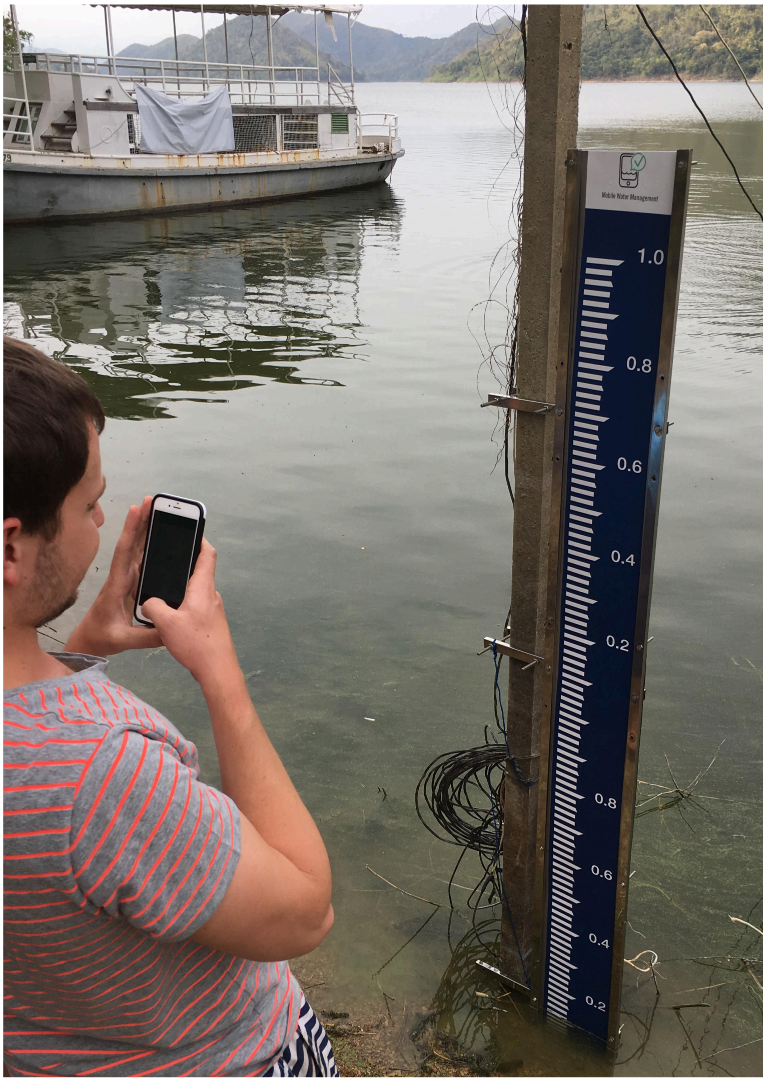

Mobile Water Monitoring Phetchaburi

Testing mobile app based data gathering in the Phetchaburi River Basin and possible applications

February 2018 – April 2018

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Preface

This report is the result of a 12-week multidisciplinary project by 6 Water Management students from Delft University of Technology, starting in February 2018. The specialisations within the team include hydrology, water resource management and water quality. During our stay in Thailand we were joined by two students from Kasetsart University in Bangkok. As part of their thesis they worked with us for 12 weeks and besides that provided much needed translation and insight. The goal of this project was to put up a showcase for a more cost-efficient water data collection system in Thailand. The project location was the Phetchaburi River in Phetchaburi province.

We would like to express our gratitude to Delft University of Technology, Kasetsart University and the Royal Irrigation Department of Thailand. Their provided equipment, transportation, data and even housing made this project a success.

A personal word of thanks goes out to dr. Thom Bogaard from Delft University of Technology, who has been our supervisor for this project. Without his help and effort in setting up this project, especially during the initial phases, this project would never have come into being in the first place. His enthusiasm before our departure to Thailand and during his visits definitely added to the success of this project.

We like to thank ass. prof. Punpim Puttaraksa Mapiam from Kasetsart University, our Thai supervisor, for her help especially during our stay in Thailand. The effort she put in to provide comfortable housing is much appreciated, as was her encouragement during her visits in Phetchaburi. Always quick to reply to our questions and going out of her way to help us whenever possible, she never let us down. Thom and Punpim, we couldn’t have asked for better supervisors.

We want to thank the RID director of Phetchaburi. The various provided resources as well as allowing us to stay in his house are very much appreciated.

We want to thank Hajo Heusinkveld and Damien Allen of Mobile Water Management for their support, both technical and informative, before and during our stay in Thailand, as well as for the provided material to create the staff gauges.

Executive summary

The Phetchaburi River in Phetchaburi province, Thailand, has a watershed with many different water resource projects. The surrounding farms rely on the Phetchaburi River for irrigation water and the drinking water companies rely on it as a source of water. However, the Phetchaburi basin has problems with yearly floods, salt intrusion and pollution.
Water monitoring stations in the region are scarce. A new telemetering system has been put in place, but due to the cost of these stations they are few in number.

This project presents a showcase for a cheap and robust water monitoring system in terms of both quantity through water level data and quality through various water quality parameters using apps on an android or iPhone device to gather and analyse the data. The app from Mobile Water Management (MWM) is used to measure the water level through reading a photo of a staff gauge. The Akvo app uses various methods like electronic devices and reading strips via a photo to measure several water quality parameters.

It was proven that construction of the staff gauges needed for the MWM app is cheap and does not require highly skilled workers. The resulting data is reliable, if the app is handled by someone trained in handling the app, and/or the data that is created is checked by a trained person. The fact that the pictures taken by the app are uploaded to the database makes for easy verification of the data. This makes verification of telemetric data possible, which as it turns out is not always reliable when compared to the MWM data.

The Akvo app has a similar advantage in the sense that verification of the data at a later moment is not only possible, but also easy. This eliminates several human errors in the data collection process and effectively increases the data quality. Right now, several RID officers are needed to collect this data. Using the Akvo app, the required manpower can be lowered.
Data analysis shows that the Phetchaburi River has significant levels fecal contamination (E. coli) and issues with low oxygen concentrations at certain moments. For this reason, it is not recommended to use as recreational, fishing or irrigation water. The boundary between salt and freshwater is constantly changing depending on weather conditions and can cause serious problems for local farmers.

When constructing the staff gauge there are multiple possible human errors that need to be avoided in order for the MWM app to work correctly. This mainly has to do with the placement of the staff gauge sticker, keeping it straight and unobstructed and also directed towards the user.

It turned out that several of the Akvo strips are not working correctly. Other than that, taking data from many parameters can also be time consuming.

We recommend that the RID looks into this method of data collection further, both as a cheap and easy way to expand their water monitoring network, and in the case of the MWM app to verify the effectiveness of the telemetering systems.

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1. Introduction

1.1 Problem statement/purpose

Currently, there are several issues in the Phetchaburi basin. The telemetering system is quite difficult to repair in case of a breakdown, and expensive to maintain and expand upon. This has led to increasing numbers of malfunctioning and/or broken measurement stations, making flood forecasting and flood prevention even harder. An expensive discharge measurement installation used for monitoring discharge downstream of the diversion dam has not been in operation for many years, as there was a lack of expertise to repair the installation. Instead, a rating curve is being applied, even in sections with tidal intrusion, combined with experience from locals in estimating discharge. This makes it difficult to accurately determine the river discharge.

In general, the water quality is not sufficiently monitored. Current measurements are only used as proof of the salinity level in case of complaints. However, this is only done once a week. The influence of the tide is not taken into account at locations where tidal influence and salt intrusion occur. Especially during dry season and low river flow, water quality issues occur due to insufficient dilution of domestic waste flow by the Phetchaburi river.

There are issues in the region with flooding as well. According to the director of the Royal Irrigation Department of Thailand (RID) for Phetchaburi province, at least one large flood still occurs every year which cannot be handled by the diversion dam. A pressing problem at the moment is that due to improper upstream monitoring there is a sub-par flood warning system between the Kaeng Krachan dam and the diversion dam. This means that when a flood arrives, the gates of the diversion dam have to be fully opened, which causes further downstream flooding problems. With a better flood warning system, the diversion dam can be opened further pre-emptively, which decreases the impact of the flood. The NGO's and population are reluctant to building new hydraulic structures to improve flood protection, because of both ecological reasons and housing reasons.

The farmers, especially on the edge of the saltwater intrusion, experience fluctuating levels of salinity. Sometimes the salt intrudes too far due to low river flow, creating problems for farmers relying on fresh water. Sometimes the salt doesn't intrude far enough due to high river flow, creating problems for farmers relying on salt water.

This project will present a showcase for a possible cheap water monitoring system, which can be used to expand the data collection infrastructure as well as verify the data obtained with the currently installed telemeter system or water quality measurement methods.

1.2 Area Description

1.2.1 Phetchaburi climate

The province of Phetchaburi is centrally located in Thailand, bordered by the Gulf of Thailand on the east and the Tanaosi mountains on the west. Phetchaburi has a tropical savanna climate, with average air temperature ranging between 23°C and 35°C, see Fig. 1.2. Phetchaburi has a distinct monsoon period between May and October. Peak precipitation occurs in September, in which over 300 mm of precipitation occurs. During the dry period in January and December little precipitation occurs, often in the range of 10 - 20 mm, see Fig. 1.3 (Thai Meteorological Department).

1.2.2 Phetchaburi river

The headwaters of the Phetchaburi river originate in the rainforests of the Kaeng Krachan national park; streams located in the southern part of the national park drain into the Pranburi river, which flows through Pranburi province. Streams located in the northern part of Kaeng Krachan national park drain into the Phetchaburi river. From Kaeng Krachan national park the Phetchaburi flows into the Kaeng Krachan reservoir, a large man-made reservoir with a hydropower dam for flood protection, hydropower, irrigation water supply and recreation. From the reservoir, the Phetchaburi river flows east where it is joined by several tributaries including a major one from the north (henceforth known as 'Northern tributary'), after which the flow is split over a diversion dam. The watershed for Phetchaburi River covers roughly all of Phetchaburi province. The watersheds for the Kaeng Krachan dam, the Northern Tributary and the diversion dam are shown in Appendix A1. Finally, the river flows roughly north-northeast through the city of Phetchaburi and the main agricultural area before reaching the Gulf of Thailand.

1.2.3 Existing structures

The Kaeng Krachan dam is a multi-purpose hydroelectric dam at the edge of the Kaeng Krachan National Park, see Fig. 1.1. It created the Kaeng Krachan reservoir, a reservoir with a surface area of 46.5 km^2 and a storage capacity of 710 million m^3 (Electricity Generating Authority of Thailand, 2013).

The Phetburi diversion dam in Tha Koi does not produce hydropower or create a reservoir, but instead diverts a fraction of the incoming discharge to an irrigation channel. This irrigation channel flows from the diversion dam towards the sea. This channel is currently being widened to be able to better cope with the flooding issues in the area.

It is currently being looked into if a new reservoir can be created in the Northern tributary. However, this idea has faced a fair amount of resistance as this would require the relocation of many inhabitants.

1.2.4 Current data collection infrastructure

The current hydrological data collection sites are sparse and many of them are non-recording, see Appendix A2. There is a telemeter network in the region, but due to the cost of such installations only 10 stations have been placed, see Appendix A3 for the locations. Furthermore, some of the existing telemeter stations are either malfunctioning or non-functional. Because of this, there is no reliable flood warning system upstream of the diversion dam. In addition, little is known about the Northern tributary, despite it having a sizable watershed.

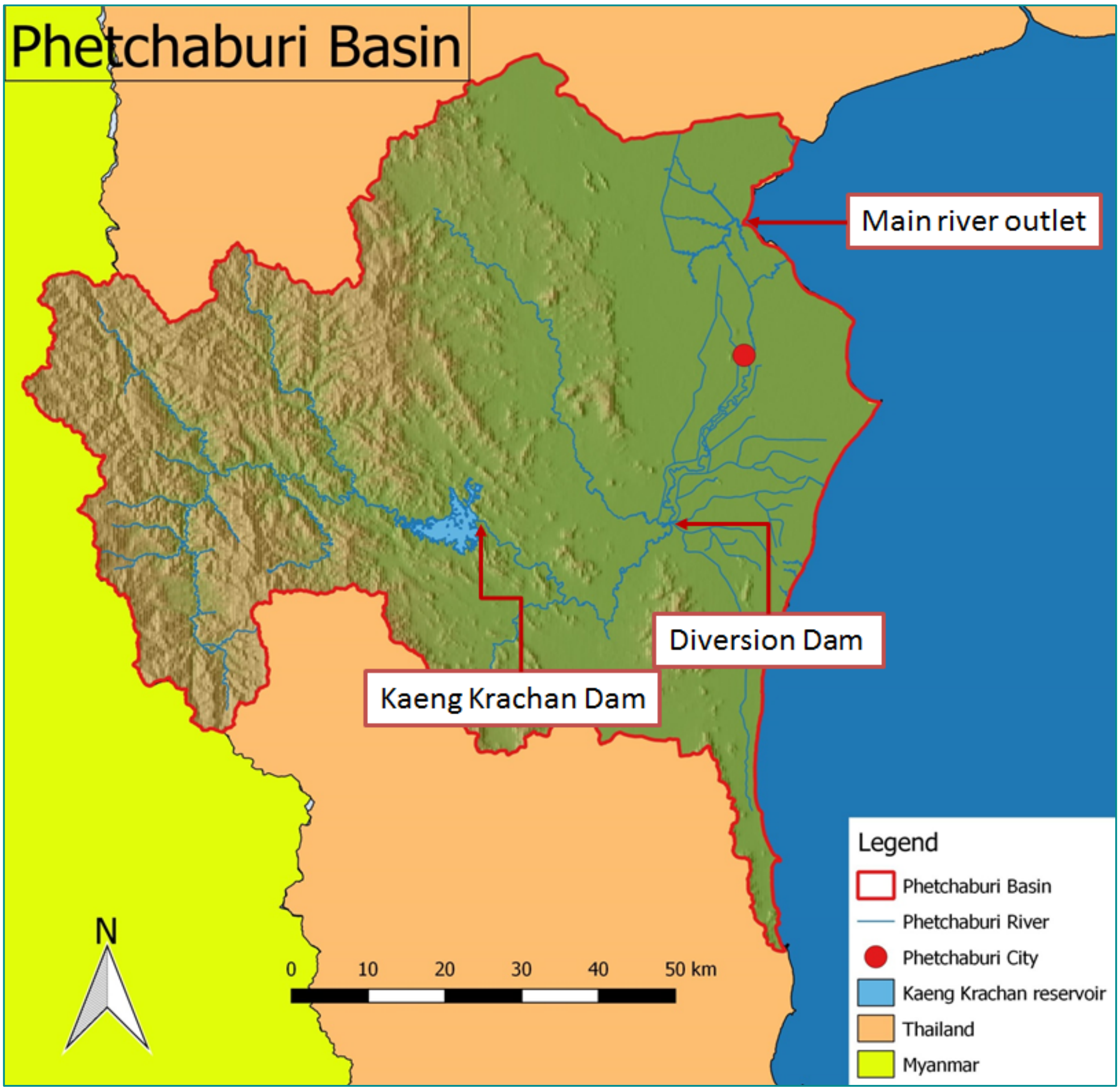

Fig 1.1: Phetchaburi river basin

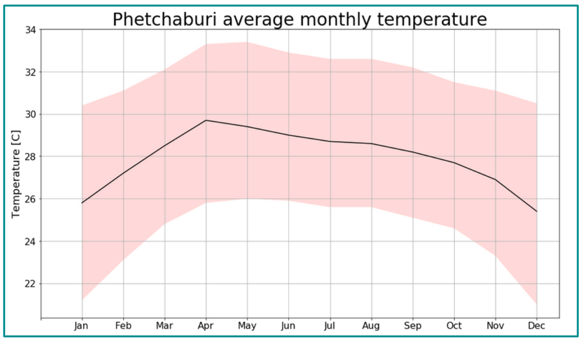

Fig 1.2: Phetchaburi average monthly temperature (Thai Meteorological Department)

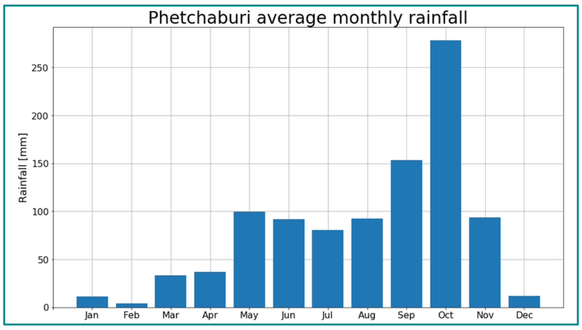

Fig 1.3: Phetchaburi annual precipitation (Thai Meteorological Department)

1.3 Thai surface water quality standards

In article 32 of the National Environmental Quality and Promotion and Preservation act (1992) the Thai environmental standards and guidelines are determined by the Thai National council for Environment. Water quality standards are an important part of the environmental standards and are based on scientific research and academic principles (Notification of the National Environment Board No.8, B.E.2537, 1994).

