Rotterdam University of Applied Sciences

School of Built Environment

Department of Civil Engineering

Mapping flood related infrastructure in the Bago-Sittaung basin in Myanmar

Final Report

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By

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PREFACE

This thesis is the product of several months of research to the Bago River basin in Bago in Myanmar and serves as my final graduation report to the bachelor program of Civil Engineering at the Rotterdam University of Applied Sciences. To conduct this research I have lived in the Irrigation Technology Center of the Irrigation and Water Utilization Management Department (IWUMD) of the Ministry of Agriculture in Bago for three months, together with Bob Dubbel and Leon Brok. Whit whom I have been working together for the first part of this research. I hereby declare that all aspects of this report and appendixes may be used for their own reports.

I am very grateful for getting the opportunity to fulfil the last part of my study in a country like Myanmar. Visiting several non-touristic sites, combined with the extreme kindness and authentic culture made my stay an unforgettable experience, for which I would like to thank the people from the Irrigation Technology Centre.

Dr. Ir. Martine Rutten, for giving me this great opportunity and for being available to share thoughts or answering questions no matter what time.

Ir. Edwin Schaap, for the guidance and supervision from the Rotterdam University of Applied Sciences.

Sai Wunna, for being available for any kind of help in and around the Irrigation Technology Center and for getting me in contact with the right persons and arranging meetings.

Dr. Aung Than Oo and Director Ms. Khon Ra, from the Hydrology branch for the clarifying interviews and share of knowledge and data about the river system.

Mr. Myint Soe, Deputy Director of the Bago local office for sharing all needed information and share of knowledge and data about the river system.

Ir. Shelly Win, from the Yangon Technical University which who I have been sharing thoughts about each other's study.

Bob Dubbel and Leon Brok for the support and cooperation to the research and our pleasant time in Myanmar.

Dennis Neleman
Rotterdam, June 2017

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Abstract

Myanmar is a rapidly developing country in South-East Asia. Due to extreme weather conditions Myanmar suffers from severe floods during the wet season and water shortages during the hot season. Floods occur on regular basis and affect thousands of households and people, farmland gets damaged and schools have to close for restorations. Irreversible decisions on the basis establishment of the water systems are to be made. Well thought-out plans could prevent future problems, therefore information about the water system is needed.

The **first objective** of this research had been the collection of missing data about flood-related infrastructures in the Bago-Sittaung River Basin and mapping it into a Geographic Information System (GIS) file, to complete the model of Ir. Nay Myo Lin.

The **second objective** was to bring out advice about possibilities for testing and/or implementing innovative measuring techniques of start-ups and Small and Medium-sized Enterprises (SME's) connected to the VPdelta program.

The last and **third objective** to this research had been to conduct a feasibility study to a hydrologic bottleneck, which had been found by analysing collected data, and bring out advice of possible measures (the case).

To obtain all necessary information and understand the river system a visit of three months was made to Myanmar. By the collection of data about flood-related infrastructure the current ways of measurement, processing of data and the storage of data have been analysed.

The current information system is mostly based on manually taken measurements and stored on paper, which makes it very prone to errors and losses. Implementation of innovative and more advanced measuring techniques would result in more reliable data on a more frequent basis.

By studying the obtained information hydrologic bottlenecks have been mapped. This report focusses on lowering the water level in the Bago River so the Tawa lock gate and sluice can be opened during the wet season, so floods can be reduced/prevented.

The decrease in water level is determined using water level data and river discharges. It is concluded that the water level of the Bago River would have to be decreased by 0.88 meter, which is a reduction in river discharge of 277m^3/s. Possible measures are given and global calculations are made to check the feasibility of each measure.

None of the measures would result in the required reduction in water level or river discharge. With a reduction of 120m^3/s (43% of the required reduction), reforestation is the most effective measure. Another promising measure is to create more storage upstream by more efficient dam operations and the creation of new reservoirs. These measures will have to be studied in more detail to predict the effects more accurate. Once the effect of each measure is known, it must be studied if a combination of these measures will reduce the water level in the Bago River by the required amount.

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1 INTRODUCTION

After almost 50 years of military junta and economic sanctions by the US, EU, Canada and Australia Myanmar is opening up to the outside world. Due to this long period of isolation Myanmar is an underdeveloped country, which is catching up rapidly. In figure 1 the location of Myanmar and the provinces is shown.

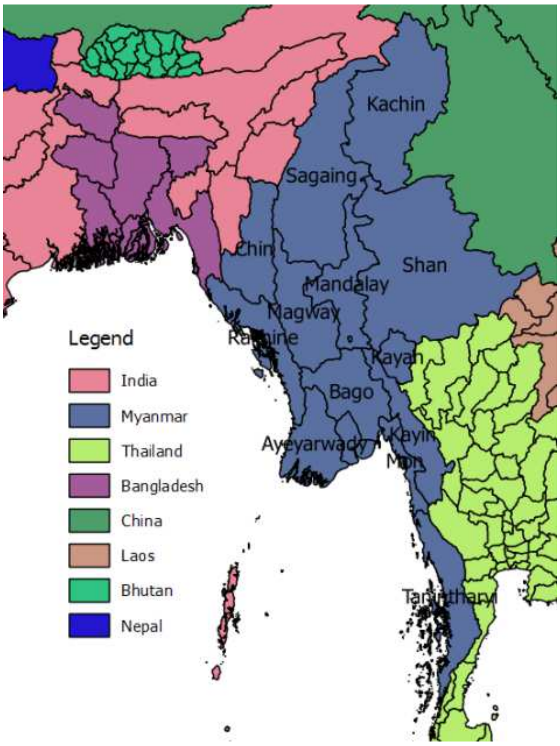

Figure 1: Location of Myanmar and provinces.

Myanmar has a tropical monsoon climate, which means most of the rainfall occurs in the wet season (May to October). The other seasons are cool (November to February) and hot (March to May) ~~season~~. The occurrence of rainfall varies in intensity, time of the year and between regions. The south-west monsoon give precipitations of 2,030 mm to 3,050 mm in the deltaic area, 2,030 mm to 3,810 mm in the north, about 1,520 mm in the Shan, even rising to 5,080 mm in the Rakhine and Tanitharyi regions and dipping to only 780 mm in the central dry zone. Temperatures varies between 43° in hot season to 10° in cold season. For inclusive development of Myanmar, agricultural growth is critical to ensure that food security is achieved throughout the country. Myanmar's population is currently at 54.36 million and is stated to reach 80 million in 2025. (Ministry of Agriculture, Lifestock and Irrigation, 2016)

Due to these extremes Myanmar suffers from severe floods during the wet season and water shortages during the hot season. In 2015 the country suffered from one of the heaviest floods in decades. The flooding has critically affected 1,152,490 million people (of which 103 confirmed death), 15,239 houses have been destroyed, more than 1.29 million acres of farm land has been inundated and 687,200 acres have been damaged. (Floodlist News, 2015)

Irreversible decisions on the basis establishment of the water systems are to be made. Well thought-out plans could prevent future problems, therefore information about the water system is needed. The Myanmar government recognizes this and has therefore accepted the support of the Dutch Ministry of Infrastructure and Environment to create an Integrated Water Resources Management (IWRM) strategy. In May 2013 the Myanmar and Dutch governments have signed a Memorandum of Understanding (MoU) to establish such a strategy. Under this MoU several projects have been carried out with success.

In 2012 educational and research institutions started the Valorisation Program Delta Technology (VPdelta) to connect science, entrepreneurship and social importance to drive innovation. One of the successful projects of the MoU is related to VPdelta. Students of the TU-Delft tested innovative measuring systems and introduced these innovations directly to the Myanmar parties, which were extremely interested. Most of the innovations seemed to be an improvement in effectivity, durability, simplicity and cost reductively in comparison to the current methods. Because of these successes the Myanmar and Dutch authorities decided to expand the scale of the project.

1.1 RESEARCH DESCRIPTION

In July 2014, Nay Myo Lin started his PhD research of “Flood Risk Assessment and Management” at Delft University of Technology. The aim of his research is to improve the effective measures for preventing and managing floods in Myanmar. His research is focused on optimization and simulation of multiple reservoirs operation in a river basin which can be used to control the stream flow at downstream point of interest. (Delft University of Technology, 2014)

The **first objective** of this research had been the collection of missing data about flood-related infrastructures in the Bago-Sittaung River Basin and mapping it into a Geographic Information System (GIS) file, to complete the model of Ir. Nay Myo Lin.

The **second objective** was to bring out advice about possibilities for testing and/or implementing innovative measuring techniques of start-ups and Small and Medium-sized Enterprises (SME’s) connected to the VPdelta program.

The last and **third objective** to this research had been to conduct a feasibility study to a hydrologic bottleneck, which had been found by analysing collected data, and bring out advice of possible measures (the case).

The first objective has been executed in collaboration with Bob Dubbel and Leon Brok, who conducted their research to graduate for their Bachelor of Science to Civil Engineering at the Rotterdam University of Applied Sciences as well. The collaboration of the second objective depended on the usage and availability of measuring equipment. In order to create this final thesis report no measuring equipment has been used, and so this part has been done individually. For the third objective each individual has chosen a case study to a specific hydrologic bottleneck. In appendix 1 all found bottlenecks are shortly described and in the end the choice provision is stated.

At first the case would be about "sedimentation of the Bago-Sittaung Canal". This expanded to the "Bago-Sittaung bottleneck" when found out that the major outlets of the canal, the Tawa sluice and lock gate, is closed most time of the year. This results in floods around the canal and also plays part in the sedimentation issues, since the flow velocities drop. It is assumed that if the gates of the Tawa sluice and lock gate could be opened during the wet season, the floods in the area would be prevented. The constant discharge would result in lower water levels in the canal and could also (partly) contribute to the sedimentation problems in the Bago-Sittaung Canal. This thesis mainly focusses on being able to open the Tawa lock gate during the wet season, the effect to the sedimentation issue will not be studied in this case.

1.2 PROJECT BOUNDARIES

This study is limited to the data collection, processing and analyses in the Bago Region and mainly to the Bago River basin and the Bago-Sittaung Canal. The Bago Region is located in the lower part of Myanmar between North latitude (16 H20") and East longitude (97 H12") and (98 H58"). Bago Region is bordered by Rakhine State and Ayeyarwady Region in the west, Yangon Region in the South, Mon and Kayin State in the East and to the Mandalay and Magwe Regions in the North.

All structures and waterways of influence to the water levels of the Bago River and the canal side of the Tawa lock gate lay within the boundaries of the case. The scope reaches to the Myitkyo Lock gate, which forms the separation between the Sittaung River and the Bago-Sittaung Canal.

In figure 2 an overview of the project area and its boundaries is stated.

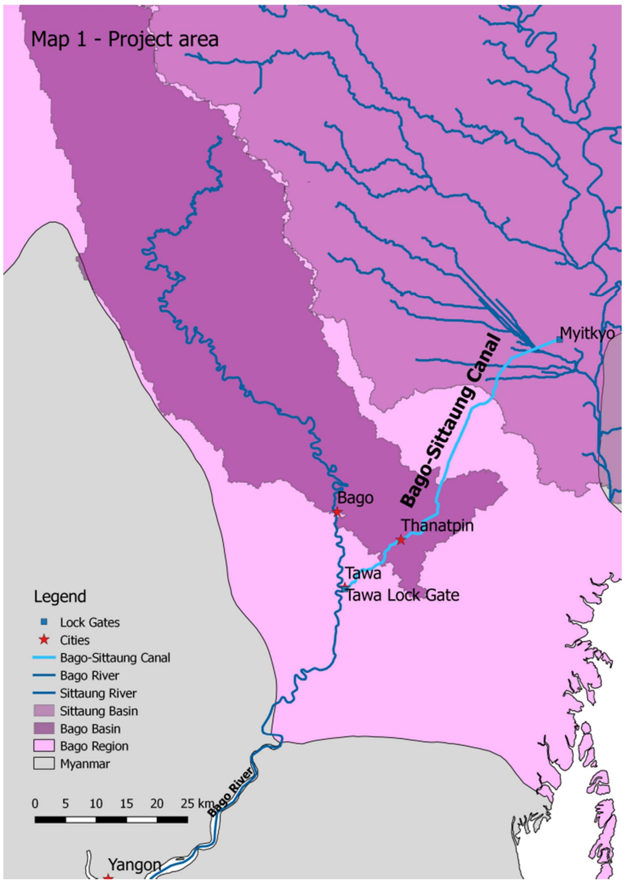

Figure 2: Project area

1.3 Research questions

Given the multiple objectives of this study two sets of questions have been drawn up. The first set of question is mainly about the monitoring techniques and the second set is about a the Bago-Sittaung bottleneck.

Questions about the monitoring techniques:

Main question
"What can be said about the monitoring of the Bago River basin and the Bago-Sittaung Canal by mapping the existing flood related infrastructure, what are the bottlenecks and what measure could be an improvement to the hydrologic system of the area?"

Sub-questions
How is the current situation being monitored and how is this data handled?

What does the obtained information tell us about the hydrological bottlenecks in the Bago area?

What innovative techniques could improve the current system?

What measure(s) could possibly solve one of these hydrological bottlenecks?

