Water level monitoring in the Sittaung river basin
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Additional M.Sc. Thesis

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Preface

This study took place at the Irrigation Technology Centre in Bago, Myanmar, which served as my home during February and March in 2015. It is the result of 10 weeks of research as part of the master program of Civil Engineering at the Technical University of Delft. The overwhelming friendliness and authentic culture made it an unforgettable experience. It was great to have the privilege of visiting so many locations and encounter the incredible development this country is going through.

Prior to the actual report, I would like to thank everyone who helped me bring this research to a successful end. First of all I want to thank the people from the Irrigation Technology Centre, who made it such a pleasant place to stay.

Dr. Ir. Martine Rutten, for giving all the supervision one could wish for. Not only for making this project possible, but also for being always there for questions, whether it was 7 in the morning or in the weekends.

Ir. Nay Myo Lin, for guiding us through the area and helping us with all the local issues and customs. Thanks for all the stories and information about Myanmar.

Ir. Thiha Aung, for welcoming and helping us at the Irrigation Technology Centre and for always being so friendly.

Prof. Dr. Ir. Nick van de Giesen, for taking over the role of supervisor and support our project.

Dr. ir. Peter-Jules van Overloop, for being such an inspiration, even though it our contact was only brief.
Abstract
The Republic of the Union of Myanmar has the fortune of governing their precious water resources just by itself. A country that has been held at a standstill for decades is now developing at enormous pace and the pressure on its water availability rises just as quick. Great challenges lay ahead and proper water management is a necessity to be able to cope with them. In order to do so decisions need to be based on obtained data and reliable models.

This report mainly focusses on the data collection, handling and storage of the water levels being recorded in the Sittaung catchment area. Thereby there is looked at enhancing the current methods and the possibilities for Model Predictive Control (MPC). Besides getting a clearer overview of what’s happening in the water system, the goal is to receive “(near) real-time water level data” as input for the SOBEK model of ir. Nay Myo Lin. The aim of this model is: “Flood mitigation through optimal operation of a network of multipurpose reservoirs.”

To obtain all the necessary information and understanding of the traditional methods that are used a visit of ten weeks was made to Myanmar. During two weeks of field trips throughout the Sittaung catchment area the current ways of obtaining, transferring, storing and using data of several branches were observed and analysed. The rest of the time was spent, processing the collected information with the help of the local staff at the Irrigation Technology Centre in Bago.

Firstly a number of developments and challenges are discussed in chapter 1. Ultimately they all lead to the following problem definition in 1.2: an integrated approach to water management is required in order to cope with all the challenges that lay ahead.

After examination of all the existing staff gages in chapter 2, it is clear that there is an enormous lack of standardization. Although a lot of data is being measured it is all done in different units and with other zero gauge levels. Standardizing these will increase the usability of each other’s data significantly.

At the moment data are collected three times a day and then travel through different offices where they are continuously stored on paper, see 2.3.2. To reduce the amount of errors that can be made and the time it takes between recording the water levels and having them available in the office, two alternative methods are reviewed, Mobile Water Management and a hybrid method in chapter 3. In both cases there is no more paperwork involved and after recording the water level it is immediately made available for other uses.

Both of them rely on a reasonable internet connection, therefore the development of this sector is studied too in section 2.5 as part of the system analysis. Following the giant steps that are being taken to improve the quality and the capacity of internet communication, it can be concluded that in 2017 the connection will be capable of handling all the necessary processes.

In chapter 4 it is concluded and recommended that since it requires significantly lower further investments it is advised to start using the hybrid method and no longer invest in automated devices, which are bound to break down at some point. By doing so a new step is taken towards real time control in the Sittaung river basin. In case it appears not to offer the demanded swiftness or reliability a new study can be done towards the implementation of e.g. Mobile Water Management in 2017.
### Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB</td>
<td>Construction Branch</td>
</tr>
<tr>
<td>CDZ</td>
<td>Central Dry Zone</td>
</tr>
<tr>
<td>DHPI</td>
<td>Department of Hydropower Planning and Implementation</td>
</tr>
<tr>
<td>DMH</td>
<td>Department of Meteorology and Hydrology</td>
</tr>
<tr>
<td>DoI</td>
<td>Department of Irrigation</td>
</tr>
<tr>
<td>DWIR</td>
<td>Directorate of Water Resources &amp; Improvement of River systems</td>
</tr>
<tr>
<td>HB</td>
<td>Hydrology Branch</td>
</tr>
<tr>
<td>ITC</td>
<td>Irrigation Technology Centre</td>
</tr>
<tr>
<td>LO</td>
<td>Local Operator</td>
</tr>
<tr>
<td>MoECaF</td>
<td>Ministry of Environmental Conservation and Forestry</td>
</tr>
<tr>
<td>MoAI</td>
<td>Ministry of Agriculture and Irrigation</td>
</tr>
<tr>
<td>MoT</td>
<td>Ministry of Transport</td>
</tr>
<tr>
<td>MoE</td>
<td>Ministry of Electric Power</td>
</tr>
<tr>
<td>MoC</td>
<td>Ministry of Construction</td>
</tr>
<tr>
<td>MPC</td>
<td>Model predictive Control</td>
</tr>
<tr>
<td>MSL</td>
<td>Mean Sea Level</td>
</tr>
<tr>
<td>MWM</td>
<td>Mobile Water Management</td>
</tr>
<tr>
<td>NWRC</td>
<td>National Water Resources Committee</td>
</tr>
<tr>
<td>NWP</td>
<td>National Water Policy</td>
</tr>
<tr>
<td>IWRM</td>
<td>Integrated Water Resources Management</td>
</tr>
<tr>
<td>OaMB</td>
<td>Operation and Maintenance Branch</td>
</tr>
<tr>
<td>SD</td>
<td>Survey Department</td>
</tr>
</tbody>
</table>
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1. Introduction

Due to its fortunate geographical location Myanmar owns almost all its water resources just by itself. In contrary to most countries nearly all its river systems have their whole catchment area within the borders of the country. With its unique history the country is still to a large extent unspoiled in terms of exhausting its natural resources compared to neighbouring countries.

The Dutch Ministry of Infrastructure and Environment has offered to support the Government of Myanmar in the development of an Integrated Water Resources Management (IWRM) Strategy for Myanmar and in May 2013 it signed a Memorandum of Understanding (MoU) with the Myanmar Ministry of Transport as focal Ministry of the Myanmar National Water Resources Committee (NWRC).

Several expert groups from both Myanmar and The Netherlands have been involved in the process of developing an IWRM study. The NWRC created the National Water Policy (see Appendix A for its objectives), which states the desire for an efficient and sustainable use of its water resources.

This report mainly focusses on the data collection, handling and storage of the water levels being measured in the Sittaung catchment area. Thereby there is looked at enhancing the current methods and the possibilities for Model Predictive Control (MPC). Besides getting a clearer overview of what’s happening in the water system, the goal is to receive “(near) real-time water level data” as input for the SOBEK model of ir. Nay Myo Lin. The aim of this model is: “Flood mitigation through optimal operation of a network of multipurpose reservoirs.”

Where in the present way data is stored on paper and hardly of any use, the purpose is to collect and have the data available in an organized manner to let the whole system operate in coherence.