The water quality standards presented in 1994 by the Thai Water Quality Management Office (Department Pollution Control) and are still used up until today. The standards are established to protect natural water sources and with that environmental conservation and public health. Many institutions in Thailand, including the Royal Irrigation Department (RID), apply these water quality standards which makes them relevant for this research as well.

The Thai water quality standards are based on a classification system which consists out of five different categories as can be seen in Fig. 1.4. Depending on the concentration of certain water quality parameters the watershed is classified in one of the five categories. In this classification category 1 has the highest quality and this water can be used for many different application including ecosystem conservation. The needed treatment for this water before human consumption is minimal. Category 5 is the worst category, water with this quality can only be used for navigation according to the Thai standards. The intermediate categories serve other purposes like fisheries, agriculture, recreation and as source for tap water production.

Important principle water quality parameters and their standards can be found in Table 1.1. For the complete list of all water quality parameters and standards the website of the Thai pollution control department can be consulted (Notification of the National Environment Board No.8, B.E.2537, 1994). The water quality standards consist out of a set of physical, chemical and biological parameters to guarantee an overall good quality of the river. One can think for example of standards on oxygen, BOD, ammonia/nitrate, micropollutants, heavy metals and bacteria. When these standards are not met damage to human health or degradation of the ecosystem can occur.

The upper part of the Phetchaburi river between the Kaeng Krachan dam and the Phetburi diversion dam requires at least category 2 since the water serves as source for drinking water production with conventional treatment and is used for irrigation and occasionally for recreation. The rest of the river downstream of the Phetburi diversion dam is used for fisheries and irrigation. Conventional water treatment is applied in the water treatment facilities along the river. This requires at least category 3, preferably higher.

The RID in Phetchaburi province has slightly different water quality standards that also take into account salinity, total dissolved salts (TDS) and Electrical conductivity (EC). These parameters are especially relevant for irrigation water, since saline water can seriously affect crops. In accordance with the RID standards, the pH must be between 6.5 and 8.5, the EC < 2000 µS/cm, salinity < 2 g/l, TDS < 1300 ppm, DO > 2 mg/l and temperature < 40 °C.

Classification	Condition & Beneficial Usages
Class 1	Extra clean fresh surface water resources used for : (1) Conservation. It is unnecessary to be treated by water treatment process, but a process for pathogenic destruction is required. (2) Conservation of ecosystem where basic organisms can breed naturally. (3) Conservation of water resource ecosystem.
Class 2	Very clean fresh surface water resources used for : (1) Consumption which requires conservational water treatment processes before use. (2) Aquatic organism conservation. (3) Fisheries (4) Recreation
Class 3	Moderately clean fresh surface water resources used for : (1) Consumption, but the water should be conservationally treated before use. (2) Agriculture
Class 4	Fairly clean fresh surface water resources used for : (1) Consumption, but requires special water treatment process before use. (2) Industry
Class 5	The sources which are not classified as class 1-4 and used for navigation.

Fig 1.4: Thai pollution Control Department water quality classification (Notification of the National Environment Board, 1994)

Table 1.1: Thai surface water quality standards on key parameters (Notification of the National Environment Board, 1994)

No.	Parameter	Statistical Value	Unit	Standard Value of Surface Water for Class				
				1	2	3	4	5
1.	Color, Odor and Taste	-	-	n	n	n	n	-
2.	Temperature	-	^{o}C	n	n'	n'	n'	-
3.	pH Value	-	-	n	5 - 9	5 - 9	5 - 9	-
4.	Dissolved Oxygen	P 20	mg/l	n	≥ 6.0	≥ 4.0	≥ 2.0	-
5.	BOD_5 (20 °C, 5 days)	P 80	mg/l	n	≤ 1.5	≤ 2.0	≤ 4.0	-
6.	Total Coliform Bacteria	P 80	MPN/100 ml	n	$\leq 5{,}000$	$\leq 20{,}000$	-	-
7.	Fecal Coliform Bacteria	P 80	MPN/100 ml	n	$\leq 1{,}000$	$\leq 4{,}000$	-	-
8.	NO_3-N	Max. allowable	mg/l	n	not more than 5.0			-

2. Methods and materials

The 2 parameters that are measured during the project are the water level and the water quality. The water level is measured by staff gauges while the water quality is measured by test strips, sensors or biological tests. Using mobile apps, this data can then be easily stored in the cloud. In section 2.1 and 2.2 a quick explanation will be given on how the apps work. The detailed user manuals for both apps have been supplied with this report.

2.1 Mobile Water Management App

The mobile app created by Mobile Water Management (MWM), is based on image recognition of a standard staff gauge, see Fig. 2.1. Simply put, a picture is taken of the staff gauge and the app is able to determine the water level. The app searches for the top of the staff gauge, after which it goes down until it can no longer see the lines on the staff gauge. At this point, when the app can no longer read the staff gauge, it measures the distance to the top. An example of the app reading the staff gauge is shown in Fig. 2.2. Here the glass table is simulating the water level. As can be seen, the app recognizes the point where the table is and does not measure further, as indicated by the red and green stripes. Since the top of the staff gauge is the reference point it can be changed to fit any of the preferred reference systems. In this case, the reference system used is Mean Sea Level (MSL).

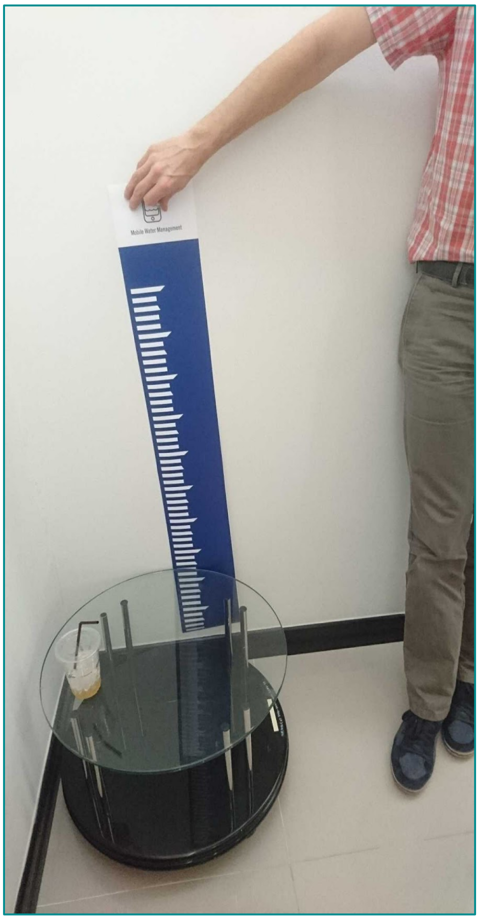

Fig. 2.1: Raw photo of staff gauge

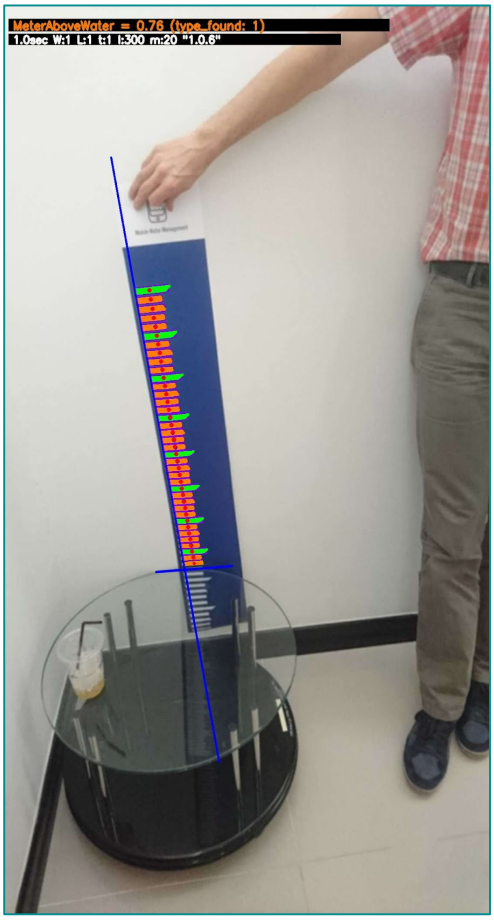

Fig. 2.2: Processed photo of staff gauge

2.2 Akvo App

Akvo Caddisfly is a simple, low cost, open source, smartphone-based (Android) water quality testing system connected to an online data platform (Akvo, 2017). The mobile application of Akvo can be used to conducted surveys to collect water quality data and other relevant data in the field and can be downloaded for free. The collected data is automatically sent to an online database called Akvo Flow where it is immediately available for rapid data analysis and visualisation. There are some minor costs involved for the data storage on the Akvo Flow app. The principle of the Akvo Caddisfly app can be seen in Fig. 2.3. The app makes it possible to perform water quality measurement without expensive equipment/lab conditions and saves time on data processing. Besides that, the app reduces human errors and collects additional useful metadata which makes it easier to interpret the testing results.

Before starting the measurements, first a survey needs to be conducted with relevant tests and questions. This survey can be created and executed by anyone with the right permission. With this survey, also metadata as geolocation (GPS), date and time can be easily collected. In this way, potential typing errors are prevented and it can be guaranteed that the measurements have been taken at the right place and the right time. Besides that, pictures of the surroundings and measuring devices are taken and stored in the database as well. This enables the evaluation of suspicious values after the measurements can be done.

The mobile app itself can use four different measuring techniques: colorimetric, test strips, sensors and microbiology. Depending on measured parameter, the available budget, desired accuracy and measuring range, a measuring technique can be selected and used as input for the Akvo Caddisfly app. An overview of water quality parameters that can be measured with the Akvo app can been seen in Fig. 2.4. All the materials are relatively affordable and available to use in the field.

Fig. 2.3: Principles of Akvo Caddisfly (Akvo, 2017)

	Colorimetry	Strip tests	Sensors	Microbiology
Alkalinity	•	•		
Aluminum	•			
Ammonia	•	•		
Arsenic		•		
Chloride	•	•		
Chlorine	•	•		
Chromium	•			
COD	•			
Dissolved oxygen (in progress)				
Electrical conductivity			•	
E. coli				•
Fluoride	•			
Hardness	•	•		
Iron	•	•		
Nitrate	•	•		
Nitrite	•	•		
pH	•	•	•	
Phosphate	•	•		
Potassium	•	•		
Sulphate	•			
Suspended solids	•			
Turbidity	•			

Fig. 2.4: Overview parameters Akvo Caddisfly (Akvo, 2017)

In general, the strip tests are used as an indicator for water quality. They are relatively inexpensive, do not require high investment costs and are easy to use. The test strips change colour when they get in contact with the water sample. The exact change in colour of the strip depends of the concentration of the parameter in the sample. When the colour change has taken place, the strip can be put on the Akvo colour reference card and a picture of the reference card with test strip can be taken with the Akvo Caddisfly app. The app compares the colour of the strip with the reference card and determines the concentration. Important is that there is enough light present when the picture is taken. The strips can only be used an indicator and not for exact measurements, errors of the strips can be in the range of 10-25%.

For more accurate measurements colorimetry is recommended since the expected error is in the order of 2%. Colorimetric testing is based on the principle of adding a reagent to a water sample. Depending on the concentration of the measured parameter the colour of the sample changes. A photometer (Lovibond MD 610) that is connected with the Caddisfly app via Bluetooth can measure the colour of the sample and determine the concentration of the substance in the sample. Important is the cleaning of the instruments and vials after the test. Coliometry requires more initial investment since the photometer needs to be purchased first. The cost of the reagents is comparable with the strip test.

The sensors for Akvo Caddisfly are available for EC and pH measurements and have an accuracy of 2-5% for the EC sensors and 0.05 for the pH device. The sensors can be connected with a mobile phone with a cable and measured values are directly uploaded to the Caddisfly app. Just like the photometer, these devices have some initial investment cost, but costs can be saved on the running costs. It is also possible to use external devices and add the measured values manually into the Akvo Caddisfly app. For the sensors, it is important to calibrate regularly, especially pH sensors are sensitive for this type of errors.

The microbiological compartment bag test (CBT) can show the presence of E. coli bacteria, a reliable indicator of fecal contamination. The microbiological test for E. coli uses the most probable number (MPN) and has a sensitivity of 95%. The Aquagenx Compartment Bag Test (CBT) can measure between 0-100 MPN and can indicate the risk on fecal contamination for drinking water following the guidelines of the WHO. A sample of 100 ml is put in a mixing bag together with a growth medium for the bacteria. When properly mixed, the sample is put into another compartment bag that contains out of five compartments with different volumes. The bag is sealed and put away for a certain period depending on the average air temperature (E. coli bacteria grow faster at higher temperatures). After waiting for the required time the compartments with bacteria present will change in colour. Depending on which and how many compartments change colour, the concentration (MPN) of E. coli bacteria can be determined by the Akvo Caddisfly app. It is important to work as sterile as possible since the test are sensitive for contamination and can have consequences on the measuring results. It is recommended to wear gloves during working with the compartment bags. Disinfection of the compartment bags is necessary before disposing since the bags can contain harmful bacteria. When it is desired to measure the water quality for irrigation or recreational standards, the sample has to be diluted ten times before putting it into the compartment bags. In this way, the concentration between 0-1000 MPN can be measured and more detailed conclusions can be drawn on the surface water quality. Without dilution, it is likely that the concentration of E. coli in river water is always above the measuring range of 100 MPN.