Questions about the Bago-Sittaung bottleneck:

Main question
"What measure(s) can be taken to reduce or control the water level in the Bago River, so the "Tawa lock gate" can be opened during the wet season?"

Sub-questions
What are the consequences of not being able to open the Tawa Lock Gate during the wet season?

By how much does the water level of the Bago River have to be lowered in order to be able to open the Tawa Lock Gate?

What measures can be taken to lower the water level in the Bago River?

1.4 Research methods

This report is established from information gathered by doing desk research to previous reports, holding interviews, a field trip and analysing obtained data about the hydrological system and structures. All interview reports and the fieldtrip report can be found in appendix 2. Schematic overviews of the river system and its structures are included in this report. These overviews are based on composed maps. Full scale maps are added to this report as appendix 3.

2 DATA COLLECTION AND PROCESSING

Most of the data collected for Ir. Nay Myo Lin his model is obtained from Mr. Myint Soe, Assistant Director of the local maintenance office in Bago region, part of the Ministry of Agriculture Livestock and Irrigation. Some other data has been obtained via Dr. Aung Than Oo and Ms. Khon Ra, Director of the Hydrology Branch of the same Ministry.

Different ministries and branches are responsible for data gathering. In the following paragraphs the involved ministries and department are described for each parameter, including the methods of measurement and processing.

All collected data is processed in to a GIS-file, the input data is added to this as appendix 4.

2.1 MINISTRIES AND DEPARTMENTS

Measurements are being taken by several ministries and departments, each for their own purpose. Within the Ministry of Transportation, the Department of Meteorology and Hydrology (DMH) and the Directory of Water Resources and Improvement of River Systems (DWIR) take measurements for weather forecasting and navigation. The Irrigation and Water Utilization Management Department (IWUMD) of the Ministry of Agriculture, Livestock and Irrigation take measurements for irrigation purposes, flood control and flood prevention. Within the IWUMD, the Hydrology Branch and the Maintenance section are the main branches concerning flood control and/or prevention. These branches are the biggest parties for data collection as well.

Knowledge about the governmental organisation structure is needed to obtain information. Data has to be requested at the responsible department and/or branch. Which party is responsible for the data depends on the location and function of the structure or measuring equipment.

The many different ministries, departments and branches and the hierarchic way of working make it very hard to share and obtain information. This problem is also applicable for the information exchange between branches or sections within the same department or ministry. For example, data from the DMH is not available for free, not even for other departments. Given the low budgets this data is often not used.

Usage of the internet is also not very common yet, although it is available at most governmental institutions. Appointments have to be made by phone and the data request should later be confirmed by email. Most information is stored on paper and it has to be processed in to a Excel-file before it can be send by email. If there is no internet available information is send by mail.

2.2 WATER LEVELS

Water level data of the Bago-Sittaung Canal and its structures are mainly used for sluice operation at local level, but also for irrigation, development projects and to gain insight in the tidal effects. Measurements are being taken by DMH, DWIR and IMUMD, at Bago City, Zaung Tu, Dam, Zaung TU Weir and at dams, sluices and lock gates.

2.2.1 Manual method

All measurements are taken manually. A local villager is hired to read the water level from a gauge three times a day. The employee writes down the water levels and calls or faxes them to the township office, from this office they send all daily data to the regional office were the data is stored on paper and processed to excel files. If the head office needs any of this data they request it at the regional office.

The process of water level measurement is very sensitive for errors and very time consuming, because it is all done manually and it passes several stations before it is stored. Besides the risk of errors, paper data is also susceptible for loss. Not only physically, but also by fire, water, animals or other kinds of damage which makes it unreadable. It is advised to change the system so less errors will be made, data can be stored safer and be shared quicker and more easily. (Ms. Khon Ra, 2017)

2.2.2 Automatic method

In a collaborative research with the Yangon Technical University and the Tokyo University an automatic water level system had been installed. The system measures the water level every 10 minutes and sends it to a server in Tokyo every hour. There are a lot of problems retrieving this data, firstly it has to be requested from the YTU, which has to request it from the Tokyo University and secondly there are to be a lot of problems with the server according Ms. Khon Ra, Director of the Hydrology Branch. (Ms. Khon Ra, 2017)

2.2.3 Promising methods

Another new system is the system of Tara van Iersel. The system is still in a very early testing phase and the first findings do still have to be reported, but the device is much promising. It measures the water level by using a parking sensor. The device sends the data via the local telephone network to a computer and also saves it on a SD-card in the device itself. This system is still in a very early testing phase.

The last promising system to monitor the water levels in Myanmar, is called Mobile Water Management. This technology allows to measure and process the water level data by making a picture, with a maximum inaccuracy of 10mm. The photo is stored in a database along with GPS-coordinates, timestamp and comments if needed. No live connection is need, the application is able to process the picture when a Wi-Fi connection is established at a later moment. The process is less prone to human errors than the current paper process.

2.3 RAINFALL

Rainfall is measured to determine how much water is entering the system, it is the most important parameter for the water balance. In the Bago River basin the rainfall is measured by the DMH and the IMUMD.

2.3.1 Manual method

The maintenance section of the IMUMD takes rainfall measurements manually. Measurements are taken at the same time (6am) as the water levels are being measured. To save labour costs this is being done the same person who measures the water level. The automatic system measures every hour, the data is saved on a SD-card which has to be collected from the device on site. Due bad road conditions it is sometimes very hard or impossible to reach the measuring station. Data from the automatic systems of the Hydrology Branch is compared with the manual measurements of the maintenance section. Whenever the manual data differs a lot from the automatic data, it is concluded that the man does not do his job right and he gets fired. It occurred that the reader did not go to the site and just called in same assumable results. Because of these errors it is not known how reliable the old (manual) data is. The check makes the manual water level data also more reliable, since it is measured by the same person. (Ms. Khon Ra, 2017)

2.3.2 Automatic method

The DMH already has automatic rainfall station in Bago City and Zang Tu. The Hydrology Branch from the IMUMD recently installed automatic systems at the Kodukwe dam, Salu dam Shwe laung dam, Wagadok dam, Thanatpin, town, Abyar sluice, Shangaing sluice and the Paingkyone sluice as well. At the Zaung Tu dam there is an automatic station as well, but this one is owned by the Hydropower Branch from the IMUMD. (Ms. Khon Ra, 2017)

2.3.3 Promising methods

FutureWater has developed HiP2P, an advanced method of obtaining high resolution rainfall data from satellite images. The method is based on combining colour saturation of vegetation with rainfall data, creating a high resolution rainfall intensity map. This new advanced technology would be very useful for the Bago River basin, since most areas are hard to reach by land during the wet season.

Disdrometrics offers an acoustic rain gauge designed to require no maintenance. The sensor does not only measure the rain intensity, but also the drop-size. The data is send to a cloud platform which makes the data remotely accessible. This device can be placed in the deforested upstream parts of the Bago River basin. This part is very hard to reach, but once set it can give valuable information about the rain intensity and the drop-size is important to determine the erosion grade of deforested lands. The only major condition is the required internet coverage.

2.4 Evaporation

Evaporation is also one of the major parameters for the water balance, but important to determine the needed irrigation water as well. Evaporation is measured by the DMH and the IMUMD using the class a pan method American standard, together with the water levels and rainfall. A pan with a fixed water level is placed in the field and is daily refilled to the fixed point. The amount of added water is the measure of evaporation. After heavy rainfall, water is taken from the pan. (Delft University of Technology, 2015)

2.5 Bathymetry

Bathymetry measurements are important for modelling and the monitoring of changes in the river bed due erosion and sedimentation. The Hydrology branch of the IWUMD measures the bathymetry in the Bago River, for this they use the SonTek RiverSurveyor M9, the S5 and the Garmin Echosounder. This equipment give reliable and accurate results but is highly expensive. Because of this there is a lack of equipment, so measurements cannot be taken on a frequent basis. Measurements are being taking about 8 till 10 times a year, more frequent during the wet season. (Delft University of Technology, 2015)

Among other things, Leon Brok is currently studying the usage of the HKV Lijn in Water Fishfinder to measure the bathymetry of the Bago River.

2.6 Flow velocities

The SonTek Riverserveyor M9 used by the IWUMD to measure the bathymetry, measures the flow velocity as well. These two parameters are used to determine the discharge of the river. The flow velocity is also an important parameter for calculations to erosion and sedimentation. The DMH and DWIR measure the flow velocity about once a year with a current meter or GPS floaters. The measurement is then combined with bathymetry and sedimentation measurements.

3 BAGO-SITTAUNG BOTTLENECK

This case arises from the field trip along the Bago-Sittaung Canal (appendix 1). At first this case would be about the sedimentation issues in the Bago-Sittaung Canal. This expanded when found out that the major outlets of the canal, the Tawa sluice and lock gate, is closed most time of the year. Major measures to the water system causes the local conditions to change as well. Which makes it more efficient to study the bigger picture.

3.1 PROBLEM DESCRIPTION

Originating in the central mountainous region of the Bago Region, the Bago River flows about 331km downstream were it eventually joins the Yangon River to debouch in the Gulf of Martaban. The total catchment area of the basin is 5,348km^2. Figure 3 shows a schematic overview of the river system, a more detailed map is added in appendix 3.

The Zaung Tu weir is constructed in the upstream of the Bago River with the main purpose to control the water levels of the Bago River and to prevent floods in Bago city. This weir has an outlet to redirect water to the Moe Yin Ghi reservoir and irrigation canals for the upper parts of the Bago-Sittaung Canal.

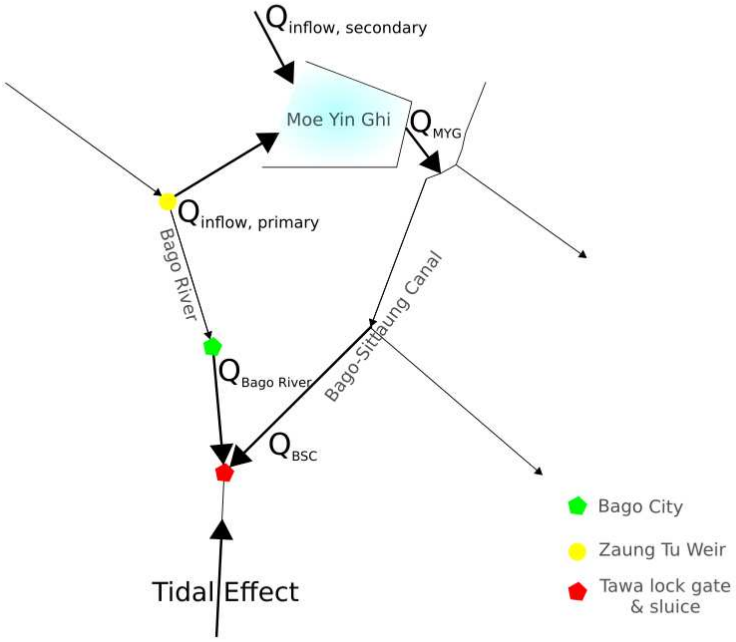

Figure 3: Schematic overview, Q = inflow

The Moe Yin Ghi reservoir was built in 1978 and is mainly fed by the Bago River, Pyin Bon Dam and the Wa Go Dok Dam, but even water released from the Baw Ni, Kaw Li Ya and Baing Da dam ends up in the Moe Yin Ghi Reservoir due small creeks. The reservoir covers an area of 40km^2 but the water levels are quite low, in contrary to the upstream reservoirs. The deepest point of the reservoir is about 3 meters deep, the overall depth is about 2 meters on average. In 2015 the biggest water variation between the highest water level and the lowest has been 2.4 meters, with the maximum between the 13th and the 15th of October and the minimum at the 17th of April. Which means that the reservoir runs almost completely dry during the hot season and fills completely during the wet season (Bago, 2015). Because of the shallow waters the Moe Yin Ghi reservoir is home to many different birds/species and it is proclaimed to wetland sanctuary and wildlife reserve of Myanmar. The reservoir has two sluices which discharge to the Bago-Sittaung Canal. (Soe, 2017)

The Bago-Sittaung Canal connects the Sittaung River with the Bago River. The canal is constructed in 1878 by the British Empire with the main purpose of shipping teak wood to Yangon. Nowadays the Bago-Sittaung Canal is used for irrigation purposes only. The canal distributes water from the upstream reservoirs to the low lands during the dry season. (Wunna, 2017)

Due too high water levels in the Bago River is the Tawa Sluice, the major outlet of the Bago-Sittaung Canal, not able to open its gates, causing floods every year and possibly sedimentation problems in the area. In addition to the better flow, lowering the water level of the Bago River itself would reduce the flood problems in the entire area.

To get a better view of the situation the area is analysed (appendix 5), which results have been used to create a problem tree (figure 5). In the problem tree the case relevant subjects are highlighted. Other points of interest play part in the researched area, but are not included in this case study because they do not have a direct relation to the Bago-Sittaung Canal and the Tawa sluice and lock gate.