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1.1 General challenges, goals and developments

Achieving “Per Capita Income” and “Standards of Living” of rural populace relying on agriculture higher than the neighbouring countries and keep abreast with developed nations.²

This is the vision from the Ministry of Agriculture and Irrigation (MoAI), which is stated on their webpage. Along with this vision they formulated the following targets³:

A. To extend net cultivated area up to 13.6 million hectare and cropping intensity 168 percent
B. To attain 4.28 mt/ha of average yield of paddy and 33 mil metric tonnes of paddy production
C. To extend the total irrigated area to 2.3 million hectare
D. To extend the activities for the accuracy of agricultural statistics
E. To encourage the production of qualified and standardized agricultural value-added products for more competitive in international market
F. To create profitable and sustainable market for farmers

Combined with the present cultivated area this adds up to the following table:

<table>
<thead>
<tr>
<th></th>
<th>Current area (million hectare)</th>
<th>Desired area (million hectare)</th>
<th>Growth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sown area</td>
<td>11.97</td>
<td>13.6</td>
<td>13.6</td>
</tr>
<tr>
<td>Irrigated area</td>
<td>2.13</td>
<td>2.3</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Table 1: Cultivated area⁴

The longing for growth and increased paddy production emphasizes the importance of Integrated Water Resources Management. Looking at the average annual rainfall map, one might conclude that it would be best to adapt the type of crop to its climate. So the regions with an excessive amount of water may be ideal for paddies, where in the dry zone other crops could be produced. However paddy cultivation is a part of the culture and has been so for generations. With the political strive for an economy based on the nation’s agriculture and rice being its main product it’s very unlikely that the choice of crop is going to change. For example the Palaung tribe, who live in the northern part of Shan State, has been growing green tea for as long anyone can remember. Now if someone would show up asking them to grow something else which would be economically more attractive, there’s absolutely no change they will want to do so. Nevertheless, new techniques and the modernisation of the whole agriculture branch are warmly welcomed. Although this results in

greater efficiency, the need for a reliable and safe water supply system doesn’t change. Where besides the geography and climate influence the water requirements the socio-political power is certainly not to be neglected either. Gigantic steps are taken to develop e.g. the Nay Pyi Taw Division into a thriving cultivated area.\textsuperscript{3}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3}
\caption{Opening of the new modern rice mill in Nay Pyi Taw}
\end{figure}

With the enormous rate Myanmar is developing the demand for power grows just as quick. Along with the desire for sustainable energy sources, the hydropower sector is of utmost importance. According to the Ministry of Electric Power (MoE) the country has a hydropower potential of roughly 100 GW. The same ministry has located over 200 sites to develop and ultimately extract about 40 GW (9.4 GW by 2030\textsuperscript{6}). This is merely the potential, at the moment there is approximately 2000 MW under construction.\textsuperscript{7}

The amount of water required for agriculture, domestic use and power supply is thereby continuously increasing and asks for comprehensive water management. One can already distinguish this trend of going from the single sector designs for irrigation to the multipurpose water systems.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure4}
\caption{Water demands}
\end{figure}

1.1.1 Monitoring development

The growing importance of water management requires a better understanding of the water system. Data management and collection is a key factor in gaining knowledge and decision making. To get an insight in the amount of monitoring that is being done one can look at the following table which displays the number of stations in Myanmar under the governance of the Hydrology Branch:

<table>
<thead>
<tr>
<th></th>
<th>2013</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water level stations</td>
<td>90</td>
<td>111</td>
</tr>
<tr>
<td>Rainfall stations</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Discharge stations</td>
<td>36</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 2: Monitoring stations (see Appendix B: Monitoring by the Hydrology Branch)

The Hydrology Branch itself is discussed further in chapter 2, the system analysis. The HB is not alone in acquiring meteorological and hydrological data, as can be seen in the overview of the operational chain in 2.2. Besides the sheer increase in the number of stations there is also a change in the type of equipment. Over the past few years some stations have been replaced by new automated stations to obtain time series data. These automated devices and their uses are handled in the system analysis.

Concerning water management there are a lot of developments going on with using satellite data or equipping satellites with all sorts of bands. To illustrate these purposes one can look at Appendix J. For this research only very local water level measurements are required, therefore these satellite’s resolution is often not sufficient and their use is further left out of consideration in this report.
Mobile Water Management
Where most new monitoring methods rely on automated systems with using for example camera´s, webcams or hydrostatical pressure measurement devices, Mobile Water Management (MWM) solely requires a smartphone. Since these automated devices are relatively expensive and demand a vast amount of maintenance, there is looked into this innovative MWM with more detail.

The system consists out of an application which can be easily downloaded from the Apple or Google Play store. Using this application, a photo is made of the water gage, which is then send to the database where the photograph is ‘read’ and a value to the water level is being appointed. This creates a paper free method and the only manual input it demands is making a photo. Together with the photo, data is transmitted about the exact location and time. With simple geometry and pattern recognizing algorithms the picture is analysed.

Some of the advantages of MWM are:
- No sophisticated equipment
- Paperless administration
- Direct availability of data
- Not influenced by human errors
- Proof that the water level has actually been measured
- Socially inclusive
- Unexposed to vandalism

The capabilities and possibilities of MWM are further discussed in chapter 3.
1.1.2 Water use
As stated and depicted before in 1.1 there is an increase in the water demand for agricultural, domestic and power generating purposes. Besides the growing quantity that is going to be required a shift within these sectors can be expected too. Hence the previously undiscussed industry is likely to become a major actor in the whole system as it is in neighbouring countries. To illustrate the difference in water consumption per sector between Myanmar and a more developed country a comparison is made with Thailand (note that hydropower is not taken into account here).

![Figure 8: Water uses per sector](image)

The figure above suggests a significant move from agricultural to industrial use. It goes without saying that the impact of this shift entirely depends on the region and the local circumstances. As for the industry there’s only a paper factory disposing water into the Sittaung river directly, which is subtracted from a tributary. In general it is complicated to develop large scale industry in most of the Sittaung catchment area, since either it has to be located on the plains, which are largely unprotected from flooding or near the sloping area of the Bago Mountain Range or the Shan Plateau. Both have their disadvantage in terms of risk or extensive land preparation. Nevertheless it is likely that the industry sector is going to expand. Therefore not only the water availability becomes problematic, but also the not to be disregarded water quality. Industry usually brings along all kinds of contamination and environmental issues, which require strict control.

![Figure 9: The Sistaung paper factory with its in/outlet marked](image)
Currently Myanmar is using about 5% (90% in the central dry zone) of the total amount of water that is theoretically available, with the emphasis on theoretically.\textsuperscript{8} Although 5% doesn’t seem a lot it is a great challenge to captivate the other part. Numerous measures have been taken to utilize the water with all kinds of reservoirs, hydropower dams, drinking ponds, irrigation systems etc. Especially the colossal variety between the wet and the dry season poses great challenges. To overcome these conditions not only new structural solutions are necessary, but previous ones can be rehabilitated and perhaps combined with other purposes.

1.1.3 River training versus room for the river
Although the Sittaung is a gently sloping meandering river and seems like a serene place during the dry season it turns into a complete different animal in the wet season, when the river is characterized by a fierce current that sweeps the floodplains clean (if not more). This bilateral behaviour complicates things significantly. Where in the dry period the river could do with hard structural measures such as shortening and narrowing by groins to increase the current velocity and thereby its depth for transportation purposes. It would have a complete opposite effect during the monsoon, which will solely be more devastating. Dealing with the high discharges was and still is a problem in the Sittaung river. According to several locals some embankments overflow on average every five years, even though there is a dam in almost all its tributaries (this is the main problem in the whole area and being handled by ir. Nay Myo Lin). Ultimately training of the river for transportation reasons isn’t a feasible option since the negative effects far outweigh the positive ones. Cargo transport over inland waterways is customary in Myanmar none the less, but due to its shallow depth, freely meandering nature and lack of knowledge about its bathymetry the Sittaung can’t be used for reliable commercial shipping of e.g. containers.

However this doesn’t mean no measures should be taken to harness the power of the river. Rather the contrary. The discharge control of the reservoirs together with a risk analysis should lead to an adequate level of protection. This is a major challenge, but further left out of this study.

1.1.4 Sedimentation of reservoirs

Little is known about the sedimentation rates throughout the country. The Irrigation Department (ID) possesses a sedimentation rate map (see Appendix C: Sedimentation rate map). On this map the reservoirs’ capacity is determined and estimated to reach its dead storage capacity after 50 years. Once the structure has been finished, no monitoring is done to acquire the actual sedimentation rate due to the expensive equipment (Hasman, 2014). Another issue was encountered when visiting the Paunglaung Dam. Here the information on the sedimentation of the reservoir was, according to the local assistant director from the Construction Branch, in Japan (who was involved in the final design).

Sedimentation is not just reserved for the reservoirs, but is also present in the canals and irrigation systems. With the climate change in mind, the intensification of rainfall will bring about higher run-offs and thereby an increased sedimentation rate (growing sedimentation is also caused by deforestation and mining in the catchment area). The tributaries are already disposing a lot of sediment on their way to the main river and so raising the bed levels simultaneously as was the case in the Bago-Sittaung canal (Nay Myo Tun). Besides the negative effect of flooding due to the increased bed level, the nutritious sediment fertilizes the soil during a flood.