In general, the main advantages of the Akvo app is that it reduces human errors, collects metadata easily and saves time on data processing. The location and date/time is always correct due to the GPS/mobile settings. Geolocation and photos guarantee that measurements are taken at the right place and the right moment and can explain suspicious values afterwards. No expensive equipment and complicated lab tests are necessary anymore and time is saved on transportation to the lab and degradation of water samples during transport is prevented. Data is automatically stored in the database which makes it less vulnerable for typing errors and saves time in data processing. An excel file with all the data can be downloaded from the Akvo Flow website.

2.3 Materials

2.3.1 Water Level

Since the app of Mobile Water Management takes a picture of their own design, the most important thing to have are their staff gauges, see Fig. 2.1 and Fig 2.2. These staff gauges are stickers, so in order to place them anywhere, they need to be stuck to a flat surface. Finally, the staff gauges need to be mounted on the measuring location.

Having found the proper measuring locations, the choices of which will be explained in section 3, the designs for each location could be made. A general design was determined, the details of which can be seen in Fig. 2.5.

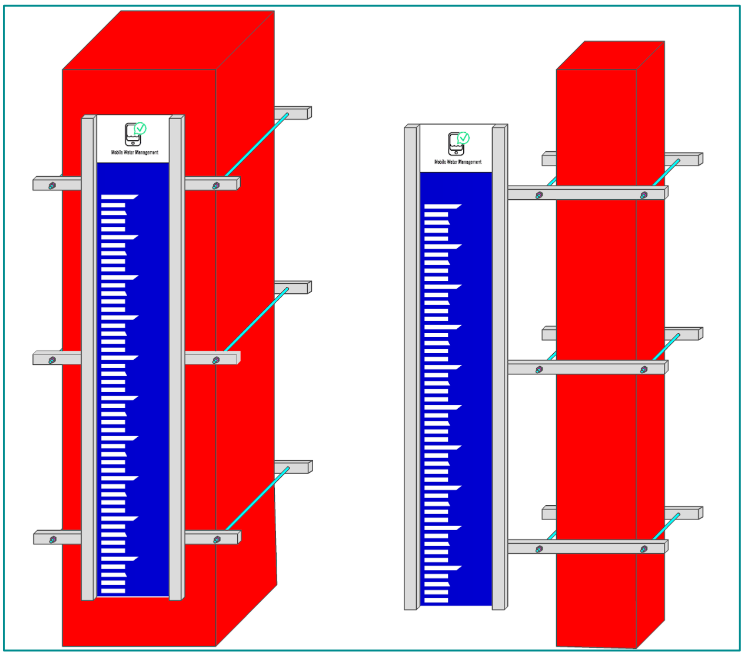

Fig. 2.5: General design for MWM staff gauge

Fig. 2.6: Finalized MWM staff gauge

What becomes clear from the general design is that none of the staff gauges are bolted into a bridge pillar. Rather, they are mounted around it and firmly tightened. There are multiple reasons why this type of design was chosen. Firstly, this is a showcase of the system. It should be easily installable and also easily removable when needed, to show the flexibility of the system. Secondly, drilling into a bridge pillar requires authorization of the government. Thirdly, drilling into a bridge pillar requires a strong drill, not a cordless drill. Since most of the locations are far away from electricity outlets, it would be difficult to drill a hole into a bridge pillar. In addition, the staff gauges are installed in the river by going into the river, so bringing electricity into that equation is not recommendable.

The materials used to build the design were all bought in stores in nearby villages. Knowing that the river has a low water quality and when nearing the river mouth, a higher salinity, a durable and less erodible material was needed. In addition, the staff gauges would heat up in the sun and cool down during the night, so the material should also have a low thermal expansion. The materials that were decided on are aluminium and stainless steel. Figure 2.6 shows a staff gauge ready to be used. Photos of the installed staff gauges and their final design can be found in Appendix B.

Finally, the data provided by the RID from their telemetering system (see Appendix I) is needed to compare with the data gathered by the MWM staff gauges in order to demonstrate that the data gathered using the app is correct and consistent or to even show irregularities in the telemetering system.

2.3.2 Water Quality

Most of the equipment to measure the water quality parameters are purchased via Akvo. The 10 measured parameters are pH, electrical conductivity (EC), nitrate and nitrite, phosphate, turbidity, iron, temperature and carbonate hardness. The dissolved oxygen (DO) concentration is also measured using a DO meter that was provided by TU delft. In addition, E. coli concentrations were also measured using equipment from Akvo. The combination of these tools was used for three objectives. Firstly, to get an overview of the Phetchaburi River characteristics. Secondly, to compare with RID measurements by doing field work with them and thirdly, to perform the measurement simultaneously. The devices from TUDelft are calibrated every time before doing this kind of field work/measurement with RID. The last objective is to validate the Merck pH strip. Earlier there were reports from users that the pH strip gave on average one pH lower than the actual value on the field, even though it worked perfectly under lab condition when this was tested by Akvo. This project made an attempt to see what would have influenced the pH strip adversely. pH strips from Hach were tested as well to see how well it works. Table 2.1 shows an overview of what parameter were measured and for what objective it was used. The brands of used equipment are given in Table 2.2.

For EC measurements, two kinds of devices were brought. The Akvo EC measurement device was here as a backup in case other EC meters malfunctioned. Akvo EC device is a pocket size device that can be attached to the phone to transfer measured data to the app directly. It was a handy tool and was used as independent measurement for EC for certain locations.

As RID has been measuring water quality (pH, EC, Oxygen and Temp) for 2 years, their data was also requested (see Appendix E) to compare with the results from the Akvo equipment. Section 3 will explain further on how the measurements of the RID will be incorporated.

Table 2.1: Water quality parameters, equipment and objectives.

Parameter	Equipment	For river characteristic	For RID measurement comparison	For pH strip test validation
Iron	Akvo Strip Test			
Nitrate and Nitrite	Akvo Strip Test			
Carbonate Hardness	Akvo Strip Test			
Phosphate	Akvo Strip Test			
pH				
-Merck	Akvo Strip Test			
-Hach	Akvo Strip Test			
-Akvo device	External Akvo Device			
-TUDelft device	External Device			
EC				
-Akvo device	External Akvo Device			
-TUDelft device	External Device			
Turbidity	External Akvo Device			
Oxygen	External Device			
Temperature	External Akvo Device			
E.coli	External Akvo tool			

Table 2.2: Brands used for measurements.

Device	Brand
pH TUDelft device	Greisinger GMH5550
EC TUDelft device	Greisinger GMH3431
Oxygen device	Greisinger GMH5630

3. Measuring Locations

3.1 Criteria

To determine the proper measuring locations for the water level and the water quality, a few criteria need to be taken into account. Since the criteria for water level and water quality are a bit different, they will be discussed separately in sections 3.1.1 and 3.1.2.

3.1.1 Water Level

Since part of the research is aimed at showing that the mobile water management app is able to gather the same data as the telemetric system, one of the criteria is trying to fix the staff gauges near the current telemetric system so the data could be compared. Another criterion is the accessibility of the location. This has two reasons, firstly the installation process and secondly the fact that someone has to be able to get to the staff gauge in order to take a measurement. If the staff gauge is hard to reach, it could be difficult to find people available to go there every day to take a picture. In addition, for the app to be able to read the staff gauge, a distance of 10m is the maximum a person should be from the staff gauge, provided that the phone is able to zoom in properly. If the zoom-in function is not that good, a distance of 5m should be the maximum.

3.1.2 Water Quality

Like the criteria for water level, the location needs to be accessible to do the water quality measurements. Since there are some cities and villages along the river, it is also interesting to see what the influence of these settlements are on the water quality of the river. It turns out that the RID was already measuring the water quality once a week at 14 locations downstream of the diversion dam. Fig. 3.1 shows these 14 locations. Since one of the goals of the project is to get the people from the RID to do the Akvo measurements, the best thing is to choose some of these locations. However, not all locations were measured with Akvo equipment in this project. In section 3.2.2 will be explained why some locations have been chosen for further measurements.

3.2 Locations

3.2.1 Water Level

Based on the criteria, 9 locations for the staff gauges were considered a match. These 9 locations are all easily accessible and it was easy to mount the staff gauges on either bridge pillars, or existing concrete staff gauges of the RID. Fig. 3.2 shows the locations of the staff gauges. In Appendix B pictures of the staff gauges on location can be found. Fig. 3.3 shows an example of the staff gauge at the river mouth. The numbering of the locations for water level and water quality are different. The numbering of the water level locations starts downstream at the river mouth and goes upstream towards the Kaeng Krachan dam, whereas the water quality is only measured downstream of the Phetburi diversion dam. The numbering for water quality starts at the Phetchaburi diversion dam, since the RID office is located there. Table 3.1 shows the names of the water quality and water level locations and the differences they may have.

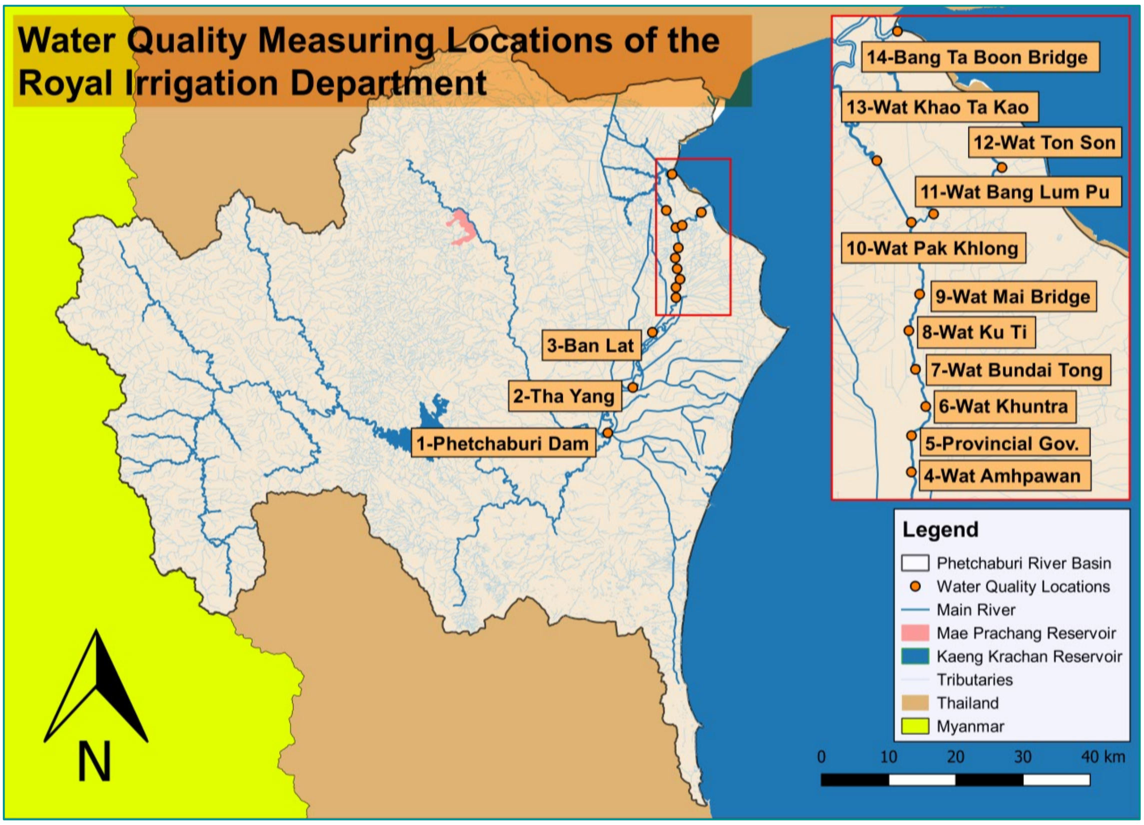

Fig. 3.1: Water quality measuring locations of the RID

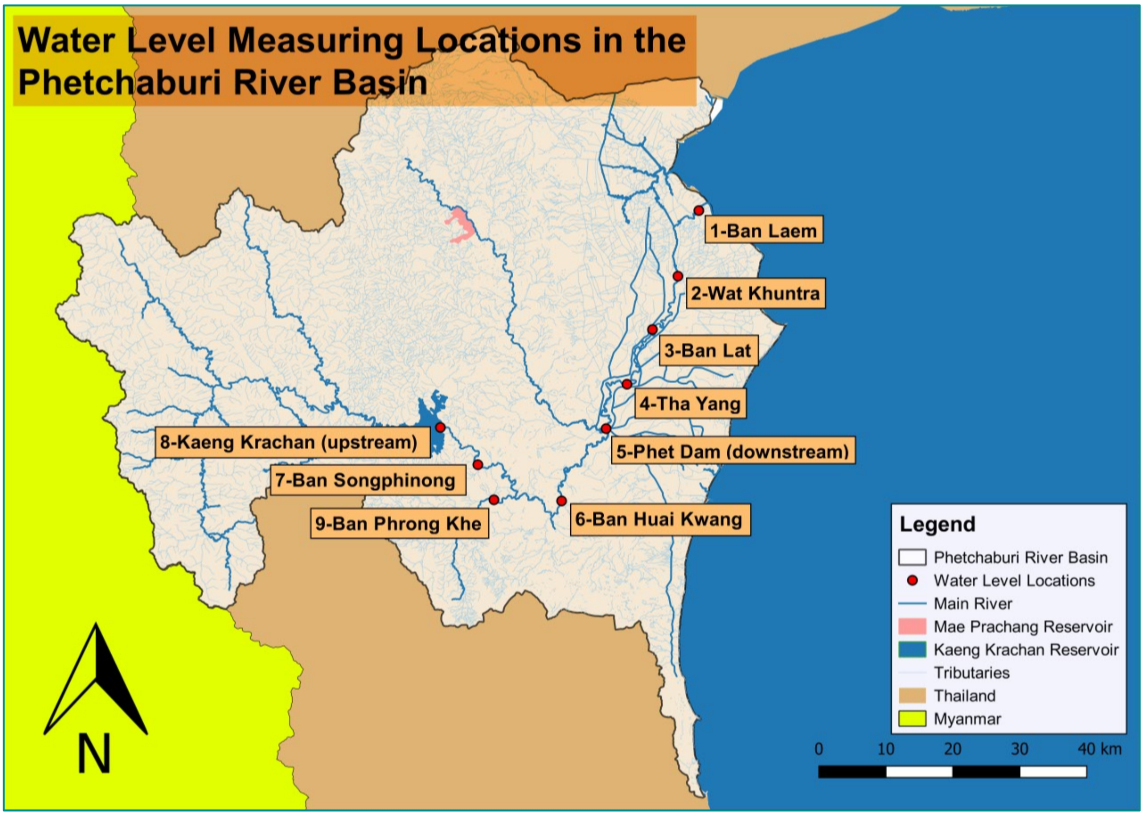

Fig. 3.2: Location of the MWM staff gauges

Fig. 3.3: Staff gauge at Location 1

Table 3.1: Spatial conformity of water quality and quantity locations

Water Quality		Water Level	
Location	Name	Location	Name
1	Phetchaburi dam	5	Phet Dam
2	Tha Yang	4	Tha Yang
3	Ban Lat	3	Ban Lat
4	Wat Amphawan		
5	Provincial Gov.		
6	Wat Khuntra	2	Wat Khuntra
7	Wat Bundai Tong		
8	Wat Ku Ti		
9	Wat Mai Bridge		
10	Wat Pak Khlong		
11	Wat Bang Lum Pu		
12	Wat Ton Son	1	Ban Laem
13	Wat Khao Ta Kao		
14	Bang ta Boon Bridge		

3.2.2 Water Quality

3.2.2.1 Land use in the Phetchaburi basin

Since the RID was already measuring 14 locations, and the goal is for them to use the Akvo app, it was decided that some of the 14 locations would be measured using the Akvo equipment. Out of the 14 locations, some were too close to each other to give a meaningful difference. Therefore, locations 4, 7 and 8 were disregarded, see Fig. 3.1. To determine which of the other locations are interesting, the land use is taken into account. Appendix C: Fig. C 1 shows 3 different types of land use.

