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Discharge and sediment transport in the Kapuas river

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Minor Field Study

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The responsibility for the accuracy of the information presented in this MFS report rests entirely with the authors and their supervisors.

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Abstract

Deteriorating water quality is a challenge which affects people of the entire world, with a growing population and increased industrialization worldwide. The problem is especially apparent in many developing nations where water resource management must be improved to secure a future sustainable supply. This study was undertaken as a bachelor degree within the MFS-program funded by SIDA. The study took place in two small rivers which are a part of the Kapuas river basin in the Indonesian province of West Kalimantan on the island of Borneo. This province has a population of 4.5 million (SI:1, 2010) and many people are dependant of water from the river system for drinking and hygiene. There is a lack of water resources management in the area such as monitoring changes in hydrology and sediment content due to industrial activities such as logging, palm oil plantation and mining. Because of this situation, the purpose of this study was to advance the data collection of sediment content and discharge. The field work was undertaken in between may 7th and july 19th 2013 which is at the end of the rainy season in the region. Two rivers were studied, river 1 with high water velocities and high sediment contents and river 2 with low water velocities and lower sediment contents. The study resulted in stage-discharge and stage-sediment relationships for daily measurements using a flow meter and lab analysis of TSS-content in water samples. Four simple methods were tested and with varying results, two methods for measuring discharge(float method and disc method) and two methods for measuring TSS by determining the turbidity (turbidity tube and turbidity by photos). The float method proved successful in river 1 with an average error of 13% and a maximum error of 26%. In river 2 with lower water velocities the average error was 46% and the maximum error 136%. The disc method was only able to produce results in river 1 with an average error of 35% and a maximum error of 65%. However the errors were, with one exception, all larger than the true value (obtained by using a flow meter). This suggests that the accuracy could be improved by adding a correcting constant to the calculations, which would be obtained through more extensive testing and calibrating. Neither the turbidity tube nor the turbidity by photos was able to produce any accurate results of determining the sediment content. However the turbidity tube has shown trends in the results and might be improved through more testing to be able to roughly determine the sediment content of water.

Keywords: Indonesia; Hydrology; Kapuas; Simple methods; Sediment transport; Discharge

Key Words

TSS (Total suspended solids) – A measurement of the total amount of solids, solved or suspended in water. A commonly used parameter of water quality

NTU (nephelometric turbidity units) – A measurement of translucency or ability of light to pass through water. A high NTU of a water sample means it is high in turbidity and absorbs light well.

Stage – The depth in a river or lake

SIDA – Swedish International Development Agency

Rating curve – A diagram where discharge (Q) or another parameter in a river is plotted as a function of stage.

Discharge and flow (m/s) – A measurement of the total volume of water per second flowing though one cross section of a river.

MFS – Minor Field Study, a student program for students seeking to do a small project or investigation sponsored by a scholarship provided by SIDA.

Sedimentation – The phenomenon where the sum of forces on a particle or other item is too small for it to remain suspended or floating in a medium and it sinks.

Kalimantan – Refers to the Indonesian part of the Island of Borneo.

LTH – Faculty of engineering LTH at Lund University

True value – The values of velocities and sediment concentration measured using current meter and a conventional filtration method.

1. Introduction

The island of Borneo is a unique place. Home to the world's oldest rain forest, it is abruptly contrasted by vast fields of palm oil plantations and supports a population of 19 million people in total. There are few places where the effect of man on nature is more evident.

It is only recently that the exploitation of its natural resources has been brought to an industrial scale. The favourable growing conditions and worldwide demand for palm oil has led to conversion of thousands of acres of pristine forest to monocultures producing the cheap additive. Logging is commonly practiced through clear cuts, often with little or no regard for regeneration of the forest. The most alarming use of land is the practice of illegal mining of gold using mercury. Apart from habitat destruction and contamination of heavy metals and pesticides these practices alter the landscape and hydrological properties of the catchment. Amount of discharge and sediment transport into the river is affected when soil binding effects of the forest is destroyed due to deforestation (Wahyu et.al. 2010).

These problems are vital to monitor when planning water resource infrastructures, for example reservoir planning. One of the many issues facing developing societies around the world today is the growing problem of supplying its citizens with clean drinking water. The united nations have passed a resolution (UN, 2010) stating that access to sanitation and drinking water is a basic human right. Despite this 783 million people lack access to an improved source of water for drinking and sanitation (UN, 2012) and according to United Nations statistics almost 50% of the population at any given time in developing countries are suffering from health problems caused by unclean water and poor sanitation. There are many areas, such as around the Kapuas river basin, where household water is taken directly from a lake, river or stream rather than groundwater or water which has been through a treatment plant. A first step towards better water resources management is to start monitoring of the water, both in regards to quantity and quality which is what this study is about.

Picture 1.1 - People bathing in one of the rivers studied.

2. Background

2.1 Kapuas river basin

The Kapuas river basin (yellow marked in picture 2.1 below) is located on Borneo in the province of West Kalimantan (Kalimantan Barat), Indonesia. The province of west Kalimantan covers roughly the same area as the Kapuas river basin since the mountain ranges are a natural geographical as well as hydrological border. The province had, as of 2010, a population of 4,500,212 (SI:1, 2010). The capital, Pontianak, which has a population of approximately 550,000 in the city (SI:2, 2010) is located at the mouth of the river near the coast. The river is utilized for drinking water, sanitation, transport, fishing etc which is why the water quality has a profound impact on the welfare of many people.

Picture 2.1 - The yellow outlines the catchment of the Kapuas River. (Rivers Network, 2013)

There has been very little management of the river basin prior to today. One of the problems is that the river runs through several counties among which the coordination in regards to watershed management is very limited. A 2004 report by Adijaya and Yamashita regarding mercury pollution in the Kapuas River identified "lack of coordination among institutions and infra-structures" as one the main problems. Counties in the upper parts of the river do not necessarily take into consideration how their downstream neighbors are affected by activities in their county. As of today it is hard to acquire continuous sets of data, due to the vastness and inaccessibility of the catchment. Poor or nonexistent infrastructure combined with extreme weather conditions large parts of the year make monitoring in the vast catchment a challenge.

2.2 Purpose of the study

The study has had two purposes:

1. Collect data and investigate the relationship between stage-discharge and stage-sediment transport in two rivers by constructing graphs for this purpose.
2. Investigate possible ways to collect data without using expensive or complicated equipment.

The collection of the data for the stage discharge and stage sediment relationships also served the purpose of being a reference value to compare to the data collected with the simple methods.

One thing that the host contact person Mr. Kiki P. Utomo at the Tanjungpura University as well as the project supervisor Jan Høybe has stressed is that the future research need to “Move from the desk to the ground”. The secondary objective was therefore to find possible methods requiring a minimal amount of gear to suit the Kapuas river system. It has been done by evaluating and adapting two well documented methods for measuring flow and sediment content as well as trying two unconventional methods. The selection of methods was based on the following criteria.

- Everything necessary for the equipment must be available locally, in Pontianak.
- In addition any components needed for testing must be cheap and durable.
- The method itself must be able to produce a result in the field.
- The testing must be easy to perform without any prior experience.

The challenge has been to find economically viable tools for measurement that are durable and can be operated by anyone.

3. Literature review

3.1 General about direct discharge measurements

Discharge is the volume of water that passes a cross section area per time unit, often described by the SI-unit m^3/s. Direct measurements can be divided into four categories (Gordon et. al. 1992)

<u>1. Volumetric measurements</u>

This is performed by filling a container with a known volume and timing the progress. Discharge is calculated as the collected volume divided by time.

<u>2. Velocity-area method</u>

This method is involves measuring the area of a cross section, estimating an average velocity for this section. By multiplying these two values, the discharge is obtained.

<u>3. Dilution gauging method</u>

By introducing a tracer substance such salt, or dye into the water the discharge can be measured by monitoring the concentration of said substance further downstream.