Figure 4: Tawa lock gate and sluice gate in the dry season

Problem tree

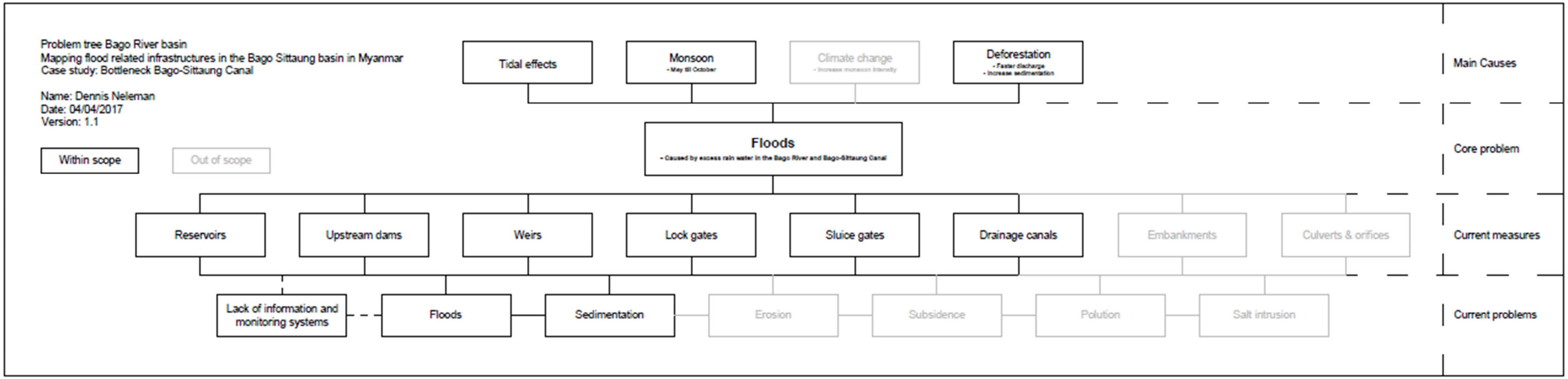

Figure 5: Problem tree

3.2 STAKEHOLDERS

The main stakeholders to this case, the floods and sedimentation problems in the Bago region, are the villagers, farmers and the government. Table 1 shows an overview of the effects and influences of each party.

Farmers are mostly living on their lands or in a nearby village. The effects of the local villagers do also apply to the farmers section. The farmer section can be divided in agricultural, livestock and fish farmers. The agricultural sector suffers the most of the floods, but the others are also effected.

The Ministry of Agriculture, Livestock and Irrigation is the most involved ministry to the flood issue, more about this and other involved ministries is described in chapter 2.1.

Table 1: Stakeholders, effect and influences.

Stakeholder	Interest	Effects;	Influence;
Villagers	High	- risk of drowning; - villages might become unreachable due bad road conditions; - closure of schools; - damage to houses and belongings; - health issues due pollution.	- built their houses on stilts; - learn how to swim; - evacuate.
Agricultural farmers	High	- crop loss due too much water and/or salt intrusion; - lack of irrigation water due sedimentation of the canal; - fertile soil due sedimentation on the lands (positive effect).	- build small local dikes; - build small local drainage systems.
Livestock farmers	Medium	- lose of livestock; - lose of food supply; - diseases to the livestock due polluted water.	- store food in sheds on stilts - evacuation plan/location for their livestock.
Fish farmers	Medium	- escape of fishes from the fish pond; - lose of food supply.	-
Government	High	The overall prosperity of the country is hampered by the floods, for example; - schools have to close; - economic growth gets hampered; - high mortality rate; - etc.	- construct flood protective structures (embankments, dams, culvers, sluices, fuses, reservoirs, weirs etc.) - establish an evacuation plan; - provide emergency supplies.

3.3 RECENT FLOODS

Due to extreme weather conditions Myanmar suffers from floods during the wet season and water shortages during the hot season. Severe floods occur on regular basis. The latest recorded floods occurred in 1973, 1974, 1976, 1988, 1991, 1991, 2011, 2004 and the most recent one in 2015. The chances of flood occurrence are 6% in June, 23% in July, 49% in August, 14% in September and 8% in October. (Department of Meteorology and Hydrology)

Information about the damage, of the earlier stated flood in 2015, has been gathered at the General Administration Department (GAD) for the Bago Region in specific and has been translated in to table 2, and 3. The information states that a total of 3,300 households and a total of 15,428 people had been affected by the floods. A total of 15,172 acres of farmland had been damaged and several schools had to be closed for restoration. (Win I. S., 2017)

Hydrologic information of 2015 is gather and used as critical event further on in this report.

Table 2: Flood effected population, amount of days the flood relief centre had been open, Source: Shelly Win.

Quarter/Village	Flood Relief Centres	Name of Flood Relief Centre	Households	Population	Days open
Kyun Thar Yar	1	Mingalar Youn Monastery	297	1485	4
Mazin	2	Mya Thar Lyoun	216	1047	6
		Kyay Ni Kan Tike Okk	367	1893	5
Zaing Ga Naing (S)	3	Shwe Phone Pwint	137	573	6
		Kyaung Thit	141	579	6
		Win Ga Bar Monastery	84	339	6
Zaing Ga Naing (N)	1	High School No. (4)	44	180	1
Kalayar Ni	1	Kalayar Ni Thein	445	2098	5
Okk Thar (7)	2	Kyaik Pon Pagoda	413	1869	6
		Datkinatharkar	220	948	6
Myothit	1	Stadium	320	1645	4
Ywathit	2	Hantharwadi Monastery	40	150	2
		Middle School (Branch) Ywathit	68	315	1
Kyaut Kyi Su	3	Mon Dahhma Youn	274	1161	3
		Baho Monastery	106	576	2
		Daw Aye Thaung School, Primary school no. (1)	41	179	2
Kali	1	Kali Dahhma Youn	87	391	2
Total	17		3300	15428	

Table 3: Number of Damaged Cultivated Lands due to Flood in Bago District 2015, Source: Shelly Win

Number of Quarter/Village	Number of Agriculture Lands	Number of Farmers	Inundation (Acres)	Drained out (Acres)	Flood Affected (Acres)	Damaged (Acres)	Total Flood Affected/Damaged (Acres)
50	201	3732	21021	21021	7443	7729	15172

3.4 Socio-Economics

Information about socio-economics is based on data of the entire Bago Region and/or Myanmar, this kind of data is not available on a smaller scale.

The Bago Region has a total population count of 4.94 million people, of which 1.18 million are living in the urban areas and 3.76 million in the rural parts. The total area of the Bago Region is 39,421 square kilometres. This results in a population density of 125.5 per square kilometre. In appendix 3 map of the population density in the Bago Region can be found.

3.4.1 Economy

The productive sector is the biggest source of income in Myanmar and in the Bago region, of which agriculture, livestock and fishery, and processing and manufacturing are responsible for 54,6% of the Gross Domestic Product (GDP). Given the huge contribution to the GDP of agriculture, and livestock and fishery, the main focus is on these branches. In table 4 the total breakdown of the GDP is shown.

Gross Domestic Product = 4913.3 billion Kyats

Currently an economic damage assessment of the Bago River basin and the Bago-Sittaung area is being made by Shelly Win. This assessment is being written in partial fulfilment for the degree of Doctor of Engineering in Water Engineering and Management at the Yangon Technical University. The report is not officially published yet, so detailed information of this assessment is not and may not be used for this study.

Table 4: Breakdown of GDP of Myanmar

Industry	Part of GDP
Goods	60.3%
Agriculture	24.3%
Livestock and Fishery	10.7%
Forestry	0.2%
Energy	0.001%
Mining	0.3%
Processing and manufacturing	19.6%
Electric power	0.8%
Construction	4.5%
Services	22.8%
Trade	16.9%

3.4.2 Land use

Table 5 and figure 6 state the use of land in the Bago Region. Most of the land consists of forest, but due deforestation the area is decreasing over the years. Nowadays 70% of the forest has been chopped down for export, small trees are growing again, but they are not big enough to sell. (Wunna, 2017)

In 2016 the Myanmar government has prohibited further lumber of forests for a period of 10 years, with climate change and politics as main reasons. Although it is prohibited, at the northern edges of the Bago River basin are still lumbering activities and the deforestation ongoing. Up from the Zaung Tu Dam till the ongoing sites most of the forest has been chopped down already.

Table 5: Land use in 2015 and 2016.

Type of land	Area in 2014-2015 (Ha)	Area in 2015-2016 (Ha)
Sown area	1,320,336	1,347,809
- Lowland	1,046,978	1,072,481
- Highland	104,472	106,872
- Alluvial land	81,023	78,303
- Garden land	86,104	87,493
- Nipa plan land	31	32
- Taungyar	2,628	2628
Reserved forest	1,593,928	1,583,166
Other forest	81,578	76,783
Cultivable waste land	86,118	73,327
Other	860,163	860,163
Total	3,942,123	3,942,123

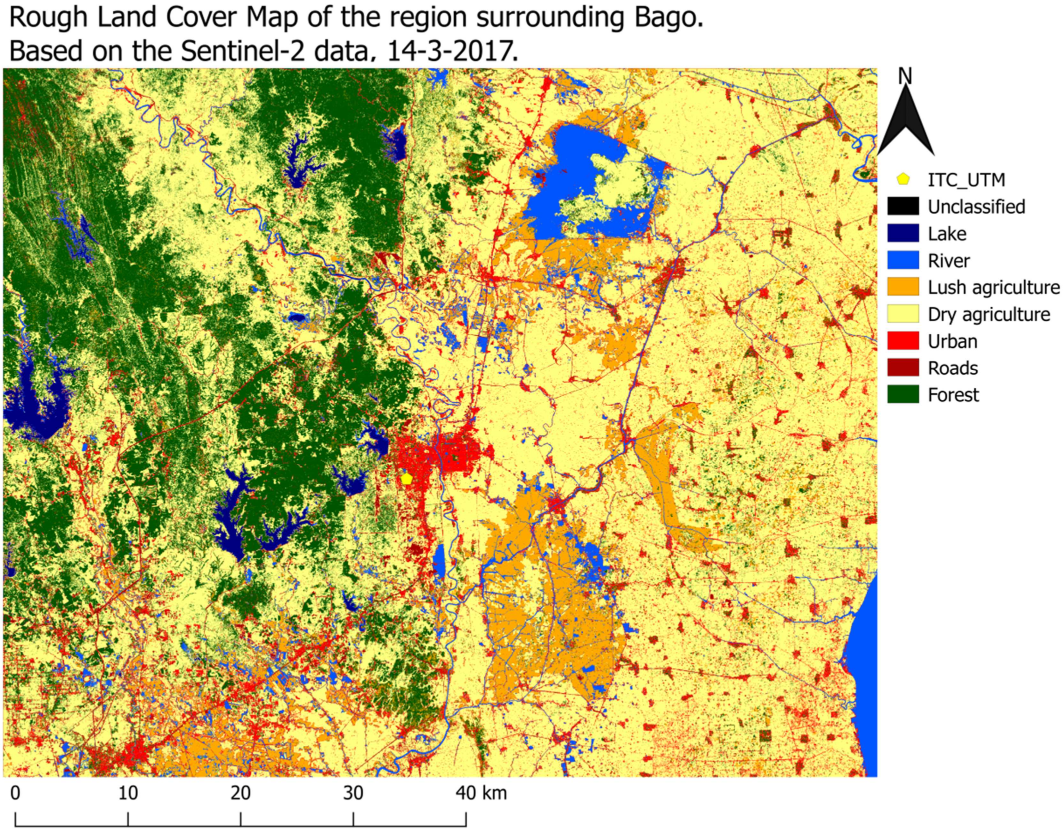

Figure 6: Rough Land Cover Map of the region surrounding Bago. Based on Sentinel-2 data 14/03/2017. (Ebe Gremmer & Nina Kattler)

3.4.2.1 Agriculture

The second major use of land is to grow crops, mostly in the lowland areas. Table 6 shows all cultivated crops in the Bago region. Depending on the weather-, and land conditions the farmers choose what type of crop they grow and in what season. Rice is the most profitable crop to grow, which is mainly because of the stable prices and the relatively high product per acre ratio.

Agricultural farmers are the most affected by the floods. In some areas the farmers are only able to grow summer paddy. Growing paddy during the wet season as well is desired. In the current situation the lands are too wet to seed and the farmers lose income.