Appendix C: figure C1 shows that downstream of the diversion dam the cities and villages start. In addition, it shows that from west to east, the forest disappears and agriculture takes over at the point of the diversion dam. This means that the upstream region of the diversion dam is of less interest for continuous measurements. The locations of interest are the diversion dam, to see the initial water quality, downstream of cities and villages, to see the impact of each of these on the river, and at the river mouth, to see the impact of the increased salinity. In addition, the locations should not be too close to each other. Based on these criteria, 9 locations were chosen for continuous measurements, see Appendix C: Fig. C 2.

3.2.2.2 Different amount of parameters

The 4 parameters measured by the RID are EC, DO, pH and temperature. With the Akvo equipment and the TU delft devices, 10 parameters are measured (mentioned in section 2.3.2), including the parameters that the RID are measuring. This means that it does not matter which of the 14 locations are chosen for the comparison between the Akvo equipment and the RID equipment. Out of the 14 locations, 9 locations were chosen to give a nice overview of the water quality of the Phetchaburi river (see section 3.2.2.1). However, due to a limited number of E. coli tests, only 5 of these locations will include E. coli measurements to have more measurements. The other 4 locations will be measured for everything but E. coli. Appendix C: Fig. C 3 shows the map of these 9 locations. Locations including E. coli are called ‘complete’ while locations without are called ‘basic’.

3.2.2.3 Comparison with RID

As mentioned in section 3.2.2.2, the parameters measured by the RID are also measured with the Akvo and TU Delft equipment. Therefore, every location can be used for comparison between both types of equipment. For practical reasons, the locations where the water quality and the water level are both measured are used to compare the data from the RID to the data from the Akvo and TU Delft equipment, see Appendix C: figure C4. It shows that 5 locations are chosen, the same as the number of downstream staff gauges, of which 4 locations are the same as the locations where the basic or complete water quality measurements are done. Only location 5 is replaced by location 6. At location 6, only the 4 parameters that are measured by the RID are measured using the Akvo and TU Delft equipment.

3.3 Final Overview

Combining both the water level and the water quality results in the following map, see Fig. 3.4. These locations will be compared with data from the RID.

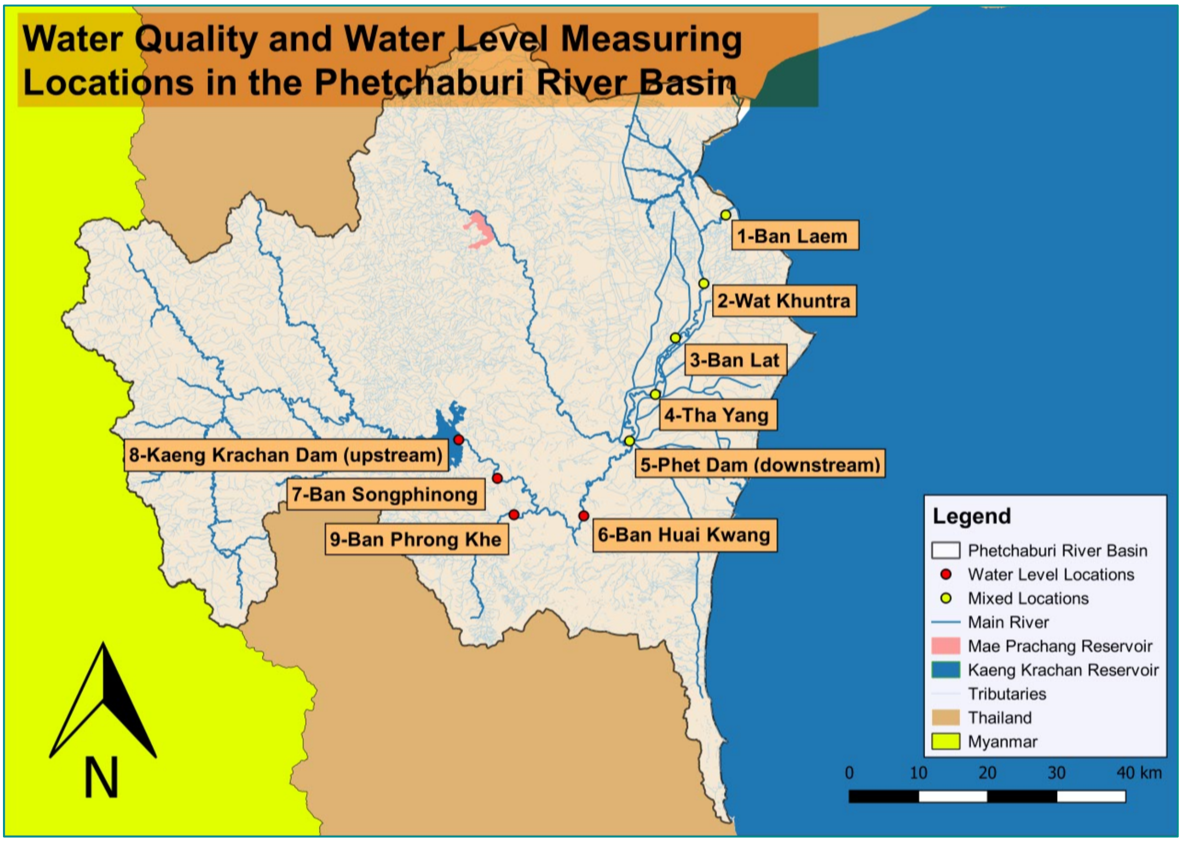

Fig. 3.4: Final overview of measurement locations.

4. Results

4.1 MWM app

4.1.1 General results and remarks

Sedimentation on the staff gauge sticker causes problems for reading the water level, especially if the sedimentation is still wet, see Fig. 4.1 and Fig. 4.2. How will the staff gauges perform when the amount of sediment on the sticker increases? This is not particularly important for the Netherlands, where surface waters are generally cleaner, but in countries like Thailand where rivers can carry a large amount of sediment this should be taken into account.

Issues with taking measurements due to the staff gauge or sticker not being fully straight. The staff gauge is recognized by a small blue strip to the left of the white marks, so if the blue strip is not visible then the staff gauge cannot be recognized at all. These issues mostly occurred with the 2 m staff gauges, which we created ourselves by combining two 1m staff gauges, see Fig. 4.3 and Fig. 4.4. However, the longest staff gauge that is currently being used in the Netherlands with the MWM app is 5m long and prefabricated in one piece. Therefore, it is concluded that the aforementioned issues have occurred due to our inability to apply the stickers fully straight, rather than an inherent problem with the application or its recognition algorithm.

In some cases, the algorithm failed to account for the reflection of the water level, see Fig. 4.5 and Fig. 4.6. As a result, the measured water level was determined below the actual water level. While in general, the algorithm seems to do a good job accounting for water reflection, there is still room for improvement.

Concerning all of the above; when a layperson takes a measurement, there is a risk that an incorrect photo/measurement is not spotted and is accepted as a correct measurement. This can be (at least partially) circumvented by properly training individuals, as well as including a numbered scale on the staff gauges and requiring a manual input on top of the automatically determined value. For example, prompting a user to enter a manually determined value in addition to the automatically determined value could provide another validity check for a measurement. If the manual measurement deviates significantly from the automatic measurement (e.g. >10%), the application could show a popup warning informing the user that at least one of the measurements is incorrect.

Fig. 4.1: Sedimentation on staff gauge (Location 3)

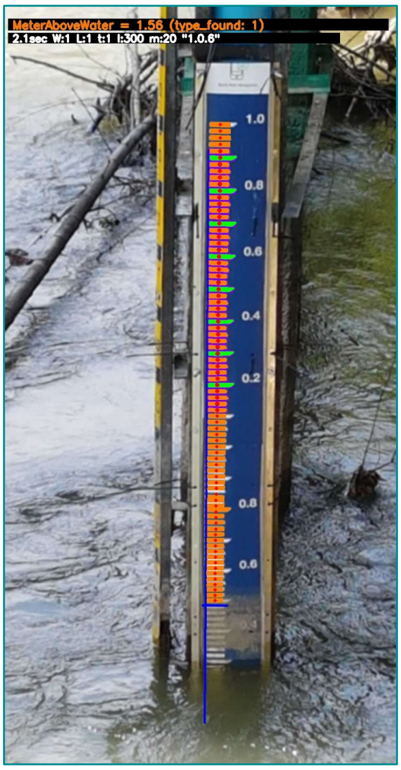

Fig. 4.2: Sedimentation on staff gauge (Location 3)

Fig. 4.3: Incorrect sticker alignment (Location 4)

Fig. 4.4: Incorrect sticker alignment (Location 9)

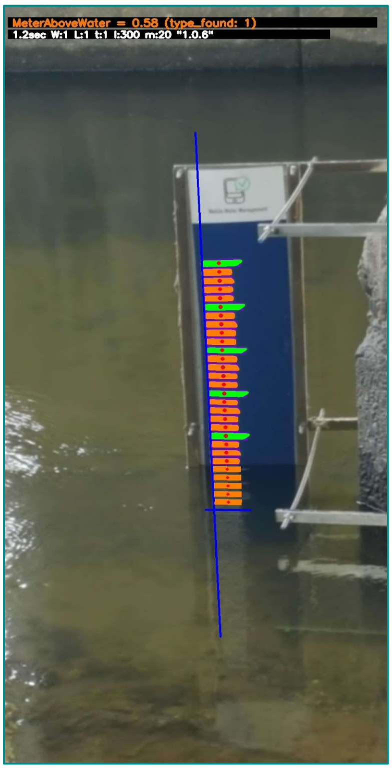

Fig. 4.5: Staff gauge water reflection (Location 6)

Fig. 4.6: Staff gauge water reflection (Location 2)

4.1.2 Data gathered with Mobile Water Management app

In Appendix D1, the data gathered with the MWM app can be found. At the station in Tha Yang (station 4) and at Ban Huai Kwang (station 6), citizen science was applied. At Tha Yang station, a Buddhist monk agreed to voluntarily take measurements of the staff gauge using the MWM application. At Ban Huai Kwang station, an officer of the RID agreed to take the measurements. The monk regularly took pictures, sometimes he forgot or skipped a day or multiple days. The RID officer at location 6 never took a picture for us after asking and explaining how the app works.

The Buddhist monk gathered interesting data to analyse, see Fig. 4.7. He took and accepted pictures without checking the quality of the measurement. This resulted in some questionable data points. Here you can see the need to check the measurements done through the app. After taking away the faulty data, the data seen in Fig. 4.8 resulted.

The figures also show a 5 cm spread sometimes, of measurements performed simultaneously. This spread might be due to waves and/or reflection of the staff gauge in the water. This will be elaborated upon further in section 5.

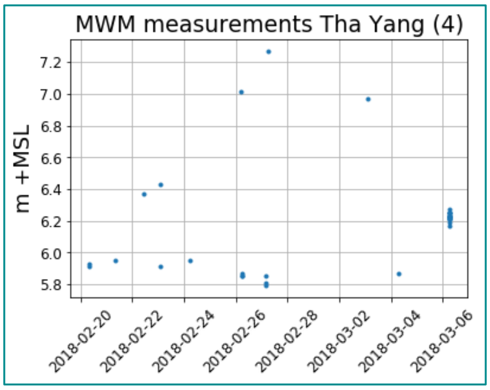

Fig. 4.7: Unchecked data (Location 4)

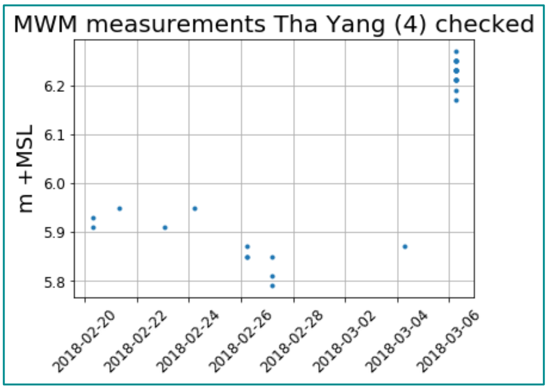

Fig. 4.8: Checked data (Location 4)

4.1.3 Comparison with RID data

The data from the MWM app was compared to the data provided by the RID. The RID data was recorded with a telemetric system. The data from both these sources is plotted in one graph. Difference graphs are added for clarity. All graphs can be found in Appendix D2. In Fig. 4.9 – Fig 4.12 the graphs for Tha Yang (station 4) and Ban Songphinong (station 7) are shown.