<u>4. Artificial structures</u>

If a more permanent measuring station is established one options is to construct a permanent structure such as a weir or a flume can be constructed allowing for a precise measurement of the discharge.

3.2 Velocity area method

The velocity area method allows you to measure the flow by calculating the cross sectional area and the average velocity of the water at a particular gauging station (Gordon et. al. 1992). The discharge is then calculated as:

$$Q = v \cdot A \qquad \text{(Eq 1)}$$

The cross section is split into several smaller sections. The mean velocity for each section is measured and multiplied it with the width (ΔW_i) and average depth of the section (D_i), resulting in a flow for the segment (Q) (Bedient et. al. 1992). The flow of each segment is summed up resulting in an average flow for the entire cross section, see equation 2.

$Q = \sum v_i \cdot \Delta W_i \cdot D_i$ (Eq 2)

As stated in the average velocity for each section can be calculated by using the "two-point method. Measurements of the velocity are made at two depths; 0,2*D and 0,8*D vertically below the surface. D_i is the full depth of the water where the two measurements of velocity are taken for a segment, see figure 2.2. The average velocity of the section is the average of these two measurements:

$v_i = 0.5 \cdot (v_{i,0.2D} + v_{i,0.8D})$ (Eq 3)

$\Delta W_i = width\ of\ the\ section$

$D_i = depth\ in\ the\ middle\ of\ the\ section$

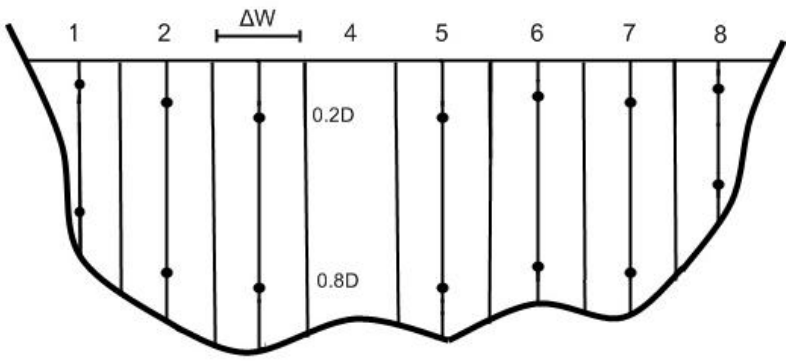


Figure 3.2.1 – Cross sectional sketch of a river showing at what depths and width intervals that the velocity measurements are performed in order to establish discharge.

For depths of 0.6m or less, the "one-point" method can be applied where one single observation is made of the velocity at 0.6D.

The following characteristics should be considered when selecting the location for measurement and the ideal site:

- The velocities should all be parallel to each other and face at a right angle to the cross-section.
- The distribution curve for velocity should be regular in the vertical and horizontal plane.
- The velocities should all be higher than 0.15 m/s.
- The channel bed should be stable and regular.
- The depth should be greater than 0.3 m.
- There should be no aquatic growth.

If a stage-discharge relationship is to be established the discharge measurements do not need to be collected in the exact same location as the stage measurements since the discharge is normally consistent in a reach of the channel nearby to the site where stage is measured (WMO 1994).

3.3 Water quality and suspended solids

When determining the “quality” of running waters one can divide the aspects one needs to consider into three rough categories; Its physical, chemical and biological features (Shaw 1983). Total Suspended Solids (TSS) is a measurement of the amount of particles, both organic and inorganic which are suspended in a body of water. It is a common parameter measured since it has an influence on water quality.

An increase in suspended particles has a number of harmful effects on fish populations (Newcombe & Jensen 1996). It can also have harmful effects on other organisms such as insect larvae and through decreased light penetration aquatic plant growth is inhibited, which both effect mollusc and crustacean populations. In general these changes lead to a more unstable bed consisting of finer material (Gordon et al 1992).

3.4 Sediment transport

The amount of sediment that reaches a river depends on the properties and processes going on in the upstream catchments. Soil and mineral particles are eroded from soil or bedrock in various processes, for example by wind erosion, rain or anthropogenic processes. The dominant contributor is water, as it both mechanically and chemically affects soil, rock and biological components. As water is drawn by gravity down through the catchment it accumulates and by its potential energy is able to transport material downstream. Material is solved into the medium or swept away with the current ending up further down in the catchment or finally in the stream itself. Suspended solids can be either organic or inorganic ranging from small particles to entities as large as trees.

It is the sum of forces acting on a single particle suspended in flowing water that determines when and if it will sediment. The viscosity and density of the medium predominantly determines settling of particles. High viscosity of the medium entraps the particles more easily in the medium and the density difference between the solids and the medium determine buoyancy. Small particles are mainly affected by the intermolecular forces acting between themselves and other adjacent particles in and of the medium. This also means they may tend to cohere together when dry and are therefore hard to erode, but more easily transported once suspended or dissolved into the medium eg. silt and clay. The sedimentation and transport of larger particles and debris is affected to a greater extent by their density (determining buoyancy) and the forces resulting from the waters velocity. The flow of water around a body creates friction and drag, which makes sedimentation more difficult as velocity increases. The Hjulström Curve plots water velocity against particle size, roughly outlining at what speed of the water a certain size of particle is transported, deposited and eroded. See figure 3.4.1. (Gyr et al 2006)

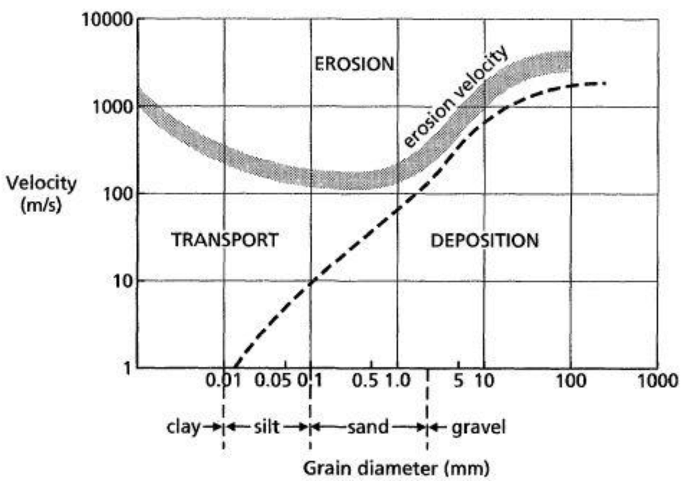
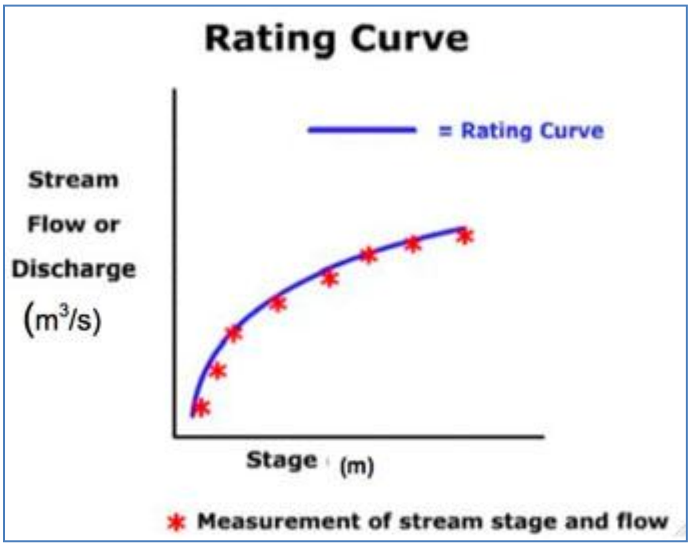


Figure 3.4.1 – The Hjulström diagram. (Answers.com, 2013)

