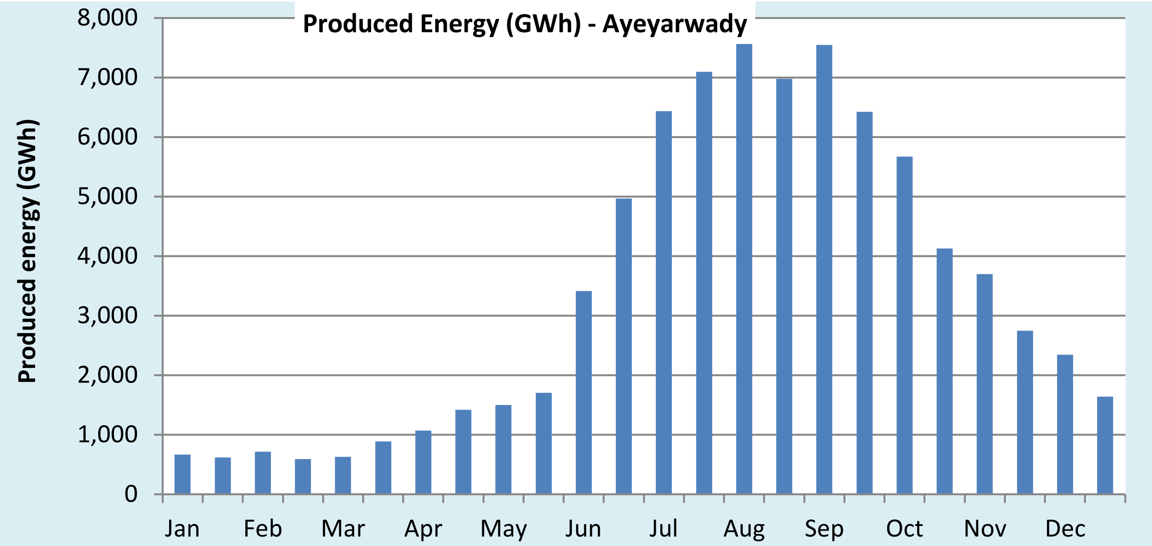


Figure 9.4.2 Average seasonal produced energy by all hydropower dams upstream in the Ayeyarwady River

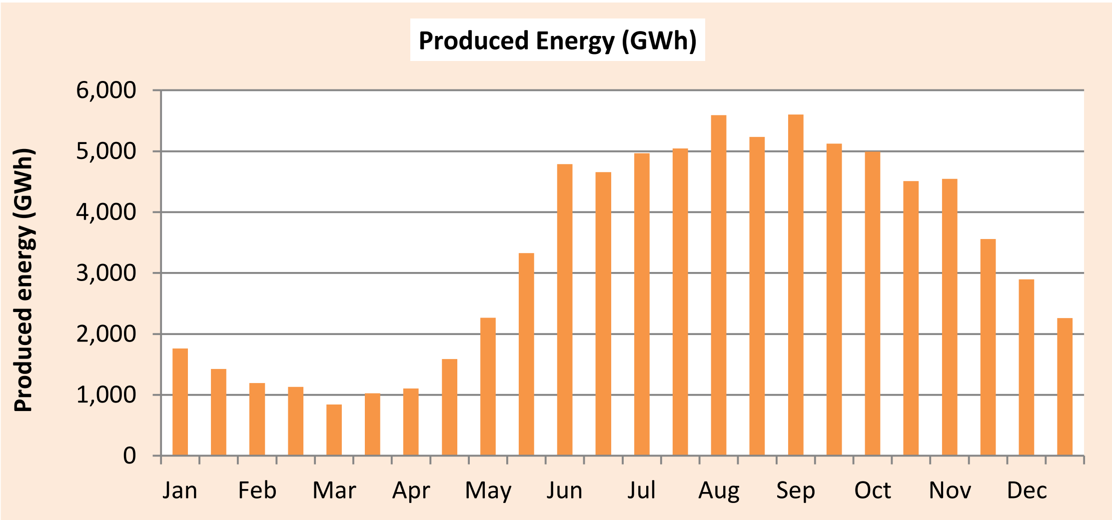


Figure 9.4.3 Average seasonal produced energy by all hydropower dams upstream in the Salween River