Figure 11: The Bago-Sittaung canal
1.1.5 Climate change
Just like in most of the World, climate change is playing and will continue to play a large role in the water related hazards in Myanmar. In a region that is already marked by its extremities in both the wet and the dry season, this is only going to aggravate. Droughts will get longer and the monsoon will intensify. The figure below, although it’s focused on the CDZ, provides a good insight in what sort of peril can be expected.

![Climate change related disaster risks by UNDP (2011)](image)

In all the risks that are depicted above, one can distinguish two types of hazards: the ones originating from the additional monsoon strength and the ones caused by the prolonged drought. Storm surges pose the biggest threat to the lower delta region. Especially since most storms approach Myanmar from the southwest, the whole Gulf of Martaban acts like a giant funnel towards the river mouth of the Sittaung. An unfortunate combination of events like spring tide and a storm surge could lead to extreme water levels with a devastating result.
Figure 13 and 14 illustrate the sensitivity of sea level rise in the Gulf of Martaban. Due to the enormous sediment loads that have been deposited here by the Sittaung, Salween, Bago and Ayeryawady river the slope of the gulf is extremely gentle. When the expected sea level rise would be about 2-3 mm/year and the slope of the land would be 1/1000, according to the Bruun rule, this would result in a coastal retreat of roughly 2,5 meters a year!

Figure 13: Illustrative water depth by webapp.navionics.com

Figure 14: Bathymetry of the Gulf of Martaban
1.1.6 Flood warning system
The previous section showed the great dangers that are generated by storm surges. Myanmar has a long history of passed cyclones, where Nargis is one of the more recent ones (see the figure below for the photographs made by Landsat). Due to its unusual approach from the east it became the most devastating natural disaster in the history of Myanmar. Although the number of casualties is still disputed, it exceeds the 100.000. For comparison, the North Sea flood in 1953 had a death toll of about 2000. Even though Nargis was a rare apocalyptic event it is not unique. With hardly any sea dikes or storm surge barriers in place and the enormous delta areas with multiple river mouths it is unlikely to be fully protected in the future considering the giant investments. The only two other options are: relocate all the people to safer ground (1) or set up a flood warning system and evacuation plan (2). Obviously the first option is out of the question, since the Ayeyarwaddy delta is the most cultivated area of the nation. An improved flood warning system including a realistic evacuation plan is the only way to go then.

This improvement is currently being implemented as part of the disaster risk reduction policy. Raising the public awareness, construction of cyclone shelters and a few sea dikes plus rehabilitation of failed embankments are the other cornerstones of this plan.

Flooding is not restricted to the low-laying delta areas. Although the flooding of the country isn’t as instantaneous as it can be in the delta, a warning system is desirable anyway. Watershed management of the reservoirs could suffice to prevent discharges that are too high. As is stated earlier this still forms a major challenge and is part of the study of ir. Nay Myo Lin.

![Figure 15: Yangon before and after the passing of cyclone Nargis](image)
1.2 Problem definition and overall goal

So far general issues and developments that are going on in Myanmar have been discussed. Ultimately they all lead to the same thing: an integrated approach to water management is required in order to cope with all the challenges that lay ahead.

Setting a goal is one thing, achieving it is something entirely different. With all the different actors that are involved it is paramount that the governance of water is based on reliable data. Besides the fact that there is a shortage or non-validated data, one of the greatest problems is the availability. Every day hundreds of operators go out and collect all sorts of data on water levels, rainfall, discharges etc. This information is then transferred from the operator to a local office, then to a regional head office and finally to the headquarters in Nay Pyi Taw. Along the way the data is stored at all the different links on paper and/or blackboard and if you’re lucky digitally too. This vast chain of collecting and transferring data is bound to end up in errors and unnecessary bureaucracy.

The whole process that is described above is not the only complication. In order to have real time control of the discharges through the rivers, the water levels in the basin have to be updated into the model continuously. Although this might be too ambitious it could be approached. Now water levels are measured three times a day and phoned to the local office the next morning or send to the head office once a month (see 2.3.2). To develop a system governed by Model Predictive Control (MPC) a faster data flow has to be realized.

The primary data collection, reading of the water levels, raises another matter. At first there’s the issue of placing the water level gauges in such a way that they are properly calibrated to its own zero gauge level and thereby to the MSL. Secondly there’s the unreliability in reading the staff gages and the exact time this is being done. Thirdly there is a lack of standardization with gages in both feet and metric units. Finally there is the problem of non-existing staff gages. Due to the severe strength of the river occasionally a staff gage gets carried away by the river (see Appendix D Day reports). For the water level measurements in the Sittaung river this results in the following fault tree. Where in the smaller boxes the responsible one is depicted and errors made during the transferring of the data and inaccuracies by a possible model are summarized under ‘processing errors’.

![Fault tree for water level data collected in the Sittaung river](image)

Figure 16: Fault tree for water level data collected in the Sittaung river
Figure 17: Lack of standardization, permanent and local benchmarks and data storage of the measured water levels
2. System analysis

In this chapter the present-day methods come to consideration. Firstly the Sittaung basin is described, including its reservoirs as its delta. Afterwards there is looked into the governance related to water management, which illustrates the complexity of all the departments and branches that are involved in this sector. Then there’s zoomed into the branches under the Irrigation Department that are associated with water level monitoring, the Construction Branch, Operation and Maintenance Branch and the Hydrology Branch. For each of these branches there is examined how the water level data are collected, handled and processed. To provide a safer and more reliant supply system, the possibilities of water pricing are debated. Considering modern monitoring tools (discussed in chapter 3), the developments regarding internet connectivity and low priced smartphones are also briefly discussed.

2.1 Sittaung river basin

Due to the local climate with its extreme rainfall periods and its lengthy drought, the river is characterised by the same duplicity. Even though there are numerous reservoirs and weirs, who manage their own watershed operations. Still there are plenty of issues yet to be solved, as stated in 1.1.3. For more general information (valley development, discharges, agriculture, crops and flood control) about the Sittaung River, see ‘Water Demand and Allocation Modelling in Myanmar’, by Rens Hasman (2014). The floodplains and bathymetry of the river are discussed into great detail in ‘Monitoring of the Sittaung River, Bathymetry and floodplains’ by Max van Rest (2015).

<table>
<thead>
<tr>
<th>Length</th>
<th>420 km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catchment area</td>
<td>34400 km²</td>
</tr>
<tr>
<td>Annual discharge</td>
<td>42 km³/yr</td>
</tr>
<tr>
<td>Annual rainfall</td>
<td>889 mm – 3810 mm</td>
</tr>
<tr>
<td>Reservoirs</td>
<td>13</td>
</tr>
<tr>
<td>Multipurpose reservoirs</td>
<td>7</td>
</tr>
<tr>
<td>Total storage capacity of reservoirs</td>
<td>4,5 km³</td>
</tr>
<tr>
<td>Agricultural area</td>
<td>757121 ha</td>
</tr>
</tbody>
</table>

Table 3: Sittaung catchment area in numbers

The tributaries originate mostly from the Shan Plateau on the east and the Bago Mountain Range on the west. Many dams and weirs are located in these tributaries, what is clearly depicted in Appendix E. The river itself is freely meandering towards its delta and also has some anabranching parts.

Figure 18: Anabranching and meandering features of the Sittaung river
The coastline of where the river is entering the Gulf of Martaban can be classified as: a west coast swell environment with trade and monsoon wind influences and a macro-tidal range with a semi-diurnal period (see Appendix F). With the tidal range varying between 4 to 7 m, the delta is mostly tide dominated. The previously mentioned bilateral behaviour of the river system causes an evenly large variety in sediment load that is being transported. Although the nutritious sediment induces great fishing grounds, it also creates (once deposited) a great runway for storm surges, as discussed in 1.1.5. The gigantic sediment suspension during high discharges provokes a temporary combination between a river and tidal dominated delta, according to Galloway’s classification.