3.5 Stage-discharge relationship

A simple way of conducting continuous measurements of discharge at a gauging station is to assume a relationship between the stage of the river and a corresponding discharge. Thereby, one can get a good idea of how the discharge at a segment varies over time by simply looking at the stage. Several measurements of the discharge and the corresponding stage are taken in order to provide a wide range of different flows and their corresponding stage. By plotting the stage of the river against the discharge for the measurements acquired the points should start to resemble a curve. A curve is extrapolated to fit the pattern of the points in the graph. The flow can then be read from the graph. (Shaw 1983)



Picture 3.5.1 A simple sketch of a typical rating curve. (CZO, 2013)

The curve can be described as a mathematical function, which is established by for example by trial and error, or as in our case by using Excel. This mathematical relationship allows for the flow to be estimated simply by solving for the flow. (Shaw 1983) The banks and flood plain of the river along with the height profile will affect the flow at different heights of stage and contribute the unique pattern of the rating curve. It is common to plot the discharge and stage on a log scale paper, as the discharge against stage in a river on a neutral scale often appears to have a logarithmic relationship, see picture 3.5.1. The following general equation is commonly used to fit an equation to the plots of the rating curve.

$$Q = c * (h + a)^b \qquad \text{(Eq 4)}$$

Where Q= flow, c=coefficient for fitting the relationship to the plots, h=stage, a= water level at Q=0 and b=another constant fitting the line to the plots. (E. J. Kennedy 1984)

As we do not know at what stages the rivers at the particular gauging sites bring no flow, the ”a” is not used. Hence, the following equation will be used when approximating a curve to the plots:

$$Q = c * (h)^b \qquad \text{(Eq 5)}$$

Natural systems are rarely stable over longer periods of time and the relationship can only be assumed to be valid for a certain amount of time for the particular gauging site. A high flood could greatly alter the bottom profile, making the relationship invalid. Thus new measurements of the cross sectional area is needed. (Dr Johnny)

3.6 Stage-sediment transport relationship

The purpose of creating a stage-sediment relationship (SSR) is the same as the purpose of creating a stage-discharge relationship (SDR) as described above. However for the SSR the stage is assumed to correspond to a certain amount of sediment transport per unit time. Samples of sediment content are sampled together with the measurements of flow and stage in the SDR. The sediment content of the water is multiplied with the flow and plotted against the stage. Looking at the diagram there should be, as in the SDR, a relationship from which one is able to tell the total amount of material being transported from knowing only stage in the river. (Lohani et al. 2007)

3.7 Float method

Also known as the orange method, the float method is one of the simplest methods of measuring the velocity of flowing water. An object is placed in the water and timed as it travels a specified distance in the upper most parts of the water. The distance is divided by the time of travel, resulting in the speed of the surface water. A recommended time for the float to travel is 20 seconds or longer. As the velocity profile of the water varies with depth as a result of friction against the bottom of the river bed, a correction coefficient is multiplied with the observed velocity. This constant varies from 0,8 for very rough riverbeds with vegetation and large rocks to 0,95 for smooth channels with minimal friction. The object should be as submerged as possible without sinking, yet visible by the observer. This is to ensure maximum effect by the water and minimum from wind and other influences. If the river is more than 10 meters wide the channel should be divided into at least three sections where the velocity is measured. (Gordon et. al. 1992)

Picture 3.7.1 – A shop frequently visited, situated 30 meters from river 1. The small models (0.5 litres) of water bottles on the bottom shelves were used for the float method. Fishing line could also be bought here making the total cost for the float method setup around one dollar.

3.8 Disc method

The total drag on a body is the sum of the friction drag and pressure drag. The total drag can be calculated through the following formula:

$$F_D = C_D \cdot \rho \cdot \frac{v^2}{2} \cdot A \qquad \text{(Eq 6)}$$

Where F_D is the force acting on the disc, C_D is the drag coefficient, ρ is the density of water, v is the velocity of the water and A is the surface area of the object perpendicular to the flow. (Hamill 2011) Figure 3.8.1 describes how the drag coefficient may be derived from the Reynolds number for different bodies:

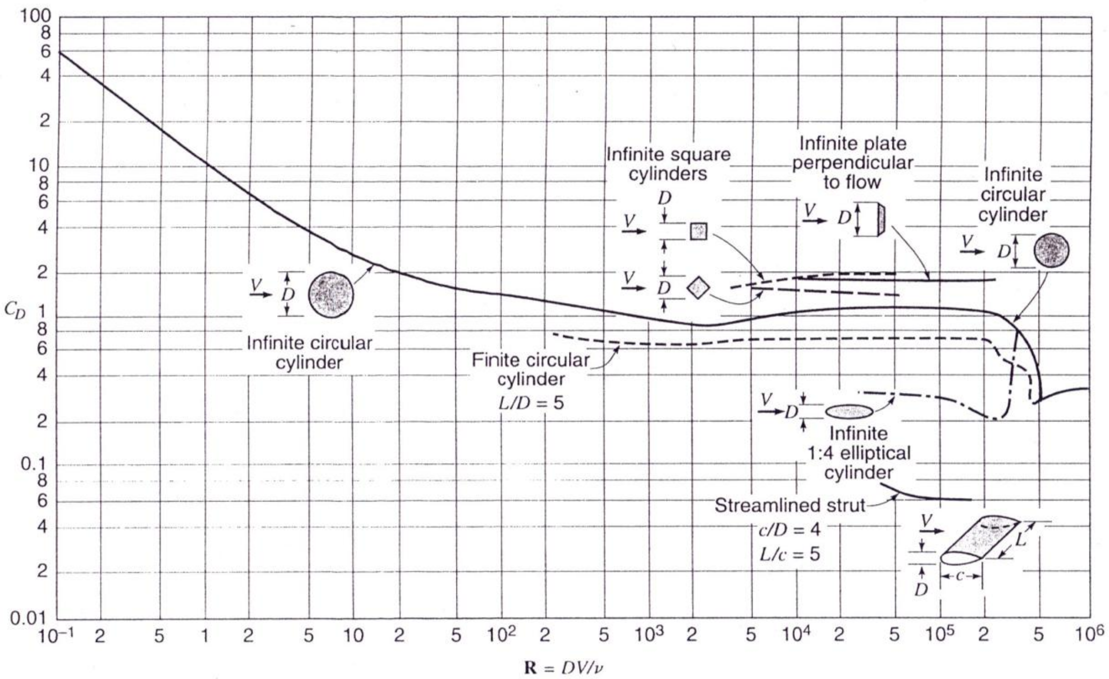


Figure 3.8.1 – Drag coefficients for different bodies submerged in water as a function of Reynolds number (Franzini & Finnemore 1985).

The drag coefficient is constant in the span between Re=10^4 and Re= $2{,}5*10^5$ for a circular plate. This means that the drag coefficient can be considered to be constant in the span of water velocities expected to be encountered in the rivers of this study. Therefore a circular plate have been used to determine the velocity since that eliminates the need to calculate the drag coefficient in the aforementioned span. If the drag coefficient was not constant the calculation would be if not impossible then much more complicated. (Franzini & Finnemore 1985)

The Basic principle of this method is to calculate the flow in a river through the total force acting on a body submerged in the river.

The velocity of the water can therefore be calculated by the following formula:

$$\sqrt{\frac{F_D \cdot 2}{C_D \cdot \rho \cdot A}} = v \qquad \text{(Eq 7)}$$

3.9 Turbidity tube

The turbidity tube is a method used to measure the turbidity, recommended by for an example the world health organisation (WHO, 2005). It determines the turbidity by using Secchi's method for determining the "Secchi depth" which consists of lowering a black and white disc into water until the viewer can no longer distinguish the white fields from the black fields (WSDE, 1991).

4. Methodology

4.1 Experimental area

Two locations have been selected for the study by the projects supervisor Jan Höybye from LTH and the local host contact person Kiki Utomo from the Tanjungpura University.