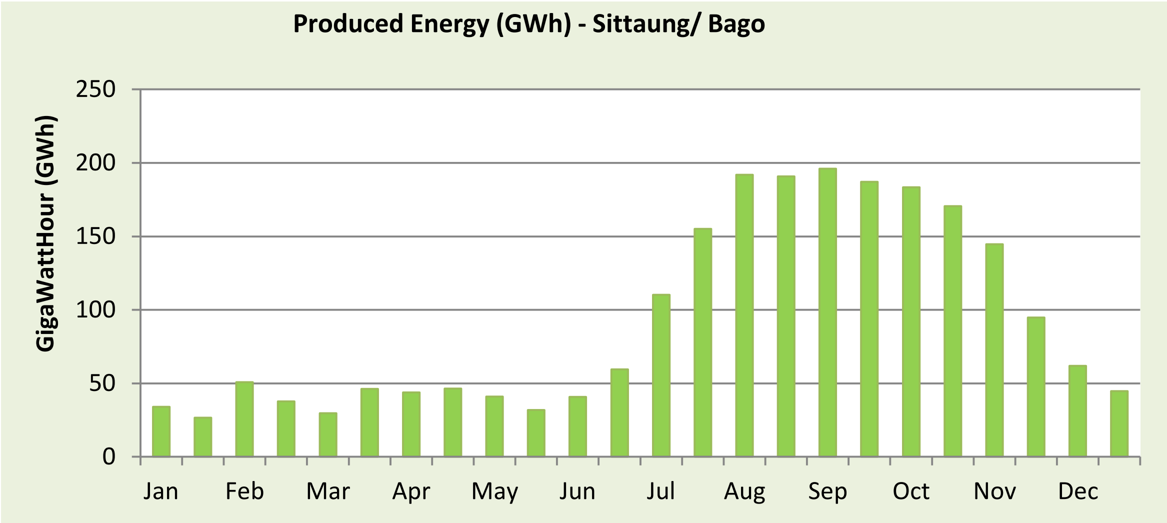


Figure 9.4.4 Average seasonal produced energy by all hydropower dams upstream in the Sittaung and Bago River

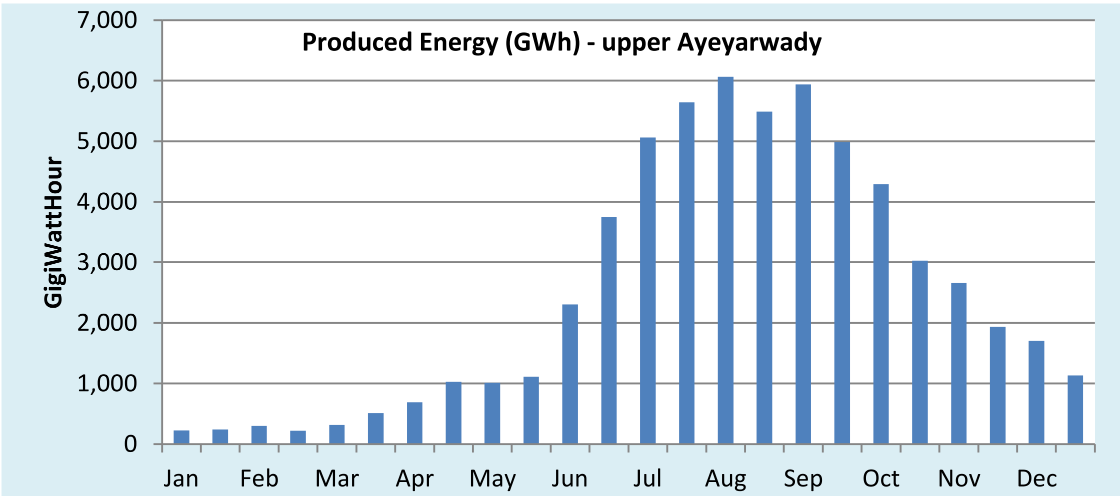


Figure 9.4.5 Average seasonal produced energy by all hydropower dams upstream in the Upper part of Ayeyarwady River