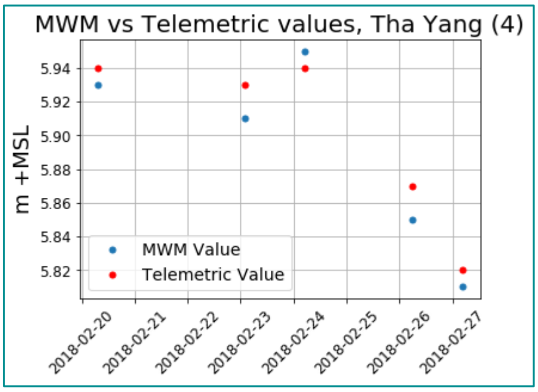

Fig. 4.9: Comparison with RID data (Location 4)

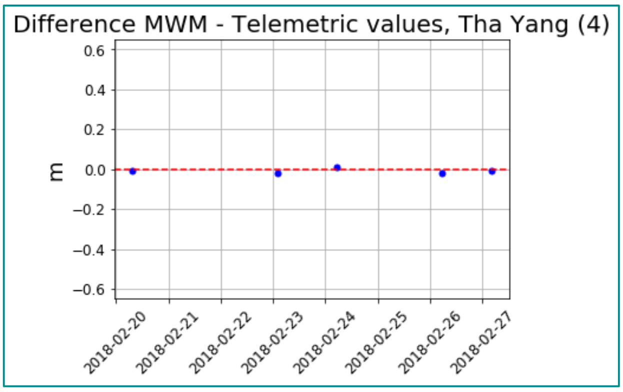

Fig. 4.10: Comparison with RID data, difference (Location 4)

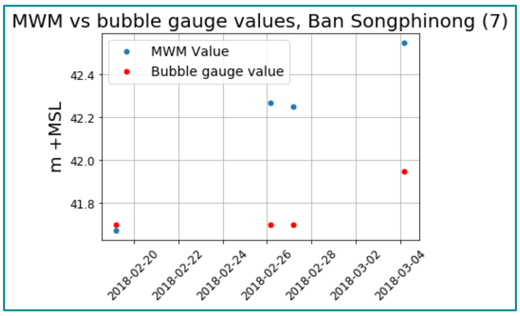

Fig. 4.11: Comparison with RID data (Location 7)

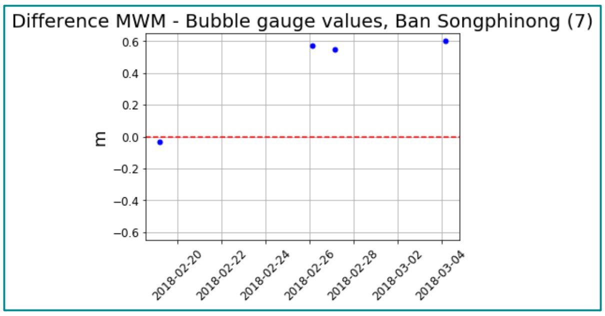

Fig. 4.12: Comparison with RID data, difference (Location 7)

The figures show that at most locations, there is a discrepancy between the MWM staff gauges and the existing telemetric system. The power of the MWM app is that it can be proven that the measurements taken through the app were done correctly by examining the pictures. The consistent errors can be explained with a difference in set-point level in the reference system. However, in most cases the differences increase and decrease in size, which could be explained by irregularities in the telemetering system. We summarized the functioning of the existing system in Table 4.1. The stations marked in green are ok, according to the verification with our data. The stations marked in yellow we suggest to check, because of some (small) irregularities. The stations marked in red show large unknown differences and require a more in-depth check of the collected data.

Even though station 4 only shows small differences in measured water level, when checking the data, it appears that the station doesn't gradually increase or decrease as expected, but there are jumps to different levels, giving a stepped graph (see Fig. 4.13 and 4.14). That is why it is advised to check whether the device is working correctly.

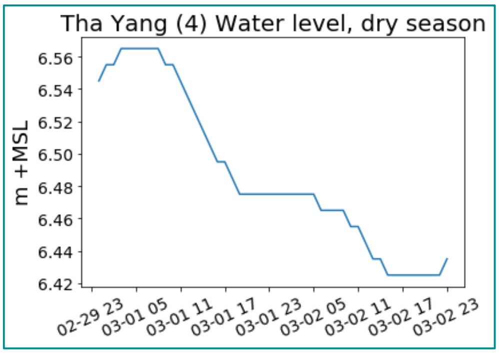

Fig. 4.13: Water level, dry season (Location 4)

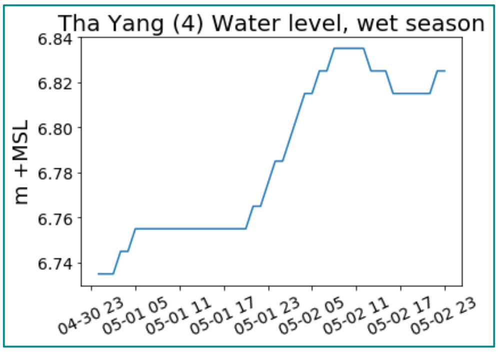

Fig. 4.14: Water level, wet season (Location 4)

Table 4.1: Differences throughout entire system

Station	Minimum difference	Maximum difference
Ban Laem (1)	4 cm	42 cm
Wat Khuntra (2)	1 cm	4 cm
Ban Lat (3)	3 cm	29 cm
Tha Yang (4)	1 cm	2 cm
Phet Dam (5)	0 cm	6 cm
Ban Huai Kwang (6)	1 cm	9 cm
Ban Songphinong (7)	3 cm	60 cm
Kaeng Krachan Dam (8)	553 cm	553 cm
Ban Phrong Khe (9)	7 cm	16 cm

4.1.4 Error analysis of MWM algorithm

To check the accuracy of the MWM method, an error analysis was performed. A lot of measurements were performed at the same time, accepting all values determined by the algorithm. This gives an idea of how the app would function if not properly checked.

This was done for two locations; Phet Dam (5) and Ban Phrong Khe (9). Phet Dam is an ideal location, as it is accessible and consists of a 1m staff gauge. Ban Phrong Khe is the least functional location in this project, as at the location there is no connection with the phone network and a relatively high amount of faulty measurements occur. This is possibly due to the incorrect application of the sticker during construction. The possible causes of failure will be discussed further in the discussion.

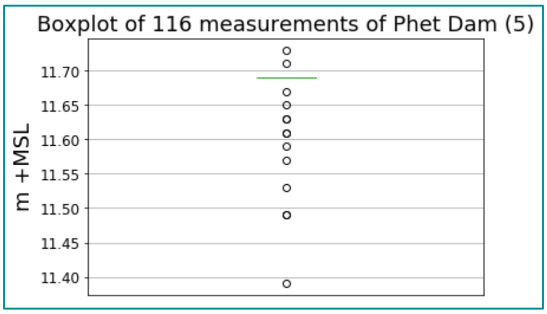

Fig. 4.15: Accuracy of measurements (Location 5)

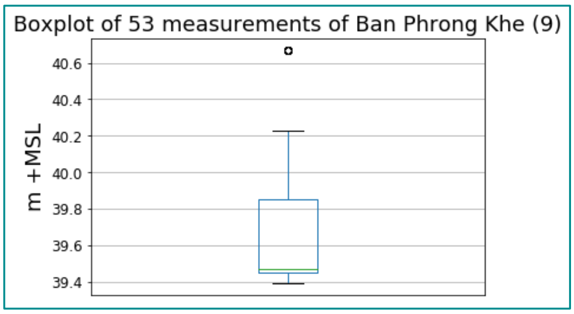

Fig. 4.16: Accuracy of measurements (Location 9)

In Fig. 4.15 and Fig. 4.16, the boxplots of the measurements for both sites can be found. The following data was recorded:

Location 5: Phet dam
Amount of times app did not recognize staff gauge: 0 out of 116
Standard deviation of measurements: 4.4 cm

Spread:	11.69 m – 102 times	11.63 m – 2 times
	11.61 m – 2 times	11.49 m – 2 times
	11.73 m – 1 time	11.71 m – 1 time
	11.67 m – 1 time	11.65 m – 1 time
	11.59 m – 1 time	11.57 m – 1 time
	11.53 m – 1 time	11.39 m – 1 time

Location 9: Ban Phrong Khe
Amount of times app did not recognize staff gauge: 9 out of 53
Standard deviation of measurements: 48 cm

Spread:	39.47 m – 15 times	40.67 m – 8 times
	39.43 m – 7 times	39.45 m – 5 times
	39.85 m – 4 times	39.71 m – 2 times
	39.39 m – 1 time	40.23 m – 1 time
	40,21 m – 1 time	

These results show that the need for human verification of the measurement done by the MWM app is necessary for a reliable dataset. The standard deviation of 4.4 cm in ideal conditions is acceptable, however the 48 cm is unacceptable to have present in your dataset.

4.2 Akvo app

4.2.1 General results and remarks

Several issues and nuisances were observed using the Akvo app during the testing period. These are as follows:

- The existing E. coli test is intended for use with drinking water rather than surface water. Because of this, the E. coli test is too sensitive for use with surface water. To solve this issue, the surface water samples were diluted by a factor 10.
- It is impossible to close the survey before the E. coli test is finished, as the E. coli test requires a waiting period of 48 h. Therefore, you run the risk of losing the data of one entire survey before finishing the E. coli test.
- The Quantofix phosphate test strips returns high phosphate levels in the range of 8-20 mg/l for river water. After further inspection, the phosphate strips were tested using demi water and store-bought drinking water, which still resulted phosphate levels in the range of 2-16 mg/l. Clearly, phosphate should be entirely absent in demi water; this shows that the Quantofix phosphate strips that were used for testing currently do not work properly.
- For some phones the app is not able to correctly register the colour card. This issue was circumvented by switching to a different Android phone, but it can be a big nuisance when a different Android phone isn’t close by.
- There are issues with merging databases from different surveys; these issues occur when merging surveys that have data obtained using Akvo measurement equipment. Only the data obtained using Akvo measurement equipment fail to merge, other data is able to merge.
- After editing a survey, the version number is not automatically updated with a new number. As a result, the edited survey cannot be published. Currently, a workaround is: after publishing the survey, refresh the page first before making further changes. Then the version number will be updated and allows for publishing an edited survey.
- In the survey, a group name always starts with a capital letter; this is annoying when a group named, for example, “pH” is present in the database.
- Existing surveys can be removed from the website, but this does not remove the surveys from the mobile phone. Furthermore, it is currently impossible to remove a single survey from a mobile phone; either all surveys need to be removed at once, or none can be removed.

4.2.2 Gathered data with AKVO app

In Appendix F, all the data gathered with the AKVO app can be found. It concerns the following parameters: DO, EC (2 devices), Salinity, pH (2 devices), temperature, iron, nitrate, nitrite, phosphate, E. Coli and turbidity. The most remarkable results are displayed below and discussed later on in this report.

In Fig. 4.17 the measured E. coli is shown. The present E. coli has been measured at Phet Dam (location 1), Tha Yang (location 2), Ban Lat (location 3), Phetchaburi Provincial Governor’s house (location 5), Wat Mai Bridge (location 9) and Wat Bang Lum Pu (location 11). The measurements were taken for three weeks.

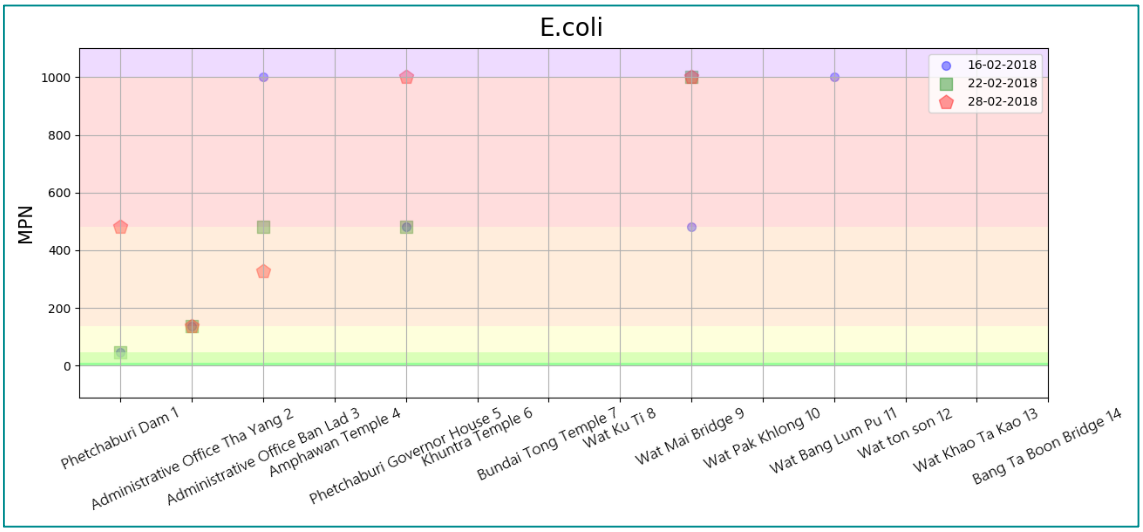

Fig. 4.17: E. coli measurements

It can be seen that as you go downstream, the amount of E. coli present in the water increases. This coincides with the present settlements that are along the river. The graph has six colour bands which indicate the safety for human use whether for recreation water or application for irrigation. The colours are explained in the table here below. Recreation water risk is based on EPA Recreational Water Quality Criteria and for irrigation it is based on US FDA Regulation. Compliant means the water quality is within the standard and can be used for irrigation ("Compartment Test Bag", n.d.).

Colour band	Range	Recreation water risk	Irrigation water quality
Deep green	0 < 10	Very low risk	Compliant
Light green	10 < 47	Low risk	Compliant
Yellow	47 < 136	Higher risk	Likely compliant
Orange	136 < 483	Higher risk	Non-compliant
Red	483 < 1000	Very high risk	Non-compliant
Purple	>= 1000 (outside measurement range)	Very high risk	Non-compliant

Fig. 4.18 shows the taken nitrate measurements. Generally, nitrate is of no issue in the river. The concentration stays within an acceptable level throughout the river. It is within the Thai standard (Notification of the National Environment Board, 1994) of 5 mg/l Nitrate.

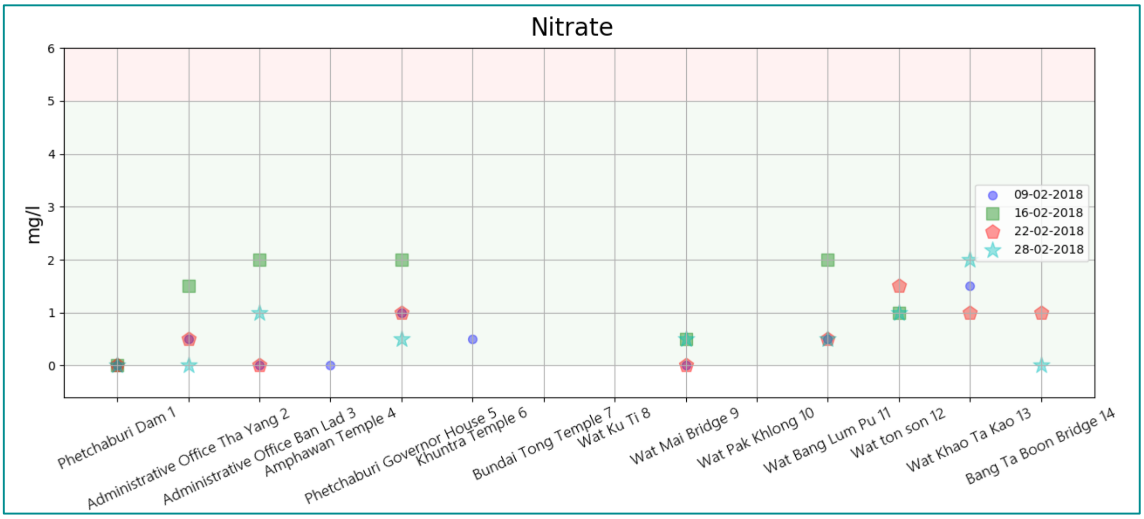

Fig. 4.18: Nitrate measurements

The oxygen concentration is above 2 mg/l at any time as can be seen from the measurement results in Fig. 4.19. The oxygen concentrations are measured in percentages and converted into mg/l manually using conversion tables (Fondriest Environmental, 2013). There is one moment in Wat Ton Son (location 12) were the oxygen concentration is getting close to critical value. In general, the Phetchaburi river fits into the second class for fishery and recreation (yellow band). These results show a same pattern as the two years of oxygen measurements from RID, see Appendix E1. Here the weekly RID water quality data of the last two years was analysed for comparison with the data measured using the Akvo app. With this amount of data, the variation in water quality per location can be visualized by means of a boxplot. Since the river splits up after location 10, (see appendix C: figure C1) two graphs are made to create a longitudinal profile of the water quality.