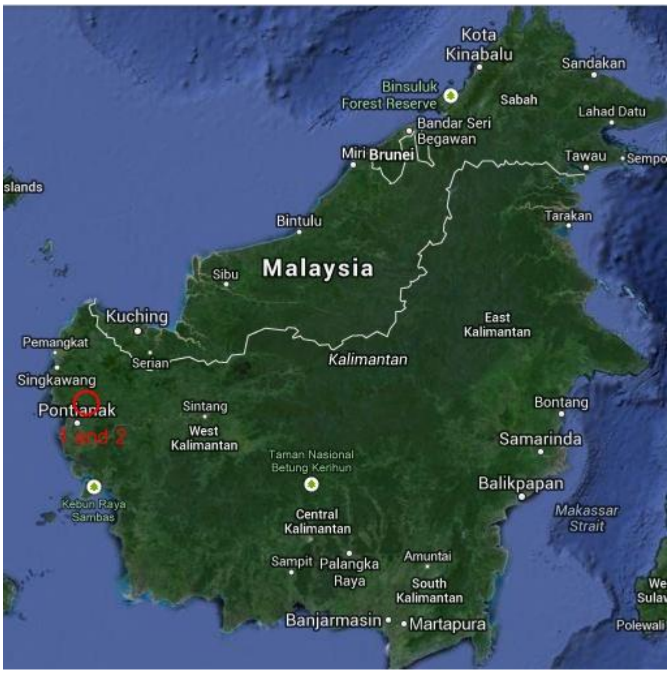


Figure 4.1.1 – Map of Borneo, red circle indicates location of testing sites. (Google Maps, 2013)

Figure 4.1.2 – Map of the area showing Pontianak the capital of the province. Red circle indicates location of testing sites. (Google Maps, 2013)

Figure 4.1.3 – Shows the area where the two testing sites are located, red circles indicate the location of site 1 and site 2. (Google Maps, 2013)

4.1.1 River 1 - Mandor

This river runs through the centre of the village Mandor, the site which have been picked for our study is next to a bridge in the centre of Mandor.

Picture 4.1.1.1 - River 1 flowing from left to right in the picture. The gauging site for this river is at the very left of the picture.

The bottom consists of fine and medium grain sand and is littered with debris here and there. This fine grain bottom in combination with the relatively high water velocities lead to a very unstable bottom and shifting bottom profiles in the area. The river carries a heavy sediment load which is believed to be related to mining activities in the upstream catchment area. Information from people residing in the area confirm that the river held water of very good quality and little sediment before the mining begun upstream around ten years ago. The course and banks of the river do not seem to have been altered and the river runs a meandering path. The banks have grass, bushes and trees growing on top. The sides closest to the water's edge are sandy and seem to be heavily eroded, as sand and lack of vegetation is what meets the water. There are no aquatic plants in the stream, possibly because of the heavy sediment load.

4.1.2 River 2 - Salatiga

The second testing site is a river which runs just outside of the village Salatiga and again the site chosen for the study is next to a bridge and accessible by motorbike. At the location, two streams converge. One (left branch picture 4.1.2.1) which is the largest stream runs past farms and residences, has a higher turbidity and carries more sediment. The second branch (right branch in picture 4.1.2.1) is very clean and run down from a catchment area consisting of peat bogs according to information by the projects host contact person Kiki P. Utomo. Because of this the site is very

Picture 4.1.2.1 - Photo taken from a bridge at gauging site, which is around 8m from where the two rivers meet. Furthest downstream in the river is at the bottom of the picture.

Picture 4.1.2.2- The dam located about 1,5km downstream of the gauging site.

popular for laundry and washing by the local people which means that it is more or less constantly visited by local villagers. The course and banks do not seem to have been altered by human activities as the river runs in a meandering path. The bottom consists of fine sand, clay and silt and in many places, logs, larger pieces of wood and some rocks. The sides are covered by plants and there are aquatic plants growing in the water, especially close to the river banks. Quite a lot of aquatic life was observed in the river; e.g. different species of fish, shrimp, snails, and insects.

Downstream from the bridge approximately 1,5 km is a large complex of rice fields which rely on the river water for irrigation. This has resulted in a dam being constructed (see picture 4.1.2.2) where the flow is regulated depending on the need for water.

4.2 Stage discharge and stage sediment transport

Stage was recorded every day, both the stage as a depth under the bridge to the surface of the water and at a specific point in the middle of the river. The latter was averaged from three values with a space of one meter between each reading, because of the shifting bottom profile due to deposition and transport of bed material. This depth is referred to in this project as the Manning's depth, as it was meant to try out another method using the Manning's equation, a plan which was never realized.

Picture 1.2.1 - The OTT Universal Current Meter used: the propeller, cord and pulse registering device.

A rope with knots tied at every meter, shown in picture 4.2.2, was tied over the river in order to record both depth and velocity of the water at specified horizontal distances from the banks. A width of two meters between every velocity measurement was used in both rivers, giving a total of around seven readings per river and gauging occasion. The procedure for measuring velocity is described in the literature study section 2.2. The cross sectional area calculated from the depth was later used in the other "simple methods". The equipment used for measuring water velocity was a Valeport current meter model 002. After some technical issues it was replaced by an OTT Universal Current Meter. The latter apparatus is shown above in picture 4.2.1. The flow was plotted against stage and a logarithmic function approximated from the values to form a stage-discharge curve.

Picture 4.2.2 – The rope which was used, tied of the river marking the horizontal sections.

1,5 litre water bottles were used for the sampling of river water. One sample per river and gauging occasion was collected. The water was in both rivers assumed to be mixed and homogenous in composition throughout the cross section. This was done by drawing samples from the middle of the river at the depth 0,5D. Care was taken as to not disturb the bottom material while drawing the sample and if bottom material was disturbed so time was given in order to let the sediment settle. The samples were taken back to the university and analysed for TSS content. The analysing was outsourced to a third party, due to practical reasons.

Picture 4.2.3 – Jonas collecting sediment samples from river 1.

Picture 4.2.4– Ludvig performing velocity measurements in river 1 using the Valeport current meter.

The TSS analysis was done by first drying filters and weighing them. 80ml of river water was filtered by vacuum suction through the filter and thereafter dried in an oven. The filters were thereafter weighed another time. The first weight of the filter was subtracted from the second weight, in order to get the weight of the filtered out material. The weight was divided by 0,08 to get the unit in grams per litre (total suspended solids g/l). The values collected were multiplied with the flow values of the same day and plotted against the stage of the day, creating a stage-sediment curve.

The discharge and TSS results described in this section are throughout the rest of this study referred to as the “true” discharge and “true” sediment content, this in order to enable comparison to the “simple methods”.

4.3 Simple methods

4.3.1 Float method

A thin fishing line was tied to a 500ml bottle filled to 95% with water (see figure 4.2.1.2), so that the cap was above water and easily visible. The bottle was thrown upstream a few meters above the person taking the measurement in order to accelerate to the same speed as the water as it passed the observer. The progress of the float was then timed. Since the length of the string was known the average velocity could be obtained by dividing the length by the time of travel. The river was divided in to three equally large sections, see figure 4.3.1.1. In each section the velocity was measured twice to form an average. As the total discharge is of interest, the already measured area profile (see section 4.2) for each of the three sections was multiplied by their respective observed velocity and the correlation coefficient 0,85 resulting in the discharge. Summing up the discharge of all three sections then gave the total discharge of the river. The constant 0,85 was used for both rivers, since the bottoms consist of sandy material with some debris.