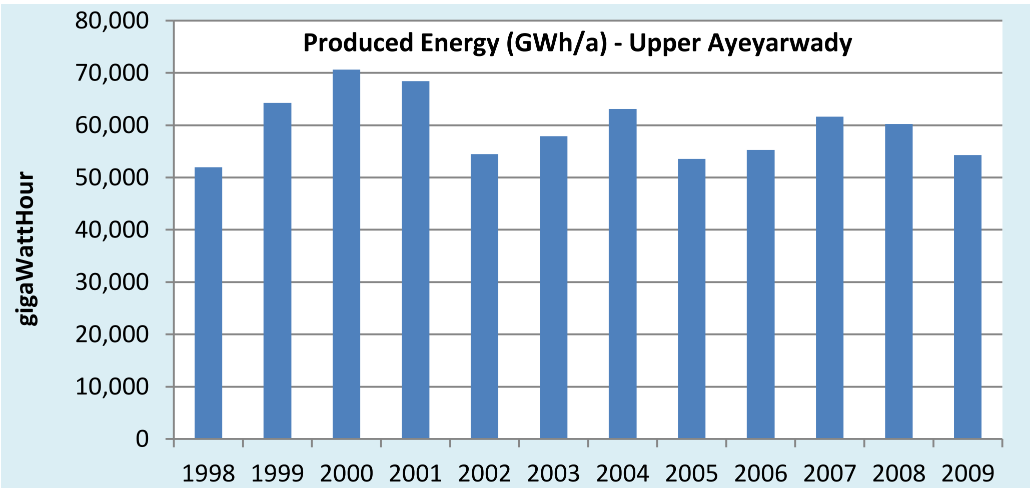


Figure 9.4.6 Yearly produced energy for upstream hydropower dams in the Ayeyarwady River 1998 to 2009

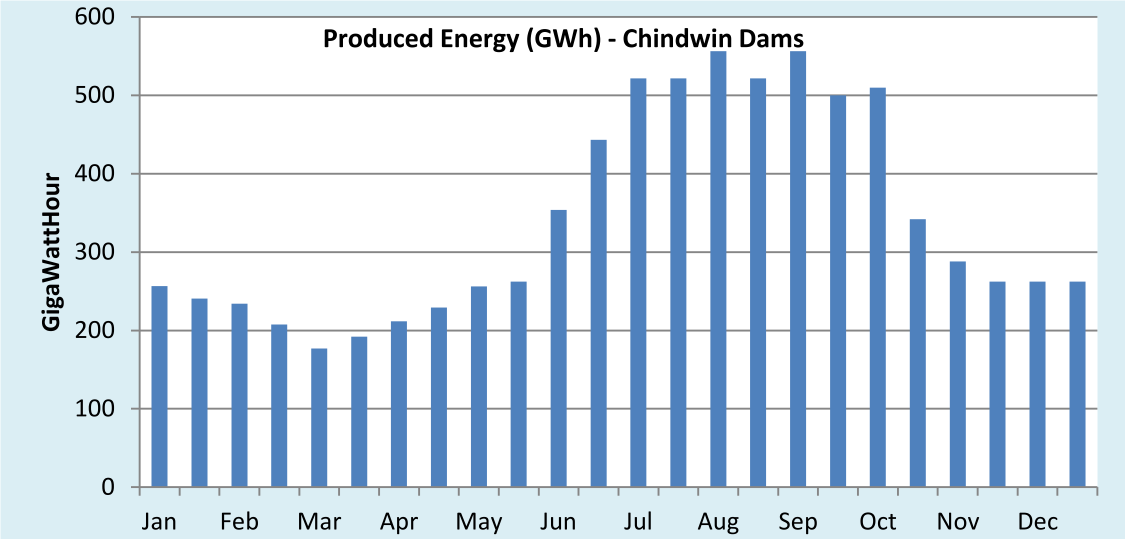


Figure 9.4.7 Average seasonal produced energy by all hydropower dams upstream in the Chindwin River