In a normal situation the farmers are able to grow rice two times a year or one time rice and one time a less water demanding crop (like beans). Locations with access to irrigation water are usually able to grow paddy two times. In the ideal situation the farmers are able to harvest their lands three times a year, two times rice and once a less water demanding crop. (Win I. S., 2017)

A rough estimation of the flooded cultivatable lands is set to an average of 20,000 to 30,000 acre every year. Because of the floods farmers are only able to grow summer rice (December to April). Rice is being cultivated during the hot season and the rainy season, during the cold season the farmers are sometimes able to grow a less water demanding crop, if they are lucky. (Soe, Individual cases, 2017)

Depending on the quality and quantity of the rice the farmers are able to get a profit of 230,000 kyats per acre. Farmers will directly benefit from the prevention of floods and distribution of irrigation water. The growth of one more crop a year would result in a 4.6 to 6.9 billion kyats more income for the farmers. This would be a huge boost for the rural areas. (Win I. S., 2017)

Table 6: Cultivated crops in the Bago region

Cereals	Paddy, maize
Oilseeds	Groundnut, sesame, sunflower, niger
Pulses	Black lentil, green lentil, bocate, soybean pigeon pea, cow pea chicken pea, butter bean
Industrial crops	Sugarcane, cotton, jute, kenaf, rubber, coffee
Kitchen crops	Chilly, onion, garlic, ginger, turmeric, potato
Fruits & Vegetables	Mango, banana, citrus, durian, water melon, dragon fruit, succulent edible tuber, mushrooms

3.4.2.2 Livestock

Table 7 shows the livestock in farms in the Bago Region, private owned livestock is not included. There is not much know about livestock farmers in the flood prone areas. It is for sure that there are duck farms located along the canal and that some villagers are dependent of their own livestock as well. In general it can be said that floods could destroy or conflict damage the food supply, spread diseases and/or kill the livestock. (Bago Region Government, 2016)

Table 7: Number of animal resources and increase rate

Animal species	April 2014 - 2015	March 2015 - 2016	Increase
Buffalo	328,397	336,847	2.6%
Cows	1,555,746	1,588,807	2.12%
Sheep/goat	73,734	79,227	7.4%
Pig	1,123,564	1,190649	5.9%
Poultry/chickens	36,710,412	40,839,344	11.24%
Duck	8,949,500	9,948673	11.2%
Turkey/Goose	145,623	150,781	3.53%

3.4.2.3 Fishery

There are three fish hatcheries in the Bago Region. The most hatched and distributed fish species are the Rohu, Mrigal, Catla fish, Carp and Tilapian. The breeding of more indigenous species like the scorpion catfish are being researched at those hatcheries. The production and distribution of fish juveniles can be found in table 8. The authorities intend to increase the fish resources by releasing fingerlings in reservoirs, weirs and natural water bodies. In total 7,376,000 fished have been released in 2015-2016, of which a million juveniles of indigenous species.

The Thanatpin and Bago fisheries are located around the Bago-Sittaung Canal. Fishes could escape the fish ponds if flooded. The actual occurrence and the damage caused by this effect is not known. (Bago Region Government, 2016)

Table 8: Production of fish juvelines

Fishery station	Area (Ha)	Production (million)	Sold out (million)	Replenish (million)
Bago	41.6	26.9	22.8	4.0
Thanatpin	250.0	12.4	12.4	2.6
Oatpho	80.3	11.7	9.2	2.4

3.5 MAIN CAUSES

As stated in the problem tree deforestation, climate change, monsoon rain and tidal effect are the main causes of the floods. Climate change is a very tough global issue and therefore not discussed in this report.

3.5.1 Deforestation

As described in chapter 3.4.2.1 deforestation is an issue in the Bago River Basin. Theoretically, deforestation causes mud slides, higher sediment grade in the river and a higher discharge during the monsoon rain. All these effects are negative to the floods.

3.5.2 Rainfall

Myanmar has a tropical monsoon climate, which means most of the rainfall occurs in the wet season (May to October). The other seasons are cool (November to February) and hot (March to May) season.

The occurrence of rainfall varies in intensity, time of the year and between regions. The south-west monsoon give precipitations rising to 5,080 mm in the Rakhine and Tanitharyi regions and dipping to only 780 mm in the central dry zone. The average rain fall in the entire Bago region is 2,230 mm over 110 days of rain. This average is measured by using data from 25 different rain gauges located in the Bago Region. (Bago Region Government, 2016)

New automatic rain station are recently placed in the Bago region. Data from this systems has not been gathered for this research, because the systems did not take a lot of measurements yet and requesting this data would have been very time consuming. Rainfall information for the Bago region originates from the rainfall station in Bago City. So far known the rain intensity over here is the highest of the entire Bago Region. The highest total rainfall measured at the Bago station is 3989mm in 1997, but in 2012 the heaviest monsoon period had occurred. In this period 3,003mm rain fell, which is 83% of the yearly rainfall. (Win S. , 1984 - 2015)

On average, the temperatures vary between from 41.1°C in the hot season till 10.3°C in the cool season. In 2016, maximum temperature has been 42.3°C and the minimum 12.4°C in the Bago region.

3.5.3 Tidal effects

The water level of the Bago River is influenced by tidal effects. The tide comes from Yangon all the way up to Bago City. At the Tawa lock gate the tidal effect can reach up to ± 1.00 meter, in Bago City this number is 0.30 meter. According to Myint this is one of the main reasons of the high water levels in the Bago River. (Soe, Data retrieval river system, 2017)

3.6 CURRENT MEASURES

A lot of different structure have already been constructed in order to prevent/reduce the floods. Information about all flood related structures is collected and mapped in to a GIS file for Mr. Nay Myo Lin. Input data for this GIS file is added in appendix 4 and the location of the structures can be found in appendix 3.

3.6.1 Dams & Reservoirs

In total there are twelve dams and reservoirs constructed in the Bago region (figure 7). The Moe Yin Gi reservoir is the only reservoir created by an embankment enclosed area.

- The Baw Ni -, Kaw Li Ya - , and Baing Da dam are mostly of influence of the Sittaung river, but some water released from the reservoirs ends up in the Moe Yin Ghi via small creeks.
- The Pyin Bon and Wa Ga Dok dam directly feed the Moe Yin Ghi reservoir.
- The Zaung Tu -, Kodukwe -, Shwe Laung -, and Salu dam are constructed upstream of the Zaung Tu weir and control the water level of the Bago River till Bago City.
- The Mazin -, Za Lat Taw -, and Alaing Ni dam are constructed downstream of the Zaung Tu weir and are also of influence of the water level in the Bago River

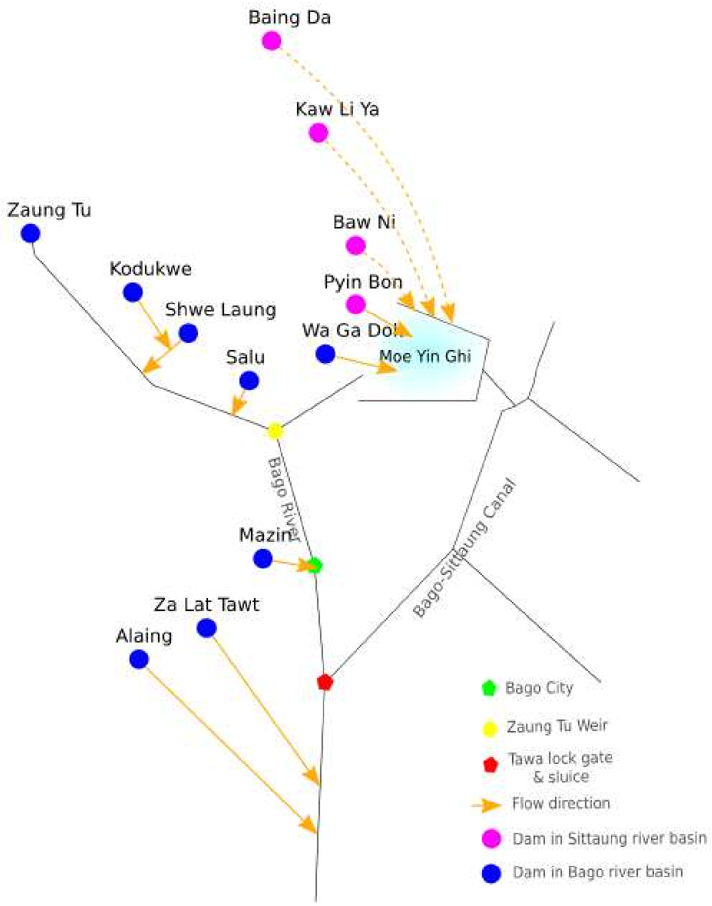

Figure 7: Schematic overview dams

The Zaung Tu -, Kodukwe -, Shwe Laung -, Salu-, and Mazin dam (the upstream dams) are the most important to the water level of the Bago River at the Tawa lock gate and sluice and so the most important to this study. The Shwe Laung dam and Kodukwe dam are under control of the construction sections of the IWUMD, which did not respond on the data request so not all data could be obtained. Data could only be obtained of the Zaung Tu, Kodukwe (only data of 2016 from the YTU) the Salu and Mazin dam.

The Zaung Tu dam is a hydropower dam, constructed in the main stream of the Bago River. The dam has an extremely high spill each year. In 2015 the dam had a total spill of about 660 million m^3. The Mazin dam had a spill of 28,8 million m^3 and a spill of 640 million m^3 in 2016. In both years there had been no spill at the Salu dam and in 2016 no spill occurred at the Kodukwe dam.

According to Ir. Shell Win from the YTU and Mr. Myint Soe, Assistant Director from the Ministry of Agriculture, Livestock and Irrigation in the Bago Region, at 07/04/2017, the upstream reservoirs should be sufficient to store the required water for the wet season. According to the model of Shellly the total outflow of the dams is too small to cause the floods. The reservoirs should have enough storage capacity to store the flood water, but in reality it does not. Floods still occur. The inflow from tributaries might be too high. (Soe, Data retrieval river system, 2017)

The Moe Yin Ghi Reservoir is a by an embankment enclosed area. The inflow comes from the west, were the embankment is open. One of the main roads, the Yangon – Mandalay highway, is located along the open side of the reservoir, as well as several villages. To protect these villages from floods the Moe Yin Ghi Reservoir has to continuously discharge excess (rain) water on the Bago-Sittaung Canal during the wet season.

3.6.2 Weirs

The Zaung Tu weir is the only weir in the Bago river basin and it is constructed upstream of the Bago River with the main purpose to control the water levels of the Bago River and to prevent floods in Bago city. This weir has an outlet to a side channel, which spilt in to the Zaung Tu - Kyaik Ha Canal, the Zaung Tu - Son Pi Canal and the earlier stated Zaung Tu - Moe Yin Ghi Canal. The Zaung Tu - Kyaik Ha Canal, the Zaung Tu - Son Pi Canal function as irrigation canals for the upper parts of the Bago-Sittaung Canal.

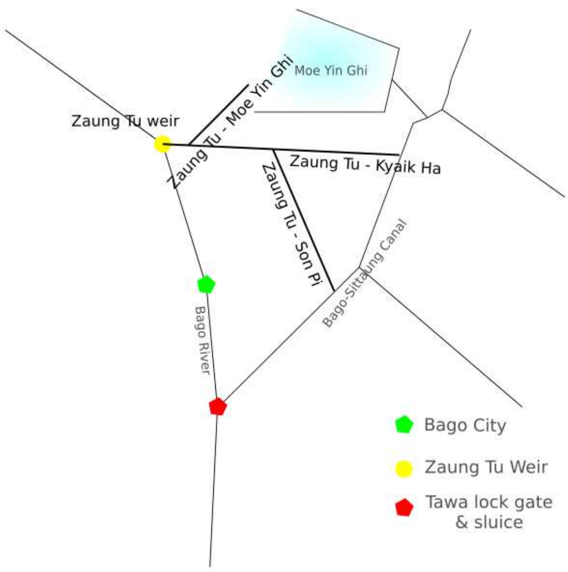

Figure 8: Schematic overview irrigation canals

3.6.3 Drainage canals

Along the Bago-Sittaung Canal there are multiple smaller drainage and irrigation canals. The Aba - Shanking Canal, Min Ywa - Kok Ko Canal, Min Ywa - Paing Kyone Canal and the Kyaikpadaing - Paing Kyon Canal are the main drainage canals. These canals discharge excess (rain)water from the Bago-Sittaung Canal to the Gulf of Martaban. The smaller canals connected to the Bago-Sittaung Canal are meant for irrigation and are negligible for the water levels in the Bago-Sittaung Canal. Cross-sections of main drainage canals are stated in appendix 4.

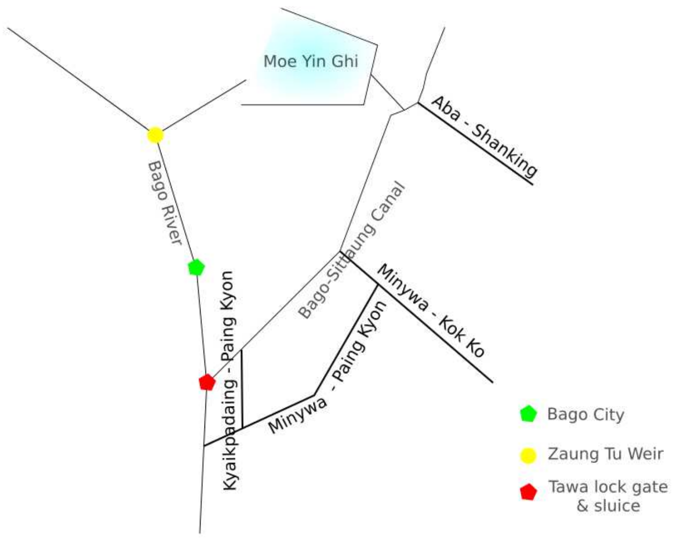

Figure 9: Schematic overview drainage canals

3.6.4 Lock gates

The Myitkyo and Tawa lock gate are the only lock gates in the Bago Region. Due the constant inflow from the Moe Yin Ghi reservoir the Myitkyo lock gate is always closed during the wet season, it is only opened to take water from the Sittaung River if the Moe Yin Ghi reservoir cannot provide enough fresh water during the hot season. The gate is only opened during low tide to minimize the salt intrusion caused by the tidal effects in the Sittaung River. (Soe, Individual cases, 2017)

The Tawa Lock Gate and Sluice are located at the end of the canal, the drainage of excess water to the Bago River is their main function. During the wet season (July – August) the gates are always closed because the water level of the Bago River is about the same or higher than the water level of the Bago-Sittaung Canal.