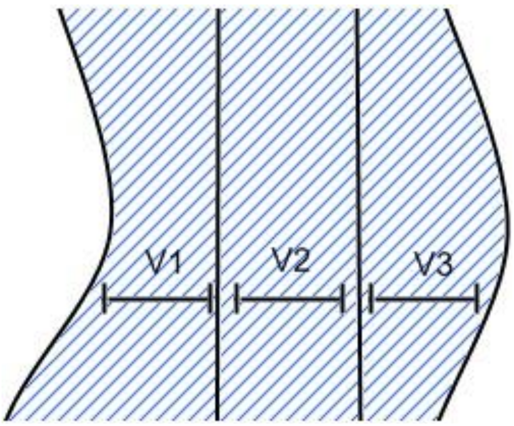


Figure 4.3.1.1 – The river viewed from above, divided into three horizontal sections

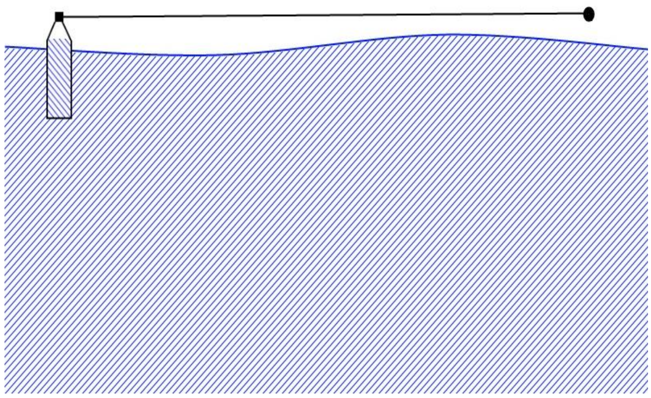


Figure 4.3.1.2 - Schematic view of the float method with the bottle at the final point of its path. Seen from the side.

4.3.2 Disc method

Three discs with the diameters 0.5 m, 0.2 m and 0.1 m were used. C_D is assumed to be constant at 1.1 and the density of water is approximated to the constant value 1000 kg/m^3. The disc is suspended at an appropriate height in the water by using strings attached to a float or by holding the string by hand, this because the metal used was quite heavy. Four strings are attached to screws close to the edge of the disc and meet at a junction above as seen in picture 4.3.2.1.

Picture 4.3.2.1 - The 0,2m diameter disc suspended in mid air.

A line continues from the junction running on a wheel to the Newton meter, which sits furthest up on the staff. The force of the water on the disc is registered by the Newton meter see figure 4.3.2.2. The staff was held so that the line could run free and the disc was suspended vertically in the water, perpendicular to the flow see figure 4.3.2.2. The staff and float are adjusted so that the disc is suspended in the desired height and held steady during measurements. The highest and lowest observed value during five seconds is recorded and to create an average of the two readings. The equations as described in the literature study (Disc method) were used to attain a velocity.

The procedure for measuring the total discharge of the river is akin to that described in "Float method". The river cross section was divided into three sections and one average measurement of Newton meters was attained in each. The total flow was calculated by multiplying the registered velocity with the area measurements collected from the stage discharge measurements.

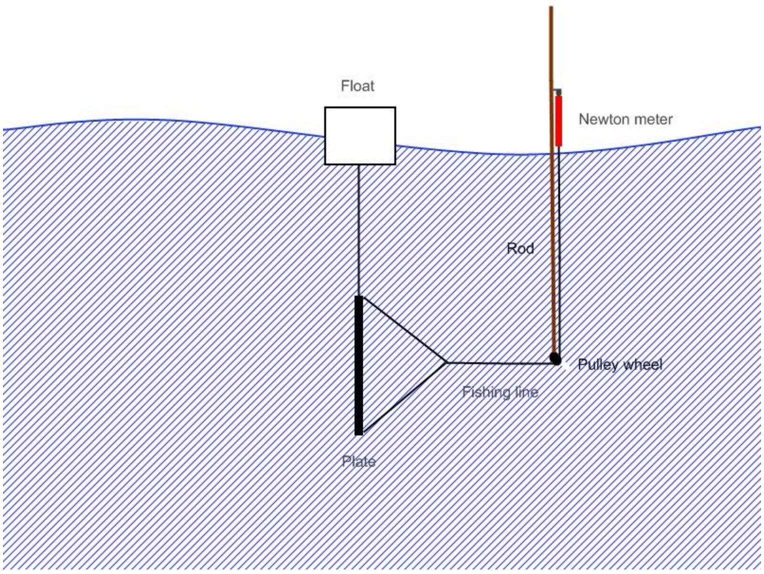


Figure 4.3.2.2 - Schematic view of disc apparatus from the side.

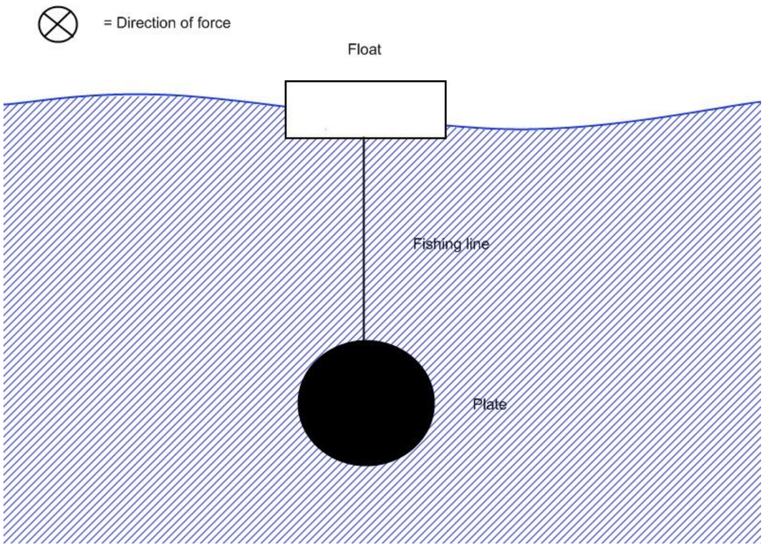


Figure 4.3.2.3 – Schematic view of disc apparatus from upstream.

The figure 4.3.2.2 and 4.3.2.3 show schematic images of the apparatus, when in use; figure 4.3.2.2 viewed from the side and figure 4.3.2.3 viewed from upstream of the apparatus.

The Newton meters used were calibrated beforehand using five different weights attached to the string. The weights were evenly differentiated in order to get readings throughout the span of the meter (0-2,4 N and 0-24N). The reading of the Newton meter was registered and compared to the theoretically correct value according to Newton's equation $F = m * a$. A constant was derived from the difference of those two values, which was later used to correct the measurements recorded. See appendix 1 for calculations.

4.3.3 Turbidity tube

It is constructed by placing a small Secchi disc (constructed according to figure 4.3.3.1) at the bottom of a clear tube. Markings are then made on the side of the tube each centimetre above the bottom where disc is held in place by a small weight according to figure 4.3.3.2. A water sample from the river is then poured into the tube until the viewer can no longer distinguish the white fields from the black fields, according to Secchi's method, and the height of the water column above the disc is noted from the markings on the side of the tube (see figure 4.3.3.2). This in turn is correlated to the amount of total suspended solids by performing a filtration analysis on a water sample drawn at the same time from the same body of water.