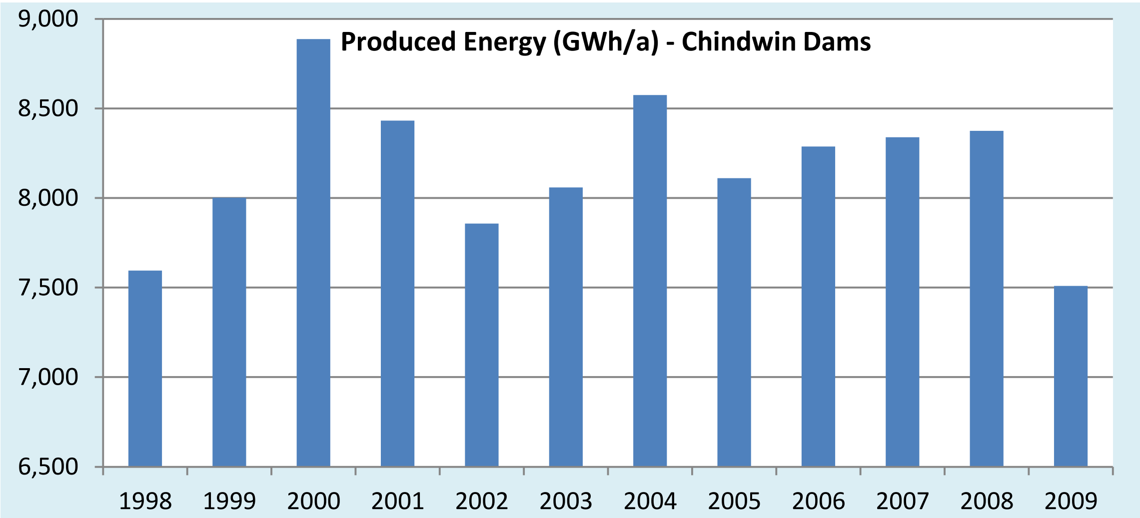


Figure 9.4.8 Yearly produced energy for upstream hydropower dams in the Chindwin River 1998 to 2009

N. Dependable rainfall

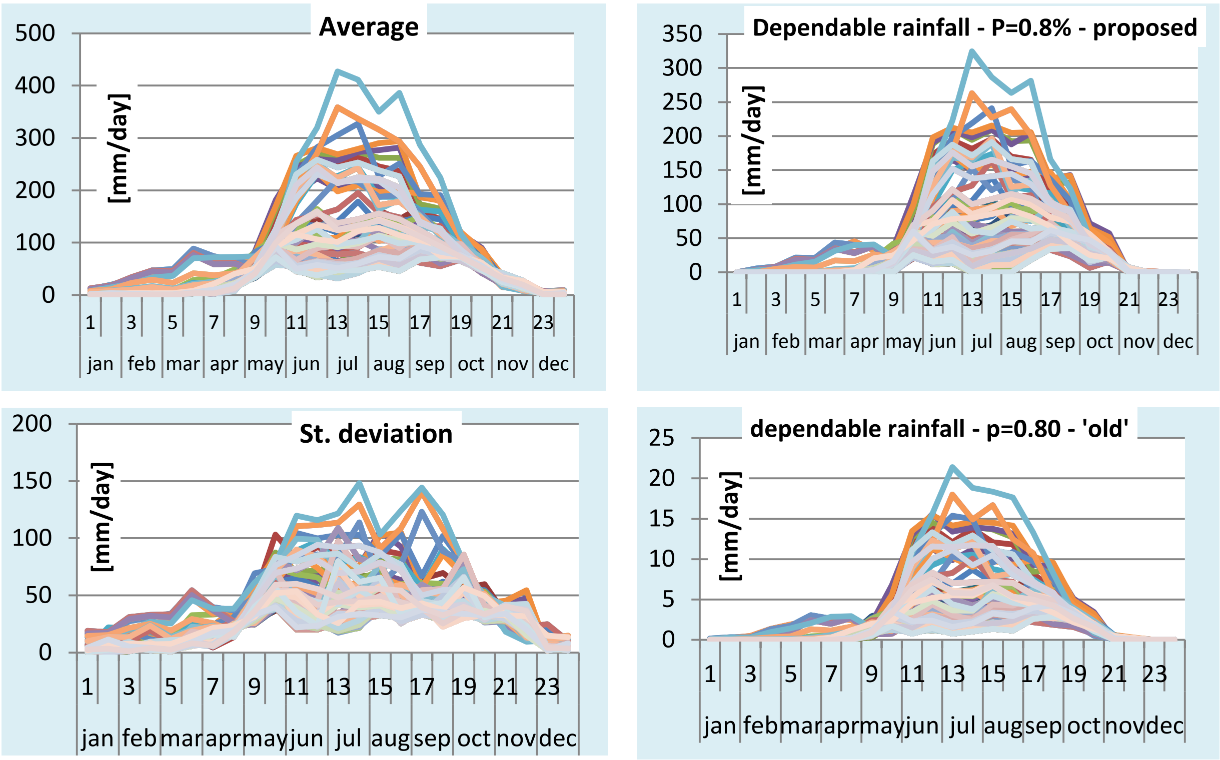


Figure 9.4.9 Dependable rainfall series (left. top)- Average rainfall (μ) for all locations: irrigation areas and reservoirs in the Ayeyarwady River Basin (left. under) – standard deviation (σ) of the data set – (right. top) – dependable rainfall. using the 80% probability of exceedance: μ-0.84*σ. (right. under) – dependable rainfall. as they are computed according to the standard procedure in the Ribasim model development process. The values are here all independent from each other.

O. Appendix 'System description'

P. Appendix 'Model Development'

Q. Appendix 'Scenario Development & Case Study area'

R. Appendix 'Sensitivity Analyses & Validation'

S. Appendix 'Analyses'

T. Ribasim Mastersheet