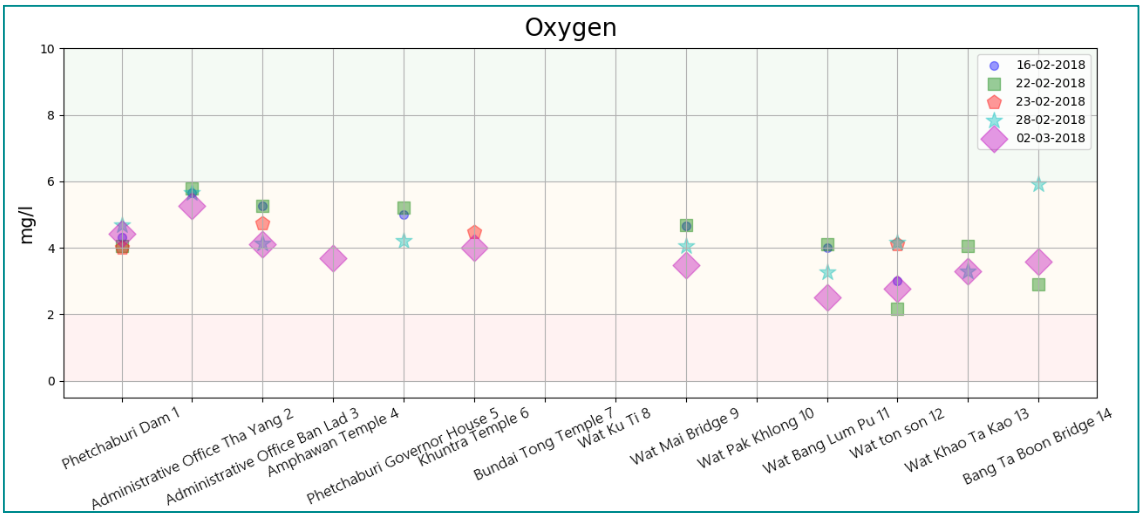

Fig. 4.19: Oxygen measurements, TU Delft equipment

In general, the results of the conductivity measurements show increasing values in the downstream direction of the Phetch river, as can be seen in the graphs below. One can also see that downstream of point 9 (Wat Mai bridge) EC values fluctuate significantly between different measuring days. In all the EC graphs the RID EC standard of 2000 µS/cm is indicated to use as a reference and to if the water still can be used for irrigation.

The conductivity measured with Akvo device shows similar results to EC TU Delft, see Fig. 4.20. A tremendously high EC is measured at Wat Bang Lum Pu (location 11) and Bang Ta Boon Bridge (location 14). This is due to the fact that the Akvo EC meter range goes up to 12500 µS/cm. Exceeding this value will yield inaccurate results. However, the Akvo EC meter results are nearly identical to those from EC TU Delft below 12500 µS/cm. It is so identical that it doesn't give additional information. Fig. 4.22 shows how similar the results of both measurement devices are. For this reason, only the TU Delft EC meter is utilized for RID measurement comparison, as it also has a greater range to measure high EC. More detailed comparison between the Akvo EC meter and TU Delft EC meter can be found in Appendix F.

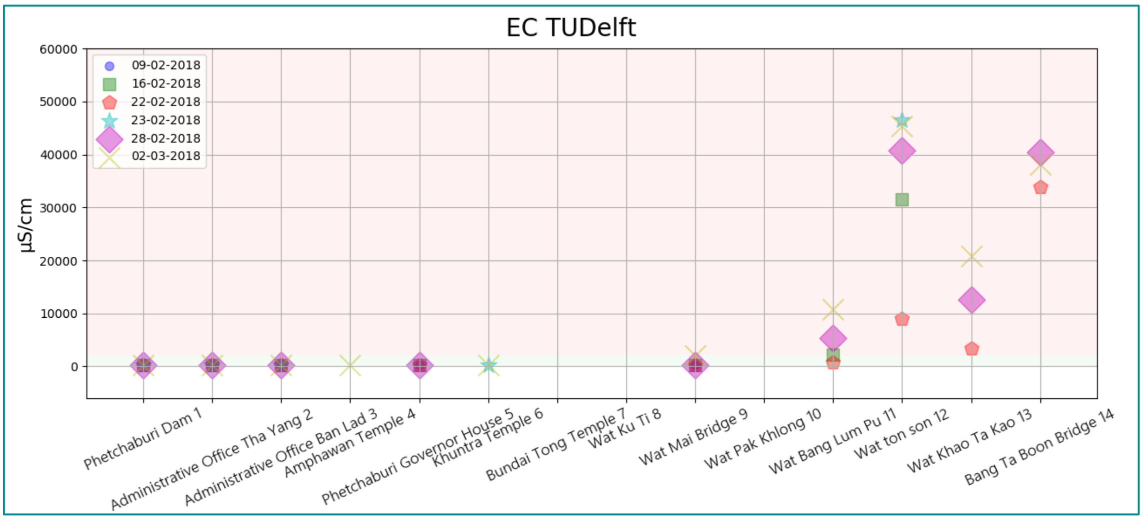

Fig. 4.20: EC measurements, TU Delft equipment

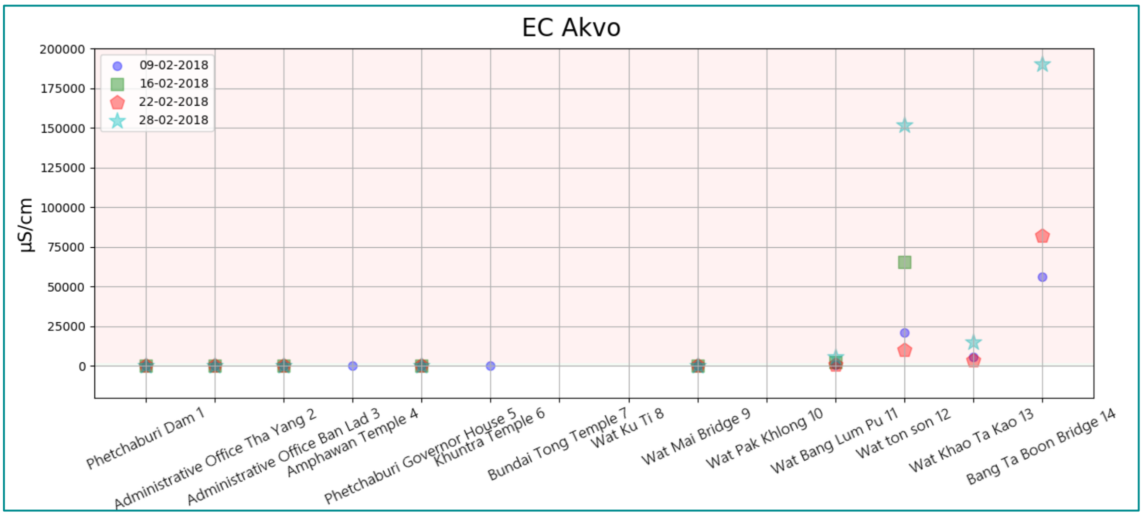

Fig. 4.21: EC measurements, Akvo equipment

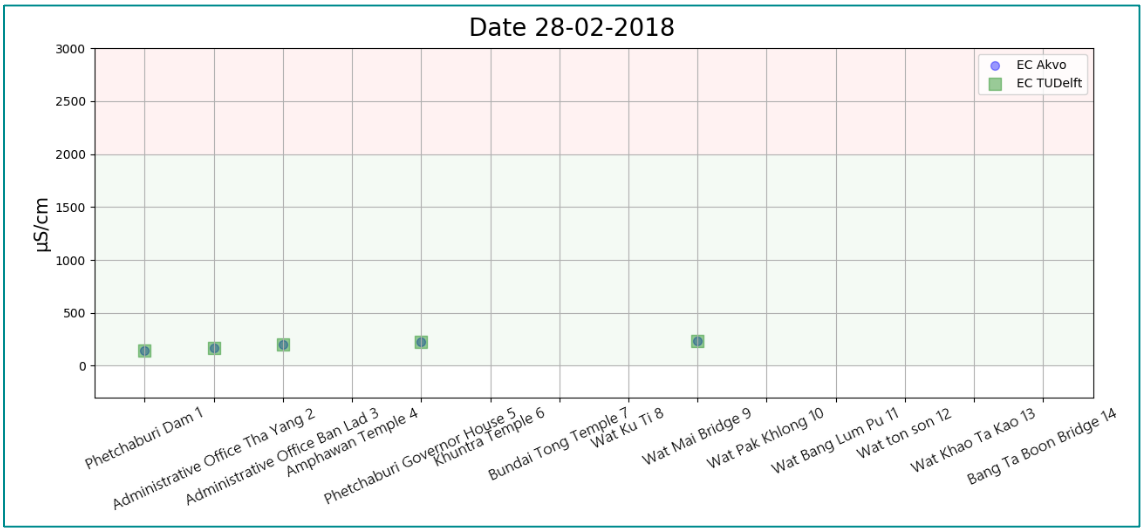

Fig. 4.22: EC measurements, comparison between TU Delft and Akvo equipment

Besides the standards for EC, the RID also utilizes standards for salinity. To check whether the performed measurements in this research also meet the RID salinity standards, the EC values are converted to salinity using a conversion factor that the RID uses as well. Fig. 4.23 shows the salinity derived from the EC TU Delft measurements. A more zoomed in version of this graph can be found in appendix F.

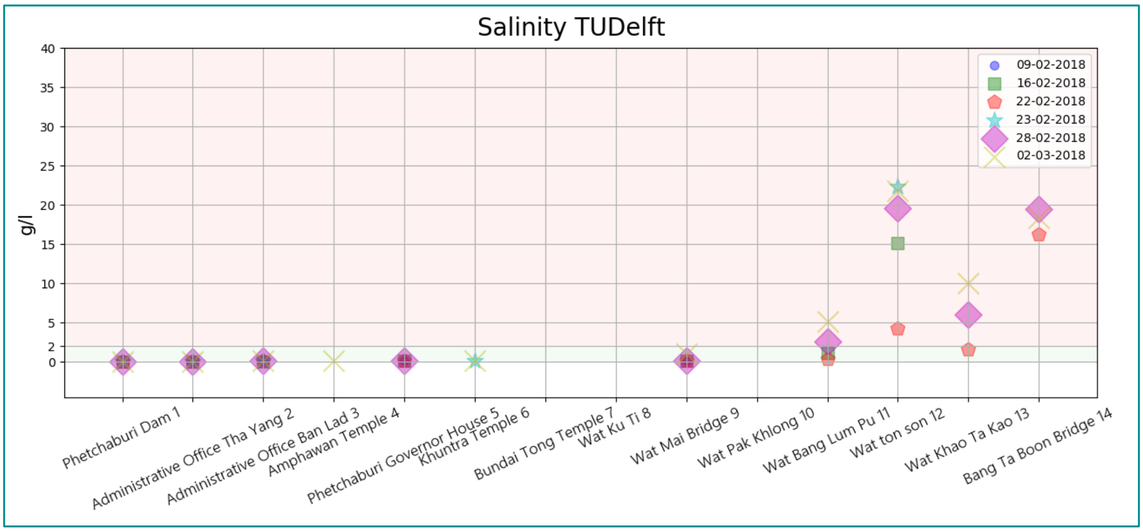

Fig. 4.23: Salinity measurements, TU Delft equipment

The pH measurements done with the TU Delft device are shown in Fig. 4.24. The pH of the river water stays within acceptable limits all throughout the river.

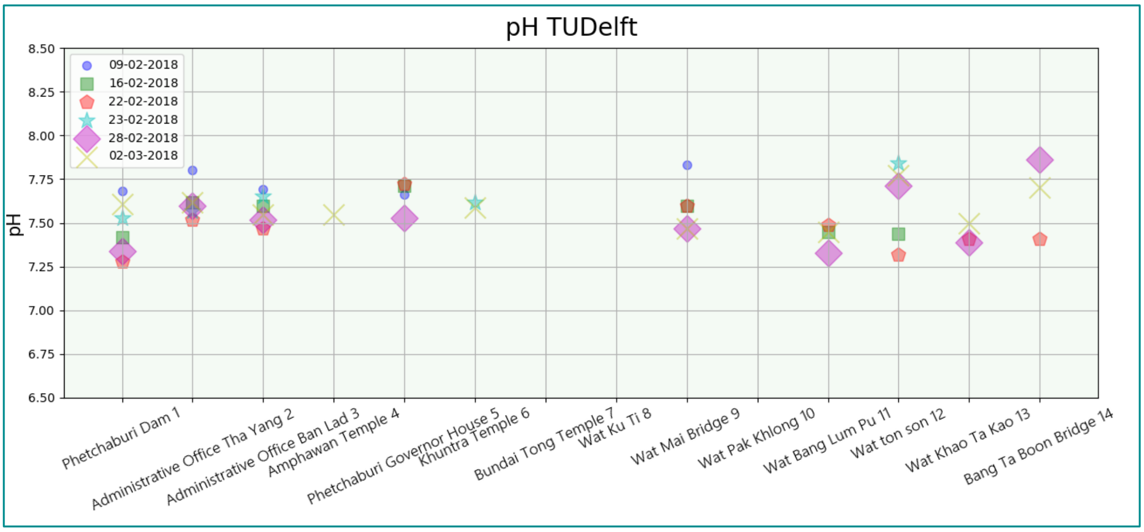

Fig. 4.24: pH measurements, TU Delft equipment

The turbidity measurements taken with the AKVO app can be seen in Fig. 4.25 Turbidity increases as you go downstream of the river.

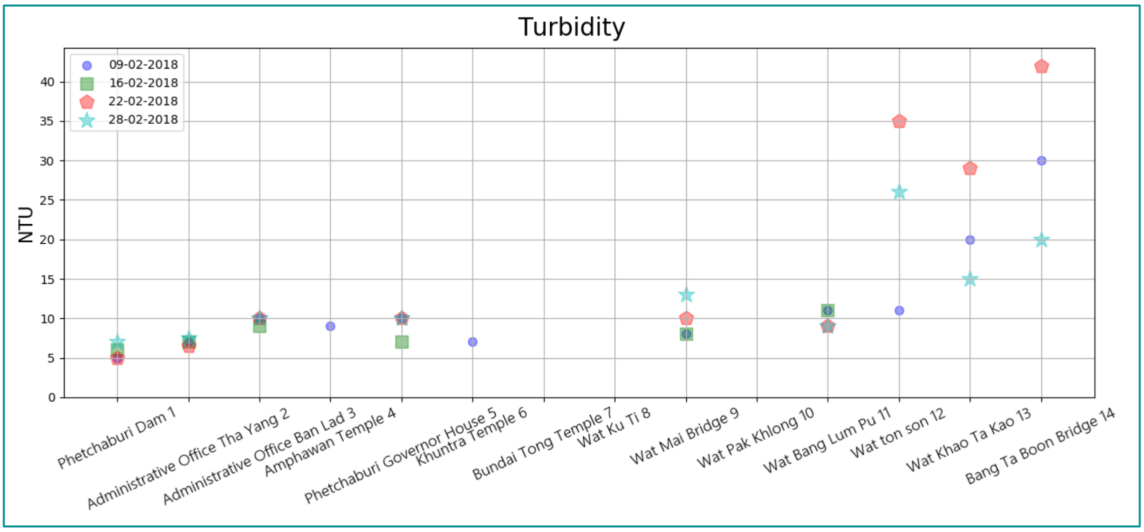

Fig. 4.25: Turbidity measurements, Akvo equipment

The phosphate measurements can be seen in Appendix F. The results are fairly high with concentration often above 8 mg/l. These results are suspicious and will be discussed in the discussion.