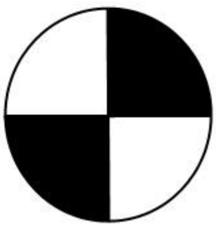


Figure 4.3.3.1 – The secchi disc at the bottom of the turbidity tube

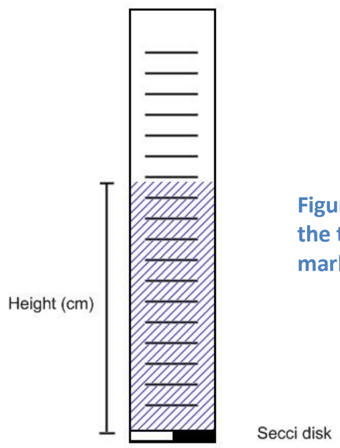
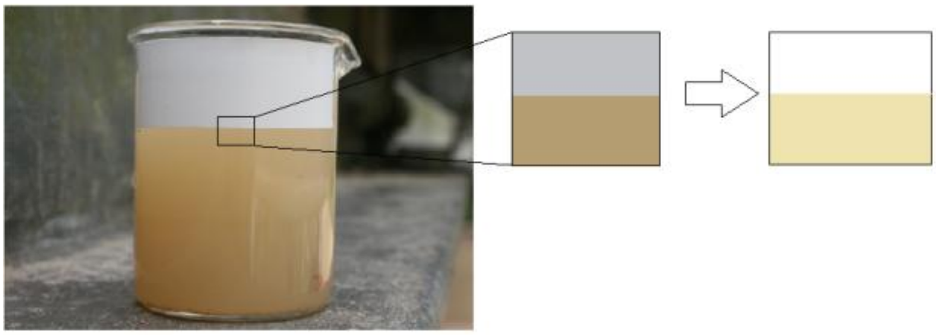


Figure 4.3.3.2 - Schematic drawing of the turbidity tube with height markings.

A reading of the turbidity was done each day in both rivers using the turbidity tube. Three samples were drawn for determining the turbidity and one sample for laboratory analysis in order to determine the TSS. The three samples were all analysed using the turbidity tube method and an average height for of the three values were calculated. The samples were drawn using the sampling procedure detailed in section 4.2.

4.3.4 Turbidity by photos

This method is meant to be an easy and fast way to measure the TSS content in river water. It is developed by Enry Firmana, Juanhan Guo, Aohan Jin and Jamaludin James, whom with this project are participating in the Indonesia Water Challenge arranged as part of a collaboration between Lund Tekniska Högskola and the Tanjungpura University. The method is used by photographing river water in a beaker against a white background. The developers have programmed an application that detects the amount of red, green and blue in the digital image produced. The image is calibrated by cropping a small portion of the image where the white foreground meets the water, see figure 4.3.4.1. The cropped picture is compensated in color by analyzing the "perfectly white" foreground and correcting eventual discoloration by the current light conditions when the photo was taken. By diluting a sample of water several times and photographing the dilutions, a database of the color corresponding to a certain NTU value can be deduced. The amount of color in the water part of the picture is then counted and corresponded to a certain value of NTU (nephelometric turbidity units) or the relationship between the colors Platinum and Cobalt (The platinum/cobalt - scale). The creators of the method suggest that the amount of color might as well be correlated to a TSS value. If this can be confirmed, future levels of TSS can be monitored by simply analyzing photos.



Picture 4.3.4.1 – A simple overview of the cropping of a photo and and the result of the calibration against the white foreground.

5. Results

Results from all days and methods are comprehensively presented, date by date, in Appendix 3, tables A.3.1 and A.3.2.

5.1 Stage discharge and stage sediment transport

5.1.1 Stage discharge

The results of the flow measurements are plotted against the registered stage for each day in River one and two. For each river there are two figures, one for each using depth under bridge and one each for the measured depth at a particular point of the river bed (value recorded for the Manning's method). The results are presented in figures 5.1.1.1, 5.1.1.2, 5.1.1.3 and 5.1.1.4. An approximated logarithmic relationship has been extrapolated in each figure, shown along with its equation.

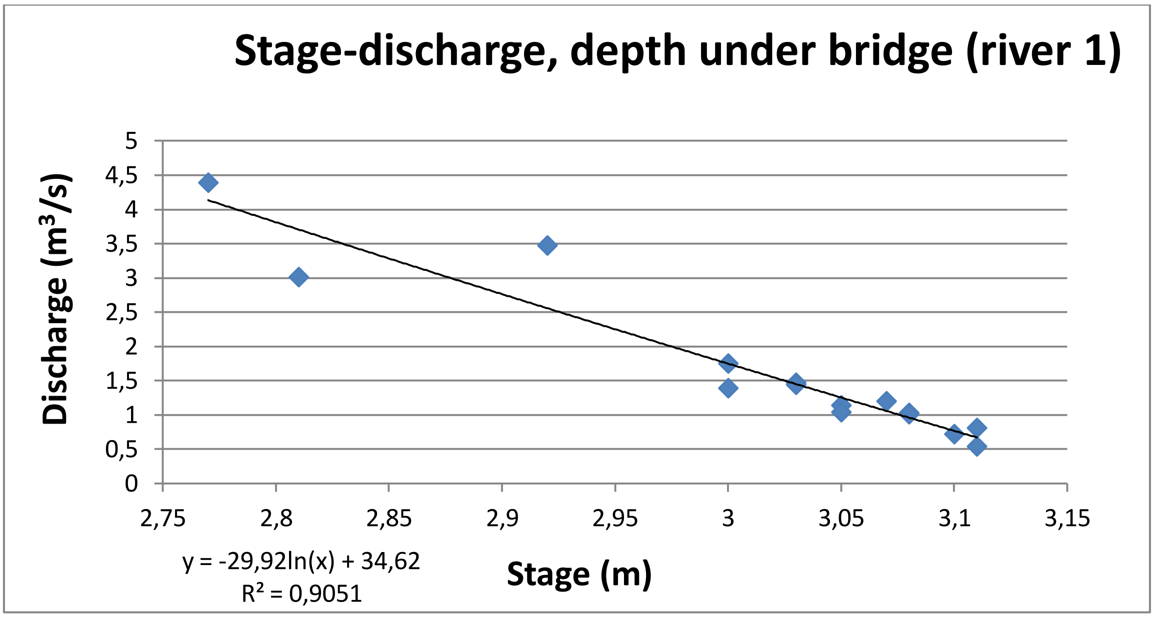


Figure 5.1.1.1 - Rating curve for river 1 using depth under bridge.

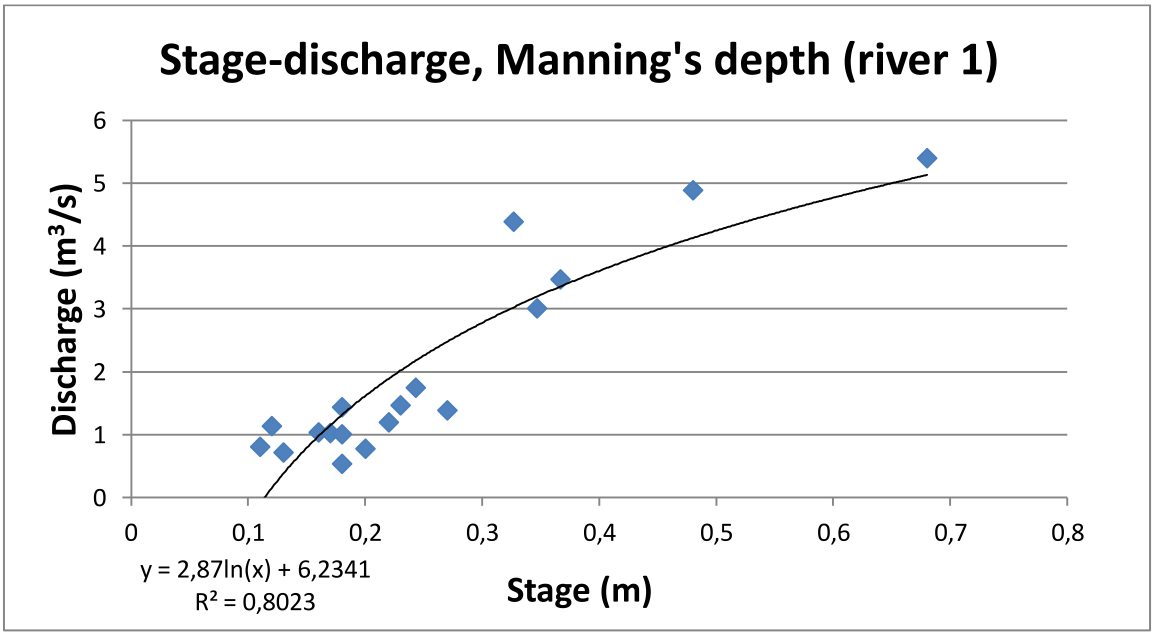


Figure 5.1.1.2 – Rating curve for river 1 using depth in the river.