Figure 19: Satellite image of the enormous sediment load entering the Gulf of Martaban

Figure 20: Galloway’s delta classification

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2.2 Governance regarding water management

Figure 21: Operational chain of the Republic of the Union of Myanmar related to water management
As can be seen in the previous figure, there is a great number of ministries, departments and branches involved in operations related to water management. Even though the figure is far from complete it is easy to conclude e.g. that a lot of water level measurements are being taken (for a complete overview of the organization within the Ministry of Agriculture and Irrigation and the Irrigation Department see Appendices G and H). The problem is then not the amount of data but its availability. Since most branches use their own zero gauge levels and with these values only known by the branches themselves, it is hard to use each other’s data. The fact that all the water gages do not refer to one and the same level (MSL) and differ in used units (metric and feet), complicates things significantly.

Then there’s the problem of data sharing and collaboration, with an increasing difficulty upwards between branches, departments and ministries. Obtaining information from another sector requires in general a personal visit and a meeting to discuss future plans and business. The chain of command and local customs are of great importance considering these encounters.

Within the operational chain there are a few possible conflicts of interests. The Ministry of Electro Power (MoE) prefers e.g. to provide a steady amount of power year round, generated by the hydropower dams. Where the Ministry of Agriculture and Irrigation (MoAI) wants to store all the water during the wet season in order to limit the discharges and dispose as much water preceding the monsoon period. A well designed piece of transparent legislation would clear things up dramatically.

Therefore it is paramount that ministries and departments join forces and try to overcome their discrepancies and policy gaps to come to an integrated solution. By using each other’s data and resources a lot of time can be saved and a better perspective of the whole water system can be gained.
2.3 Water level monitoring

The section before indicated already that there are many offices involved in obtaining water level measurements. From here on the focus lies on the gathered data by the Hydrology Branch (HB), the Construction Branch (CB) and the Operation and Maintenance Branch (OaMB). These branches are all part of the Irrigation Department (ID), who is the main responsible for operational water management. For an overview of the department’s organization please see Appendix H.

2.3.1 Water gages

**Hydrology Branch**

The Hydrology Branch is led by a Director and has two Assistant Director’s offices at Yangon and Mandalay respectively. The Hydrology Branch carries out the tasks and activities of observing, measuring, recording, processing and investigating of the hydrometeorological data information for water resources development and future irrigation projects. There exist a total number of (90) stations registering water levels of streams and rivers, (20) numbers of rainfall stations and (36) numbers of discharge measuring stations under the Hydrology Branch, scattering over different climatic regions of the country.¹⁰

The HB controls 8 locations along the Sittaung and 3 in its tributary Paunglaung, where they measure the water level. First they used feet, now they installed staff gages with centimetres as a unit. The HB uses the local benchmarks for the placement and calibration of the staff gages. These local benchmarks usually consist of a nail in a nearby tree to facilitate a quicker process. The permanent benchmarks are often located in state owned property that does not necessarily have to be close to the river. By having these local benchmarks a huge amount of time is saved by not having to carry the exact height by levelling from the permanent to the local benchmark. Once the staff gages are installed they are unregularly checked, can be 3 times a year but also once per two years. During high discharges and overflowing of the river it is not uncommon that the gages are swept away and no data are collected.

Table 4: Locations of the different water level measurement stations in the Sittaung river under the Hydrology Branch

<table>
<thead>
<tr>
<th>Sr. no.</th>
<th>Station Name</th>
<th>Location</th>
<th>Township</th>
<th>Parameters Monitored</th>
<th>Method / Instrument</th>
<th>Monitoring Frequency</th>
<th>Mobile Signal strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Myohla</td>
<td>19° 25’</td>
<td>Yedashe</td>
<td>Water Level</td>
<td>Ordinary</td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Ohnpin</td>
<td>18° 49’</td>
<td>Oatkwin</td>
<td>Water Level</td>
<td>Ordinary</td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Buvakale</td>
<td>18° 41’</td>
<td>Oatkwin</td>
<td>Water Level</td>
<td>Ordinary</td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Zalokeygi</td>
<td>18° 36’</td>
<td>Phyu</td>
<td>Water Level</td>
<td>Ordinary</td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Thaungbu</td>
<td>18° 31’</td>
<td>Phyu</td>
<td>Water Level</td>
<td>Ordinary</td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Kwinchaungwa</td>
<td>18° 14’</td>
<td>Penwegone</td>
<td>Water Level</td>
<td>Ordinary</td>
<td>Daily</td>
<td>Poor</td>
</tr>
<tr>
<td>7</td>
<td>Innpalwe</td>
<td>17° 55’</td>
<td>Nyaunglebin</td>
<td>Water Level</td>
<td>Ordinary</td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Thuyethamein</td>
<td>17° 46’</td>
<td>Waw</td>
<td>Water Level</td>
<td>Tidal</td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Mingalun</td>
<td>17° 39’</td>
<td>Daik-U</td>
<td>Water Level</td>
<td>Tidal</td>
<td>Daily</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Kyauktawpalaing</td>
<td>17° 38’</td>
<td>Daik-U</td>
<td>Water Level</td>
<td>Tidal</td>
<td>Daily</td>
<td>Poor</td>
</tr>
<tr>
<td>11</td>
<td>Mokkhamu</td>
<td>17° 51’</td>
<td>Nyaunglebin</td>
<td>Water Level</td>
<td>Tidal</td>
<td>Daily</td>
<td>Poor</td>
</tr>
</tbody>
</table>

Construction Branch

The CB is in charge of the dam and irrigation network construction. There are nine Construction branches under the ID in Myanmar. As soon as the whole irrigation network (weirs, channels, sluices etc.) is finished the governance of the dams and irrigation networks is transferred from the Construction Branch to the Operation and maintenance branch. Until this moment the Construction Branch does its own monitoring. It uses both feet and meters as units for their staff gages. There doesn’t seem to be a standard when to use what. Mostly they use feet but at a few dams they use meters with determining the water depth of the reservoir.

During our visit at the Paunglaung Multipurpose Dam we also examined the weir. As can be seen in figure 23, there was an automated water level device installed last year. Unfortunately it was broken and the normal staff gages were used to measure the water level.

Figure 22: Placement of the staff gages by levelling from the local benchmark in Ohnpin

Figure 23: Defect automated water level reader on the weir of the Paunglaung Dam
Operation and Maintenance Branch
The OaMB uses feet for their staff gages. They have a few in the Sittaung but mainly take care of the distribution within the irrigation system. Besides this task they’re responsible for flood protection works and small construction works. They don’t have the heavy equipment and machinery like the Construction Branch. Their budget is limited so they’re struggling to maintain all works and keeping the sluices and inlets in operation. Nevertheless they did replace the staff gages last year and they were still in decent state and standardised.

To illustrate the lack of cooperation, when the governance of the Yezin Dam was given to the OaMB they painted their own measurement scales on the stone pitching, where the regular staff gages from the CB were already in place. Now there were four types of measurement tools positioned within 50 meters from each other (2 rows of staff gages, an automated water level device and the painted scales). The automated device which was installed in 2014 was not particularly in favour with the local operator. It transmits its data over the internet, but due to the bad connectivity it just worked sometimes. Besides the problem of data transferring an accuracy difference with the regular staff gages was found of roughly 12,5 mm. According to the local officer this is due to processing errors of the automated device due to resonance from waves etc.
2.3.2 Data acquisition and storage

**Hydrology Branch**
The operators measure the water level three times a day, 6 am, 12 am and 6 pm. Previously they send it every month by mail to the main office in Yangon, where it was stored on paper. Nowadays the HB just switched to a system where the local operators are provided with smartphones, so they can phone the water level information through daily. In the office at Yangon it is then stored in Excel sheets.

**Construction Branch**
Record the water levels daily. The data is first phoned to one of the nine Assistant Directors offices of the Construction Branch. Stored in both excel as on paper. Secondly the office sends the data to the headquarters. Here all data is also stored on paper. The construction branch itself uses the excel data.

**Operation and Maintenance Branch**
The OaMB measures the water level once per day in the dry season and 3 times during the wet season. When the spillway of a reservoir is used, the water levels are collected hourly. In the monsoon period additional workforce is hired, for roughly 3$ a day, to handle all the demanded measurements and observations.