The measured iron concentration in the river is low at all measuring sites and does not give any indication of pollution. Since iron is an indicator for pollution with other metals, no further research on this topic is necessary. The exact results of the iron measurements can be found in Appendix F.

4.2.3 Comparison with RID measurements

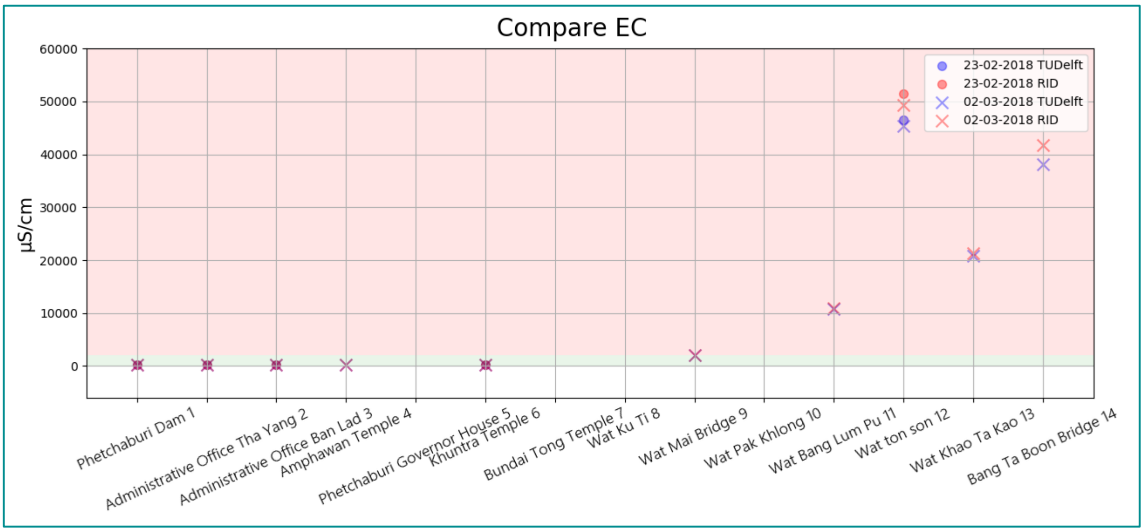

Fig. 4.26: EC measurements, comparison between TU Delft and Akvo equipment

Looking at Fig. 4.26, when comparing the EC data to the data gathered by the RID it is clear that both are similar. Only with higher EC values the difference starts to show.

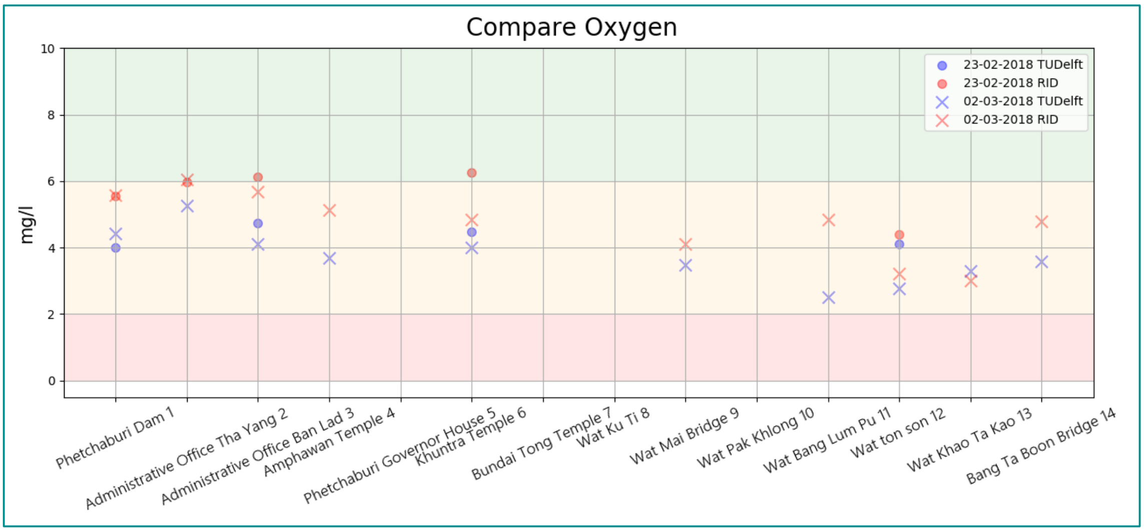

Fig. 4.27: Oxygen measurements, comparison between TU Delft and Akvo equipment

As can be seen in Fig. 4.27 the measurements done by the RID's oxygen meter are consistently about 1 mg/l higher. It is likely that the values of the RID data for dissolved oxygen over 2 years as shown in Appendix E1 contain the same error.

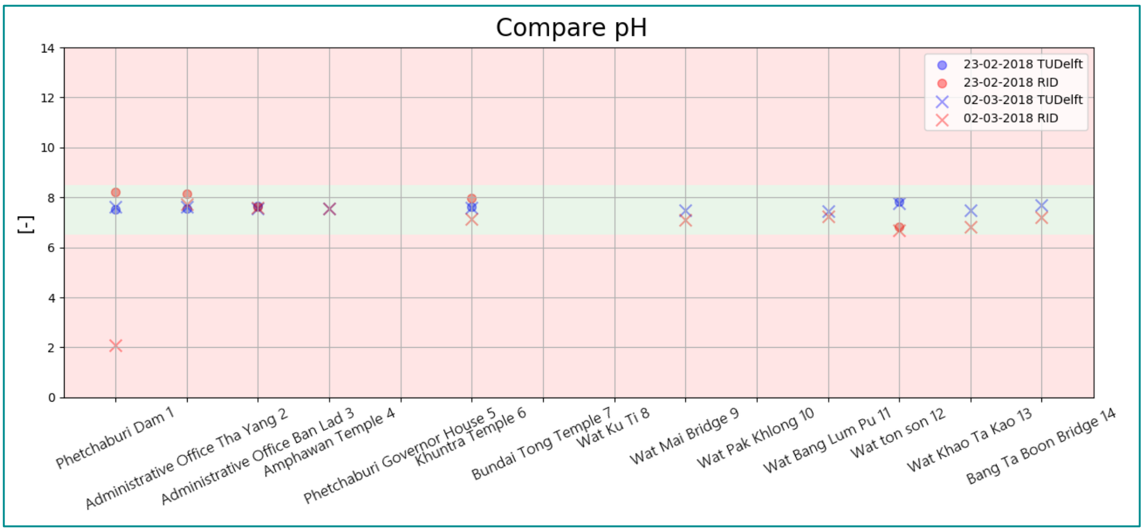

Fig. 4.28: pH measurements, comparison between TU Delft and Akvo equipment

In general, the gathered pH data corresponds well with the data gathered by the RID. There was one instance where pH determined by the RID was significantly lower; this measurement was done at location 1 on 02-03-2018. It turned out that this measurement is incorrect due to a typing error. Otherwise, the measured pH is within acceptable limits throughout all measurement locations.

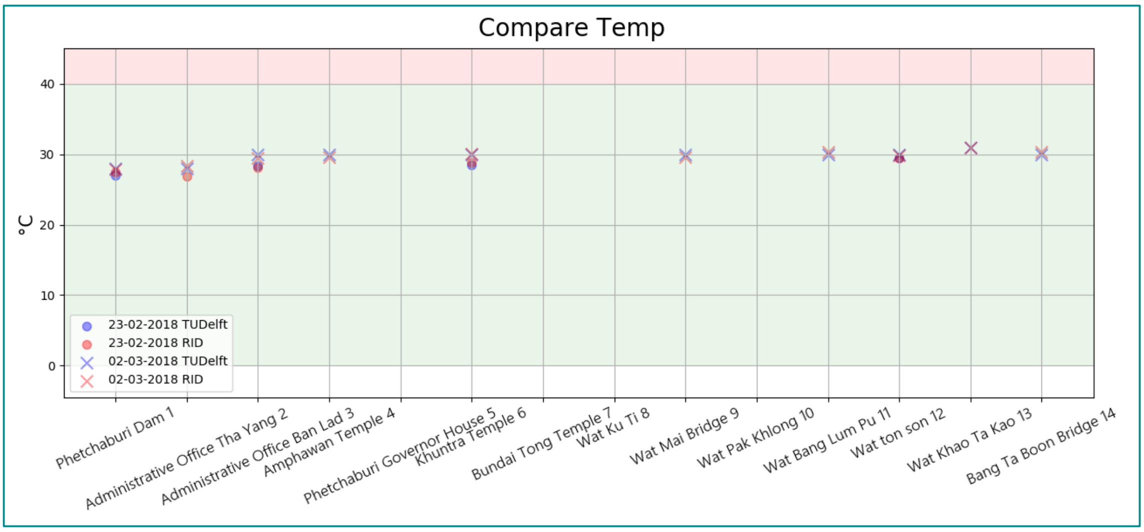

Fig. 4.29: Temperature measurements, comparison between TU Delft and Akvo equipment

The temperature data collected by the RID corresponds well with our collected data, and shows acceptable values for all the measurement stations.

4.2.4 AKVO pH validation

The Hach pH strips did not work as intended. Only 5 results were obtained out of 32 measurements. Due to underwhelming amount of results, no further analysis was done on this strip test.

Correlation between the pH measurement device and four parameters (carbonate, EC from TU Delft meter, temperature and turbidity) are calculated and displayed in Table 4.2. The correlation is between 1 and -1 including those two values. Value of 1 states a perfect positive linear relationship and -1 stating a perfect negative linear relationship. Value around zero means there is no linear relationship.

The Merck strip test has a moderate positive linear relationship with all parameters. The Akvo and TU Delft meter is less sensitive to those and sometimes showing negative linear relationship unlike the Merck strip test.

Table 4.2: Correlation between measurement devices and several parameters

Parameter	pH Merck	pH Akvo	pH TU Delft
Carbonate	0.422	-0.35	-0.26
EC TU Delft	0.576	0.026	0.298
Temperature	0.501	0	-0.19
Turbidity	0.539	-0.41	-0.21

5. Discussion and Conclusion

5.1 MWM app

5.1.1 Measurements with MWM app

The MWM app showed some spread in its measurements when taken at the same time, where it can be assumed that the actual water level did not change. These spreads can be due to small waves and reflection in the water. The algorithm didn't always properly recognize the water level and sometimes saw the reflection as part of the staff gauge when the picture was taken from right in front of the staff gauge, see Fig. 5.1.

When the stickers weren't perfectly straight on the staff gauge, the app sometimes saw the water-boundary too high on the staff gauge. Cutting it off mid-way. We suspect this is because the algorithm wants to put a straight (blue) line on the left side of the stripes. When the blue line intercepts one of the stripes, or the metal bar on the left, it often recognized this as water-boundary, see Fig. 5.2. There were also cases that the app could not recognize a staff gauge at all if the space between the metal bar and the stripes was not big enough. This prevented the app from properly putting a straight line next to the stripes in the blue part of the sticker, making it impossible to recognize a staff gauge, see Fig. 5.3.

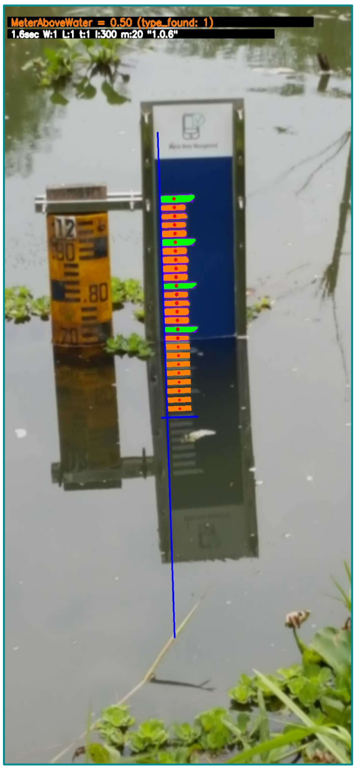

Fig. 5.1: Water reflection

Fig. 5.2: Incorrect sticker alignment

Fig. 5.3: Staff gauge not recognized

5.1.2 Comparison with RID data

When comparing our data to the telemetric data, we identified some differences and possible irregularities in the RID's telemetering system. To be sure our data was correct, the pictures were downloaded from the MWM dashboard to see if the measurements were done correctly. This method of visual verification decreases the potential error in the data. This is also the main reason why Dutch water boards use the MWM app: to check whether their automatic stations are still functioning correctly, as that data is much harder to verify.

When looking at the existing telemetric data and our MWM data at Ban Laem (location 1), differences of up to 42 cm were determined. However, it still cannot be fully concluded where the differences between the data sets originate from. This is because at this location, there is quite some boat-traffic. The waves these boats create are quite significant, and can be the cause of the extreme differences seen in the data. It is advised to double-check this, to be sure the system is working correctly.

At What Khuntra (location 2), the RID's data is almost similar to our data. The slight differences that was found could be because slight differences in set-point height (order of cm's). It could also fall within the measurement error of either MWM's method or the telemetering system.

At the Ban Lat (location 3) station, it is advised to check the telemetering system. This is because of the change in difference between our measurements and the RID's measurements. Sometimes MWM records a higher value, and sometimes RID records a higher value. These inconsistent errors are unlikely to stem from a difference in set-point height, as this error would be consistent. The source of the differences is difficult to determine. However, the MWM data is visually verifiable whereas the telemetric data is not.

The Tha Yang (location 4) station shows the least difference in water level with our measurements. This would suggest the station is working fine. However, when looking at the raw data of the RID, the shape seems to be off. It shows a stepwise measurement of the water level, which is different from the data given by the other stations in Phetchaburi. This could be because it is an older measuring device with a lower resolution. This could not be checked at this point during the study. It is recommended that this station is inspected by either the RID or KU for possible signs of malfunctioning or damage.

At Phet Dam (location 5), the difference between the MWM data and the telemetric data was minimal.

At the station Ban Huai Kwang (location 6), differences of up to 9 cm are seen. However, these differences are quite consistent. This is likely caused by a slight difference in set-point height.

At Ban Songphinong (location 7), the difference is small at first. However, it seems that the automatic system is not recording smaller (up to 50 cm) changes in the water level. The station indicates a constant level, where the staff gauge shows an increase in water level. When the MWM data shows a water-level increase of almost 100 cm, the automatic system shows an increase of about 20 cm. It is recommended to investigate these differences in the data.