Figure 10: Tawa lock gate

3.6.5 Sluice gates

There are 20 sluices located within the project area. Most of them are small and designed for irrigation purposes around the Bago Sittaung Canal. The Tawa-, Paing Kyon-, Minywa-, Kyaikpadaing-, Shan Gaing sluice and the Moe Yin Ghi outlets are of a larger scale and designed for flood control.

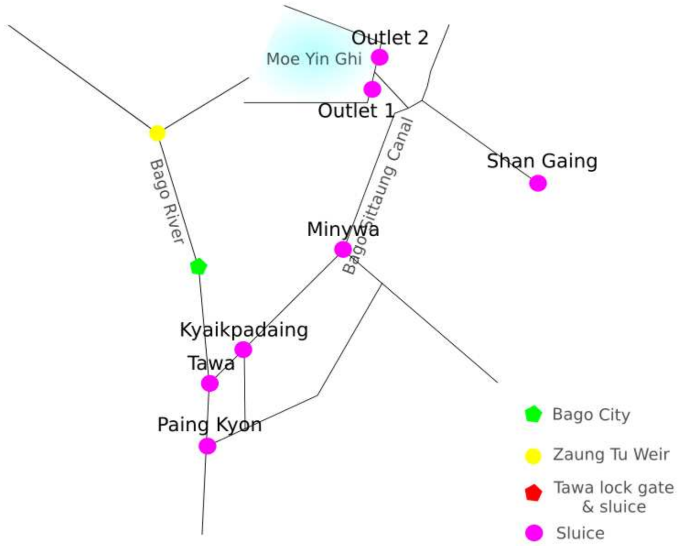

Figure 11: Schematic overview sluice gates

3.7 CURRENT PROBLEMS

In this part the current problems are described. Subsidence and pollution do not have a direct relation to the case and are included in appendix x - analysis report.

3.7.1 Floods

As stated in chapter 3.3, the Bago River basin is flood prone area. Floods still occur on regular basis. Like in 2011, two severe floods occurred in the Bago River Basin in July and August. Nearly all of the rivers and creeks were flooded and an adjacent paddy field area of 498 km2 was inundated. Thousands of households and properties were also affected with the duration of inundation above five days for each event. (Win, 2014)

Heavy rainfall burdens the water system during the wet season. Water from the upstream is partly redirected to the Moe Yin Ghi reservoir, which has to constantly discharge excess water on to the Bago-Sittaung Canal. Because of the higher water levels in the Bago River the Tawa lock gate cannot be opened causing floods in the area.

In 2015 the water level of the Bago River had been higher than the water level in the Bago-Sittaung Canal for 25 days, with the longest period between the 25th of July and 6th of August (13 days). In that period the water level had been continuously higher with an average of +0.53m , the maximum over height had been 0.88m. In 2016 the water level of the Bago River had been higher than the Bago-Sittaung Canal for 22 day, with the longest period between the 8th and 12th of July and after from the 15th till 18th (8 out of 10 days) with an average of 0,25m, the maximum over height had been 0,88m as well. Figure 12 shows a graph of the water levels in the Bago River and the Bago Sittaung Canal. (Bago, 2015)

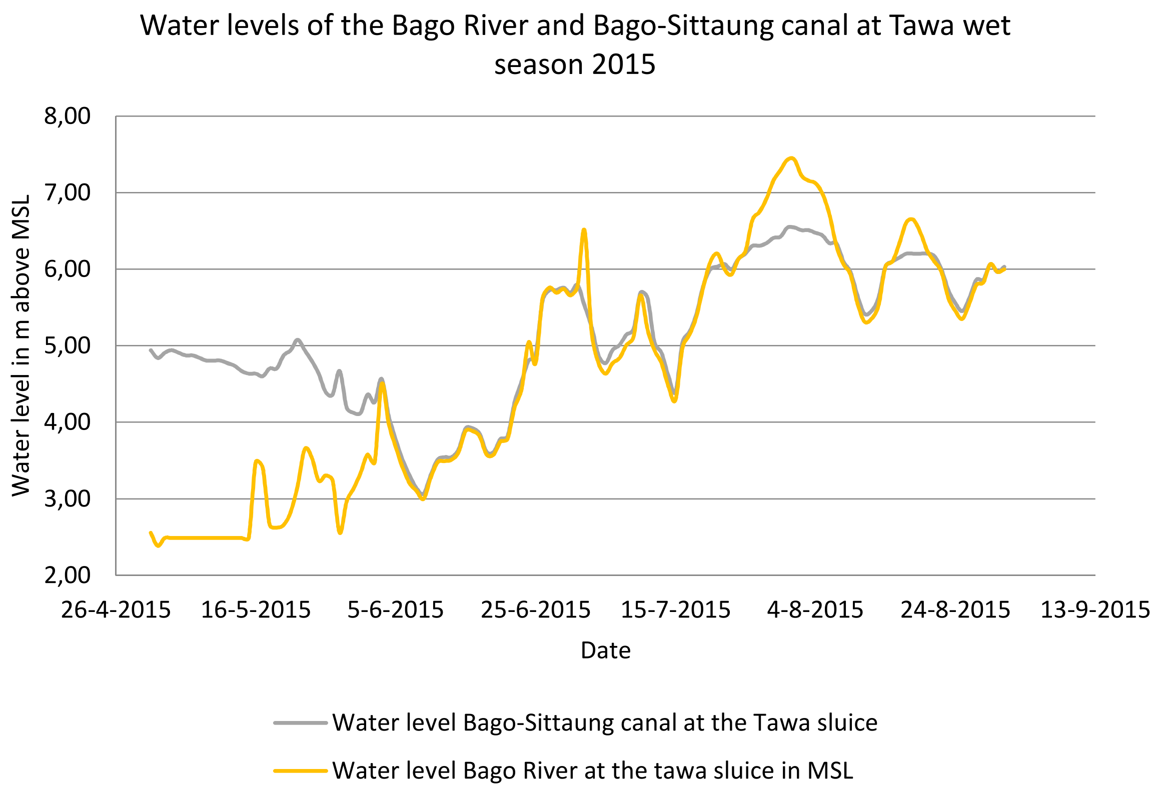

Figure 12: Graph with water levels of the Bago River and Bago-Sittuang Canal at tawa during the wet season of 2015

According to Mr. Myint Soe the water level of the Bago River has to be lowered by 30 cm to be able to discharge excess (rain) water from the Bago-Sittaung Canal and according to the hydrographs of Shelly Win, the floods are caused by a raise in discharge of 400m^3/s during the wet season. These hydrographs could not be shared, so not included to this report. (Win I. S., 2017)

In a normal situation the Bago River able to discharges about 600m^3/s without flooding. Between the 25th of July and 6th of August the average discharge has been about 875m^3/s (appendix 4)., which means that the floods are caused by an additional 277m^3/s Which seems to be consistent with Shell her calculations. To prevent floods this discharge has to be stored over 13 days. A extra storage of 311 million m^3 is required.

There is no detailed flood map of the area available. Based on interviews a rough estimation of flood prone areas has been made. In Figure 13 the area is divided several subareas, for each zone a global level of inundation, risks and effects are described. Area III and VI are the most affected, area IV is also prone to floods.

Area I: The land on this side of the Bago River is higher elevated, than at the other side, no floods occur in this area. The land is mainly used to grow rice and the farmers here are able to harvest twice a year, described as the normal condition in chapter 2.4.1.

Area II: This area is higher situated and protected against floods by the Bago River Embankment, which is why this area does not suffer from floods as well. The area is being irrigated from the Zaung Tu – Son Pi canal, because of this the farmers have the normal farming conditions as well.

Area III: The lands in this area are situated the lowest of the northern side of the canal. The area floods every year by excess water from the Bago Sittaung Canal. Although this area is being irrigated by the Zaung Tu – Kyaik Ha canal, farmers are only able to harvest paddy once a year. Measures have to be taken to prevent floods and improve the liveability in this area.

Area IV: This area is on average. It floods once every two years and the farmers are able to grow to the normal conditions.

Area V: This is a higher situated area which is not prone to floods. Farmers are able to grow paddy twice a year. good area 2 time rice flood 1x 2 year

Area VI: This area suffers from heavy floods due tidal effects every year. Discharging excess water from the Bago-Sittaung Canal via the drainage canals is not an option during the wet season. More water will be send to this area and the floods will be worse if do so, it would be moving the problem and not solving it.

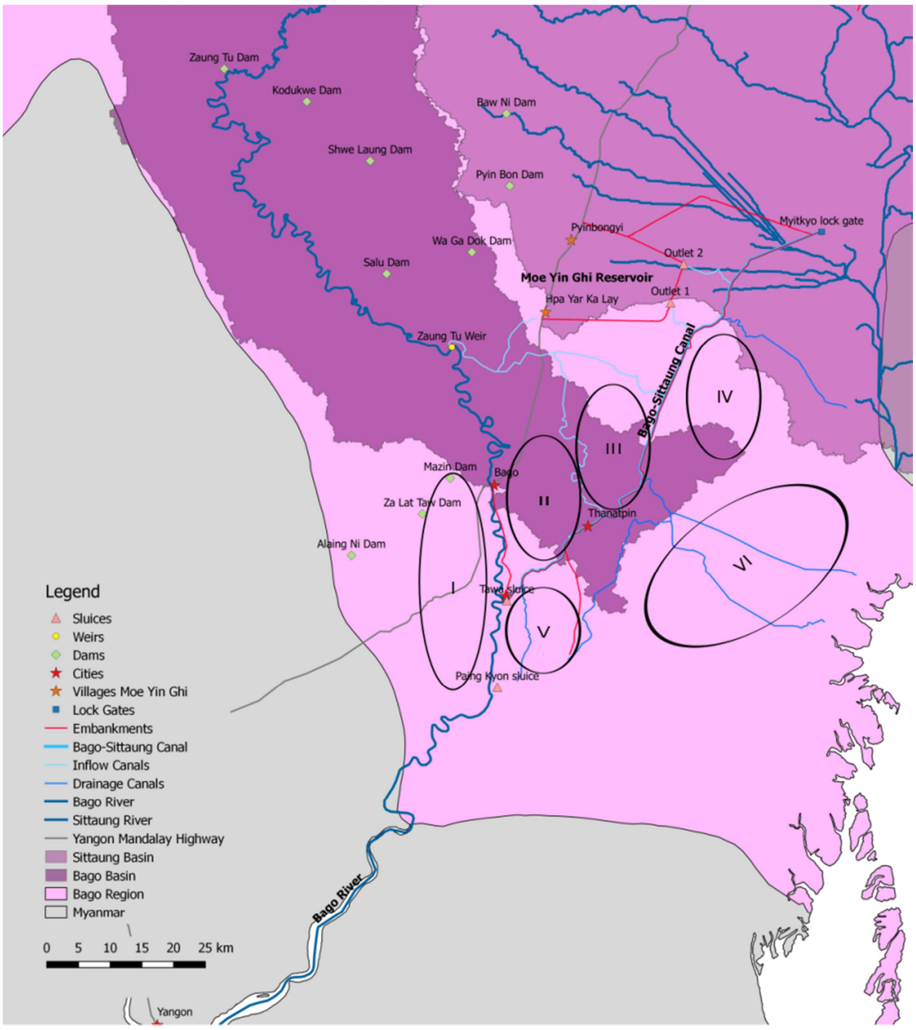

Figure 13: Floodzones

3.7.2 Erosion & Sedimentation

The Bago River and Bago-Sittaung Canal suffer from erosion and sedimentation issues, which lowers the capacity and endangers villages located along the river.

Sedimentation gets measured by the comparison of bathymetry measurements with the design profile. Measurements are being taken using the SonTek m9 RiverSurveyor . Due to the high purchase cost of this measuring system there is only one available in Myanmar. The lack of equipment results in poor monitoring, which is why the scale of the problem is not clear yet. Reservoirs are even never been measured yet. The RiverSurveyor is used a few times per year to measure the bathymetry of the Bago River. Based on these measurements maintenance works have been planned and executed.

In the past years major maintenance works to the Bago River and Bago-Sittaung canal have been executed. In 2011 several sandbanks have been excavated from the inside bends of the Bago River. Over 3 months, 770,000m^3 of soil had been removed costing about 2900 million Kyats. In 2014 the Bago-Sittaung Canal has also been dredged as a part of a big maintenance project of the Bago Sittaung Canal. 1,047,297 sud = 29.5 million m^3 of sediment had been removed in 3 months, using about 200 excavators. The total project included repair works to embankments and sluices as well and costed 25 billion Kyats. The excavations only costed about 7,500 million Kyats.

There are no bathymetry measurements of the reservoirs, the scale of the problems is not known. Therefore, it is hard to say something about the optimisation of the actual current storage capacity and operational use. It is recommended to measure the bathymetry of the reservoirs and compare them to the design drawings.