The local operator calls the local maintenance office every day in the morning and passes on the measurements of the previous day and the morning one. At the local office the water levels are stored on paper and blackboard (only space for several days). Afterwards the water levels are phoned to the district office, where the data is stored in the same way. Here the assistant director decides about the operation of the reservoirs with his experience and the received data. Finally the water level data is phoned to the head office where it is also stored on paper.

<table>
<thead>
<tr>
<th></th>
<th>Hydrology Branch</th>
<th>Construction Branch</th>
<th>Operation and Maint. Branch</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>3 times per day</td>
<td>3 times per day</td>
<td>3 times during wet season and once in the dry</td>
</tr>
<tr>
<td><strong>Acquisition</strong></td>
<td>By mail every month</td>
<td>Daily by phone</td>
<td>Daily by phone</td>
</tr>
<tr>
<td><strong>Storage</strong></td>
<td>Excel and paper</td>
<td>Excel and paper</td>
<td>Paper</td>
</tr>
</tbody>
</table>

Table 5: Data acquisition and storage of water level measurements
2.4 Water pricing

Water pricing in order to fund safe water supply, sanitation and stimulate water savings should be considered seriously. Higher quality of the water supply system will also decrease the non-revenue share. A fair pricing mechanism for water should be found and implemented, for example based on the ‘user and/or polluter’ pays principle. In order to get a grip on the developments regarding water pricing, first the exact present legislation and its predecessor are stated in the following section.

2.4.1 Water tax and embankment tax law

The Pyithu Hluttaw session of 1982, under law1, enacted the water Tax and Embankment Tax Law. The rates legible, according to the enactment are:

(a) Water tax at the rate of ten kyats per acre for localities enjoying irrigable water from government diversions and reservoirs.

(b) Embankment Tax at the rate of five kyats per acre for localities under the protection of government embankment and drainage canals.

(c) Charges of ten kyats per acre for localities enjoying both irrigation as well as flood protection facilities.

Starting from the 2007-08 financial year, the Government of the Union of Myanmar enacted the Water tax and Embankment Tax Law. The legible rates according to the enactment are:

(A) For the beneficiary areas of irrigation system constructed and maintained by the state water tax is as follows:

(1) If it is fully irrigated from land preparation to heading stage at the paddy cultivation areas the water tax is 1,950 Kyats per acre.

(2) For any other crops except paddy, the water tax for use of irrigation water for crop cultivation is 900 Kyats per acre.

(3) At the paddy cultivation areas, if it is irrigated only for land preparation (or) transplanting (or) seedling (or) reproduction (or) heading (or) partial irrigation, the water tax is same as the other crops at the rate of 900 Kyats per acre.

(B) For the beneficiary areas protected from flood with the embankments and drainages constructed and maintained by the State, the water tax is 5 Kyats per acre.

(C) If any cultivated land is inclusive both for paragraph (A) and (B), the water tax is the same rate as in paragraph (A).


The table above shows the enormous jump in collected tax that the revised ‘Water Tax and Embankment Tax’ law had from 2007 and on. This is solely due to the rise of the water pricing, since the cost for protection by embankments stayed at a mere 5 Kyats per acre. Secondly the table depicts the gradual decrease in water tax yielded after the first year that the law was fully enacted. According to ir. Nay Myo Lin this is due to the lack of official authority that the tax collectors have, because some farmers don’t want to pay taxes. Looking at the table, one can assume that over the years this group increased. Currently a solution is being developed where the tax collectors do have the authority to force everyone to pay, according to the legislation.

2.4.2 Discussion

The legible rates that are now in use already stimulate water saving by using different rates for the paddy fields and other crops. Nevertheless paddies are also farmed in the central dry zone of Myanmar (due to the wet season). This indicates that either the difference in tax rates is not effective enough to promote other crops or storing the water and use it for other crops during the year is less favourable than having a paddy season too.

In order to further stimulate water saving, a pricing mechanism where there’s paid for the quantity of water used, could be introduced. To show this method’s effect: in Abu Dhabi City they decided to change the pricing policy of water. The new policy is based on fixing meters in buildings and charging the consumers for the actual amount of water consumed, instead of a system which was based on a flat rate per month irrespective of the amount of consumption. A quick analysis of the effect of the new pricing policy showed that, 73% of the households in the sample reduced their consumption by an average of 29%.

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Although this is a very effective method, it’s complicated to implement it in Myanmar. With the pricing system of today there’s hardly any monitoring required within the irrigation system. During the wet season there’s plenty of water for the lot. In the dry season, depending on the area, there’s either:

- Still enough water for everything and people can use how much they want.
- Water is slightly scares and a rotational scheme, which is made by the local group of farmers themselves, is used.
- A shortage of water, so a smaller or no area is cultivated.

All of the above need little or no monitoring (in terms of water use) of the sluices etc. To go then from an operating system to a system where everyone pays exactly for the amount of water used, is quite a challenge. The only option, without extensive monitoring, is charging the users for instance per day that they’re using the water provided by irrigation channels, with a set amount that’s being supplied per day. Obviously this only creates extra revenue when it’s the dry season and in areas that don’t have an abundance of water year round. Even then it is still a question whether the costs of implementing and running such a system would be compensated by the additional earnings.

Water pricing isn’t a tool for the government to just gain some earnings, rather it should create a ‘win-win’ situation. With the revenue from the water taxes the supply should be safe and of higher quality. When the policy and agreements are clear to everyone, both parties are accountable for their responsibilities. The understanding that paying taxes will benefit themselves should by itself turn around the decrease in collected tax and stimulate water saving.
2.5 Internet connectivity

Myanmar Posts and Telecommunications (MPT) is no longer the only internet provider in the country. Ooredoo and Telenor, as first foreign operators, joined the market in August 2014 and September 2014 respectively. The sudden competition made SIM card prices drop from 150 US$ to 1,50 US$ instantly. In such an underdeveloped country one can imagine what opportunities this brings along. With a population of around 60 million people who never had the privilege of owning a phone there’s a huge market.

The three operators have set different goals for the future. Telenor has four targets they want to achieve in 5 years, 2019\textsuperscript{15}:

- 90% population coverage
- 8,000 base stations
- 100,000 points of sale
- Generating local employment

Ooredoo is a bit less specific in their goals, but says to be able to provide coverage to 25 million people by the end of this year, 2015\(^\text{16}\). MPT who is still the market leader doesn’t provide any information about their future plans, they just mention that they are, and want to stay Myanmar’s number one telecommunication operator\(^\text{17}\).

\textbf{Figure 28: Ooredoo coverage}


Internet connection itself requires more than a few operators. In order to provide stable coverage a lot of infrastructure has to be installed. The current network already doesn’t have enough capacity. A stable connection requires a certain amount of redundancy in fibre infrastructure. In case one provider goes down, the other can take over. Due to the lack of redundancy, outages are more rule than exception. However, all operators are involved in projects to increase and improve the connection.

MPT signed a 2 billion dollar contract with the Japanese companies KDDI and Sumitomo to improve the entire infrastructure and services. They are installing a subsea cable SEA-ME-WE 5 which will connect Myanmar to the network of another 17 countries, besides the 33 that it does now. This cable is planned to be in operation in the second half of 2016.

So far MPT is the only one who possesses international fibre connections and so they’re selling capacity to Telenor and Ooredoo at exuberant prices. This should change in August 2016, when the cable MYTHIC (Myanmar-Malaysia-Thailand Internet Connectivity) is set to be in use. The cable is privately owned and is going to open up the competition by selling capacity to whoever wants it. Together with MPT’s new SEA-ME-WE 5 cable this should drastically lower the price of data for the consumers.
2.5.1 Internet connectivity in Sittaung-Bago basin
At all locations along the Sittaung river where we went there was enough internet reception to be able to upload photographs. It does need to be stressed that the connectivity was usually very local and in 20 meters there could be a difference of having a 3G connection or none at all. Nevertheless it was easy to find places with sufficient connection. Considering the tremendous development in internet coverage and capacity, the problems of having to look for a place with connection should be soon of the past.