The collected MWM data at Kaeng Krachan dam (location 8) is very scarce. Only one proper measurement could be performed with the MWM app. This is because on the first visit after installing the staff gauge, the water level had already dropped to below the staff gauge range and remained so for the remainder of the project. However, this one measurement shows a 553 cm difference. This is suspected to be due to a difference in set-point height, but this cannot be validated because of a lack of further data. The MWM staff gauge was installed according to the physical staff gauges present. Here it is also advised to redetermine the height in meters above mean sea level to see which of the measurement devices is correct. No conclusion can be made about the differences between the systems, since it is impossible to see whether the error is consistent.

The automatic system at Ban Phrong Khe (location 9), the tributary, shows a consistently lower water level of about 7 cm. Sometimes, the difference increases to a maximum of 16 cm. This can be explained due to a small man-made dam in between the MWM staff gauge and the automatic system. The water at the automatic station is flowing at a different phase than at the MWM staff gauge. This could explain the consistent error of 7 cm. However, this could also be caused by a difference in set-point level. The jump in difference from 7 cm to 16 cm could be due to a small irregularity in either the automatic system or the MWM app, however the MWM data was visually verified for validation. We also found a hole in the pipe of the automatic system. As we are unfamiliar with the workings of the telemetric system, we do not know if this is relevant. This is why we advise to check the functioning of the system.

5.1.3 Error analysis of MWM algorithm

When performing the error analysis at Phet Dam, a spread was found in the measurements. These were mostly caused by the reflection of the staff gauge in the water. This only occurred when the picture was taken right in front of the staff gauge, perfectly aligning the staff gauge with its reflection. In general, the results here are good, with a standard deviation of 4.4 cm. But the highest outlier showed a difference of 30 cm, confirming the need for human verification of the measurement.

The error analysis at Ban Phrong Khe was less successful. A standard deviation of 48 cm was found, which is unacceptable. This again shows the need for human verification of the measurement. This would make sure that these faulty measurements would never be accepted in the dataset. The Ban Phrong Khe staff gauge was the least ideal staff gauge of this project, with the most deviation in the sticker that was placed on the staff gauge. The staff gauge was 2m tall and was made with 2 stickers of 1 m. This made it extra hard to perfectly align the sticker. The lack of reception at this location also makes it hard for human verification of the measurement, since the photo could only be sent to MWM when reception was restored. This would also be the moment when one could see if the algorithm had made a mistake. A solution to this would be to have the algorithm be available on the apps offline, and not only on the server of MWM.

A consolation to the fact that our 2 m staff gauge is showing difficulties is that in the Netherlands, a 5m staff gauge is functional. This shows the algorithm is able to perform measurements on a larger scale. If the 2 m staff gauge is made by a machine, or a more experienced person, it would most probably show a smaller deviation in the measurements.

5.2 AKVO App

5.2.1 Gathered data with AKVO app

The measured E. coli shows an increase when going downstream. When looking at the land-use map (Appendix C) it can be seen that after human settlements, the E. coli present in the water increases. This can be explained with the fact that untreated wastewater is being discharged in the rivers. After every human settlement, the total amount discharged increases, making the river more polluted. At location 2 Administrative Office Tha Yang, the E. coli MPN value is consistently in the orange range. It means it has a high risk when it is used for recreation water and it is also not recommended to use for irrigation. This whole test seems to suggest that water after location 2 shouldn't be used for recreation or irrigation (non-compliant). Location 1 at the Phetch Dam is the cleanest of all location. Though, there is one moment in which the E. coli MPN value reached the "High risk" category and it is non-Compliant. This may be concerning as this water is used for irrigation. To get an understanding if this value is an outlier or not, more E. coli test should be done.

Nitrate levels show an acceptable level throughout the river. This indicates that the farmers among the river do not use an excessive amount of fertiliser for their crops and that the total amount of nitrates discharged by wastewater is still acceptable during the period of measurement. However, the measurements for this research are only done in a specific period of the year. Previous research shows that high nitrate concentrations can occur in dry periods during extreme dry years or during the first flush after a long dry period (Voravong et al., 2014). This pollution is likely caused by the runoff of pig farms and fish/shrimp farms and takes place mainly in the coastal zones near Bang Ta Boon and Baan Laem. Monitoring of nitrate concentration in these areas in different seasons can still be useful for example with a monthly interval. High nitrate concentrations can have negative consequences for human health, the environment, biodiversity of the area and even the agricultural production itself.

The Thai surface water quality standard for the dissolved oxygen concentration is 4 mg/l for irrigation (agriculture) and 6 mg/l for fishery and recreational purposes. The RID keeps a standard of 2 mg/l DO for the Phetch river. The DO concentration measured with the TU Delft equipment remains above the 2 mg/l, yet does not always reach the 4 mg/l standard. The Phetch river is also used as a source for drinking water. However, water with a DO concentration of less than 4 mg/l is not suitable to use as a source for conventional drinking water production according to the Thai standard.

Salinity levels and EC are within the standards for most parts of the river. The salinity and EC starts to increase from Wat Mai Bridge (location 9) as they approach closer to the river mouth. The standard in terms of EC has been exceeded here once. Downstream of Wat Mai Bridge (location 9) shows very high salinity and EC levels. A high fluctuation in these parameters is observed. The measured salinity in this project shows close resemblance with the 2 years' salinity measurement from RID as can be seen in Appendix E2 for the dry period.

The pH of the river seems to be stable, and within acceptable levels. This indicates that there are not a lot of chemicals being released in the river by, for example, industry.

Turbidity on its own doesn't tell immediate what problems there are in the water. It is an indication of how much particles are or in other words how clear the water is. The measured turbidity shows an increase after passing Administrative Office Tha Yang (location 2). That may be explained by human activities as there is a village. Further downstream of Wat Bang Lum Pu (location 11), the turbidity is much higher. This might be explained with the farms situated in that area.

Phosphate measurements seem to be inaccurate and show a random value. The values received are very high. The measurement method was controlled with tap- and demi water, and the received phosphate concentration was still very high. Based on this, we concluded that the used method for measuring phosphate concentration is highly inaccurate and we don't recommend using this method yet. Until more is known about the cause of this problem and how to avoid it. This is currently under evaluation.

As already discussed, iron is not indicated as a serious problem for the river water quality in Phetchaburi.

5.2.2 Comparison with RID data

When comparing the gathered EC data through the AKVO app with the data collected by RID, it can be seen that the values closely coincide. With higher values, the difference becomes higher. This could indicate a need to re-calibrate the sensors.

The dissolved oxygen concentration measured by the TU Delft equipment is consistently 1 mg/l lower than the DO measured by the RID. This offset is quite significant and should be reason to re-calibrate both sensors. It was mentioned that the RID had replaced their old DO sensors with a new model, which unfortunately broke and they were forced to switch back to the old model. As mentioned in 5.1.1, the Thai DO-standard for surface water is 4 mg/l for irrigation and drinking water. Downstream from the Phet dam these standards are not always met. When going further downstream, the RID measured DO concentration nearly reduces to 2 mg/l. This is still above the RID standard of 2 mg/l. However, if the offset between the TU Delft equipment and the RID equipment is caused due to calibration issues of the RID sensor, this could mean that in fact the DO concentrations are less than 2 mg/l.

The pH data measured show little difference. The RID does not perform calibration of the device, so larger deviations were expected. It is still recommended to calibrate the pH device just before doing the field work, but nonetheless the data is more similar than expected.

The measured temperatures were practically identical for both RID data as well as our data.

5.2.3 Akvo pH validation

The Merck pH strip test shows high positive correlation with the four considered parameters (carbonate, EC from TU Delft measurement device, temperature and turbidity). Unlike this strip test, the electronic pH measurement device from TU Delft and Akvo shows a negative correlation with carbonate and turbidity. The correlation with EC and temperature is smaller than the strip test. It seems like the strip test has a different correlation than the electronic pH measurement devices as his counterpart. Thus, yielding a much different pH result.

6. Recommendations and further research

During this project, several final recommendations and (research) opportunities, that either did not fit within the scope of this project or did not fit within the available time frame, were found.

6.1 Recommendations for Thailand

The recommendations for water monitoring in the whole of Thailand are found below.

6.1.1 Manual staff gauges

The Mobile Water Management (MWM) system could be (easily) applied to the manual staff gauge locations. This would have multiple advantages:

- Automatic data processing and storage
- Minimizing human errors
- Certainty that a measurement is done and at the right time and location
- Checking measurements from the office in real time

6.1.2 Telemetering system

The MWM system could be used to complement the telemetering system as follows:

- Validation of the telemetric water-level data. This is how the MWM system is being applied in the Netherlands as well.
- The MWM system allows for cheap densification and extension of the current network.
- It can be used as a backup system when an automatic station breaks down.

6.1.3 Water quality network

The AKVO app gives some opportunities for Thailand:

- It can be used for easy and quick water quality indication
- Automatic data processing and storage
- Easy and cheap to create or expand upon a water quality monitoring system
- Adding extra parameters for monitoring can be done easily
- Minimizing human errors
- In-the-field measurements can be done with high accuracy;
- Which opens the way for replacing lab-testing

6.1.4 Water quality classification

It was found that the river-classification of the RID is not strictly applied. A classification of 4 was given to the Phetch river, which means it is only used for industry water. However, the river is also being used for irrigation water (class 3) and for fishery (class 2). The lower the class, the stricter the standards should be. A proper investigation of the use of the rivers is needed to make sure these classifications are correctly applied.

6.1.5 Water quality standards

At the moment, salinity and TDS are calculated with a conversion factor of the EC. The only property of the water that is being measured is EC, but three parameters are being determined by it. Doing this is based on assumptions of the relationship between TDS, salinity, temperature and EC. However, the standards applied to surface water do not follow the same relationship. An EC of 2000 μS/cm (which is the standard) would come down to a salinity of 1 g/l (at a temperature of 20 ℃). But the standard for salinity is set on 2 g/l. This results that by measuring an EC that is higher than the allowed standard, the salinity could still fall within the standards, while only EC is measured. A similar issue occurs with TDS; a relationship between EC and TDS is assumed, and EC is converted to TDS. However, TDS is never actually measured in the field. It is recommended to use EC as standard, instead of salinity and TDS. Since EC is the actual parameter being measured in the field, and salinity or TDS standards are estimated with it.

6.1.6 Sharing data

During this project, it was found that multiple (governmental) bodies measure the same parameters in the river, often at the same locations. However, they do not communicate or share their gathered data. Using a digital and online data storage system makes sharing data a lot easier, and can reduce the costs for Thai society as a whole.

6.2 Phetchaburi catchment

After researching the Phetchaburi catchment and analysing the problems that are occurring, some recommendations are made for the Phetchaburi area in this section.

6.2.1 Rainfall-Runoff model

To know what discharge and water level can be expected, a rainfall-runoff model is needed in the area. This model can then be used as an early flood warning system, making it possible to minimize damage done by floods. Preventive measures can then be taken like making it possible to adjust dam discharge in time to prevent or minimize the occurrence of flooding.

For a successful rainfall-runoff model, we recommend to pay extra attention to the following:

- A continuous discharge dataset is preferred for accuracy, the hydropower station at Kaeng Krachan dam could be of help with this.
- Rainfall measurements are needed to be able to have an input for the model. At least one to two hydrological years of rainfall data is required to calibrate and validate the rainfall-runoff model properly.
- It is important to validate water-level measurements, to have a reliable dataset for calibration of the model, and to validate the model afterwards.

6.2.2 Salt intrusion

The Phetchaburi province has a lot of different types of agriculture. Some of it relies on salt water while others rely on freshwater. It was found that the boundary between fresh and saline water is a problem area for farmers. Due to a high variation in river discharge the salt intrusion length differs a lot, causing many problems for the farmers. About twice a day there is a significant additional discharge from the dam, disrupting a standard approach to tidal influence data analysis. This shifting boundary makes it hard for farmers to get the water quality they need and count on. Investigating the salt intrusion at different discharges and different tidal stages is necessary to tackle this problem. To do this, the following is needed:

- Investigate the tidal excursion by measuring the flow speed and water level throughout the full tide. This will make it possible to calculate the parameters needed for the tidal influence on the river.
- The discharge of the river is needed, before the tide has an influence. This should be done at Phet Dam, since it cannot be said for sure whether the Tha Yang station is outside of the tidal influenced area.
- EC measurements are needed along the river to measure how far the salt intrudes into the river, and in what concentration.
- Analyse the area to get a clear picture of the water quality requirements of the farms.

6.2.3 Discharge management scheme

In order to minimize the difference in salt intrusion length during the tides and between dry and wet season, a discharge management scheme is needed.
Timing the discharge with the tides would be an effective way to fight the different salt intrusion lengths during high- and low-tide. This is a way of discharge management that requires an almost constant adjustment of the discharge at Phet Dam.
Another way to give farmers in the area more certainty of the water quality is by strictly applying a minimum and maximum discharge, based on salt intrusion length. This will result in sweet and salt water boundaries, where farmers know not to take in water.

Kasetsart University owns an Acoustic Doppler Current Profiler (ADCP) that can help with data collection. The ADCP was configured and tested successfully. Since compass calibration was not performed until after the measurements were completed, no discharge value was received. However, it was clear that the device is fully functional.

6.2.4 Warning system infrastructure

Upstream of the Phetchaburi diversion dam yearly flooding occurs. Using the water level data, a warning infrastructure could then be built for two purposes:

- (Early) Flood warning
    - With a flood warning system, the RID can take measures to minimize the impact of a flood by for instance increasing the dam discharge.
    - To let citizens know when a flood is coming. This would help them minimize the damage done by the flood.
- Salt/fresh water warning, for farmers to know when to (not) use the river water for irrigation.

6.3. Water monitoring apps

6.3.1. Improvement on MWM system

1. Further testing of the staff gauges. Most of the problems occurring with the staff gauges came from the 2m scales, it could be further researched whether human errors during construction can be sufficiently limited. Furthermore, the effects of reflections, which sometimes resulted in faulty data, should be further researched.
2. The system can be expanded to include a rain meter and groundwater level meter. Measuring precipitation and groundwater levels is necessary for, for example, a rainfall-runoff model. New devices, such as acoustic sensors, need to be developed for this. However, the way the database works will remain the same.
3. Increasing the frequency of manual measurements to for instance hourly measurements is impractical. However, if a staff gauge is placed in sight of a camera with a sufficient resolution, the images of the camera could be used to provide data by processing the photo using the algorithm of the app. The current CCTV-network takes a picture every 15 minutes and uploads this to their website. One of the staff gauges was placed in front of one such camera. Sadly, this camera did not have the required resolution to read its data. But should this method work with a camera with a sufficient resolution, this could provide a continuous data collection system at a much lower cost than the telemeter system currently used in Phetchaburi.
4. The app should not show staff gauges that are far away as options to do a measurement for. This way, faulty measurements cannot be taken. An alternative is to show a warning when a measurement is being taken at the wrong station, including a warning in the database when reviewing the data.
5. A download button should be added to the MWM dashboard, for easy data analysis.

6.3.2. Improvement on AKVO system

1. Further testing of the Quantofix phosphate strips; the values obtained using these strips were impossibly high (even for demi water). It is not clear whether the used batch of strips was bad, whether the test itself was incorrectly developed or whether the results were possibly influenced by an unknown constituent in the surface water.
2. Bug fixes and “quality of life” improvements, as discussed in section 4.2.1.

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