It is expected that the reservoir of the Zaung Tu Dam suffers the most from sedimentation, this because it is constructed in the main flow of the river and is the nearest to the deforested areas.

3.8 POSSIBLE MEASURES

The water level in the Bago River can be lowered by reducing the tidal effects, enlargement of the river capacity and by creating more storage upstream. Other local measures like creating embankments and enlargement of the discharge of the Bago-Sittaung Canal can be taken to prevent floods. These local measures will not lower the water level of the Bago River and so, do not fit in to the scope of this study. These measures will be discussed in chapter 4.

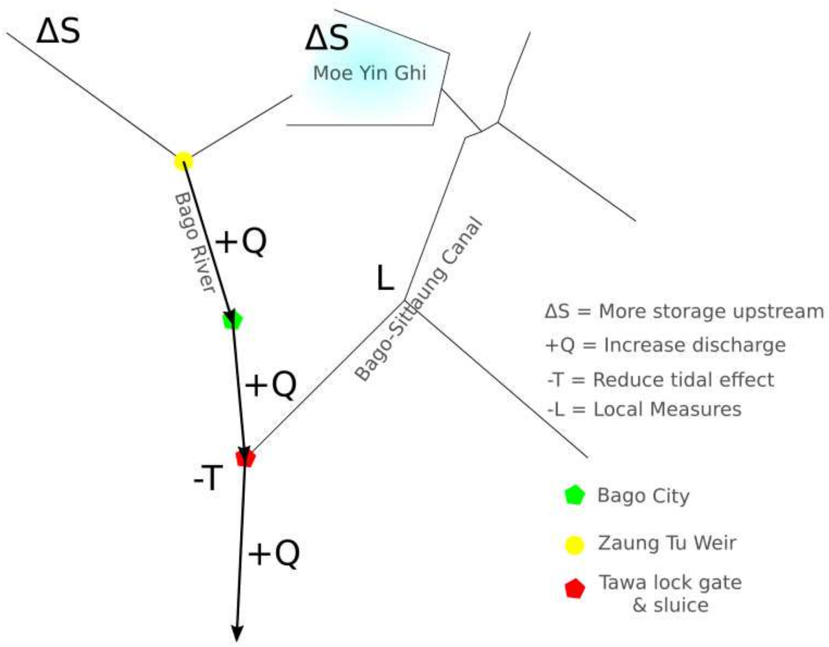

Figure 14: L location of possible measures

The feasibility of some measures is substantiated with basic calculations. The critical event in 2015, during which the water level of the Bago River was higher than the water level in the Bago-Sittaung Canal for 13 days, is used as basis of the calculations. during this event the river had a minimum discharge of 598m^3/s, a maximum of 1103m^3/s and an average discharge of 877m^3/s.

The river capacity is not exactly known, it is assumed that floods occur whenever the water level in the Bago River is higher than the water level in the Bago-Sittaung Canal. As stated in chapter 3.7.1 the floods are caused by a raise in discharge of 400m^3/s in the wet season, according to the hydrographs of Shelly Win. Based on the hydrograph and the critical event of 2015, it is assumed that floods start to occur by discharges larger than 600m^3/s.

It is assumed that whenever the surplus amount of water can be stored, floods will be prevented. In order to determine the amount of needed storage, the difference between the average measured discharge and the assumed river capacity is multiplied over the critical period of 13 days.

$$\Delta S = Q_{flood;avarage} - Q_{capacity} * t$$

Wherein:

Parameter	Descrtiption	Number
ΔS	Required storage	-
$Q_{flood;average}$	Average measured discharge during the critical event in 2015	877m^3/s
$Q_{capacity}$	River capacity	600m^3/s
t	Time of critical event	13 days

$$\Delta S = 877 - 600 * 13 * 24 * 60 * 60 = 311{,}040{,}000 m^3$$

About 311 million m^3 extra storage is needed to prevent future floods.

3.8.1 Reduction of the tidal effect

During the flood in 2015 the water level of the Bago River was 0.88m higher than the water level of the Bago-Sittaung Canal. Removal of the tidal effect at Tawa would lower the water level by one meter, which is enough to be able to open the Tawa Lock Gate and sluice. According to Mr. Myin Soe, the water level has to be lowered just by 30cm.

Tidal effects can be lowered by the creation of a fuse in the mouth of the river. The Bago River is increasing in width downstream. The wider the river the more costly the construction will be, therefore it would be better to construct the fuse at the point where the river is quite narrow. 27.5km downstream of Tawa is a possible location to create a fuse, the river is about 125 meters wide over here.

Creating a fuse would block the tidal effect and lower the water level in the river, but it also blocks the river discharge from the inland. It can be said that by lowering the water level in the river extra storage is created. Whenever this storage is filled before the critical event ends the measure is insufficient. Figure 15 shows a schematic view of the situation.

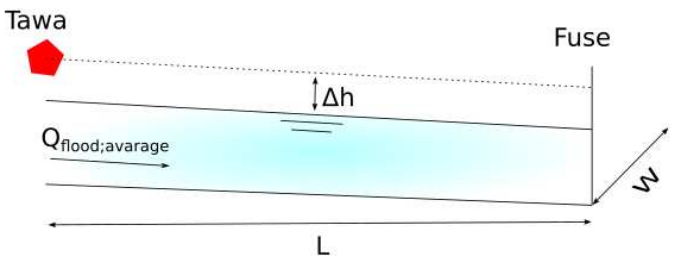

Figure 15: Sketch of situation

At first the created storage is calculated.

$$\Delta S = L * W * \Delta h =$$

Wherein:

Parameter	Descrtiption	Number
ΔS	Created storage	-
L	Length from Tawa till the Fuse	27.500m
W	Avarage width of the river	95m
Δh	Reduction of water level	1m

$$\Delta S = 27500 * 95 * 1 = 2612500 m^3$$

Secondly, the time it takes to fill this storage is calculated.

$$t = \frac{\Delta S}{Q_{\text{flood;average}}}$$

Wherein:

Parameter	Descrtiption	Number
t	Time need to fill the created storage	-

$$t = \frac{261500}{877} = 2979\ sec = 49\ min\ 42\ sec$$

The extra capacity created by removal of the tidal effect will be filled in about 50 minutes, whilst the critical event takes 13 days. Meaning that the fuse will only be an obstruction for excess river water. Extra discharge by opening the Tawa sluice and lock gate is not yet included in this calculation. Opening the lock gate and sluice would result a higher discharge in the Bago River and so less time will be needed to fill the created storage, which is not desired.

The newly created storage is insufficient due the duration of the critical event and the discharge during this event. Lowering the water level of the Bago River by the creation of a fuse would result in floods due to the obstruction of the river discharge. A bottleneck would be created. This measure is not suitable for the problem.

3.8.2 Bago River capacity enlargement

The capacity of the Bago River can be increased by sediment removal, deepening and/or widening the river or by canalising downstream of the river.

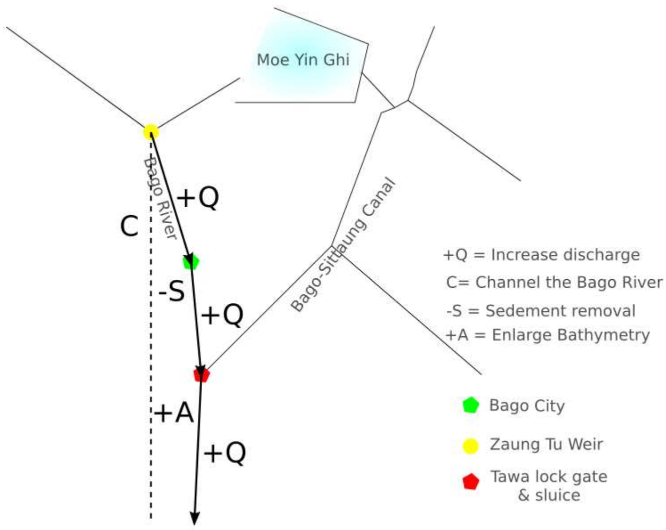

Figure 16: Sketch of various measures to enlarge the capacity of the Bago River

3.8.2.1 *Sediment removal*

Water level measurements were carried out before and after the maintenance works described in chapter 3.7.2 (figure 17). The graph shows a reduction in water level after the maintenance works and suggests that sediment removal is an effective measure, but the graph is based on two different monsoon periods. According to the rainfall data, more rain (240mm) fell in the monsoon period of 2011 compared with the monsoon period of 2015. These two events cannot be compared. Based on this graph it is not possible to conclude that sediment removal reduces the water level of the Bago River significantly.

Erosion and sedimentation is also a time dependent process. Over the years sedimentation issues will return. According to Mr. Myint Soe maintenance works like in 2011 have to be executed once every 8 years. Due to the constant return, this measure is not sustainable enough for the problem.

The above mentioned reasons make this measure not suitable for the scale of the problem. Maintenance to the river is needed to not worsen the situation but it is not sufficient enough to reduce the water level drastically.

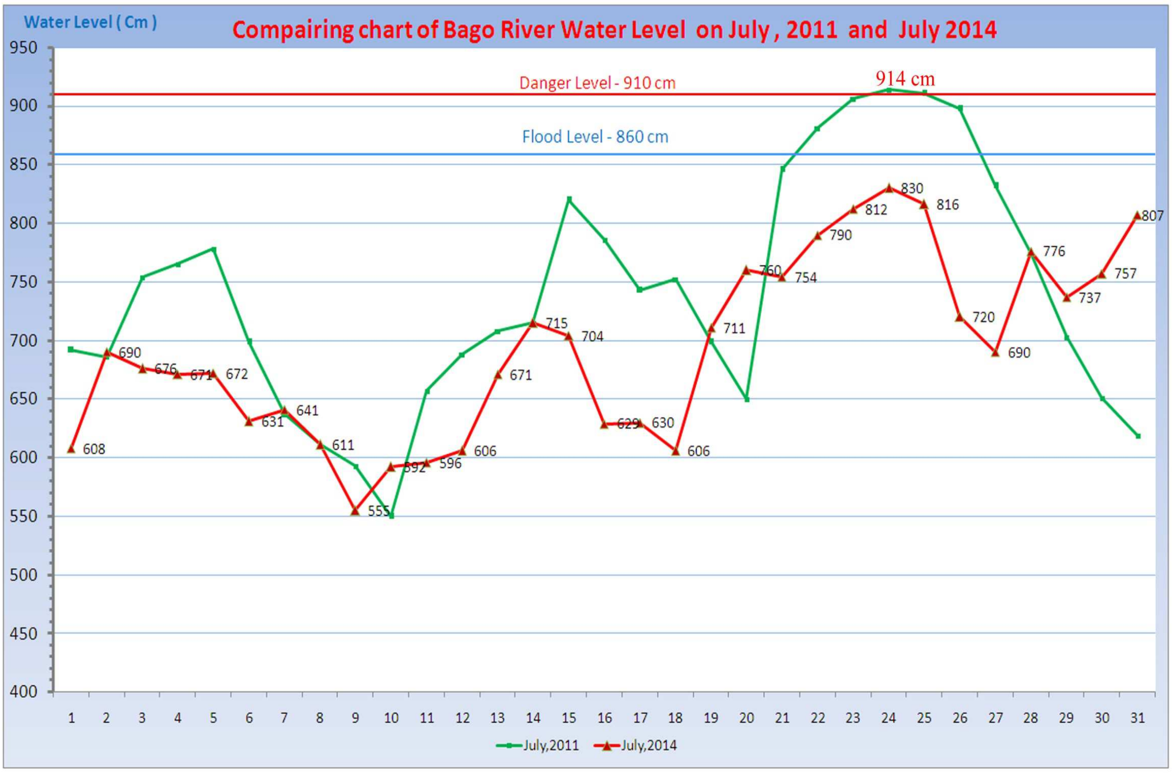

Figure 17: Water levels of the Bago River, at Bago City, before and after sediment removal

3.8.2.2 Deepening/widening the Bago River

Creating a bigger flow area by widening and/or deepening the Bago River would result in a larger capacity. By how much the river has to be deepened and widened is calculated using the assumptions made at the beginning of this chapter.

$$Q = v * A$$

Wherein:

Parameter	Descrtiption	Number
v	Flow velocity	-
A	Flow area	

Assumed is that the flow velocity stays constant, whenever changes in discharge and flow area occur. A factor is calculated over the average discharge of the flood period and the river capacity. The flow area would have to be enlarged by the same factor to be able to discharge the flood water.

$$factor = \frac{Q_{flood;avarage}}{Q_{capacity}}$$

$$factor = \frac{877}{600} = 1{,}46$$

Widening and/or deepening the Bago River by 46% does affect a lot of people living along the Bago River. These people would have to be relocated and compensated for their losses. Besides the people, the flow velocities in the river will drop in the hot season, resulting in sedimentation issues. Widening/deepening the Bago River is not preferred.

3.8.2.3 Increasing the flow velocity by canalising the Bago River

Another measure to enlarge the capacity of the Bago River is to increase the flow velocity. This can be done by straightening/canalising the river. Again basic calculations are made using the Manning formula. Assumed is that the discharge, manning coefficient, flow area and hydraulic radius in the old situation are equal the new situation. This way a factor can be extracted from the slope.