On the maps of coverage by Ooredoo and Telenor it’s clearly shown that the Bago Mountain Range isn’t an area that has priority with connecting it to the internet. Since the reservoirs are constructed in the mountainous area we did notice there was no direct connection at the Yenwe multipurpose dam. Downstream at its weir the connection was there again. Except for the Phyu Chaung dam, where there was reception, we didn’t visit any other reservoirs in the Bago Mountain Range. At the reservoirs around Nay Pyi Taw there was no problem finding internet connection.

2.6 Low priced smartphone development
In recent years phone companies are looking to replace the relatively limited feature phones with affordable smartphones in developing countries. At first this idea didn’t appeal to the bigger companies like Apple, but since the market is so big they’re all in the race of selling their phones in Africa, India etc.

Last year Firefox introduced its “low priced” smartphone in India for 33 US$. Although this phone was by far the cheapest it did not catch on. In general people do not like to buy a phone which is designed to be cheap. Instead the Indians massively bought the slightly more expensive Android phones, which weren’t advertised as especially cheap\(^\text{18}\). Nevertheless the development of low priced smartphones continues and soon the price gap between the old fashioned feature phones and affordable smartphones will be closed.\(^\text{19}\)

\[ \text{Figure 31: Firefox OS, the cheapest smartphone now available} \]

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3. Implementation of new monitoring techniques

In order to run a simulation model of the water system it is of great importance that the data input is reliable and continuous. To achieve this continuity the delay between measuring the water level and uploading it into the model has to be as limited as possible. Having this in mind, there are two alternatives discussed in this chapter. At first the innovative Mobile Water Management (MWM) is reviewed, which was introduced in section 1.1.1. Afterwards there is looked into the possibilities of using Google Sheets to store the measured levels and having them available immediately.

3.1 Mobile Water Management

As the name already indicates, it is about water management using mobile phones. With an application that can be simply downloaded from the Google Play Store, one is able to measure water levels instantly. It only needs a picture of the staff gage. This picture is then read by a model and once that has been done it returns the obtained value on the screen of the operator.

This method gets rid of all the paperwork that used to be involved in handling the water level data. In contrast to other ‘modern’ equipment it does not need a large investment in all sorts of devices. As shown in section 2.3.1 this equipment breaks down easily and demands a lot of maintenance. In the National Water Policy it is stated that it desires operations that are socially inclusive. With this monitoring method all local operators keep being employed and are part of the system, where an automated water level reader replaces them. Next to measuring water level additional applications are developed such as: measuring ground water levels, discharges at a gate or sluice and water quality. Therefore it is possible to extend the monitoring in the future in other variables. These extra features make it easy to track down the water distribution within the irrigation system, which can be demanded by local legislation.

Pricing for the MWM system goes by the number of monitoring locations not by the number of phones registered. This makes crowd sourcing possible and could reduce monitoring costs.

The application works with metric units and also with feet and inches as is already being done in California. There are no additional requirements for the staff gages. However, a standardized format would smoothen the process of reading the gages by the model. At the moment a large part of the water gages could not be read by the model. When this is the case the photos are registered and they can be given a value manually. The procedure is then to collect a sufficient amount of photos to train and optimize the pattern recognizing algorithms. After a while the manual handling of the staff gages can then be replaced by fully automated reading (Hajo Heusinkveld).
<table>
<thead>
<tr>
<th>Camera</th>
<th>5 MP (preferably 8 MP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPS receiver</td>
<td>Yes</td>
</tr>
<tr>
<td>Tilt sensor and compass/magnetic heading sensor</td>
<td>Yes</td>
</tr>
<tr>
<td>Local storage</td>
<td>none</td>
</tr>
<tr>
<td>Operating system</td>
<td>iOS (6.0 or higher) and Android (3.0 or higher)</td>
</tr>
<tr>
<td>Network access</td>
<td>2G or faster (2G, 3G, 4G, WIFI)</td>
</tr>
<tr>
<td>Maximum distance from staff gage</td>
<td>10 m with max. zoom</td>
</tr>
<tr>
<td>Orientation of phone when taking the picture</td>
<td>Portrait (upright)</td>
</tr>
<tr>
<td>Data storage</td>
<td>Within clients’ ICT-network or in the cloud</td>
</tr>
</tbody>
</table>

Table 7: MWM requirements

From the table above it needs to be stated that if no internet connection is directly available, the picture is stored on the device and uploaded as soon as there is internet communication again. As mentioned in section 2.5.1, we were able to have sufficient internet reception at all the places we visited along the Sittaung river. Due to the instability of the connection it was sometimes hard to upload the photos. The locality of the internet brings another problem: the operators are technically not allowed to leave their post and are therefore unable to walk to a location where the connection is stable. The capabilities of the algorithms in the model are not known considering ‘difficult-light-situations’. Since the water levels are measured at 6 AM, 12 AM and 6 PM there could be issues with either not enough light or with too much glare from the water.

Currently the local operators are provided with Huewei y330 smartphones to phone through their measurements to the office. Unfortunately these phones are not equipped with the necessary 5 MP camera but with a 3,15 MP one.

Figure 34: The smartphone, Huewei y330 (3.15 MP camera), that is distributed among the operators from the HB
3.2 Hybrid method

This alternative is focused on a limited amount of procedures and a quick way of having the data available for modelling. The idea is that the local operator obtains the water level and puts it directly in the Google Sheets. Thereby it is not required to call the local office and store it on paper and then call another office etc. This reduces the steps that are otherwise prone to human error. Just like with the MWM there is no need for internet connection at the water gages itself. Google Sheets has the option of storing the data first on the device and as soon as the operator has reached an area where there is internet communication possible it uploads the data by itself. The data is then immediately available for everyone with the account. Finally it only requires an extra action to copy the water levels into a model. For having this method in operation, one could use the manual that is attached in Appendix I. Combined with a brief training this manual should suffice in getting the system in operation.

Using this method the staff officer has to send an email to the system administrator to gain access to the water level data file and once this has been obtained only has to invite the local operators to the same file. The local operator could then upload the recorded water levels directly.

Like the MWM, this alternative has to cope with the same problem: the local operator at the river of reservoir has to stay at its location and is not allowed to look for a place with internet connectivity to upload the data. An agreement with the Irrigation Department about this is required. Unlike for running the MWM, the phones that have been distributed are perfectly able to perform the necessary actions.

Ultimately this is then a solution that combines a bit of MWM with the present desired way of phoning through the measured data and saving them in Excel. By using this alternative there is only the input from the local operator and no other human errors except for reading the staff gage can be made.
3.3 Discussion

For being able to choose a monitoring method, the current method, MWM and the Hybrid method are compared in a qualitative way and later in a more quantitative manner. In the table below, the qualitative approach is depicted, where positive effects are marked with a ++ or + and negative effects with - or --.

<table>
<thead>
<tr>
<th>1. Data quality</th>
<th>Current method</th>
<th>MWM</th>
<th>Hybrid method</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>-</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>2. Data availability</td>
<td>-</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>3. Transfer speed</td>
<td>--</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>4. Costs</td>
<td>+</td>
<td>--</td>
<td>-</td>
</tr>
<tr>
<td>5. Socially inclusive</td>
<td>+</td>
<td>+/-</td>
<td>+/-</td>
</tr>
<tr>
<td>6. Required infrastructure</td>
<td>+</td>
<td>-</td>
<td>+/-</td>
</tr>
<tr>
<td>7. Complexity of implementation</td>
<td>n.r.</td>
<td>-</td>
<td>+/-</td>
</tr>
</tbody>
</table>

Table 8: Qualitative comparison between monitoring methods

Here the given values are discussed per different aspect:

1. Mobile Water Management is the only method that proves that the water level has actually been measured and has a set standard deviation. The Hybrid method is still exposed to the human flaws of correctly reading the water gage and putting it in the Google Sheets.

2. With the current method, the availability of data is a big problem. Often just stored on paper and in Burmese and when stored in Excel sheets, these still have to be gathered. For MWM and the Hybrid method the data is directly online accessible.

3. Even though the times of sending the water level measurements once per month are over, it usually still takes over a day to receive the data in the final office. Between MWM and the Hybrid method the time it takes to put the measurement in the Google Sheets and uploading the large amount of data with MWM are expected to cancel out against each other.