Figure 5.1.1.2, plotted using the Manning's depth for river 1, has enough values to make is resemble a rating curve, but figure 5.1.1.1 using depth under bridge does not look complete. Stage under the bridge was not measured the first two days, which unfortunately had the two highest flows. Both figures have many plots in the lower parts of the diagram, the ones in figure 5.1.1.1 using depth under bridge seem more coupled, forming a seemingly linear trend. The logarithmic function portrayed in figure 5.1.1.1 looks almost linear, suggesting that it does not have values in the higher range of stages.

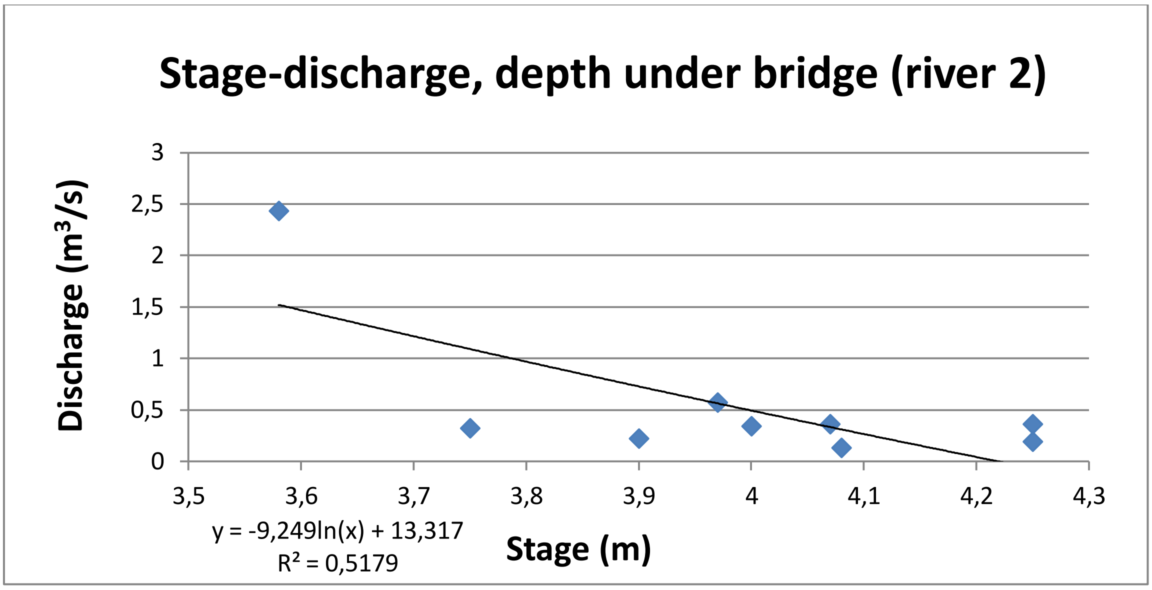


Figure 5.1.1.3 – Rating curve for river 2 using depth under bridge.

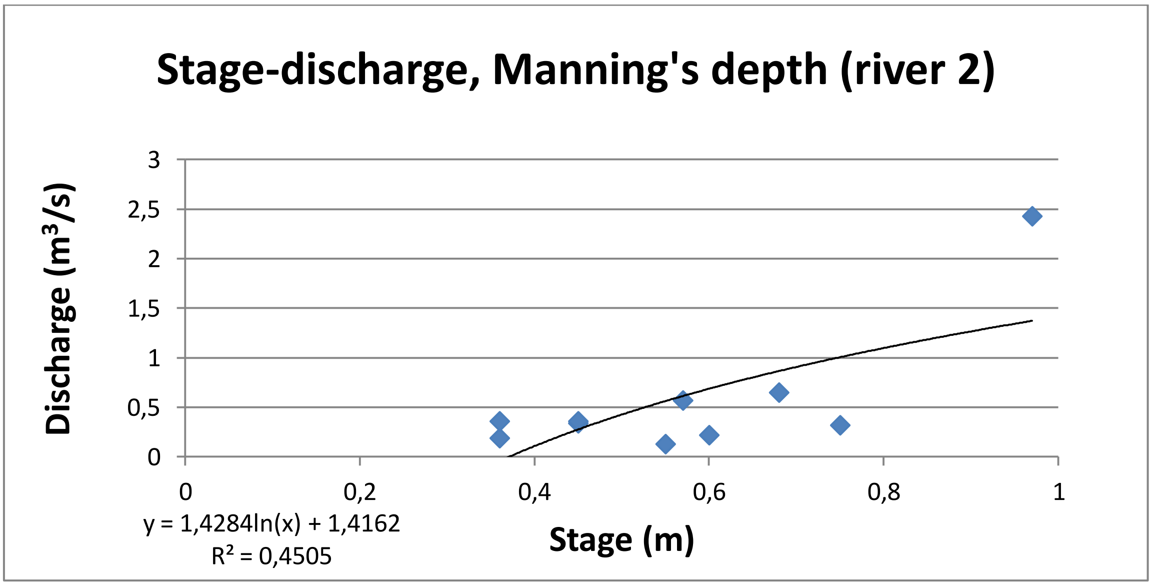


Figure 5.1.1.4 – Rating curve for river 2 using depth in the river.

The observations of stage and discharge in river 2 do not show any sign of a relationship. Figures 5.1.1.3 and 5.1.1.4 above show no clear trends in the distribution of plots. The plots in figure 5.1.1.3 show eight plots with the same discharge, but with differences in stage of as much as 0,6m. The one deviating plot in each of the figures, at almost 2,5m^3/s does however show a high stage, which is to be expected. Not enough data, or perhaps not good enough data, has been collected in order to provide good rating curves for river two. The flows of river 2 have some days been immeasurably small. See appendix 3, table A.3.2, for detailed results and dates of the measurements.

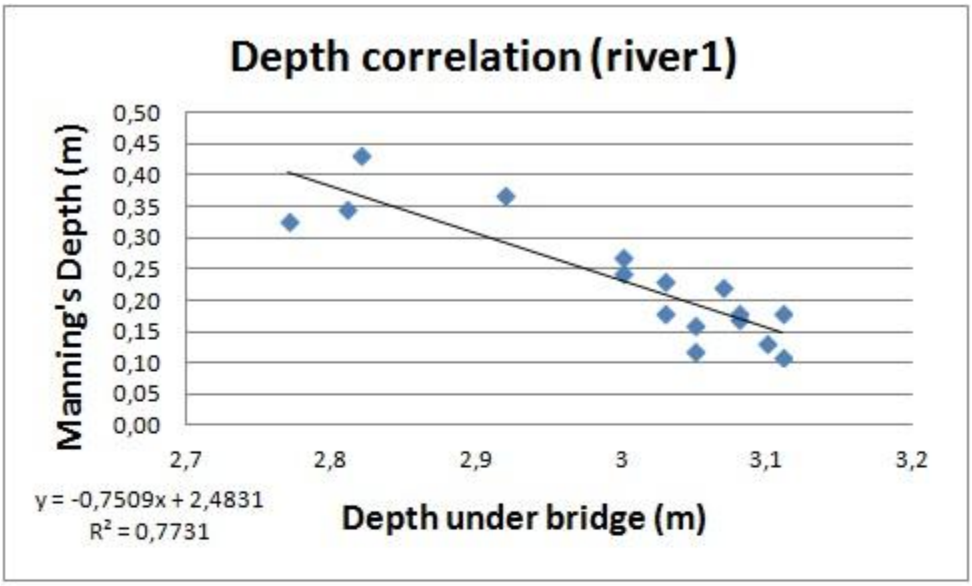


Figure 5.1.1.5 - Depth in the river plotted against depth under bridge for river 1.