Manning formula:

$$Q = A * \frac{1}{n} * R_H^{\frac{2}{3}} * S^{\frac{1}{2}}$$

In which:

Parameter	Descrtiption	Number
n	Manning coefficient	-
R_h	Hydraulic radius	-
S	Slope	-

The slope is determined using the water level at the Tawa sluice (+21.8m MSL) and the water level at the Paing Kyon sluice (+17.8m MSL) on the first of August 2015. The Paing Kyon sluice is located 12.8 kilometres downstream of the Tawa sluice.

$$S = \frac{\Delta H}{L}$$

$$S_{now} = \frac{3}{12{,}800} = 0.00023$$

Straitening this part of the river results in a lower length (10km) and a steeper slope.

$$S_{new} = \frac{3}{10{,}000} = 0.0003$$

From these two slopes a factor is determined. It must be considered that S is a root function and so the factor will also be rooted.

$$factor = \sqrt{\frac{S_{new}}{S_{now}}}$$

$$factor = \sqrt{\frac{0.0003}{0.00023}} = \sqrt{1.3}$$

The new capacity of the river is calculated.

$$Q_{critical\,,new} = Q_{critical,old} * \sqrt{1.3}$$

$$Q_{critical\,,new} = 600 * \sqrt{1.3} = 684\ m^3/s$$

The calculation indicates that the river capacity could be increased with $84m^3/s$ (14%) by straightening the downstream. Applying this measure would result in a higher flow velocity and a lower water depth upstream of the measure. Erosion takes place near the upstream end of the shortened reach and sedimentation in the downstream end (figure 18). The shortened part will have a higher sediment transport than the old channel. Erosion and sedimentation also progress upstream until the river channel has reached the same slope and water depth as before the shortening (figure 19). However, this result in the lowering of the bed and water levels upstream. Other theoretical effects of shortening the river are the increase of tidal effect and a reduction of storage capacity in the river itself. (Crosato)

Increasing the flow velocity of the Bago River by canalising it would be a major operation affecting a lot of villagers and farmers. Water will be discharged faster, which is a pro in the wet season but a con in the dry season and the increase of tidal effect could increase the salt intrusion. Therefor it is not recommended to apply this measure.

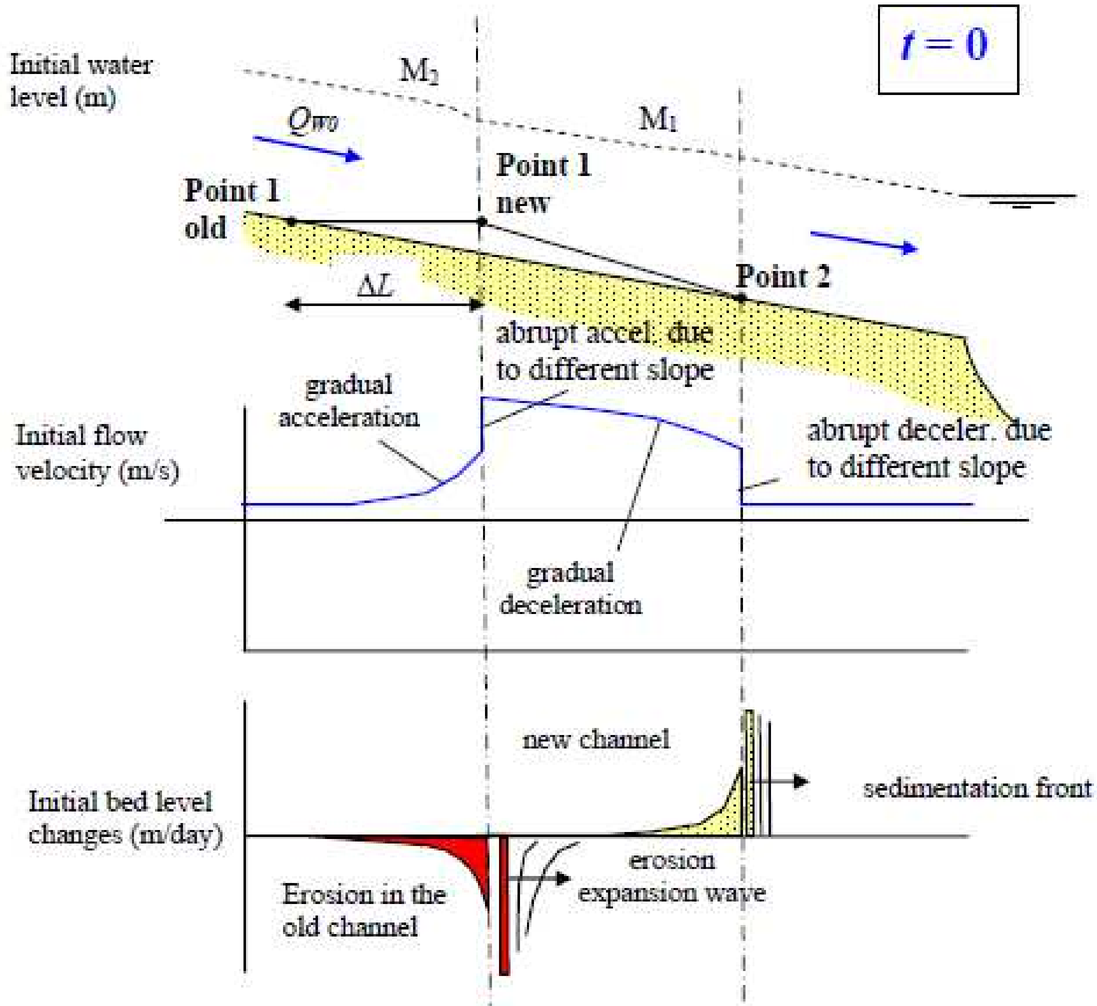

Figure 18: Short term variations caused by shortening of the river course, source: Crossato

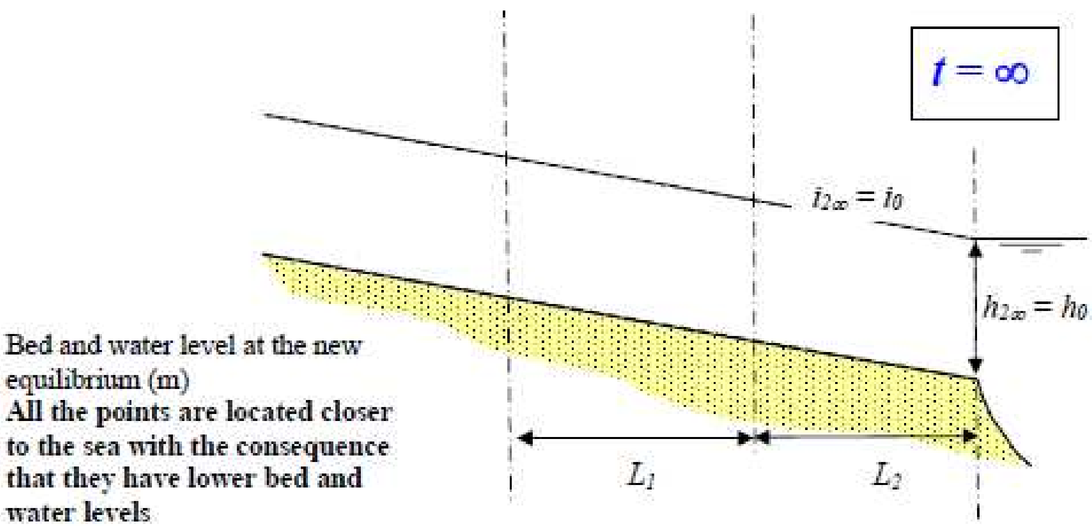

Figure 19: Long term variations caused by shortening of the river course, source: Crossato

3.8.3 Create more storage upstream

More storage can be created upstream by reforestation, more efficient dam operations, enlargement of the Moe Yin Ghi or the construction of a new dam.

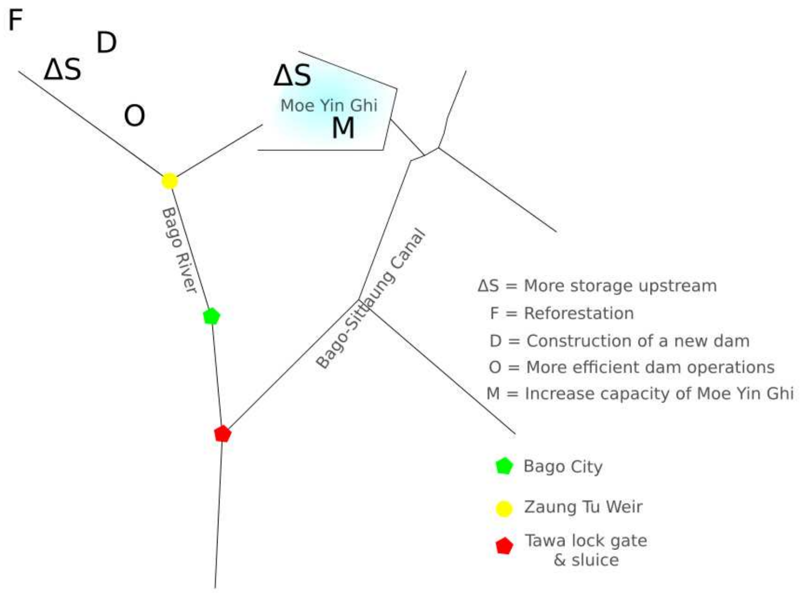

Figure 20: Sketch of various measures to create more storage

3.8.3.1 Reforestation

Forests create a delay in the discharge, enlarge the evapotranspiration and reduce sedimentation. It is a durable solution, good for the wildlife and ecosystems and it requires minimal maintenance. Less water will enter the river and the amount of water will be distributed more over time. To determine the influence of reforestation, some global calculations were made.

Catchment area total:

Parameter	Descrtiption	Percentage	valuer
A_{total}	Catchment area Bago River	100%	5348km^2
$A_{forest,original}$	Original forested area	40%	2139km^2
$A_{deforestated}$	Deforested area	70% of 40%	1497km^2
$A_{forest,now}$	Remaining forested area	12%	642km^2
$A_{other,original}$	Other/agricultural area, deforested area excluded	60%	3209km^2
$A_{other,now}$	Other/agricultural lands, deforested area included	88%	4706 km^2
RC_{forest}	Run off coefficient forested areas		0,15
RC_{other}	Run off coefficient clayey soil (5-10% slope)		0,60

At first the total discharge is split up in the amount of water coming from the forested areas and the amount of water from other lands, mostly agricultural or deforested areas.

$$Q_{now} = Q_{forest} + Q_{other}$$

$$Q_{forest} = \left(\frac{A_{forest,now} * RC_{forest}}{A_{forest,now} * RC_{forest} + A_{other,now} * RC_{other}}\right) * Q_{now}$$

$$Q_{forest} = \left(\frac{12\% * 0{,}15}{12\% * 0{,}15 + 88\% * 0{,}6}\right) * 877 = 28{,}9\ m^3/s$$

$$Q_{other} = \left(\frac{A_{other,now} * RC_{other}}{A_{forest,now} * RC_{forest} + A_{other,now} * RC_{other}}\right) * Q_{now}$$

$$Q_{other} = \left(\frac{88\% * 0{,}6}{12\% * 0{,}15 + 88\% * 0{,}6}\right) * 877 = 848\ m^3/s$$

$$Q_{now} = 28{,}9 + 848 = 876{,}9\ m^3/s$$

Secondly, the original situation is calculated (with a forested area of 40%). The same formula is used, Q_{other} is divided to a newly forested area and agricultural lands.

$$Q_{original} = Q_{forest} + Q_{other}$$

$$Q_{forest} = \left(\frac{A_{forest,now} * RC_{forest}}{A_{forest,now} * RC_{forest} + A_{other,now} * RC_{other}}\right) * \frac{RC_{forest}}{RC_{other}} * Q_{now}$$

$$Q_{forest} = \left(\frac{40\% * 0{,}15}{40\% * 0{,}15 + 60\% * 0{,}6}\right) * \frac{0{,}15}{0{,}6} * 848 = 30{,}3\ m^3/s$$

$$Q_{other} = \left(\frac{60\% * 0{,}6}{40\% * 0{,}15 + 60\% * 0{,}6}\right) * 848 = 726{,}9\ m^3/s$$

$$Q_{original} = 30{,}3 + 726{,}9 = 757{,}2\ m^3/s$$

Difference between the current and new situation is the possible reduction of discharge by reforestation.

$$Q_{difference} = Q_{now} - Q_{original}$$

$$Q_{difference} = 876{,}9 - 757{,}2 = 119{,}7\ m^3/s$$

The surplus discharge left over after reforestation would be

$$Q_{surplus;reforestation} = Q_{flood;avarage} - Q_{capacity} - Q_{reforestation}$$

$$Q_{surplus;reforestation} = 877 - 600 - 119.7 = 157.3\ m^3/s$$

Growing back new forest would reduce the discharge of the Bago River by about 120 m^3/s, which is a reduction of about 18% of the total discharge and more than 40% of the surplus discharge. This is still very global due assumptions in area and runoff coefficient, more detailed calculations will be more beneficial.