4. The current method exists of a long chain of actions, which require labour and therefore also money. The Hybrid method needs another 17 smartphones (e.g. the same as bought earlier), which results in an additional investment of 17 * 50€ = 850 €. The costs for MWM include 28 monitoring posts and the same amount of smartphones that meet all the desired specifications. This results in a total of roughly 28 * 80 € = 2240 € + 28 * MWM costs. Note that the local price of smartphones is continuously evolving, see section 2.6.

5. Although both MWM and the Hybrid method are not fully automated operations, they do get rid of a few links in the chain of actions of the current method. Therefore they are judged to be slightly less socially inclusive.

6. Basically none of the three methods need additional infrastructure in terms of equipment or internet communication facilities. However, MWM and the Hybrid method do require a reasonable internet connection and the local operator might have to travel to such a location. In order to prevent this better internet connectivity is demanded,
especially by MWM, which has to upload more data. As is stated in chapter 2.5 this is a matter of time.

7. With the current method as reference level, Mobile Water Management is slightly more difficult to make it a convenient running system than for the Hybrid method. This is caused by the required time of training and adapting the algorithms to the local circumstances before it becomes an automated process. The Hybrid method is relatively similar to the traditional system and only necessitates a short explanation about entering the data into the Google Sheets.
4. Conclusion and recommendations

The Republic of the Union of Myanmar has the fortune of governing their precious water resources just by itself. A country that has been held at a standstill for decades is now developing at enormous pace and the pressure on its water availability rises just as quick. Great challenges lay ahead and proper water management is a necessity to be able to cope with them. In order to do so decisions need to be based on obtained data and reliable models.

The methods of today include many stations between the person that records the water levels and the moment they are stored. During this long and slow path the data is extremely exposed to human errors. Further, the staff gages drastically need standardization! Among all ministries and departments a decision has to be made to either use metric or British units, and adopt one and the same zero gauge level. This will improve the usability of each other’s data. A lot of data is being registered, but very difficult to use since it often is stored locally and on paper. To make a design using such data it takes a tremendous amount of time to obtain the parameters’ values. Digitalization is paramount.

Considering all the different water uses and demands it is of great importance that ministries and departments join forces and try to overcome their discrepancies and policy gaps to come to an integrated solution. By using each other’s data and resources a lot of time can be saved and a better perspective of the whole water system can be gained.

Water pricing in order to have a reliable and safe water supply and stimulate water saving where possible is a difficult goal to achieve. The current methods need little or no monitoring (in terms of water use) of the sluices etc. To go then from an operating system to a system where everyone pays exactly for the amount of water used, is quite a challenge. Due to the unlikeliness of an applied water pricing system, this does not offer an additional motive for increased monitoring within the irrigation system. Monitoring in the agricultural area is only of use if there’s a water shortage and if the farmers have to pay by the amount of used water.

Following the rapid developments in the internet infrastructure that is being constructed, a stable and swift internet connection should be available along the Sittaung river by the end of 2016.

Where the temporary method of phoning through the recorded water level data is still a relative time consuming and fault sensitive operation, MWM and the hybrid method as described in chapter 3 offer a more reliable and quick alternative.

Mobile Water Management proves that the water level actually has been measured and is not made up and it has a set standard deviation that is not influenced by human capabilities. Additionally it knows the exact time that the measurement was being taken, which could be useful for a model. It does require a new investment in a set of smartphones with the demanded capabilities and at this moment the locality of the internet still forms a logistical problem of being allowed to move to places with sufficient internet.

The hybrid method could offer an intermediate solution. By using the Google Sheets the data are also instantaneously available and ready to use in any sort of model. It does necessitate a smaller investment, since the operators along the Sittaung river already have been supplied by smartphones. Therefore only 17 additional ‘cheap’ smartphones are needed instead of 28 more sophisticated ones.
The only requirement is a brief visit to hand over the manual and perhaps a short explanation. Just as for the MWM it does needs to cope with the locality of the internet connectivity and an agreement with the Irrigation Department is demanded. However, the amount of data that has to be transmitted is very limited and therefore also the quality of the connection.

Since it requires significantly lower further investments it is advised to start using the hybrid method and no longer invest in automated devices, which are bound to break down at some point. By doing so a new step is taken towards real time control in the Sittaung river basin. In case it appears not to offer the demanded swiftness or reliability a new study can be done towards the implementation of e.g. Mobile Water Management in 2017.

4.1 Further studies
At this moment the MWM application requires uploading the photos made from the staff gages. Therefore the amount of data that has to be transmitted is in the order of a few MB, which requires a proper internet connection (2G at least). One could look into the possibilities of reading the water levels on the device itself and only send the recorded water level, location and time to the main server. This will reduce the amount of data that needs to be sent dramatically into a few KB.

As discussed above the MWM and most likely also other future monitoring methods rely on a certain quality of the internet connection. Since this is rapidly evolving now Telenor and Ooredoo joined the competition, one could investigate the internet connectivity at the beginning of 2017 when the internet redundancy should be improved by the MYTHIC and SEA-ME-WE5 cables.

Figure 35: The Sittaung river delta
References


Appendices

Appendix A: National Water Policy

“The goal of the national integrated water resources management policy is to develop, share and manage the water resources of Myanmar in an integrated, holistic and socially inclusive manner, to contribute significantly to the poverty alleviation, to the green growth and sustainable development of the nation, by providing access to water of equitable quantity and safe quality for all social, environmental and economic needs of the present and future generations.” The objectives are formulated as:

(i) Prepare and propose an overarching national water policy based on national water needs and national development policy.
(ii) Realization of a sector apex body and strengthening of inter-ministerial cooperation, communication and information sharing.
(iii) Invest in water sector by the government to properly manage the country’s overall water resources and priority river basins, including development of physical infrastructure, institutions and capacity building.
(iv) Increase the efficiency and accountability of service providers in the water supply, sanitation and hygiene, hydropower and irrigation sectors.
(v) Disseminate knowledge and create awareness, develop responsible behaviours and create enabling environment for sustainable water use.
(vi) Provide national policy and stand point on use of shared water resources and develop cooperation among riparian countries.
(vii) Enhance water information, knowledge, know-how, technology, cooperation, consultation and partnerships.
(viii) Invest in water, sanitation and hygiene education, vocational training, capacity building, monitoring and enforcement, and learning.
Appendix B: Monitoring by the Hydrology Branch

The Hydrology Branch is led by a Director and has two Assistant Director’s offices at Yangon and Mandalay respectively. The Hydrology Branch carries out the tasks and activities of observing, measuring, recording, processing and investigating of the hydrometeorological data information for water resources development and future irrigation projects. There exist a total number of (111) stations registering water levels of streams and rivers, (21) numbers of rainfall stations and (36) numbers of discharge measuring stations under the Hydrology Branch, scattering over different climatic regions of the country. Moreover (213) numbers of rainfall stations are also installed in the existing dams, weirs, tanks and sluice gates for the purpose of Hydrological analysis and proper management of operation system. Among all of them, (18) numbers of rainfall stations and (7) numbers of water level stations have been upgraded as auto stations to obtain time series data.

Geological investigation is undertaken by the Geological Branch, administered by a Director. It has four sub-units, located at project sites, supervised by Assistant Directors, and remain engaged in

Figure 36: Tasks performed by the Hydrology Branch

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Appendix C: Sedimentation rate map

Figure 37: Sedimentation rate map
Appendix D: Day report

Date: 20-02-2015
Location: Ohnpin
Operation: Checking the state of the existing staff gages and measuring their installed height again.
Contact: Mr. Neing, Staff officer of Hydrology branch

Current state of monitoring the water level:

During the last Monsoon season some of the staff gages were flushed away. After they noticed the remaining ones were taken away to preserve them. In total there were 4 gages installed of which I found one remaining one leaning against a tree.
The Hydrology branch was there to check upon the current gages and install new ones if needed. Since the previous ones were no longer there they will install new ones besides measuring and checking the ground level.
Here the previously mentioned tree gets into play. This tree is placed roughly 30 meters inland from the river embankment. There is a nail with a little banner attached to the tree, referring to the absolute height compared to the MSL. The nail is placed at its height by levelling from the local benchmark. Where this nearest benchmark is located was not known at this moment. There is a database with all the locations from the benchmarks at the Settlement and Land Record Department. The accuracy of the nail is hard to estimate, depending on the accuracy of the local benchmark, the distance between and changes in height of the tree itself.
For measuring the height at which the new staff gages should be installed the nail in the tree is used as a reference level. This saves a lot of time and effort since now the reference level is close to the river, probably unlike the nearest benchmark. From this nail they use the levelling technique to make a temporary reference level just next to the water level of the river, so later they can install the new staff gages and they also measure the water level.