In another study to the effect of reforestation to the Margecany–Hornad river basin in Slovakia has been researched by advanced modelling. “The scenario considers a 50% increase of forest areas. The model results show that the reforestation scenario decreases the peak discharge by 12%. Investigation of peak discharges from the whole simulation period, shows that the scenario results are reduced by 18% on average. Also, the time to peak of the simulated hydrograph of the reforestation scenario is 14 h longer than for the present landuse.” (A. Bahremand, 2007)

3.8.3.2 *More efficient dam operations*

By releasing more water during the dry season, more storage is created for the wet season. The boundary condition is that the reservoirs are completely filled again after the wet season, so they do have enough fresh water for the next dry season.

Basic calculations are made using the dam information of the dams upstream of the Tawa lock gate and sluice, to check the time needed to empty the reservoirs so the flood water can be stored. All dams upstream of the Tawa lock gate and sluice (figure 7) are included in this calculation. Salient data of the Kodukwe-, and Zaung Tu dam could not be obtained, because they are being maintained and controlled by the Construction-, and Hydropower branch who did not reply to the data request. Missing data is assumed based on scale comparisons with the known information.

Dams	Capacity	Water spread area	Design discharge
Mazin	30 million m^3	6,2 km^2	0,8 m^3/s
Salu	130 million m^3	19,4 km^2	17,0 m^3/s
Shwe Laung	140 million m^3	16,5 km^2	17,0 m^3/s
Kodukwe	180 million m^3	26,7 km^2	21,1 m^3/s (assumption, factor 1,3 with capacity of Shwe Laung)
Zaung Tu	410 million m^3	49,5 km^2 (assumption, factor 3 with capacity of Shwe Laung)	51 m^3/s (assumption, factor 3 with capacity of Shwe Laung)
Total	900 million m^3	118,3 km^2	106,8 m^3/s

311 million m^3 extra storage is needed. In order to achieve that, the water level in all the reservoirs have to be lowered by about 4 meters. The time needed to release this amount of water from the reservoirs is calculated.

$$t = \Delta S / Q_{outflow;total}$$

$$t = \frac{311{,}000{,}000}{106.8} = 2{,}911{,}139\ sec = 4.8\ weeks$$

Assuming that the reservoirs are completely full, there is no water entering the reservoir, no evaporation and no problems occurring downstream, the time needed to create the required storage is about 4.8 weeks. Although this is quite a long time, the measure is still promising because there will be no need for new expensive constructions or intervention to the current system. The creation of more storage by more efficient dam operations should be studied in more detail.

3.8.3.3 *Enlarge the capacity of the Moe Yin Ghi*

Enlargement of the Moe Yin Ghi reservoir would result in more storage and a lower inflow to the Bago-Sittaung Canal. Expending to the west requires the relocation of the Yangon-Mandalay highway and several villages, which is ruled out according to Mr. Myint Soe.

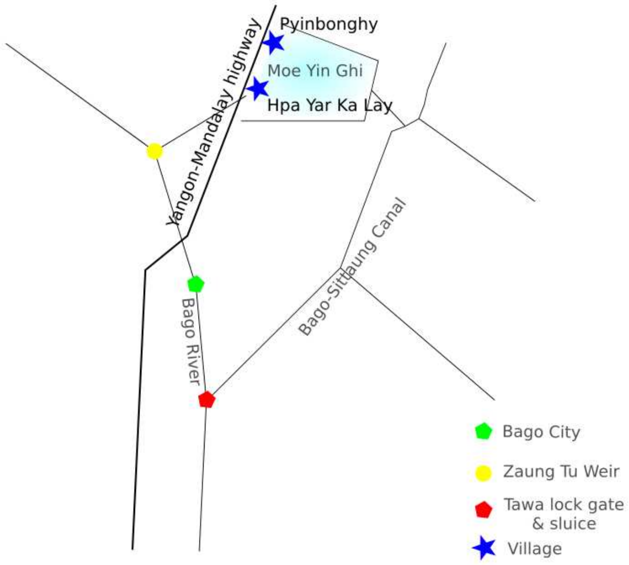

Figure 21: Schematic overview of the location of the Yangon-Mandalay highway and villages

As stated in the problem description the Moe Yin Ghi reservoir covers 40km^2 and has an average water depth of 2 meters. Deepening the reservoir would enlarge the capacity. In order to store enough water the reservoir has to be deepened by 10.1 meters, which is not feasible. If the reservoir is deepened the outlets would not be able to empty the reservoir because of a too low sill level, the farmers will not be able to pump out water for irrigation purposes due a too low water head, farmers will no longer be able to grow crops in the reservoir during the dry season and deepening the reservoir will change the environmental conditions of the reservoir which is also proclaimed as wildlife reserve.

Enlargement of the Moe Yin Ghi reservoir would only create more problems, this measure should not be considered any more.

3.8.3.4 Construct a new dam(s)

The creation of a new dam would directly result in more storage. In the current situation the reservoirs upstream of the Tawa sluice and lock gate are able to store 900 million m^3 in total. To prevent future floods 311 million m3 extra storage is needed.

Currently the construction of a new dam and reservoir in the upstream of the Bago River basin is already being studied by Japanese authorities. The main purpose of this dam would be to provide fresh water for the economic zone in Yangon. Information about the storage capacity could not be obtained.

The construction of new a new dam or maybe even multiple dams is very costly. However, by the construction of a hydropower dam it could earn itself back. This way the dam meets multiple demands and might even be profitable over time.

The creation of new reservoirs would also result in ecological, archaeological and environmental losses.

It is recommended to look in to the possibilities of the construction of new dams further more.

4 DISCUSSION

In this chapter the uncertainties and out of scope topics are being discussed.

4.1 INFORMATION

The analyses in thesis are mostly based on interviews with local authorities. These local authorities are extreme knowledgeable about the water system. Their knowledge is mostly based on years of experience. Although their input is not often substantiated with actual numbers the information is still reliable. Slight errors in the information do not affect the outcome of this research.

The information used as input for the calculations are based on manual measurements in a critical event. Within this process errors can be made easily, which would result in wrong input. The data used for this thesis might have small deviations. These deviations could result in slightly more positive or negative results. However, the influence of these deviations on the results are negligible. Global calculation and estimations made in this thesis could still be done based on this information.

During interviews with Dr. Aung Than Oo and Ms. Khon Ra from the Hydrology branch it is noticed that the communication between universities and governmental departments is very poor. The authorities are aware of specific bottlenecks, which are ideal to be studied by students, and unaware of the topics being researched. Better communication and collaboration between universities and relevant departments could speed up the development of the country and solvation of the water issues.

4.2 CALCULATIONS

The discharge of 600m^3/s used, in chapter 3.8.2.2, to determine the required extra storage is an assumption of which all calculations are based. The actual river capacity is not known. The assumption is based on discharge measurements taken during the critical event in 2015 at Bago City. The assumption of 600m^3/s might be too high. A lower capacity would be of great influence to the outcomes. More storage would be needed, which would result in to less favorable outcomes.

The forested and deforested areas used to calculate the effect of reforestation in chapter 3.8.2.1 are partly based on the forested area in the entire Bago region and interviews with Mr. Myint Soe, Sai Wunna and Shelly Win. The actual forested and deforested areas in the Bago River basin are not known. More research would have to be done to determine the needed parameters before a detailed model study can be done. Important input for a model study to the effect of reforestation on the floods are; digital elevations maps, soil type, land use, precipitation and potential evaporation time series. Digital elevation maps are already available and land use can be studied using satellite images. Rain gauges of Disdro can be used to measure the precipitation, these gauges require no maintenance and also measure the drop-size.

4.3 Out of scope measures

Other physical measures which can be taken to reduce the floods are the enlargement of the discharge of the Bago-Sittaung Canal and placement of embankments. These measures are not elaborated and noted in chapter 3 because they do not result in a lower water level in the Bago River, of which the case is aimed.

4.3.1 Enlarge the discharge of the Bago Sittaung Canal

By opening the Minywa sluice gate (figure 11) it is possible to unburden the Bago-Sittaung Canal. Water will then be discharged to area VI on figure 13. This area is also prone to severe floods, caused by tidal effects and so bringing more water to this area is not recommended.

4.3.2 Local embankments

Placement of embankments, temporary or permanent, could offer protection to the farmers and villagers in the most critical areas.

5 CONCLUSION

The governmental institutions are aware of the importance of monitoring the water systems, but do not have the funds and knowledge to drastically upgrade the system. Although some improvements have been made, by placing automatic rain gauges, is the current monitoring still very poor.

In the current situation water levels, rainfall, evaporation and flow velocities are mostly manually measured and processed three times a day. Within the process of manual measurement taking a lot of errors can be made. The data is often stored on paper, which make it vulnerable for losses as well. Bathymetries are automatically measured and processed using the SonTek RiverSurveyor M9, the S5 and the Garmin Echosounder.

Many different ministries and departments are involved in measurement taking. Each party collects, processes and stores information for their own purposes and responsibilities. Data has to be requested from the responsible party, therefore knowledge about the governmental institutions and their responsibilities is needed. Once requested, the data is being digitalised and send by mail or delivered on a CD or USB-drive.

Implementation of more advanced innovative (automatic) measuring techniques would result in more frequent and more reliable information. These systems automatically digitalise and process the data, which make it much easier to share and work with.

Innovative measuring techniques which could improve the current way of measurement taking, processing and storage are;

- Mobel level tracker of Mobile Water Management, for water level measurements;
- Car sensor in PVC pipe of Tara van Iersel, for water level measurements;
- HiP2P of FutureWater, for rainfall measurements;
- Disdro rain gauge of Disdrometrics, for rainfall and drop-size measurements;
- the Fishfinder of HKV lijn in water, for bathymetry and depth measurements.

It must be noted that some of these measure techniques require a phone or internet connection. In the remote areas this, from where information is mostly needed, these connections are often weak or not available.

The Bago Region is prone to severe floods caused by tidal effects, climate change, heavy monsoon rain and deforestation. Because of the varying river discharges and flow velocities over the year, erosion and sedimentation issues occur. In total eight hydrological bottlenecks have been found by analysing the obtained data, most of them arise from interviews with local authorities. The closure of the Tawa sluice during the wet season had been the bottleneck focussed on in this thesis.

Due too high water levels in the Bago River is the Tawa Sluice, the major outlet of the Bago-Sittaung Canal, not able to open its gates, causing floods every year and possibly sedimentation issues in the Bago-Sittaung Canal and Bago River.

Agricultural farmers are the most affected by the floods. About 20,000 to 30,000 acre of farmland floods every year, causing farmers to grow rice only once a year. With a profit of about 230,000 kyats per acre the yearly losses add up to 4.6 to 6.9 billion kyats a year. Besides agricultural damage the flood of 2015 damaged 3,300 households, a total of 15,428 people had been affected and several schools had to be closed.

During the flood in 2015 the water level of the Bago River had been higher than the water level in the Bago-Sittaung with an average of 0.53m and a maximum over height of 0.88 meter.

In order to lower the water level of the Bago River by 0.88m several measures can be taken.

- The tidal effect could be reduced, which lowers the water level by one meter.
- Enlarge the capacity of the Bago River(277m^3/s), by;
    - sediment removal (incensement in flow area),
    - deepening/widening the Bago River (incensement in flow area),
    - canalisation (increasement in flow velocity).
- Creation of more storage upstream (311 million m^3), by;
    - reforestation,
    - more efficient dam operations,
    - enlargement of the Moe Yin Ghi reservoir,
    - construction of a new dam.

None of the measures is able to reduce the water level of the Bago River by 0.88 meter. The most promising measures are;

- **Reforestation** would result in a reduction in river discharge of 120m^3/s (43%) of the total 277m^3/s. The measure is a durable solution, good for the wildlife and ecosystems and it requires minimal maintenance.
- **More efficient dam operations** could result in more storage upstream. The upstream dams would have to continuously discharge for 4.8 weeks to create enough storage. With this measure there is no need for new expensive constructions or intervention to the current river system.
- By the **Construction of a new dam(s)** sufficient storage can be created. The costs of this measure are high but could earn itself back by the creation of a hydropower dam. The stored water can be used for in the dry season. The creation of new reservoirs would also result in ecological, archaeological and environmental losses.

6 RECOMMENDATIONS

In order to improve the current information system it is recommended to;

- digitalise the existing data into Excel-, and GIS-files,
- start measuring water levels by Mobile level tracker of Mobile Water Management,
- study the possibilities for implementation of HiP2P and Disdro gauges for rainfall measurement in at remote locations,
- create a shared database with all involved ministries and departments to make information accessible more easily.

To lower the water level in the Bago River it is recommended to;

- conduct a model study to the actual effects of reforestation as done to the Margecany–Hornad river basin in Slovakia.
- conduct a study to the current dam operations and effects to the river discharge,
- study the possibilities of the creation of new upstream reservoirs,
- combine the results of the studies and determine the best combination of measures.

In order to speed up the development in Myanmar it is recommended to;

- improve communications between involved ministries and universities, by monthly skype calls or e-mail updates about ongoing researches an bottlenecks in the area to plan future studies aimed at specific actual problems.

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Appendix 1 - Case description & Choise provision

Appendix 2 - Interviews and field trip

Appendix 3 – Maps

Appendix 4 – Information

Appendix 5 – Analysis report