They used the measured water level to compare with the one that was measured when the previous staff gages were installed. According to the local people and the operator the water level was roughly the same as last time. However, the people from the Hydrology branch measured a water level that was 4,3 meters lower! After they made this discovery they measured their way back to the nail and came to a difference of just 1 cm. The distance from the nail to the river itself was more or less 150 meters and a height difference of about 4 meters.
Since this huge difference of 4.3 m between this measurement and the one before, the height of the nail will be controlled by the survey team during our trip along the river in a few weeks. After this has been done, they will look where the error originated from.

On top of the embankment there was 3G internet connection. However it was just locally, 40 meters further inland there was already no more connection at all.

Remarks:

- Last monsoon season wasn’t particularly high compared to previous ones. Nevertheless most staff gages flushed away at this location. They’re installed by hammering in a wooden stick when after the gage is nailed to it. The penetrating depth of the stick looks to be about 0.5-0.6 meter.
- All gages are supposed to be read three times a day, 6 AM, 12 PM and 6 PM.
- Gages are checked by the Hydrology branch unregularly. Sometimes 2 or 3 times a year but they can also be unvisited for over a year.
- The old gage that was found looked different than the new ones. The measurement stripes and numbers were at both sides in a regular pattern. The new ones have all the stripes at the right side and the numbers left. Both numbers are in centimetres. The numbers are painted on using a template after the height-range is determined.
Location: Byatkalay  
Operation: Checking the state of the existing staff gages.  
Contact: Local operator

At this location 3 out of 4 staff gages were still standing. The Hydrology branch came by the day before to check upon the gages and see which ones needed changing. They concluded that one was needed to install where the previous one was gone and the other one can be used for replacement. The remaining 3 gages were all in an equally poor state so it wasn’t certain which staff gage was going to be replaced yet. 

The local operator appeared to be really ‘local’, her house was standing no more than one meter away from the highest water gage. 

The staff gages here are also levelled with a nail in a nearby tree as reference. Just like at the other locations this nail is positioned by levelling from a benchmark. The tree was only 10 meters away from the highest water gage and about 40 meters to the river. 

Right next to the water level gages there was 3G internet connectivity.

Remarks:

- Water level was lower than the staff gage could measure. This problem is ‘handled’ by the judgement of the local operator, which further estimates the water level where the water gage no longer applies.  
- At the monitoring locations there are usually four staff gages installed. This in order to measure the water level throughout all the seasons. The placement and exact location of each single staff gage is determined in such a way that all staff gages should overlap at least a little. At least this should be one of the goals to make sure the water level can be accurately read all year. However, the set-up at this location has a gap of roughly 0,5 meter right in the middle of the whole water level range.  
- We noticed that the sunlight can cause problems with taking good ‘readable’ pictures. Since all staff gages should be monitored with either a little or a lot of light, 6 AM (first light) 12 AM (midday) 6 PM (last light). This problem is something to consider with the MWM application.  
- Staff gages very difficult to read due to dirt. According to the local operator they were 2 year old and sometimes cleaned.

Figure 42: Position of 2 year old staff gages. Water is lower than lowest gage can measure and ‘gage 1’ doesn’t overlap with ‘gage 2’ (neither do ‘gage 2’ and ‘gage 3’).
Appendix E: Sittaung river basin map
Appendix F: Global wave and tidal environments

Figure 43: World-wide distribution of wave environments

Figure 44: Tidal range across the Globe
Figure 45: Tidal environments
Appendix G: Outline of the Ministry of Agriculture and Irrigation

Figure 46: Organizational chart of the Ministry of Agriculture and Irrigation

Appendix H: Outline of the Irrigation Department

Organizational Chart of Irrigation Department

Officers (engineers) 831 persons
Other staffs 12124 persons
Total 12955 persons

Figure 47: Organizational chart of the Irrigation Department

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Appendix I: Mobile Water Level Monitoring Manual

**Set-up**

1. Download the 'Google Sheets' app on your mobile phone.
2. Open the file 'Google Water Levels'
3. Login with the e-mail address and password of your office
4. Tap the option 'button' next to the file named 'WaterLevelData'
5. Choose the option 'Keep on-device'
6. You're done, you can close the app.

**Operating**

1. Open the 'Google Sheet' app on your mobile phone
2. Open the file named 'WaterLevelData'
3. Scroll to the bottom of the list and open the data by double-tapping a cell
4. Tap on the 'i' sign in the top left corner
5. You're done, you can close the app.

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**Operator Manual**

**Office Staff Manual**
Appendix J: Monitoring by satellites

**Landsat**
Landsat’s spatial resolution is 30 m for the reflective bands, and 60 to 120 m for the thermal bands, respectively. The thermal imager is mounted on the Landsat satellites since 1982, which regularly collects data that is archived by USGS.

**Precision farming land management**
Goal: increase crop yields, cut costs and decrease environmental impact.

Important agricultural factors like plant health, plant cover and soil moisture monitored by a combination of Landsat and radar images. The Landsat provides clear images every 16 days, but is useless in cloudy conditions. The thermal band on the Landsat is able to detect crop health by seeing them transpire, which indicates its health. Other bands can see the area that’s covered by vegetation. The radar images, which are not influenced by clouds, are collected daily and measure the soil moisture.

![Figure 49: Image on the left by radar and on the right by Landsat](image)

![Figure 50: WDI indicates the rate of evaporative water. Green area is irrigated overnight, yellow area is dry and red is fallow land](image)
Locating groundwater discharge

By analyzing processed thermal images along with the panchromatic and near-infrared spectral bands potential discharge locations can be identified. If the discharging groundwater is hotter or colder than the surface water that it discharges into, a thermal anomaly may be detectable in the surface water.

**MODIS**

MODIS (Moderate Resolution Imaging Spectroradiometer) is a key instrument aboard the Terra (EOS AM) and Aqua (EOS PM) satellites. Terra’s orbit around the Earth is timed so that it passes from north to south across the equator in the morning, while Aqua passes south to north over the equator in the afternoon. Terra MODIS and Aqua MODIS are viewing the entire Earth’s surface every 1 to 2 days, acquiring data in 36 spectral bands, or groups of wavelengths with resolutions of 1,000 m, 500 m and 250 m.

The MODIS satellite is also equipped with a land surface evapotranspiration product which represents all transpiration by vegetation and evaporation from canopy and soil surfaces, expressed in 1-dimensional vertical mm/day units. ET is computed globally every day at 1km, using MODIS land-cover, and FPAR/LAI data and global surface meteorology from the GMAO. ET is used for water balance calculations for hydrologic management, as a carbon cycle constraint, and for drought and fire danger mapping.

Other hydrological related uses are the determination of the amount of land cover, vegetation indices and measuring the soil temperature.

**GRACE**

The Gravity Recovery and Climate Experiment (GRACE) satellite was launched in March of 2002, the GRACE mission will accurately map variations in the Earth’s gravity field over its 5-year lifetime. The GRACE mission will have two identical spacecraft’s flying about 220 kilometers apart in a polar orbit 500 kilometers above the Earth.

Instead of making pictures it senses the Earth gravity field in the following way: the two GRACE spacecraft fly over Earth one behind the other. If the first satellite flies above a continent, for example, it’s accelerated away from the trailing satellite (gravity is stronger over the continents, which are heavier than the oceans). By measuring tiny changes between the GRACE satellites as they pass one after the other over an area, scientists map bumps in the planet’s mass. It’s even possible to tease apart the weight added by underground water. Together with the surface water it is a measure for all terrestrial water storage.

Figure 51: The ‘reddish’ areas indicate potential groundwater discharge.