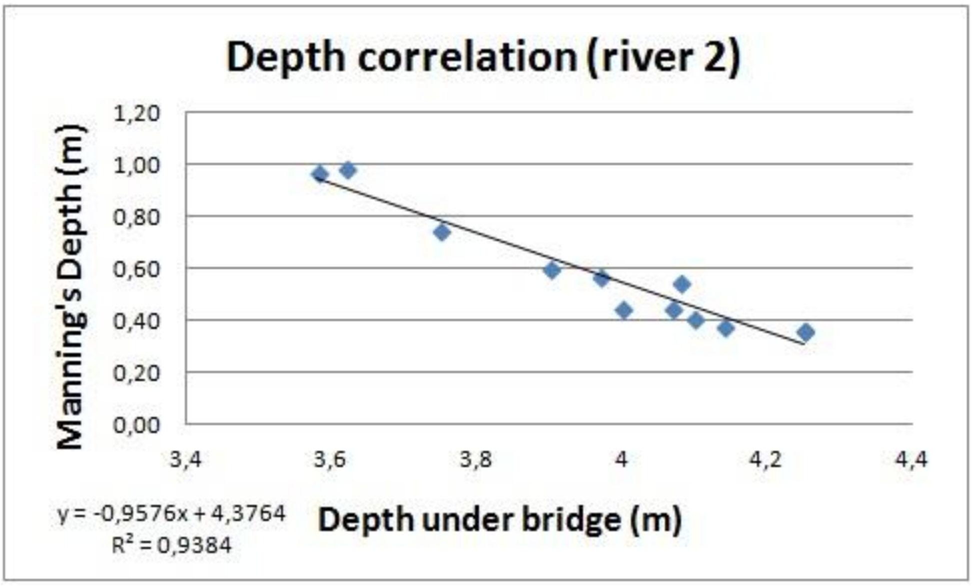


Figure 5.1.1.6 – Depth in the river plotted against depth under bridge for river 2.

The correlation between the Manning's depth and the depth under the bridge is shown in figures 5.1.1.5 and 5.1.1.6 above. They are meant to give an idea of how much the bottom changes from day to day. The supposedly more reliable and geographically stable bridge as a reference is compared to the depth in the river. As seen in the figures, the riverbed of river 1 varies to greater extent than the one in river 2, at least according to their respective R^2.

5.1.2 Stage sediment

For the sediment rating curves, the total amount of transported material (per second) as a function of stage is plotted using the depth in the river. A linear function is approximated to represent a relationship between the total amounts of material transported depending on the depth in the river. The Manning's depth has been used in both rivers. Results are shown in figures 5.1.2.1 and 5.1.2.2.

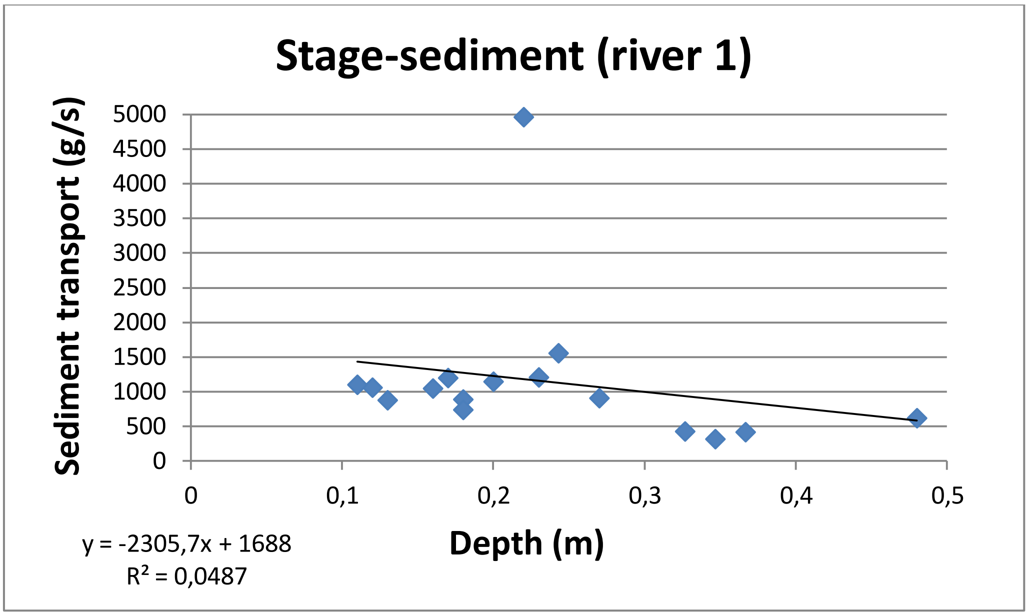


Figure 5.1.2.1 - Stage-sediment rating curve for river 1.

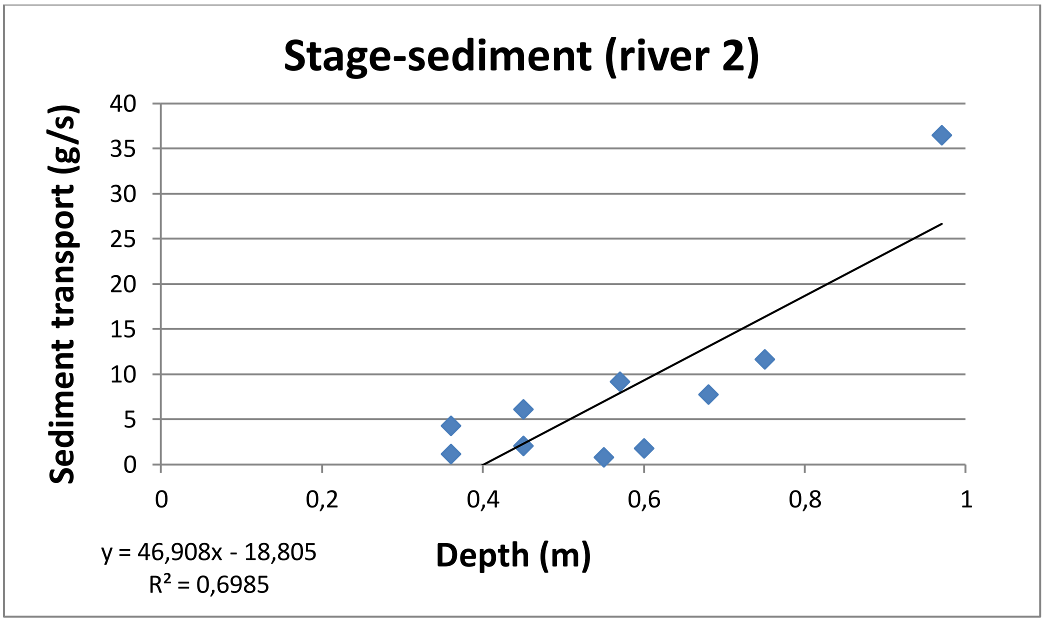


Figure 5.1.2.2 - Stage–sediment rating curve for river 2.

The two figures show no clear correlation between stage and total amount of sediment transported. Interestingly enough, figure 5.1.2.1 for river 1 suggests a decrease in TSS transport as stage rises, which is the exact opposite of what is to be expected. Figure 5.1.2.2 for river 2 shows an increase in transport as stage rises. Only some days presented a flow fast enough to measure discharge in river 2, hence not as many data points were obtained for figure 5.1.2.2.

Most data points in figure 5.1.2.1 are around 1000g/s. One value observed at about 0,2m in stage shows a transport of 5000g/s, which deviates greatly from the rest of the plots. The highest measured value in figure 5.1.2.2 for river two does however follow the trend which was expected, that a higher discharge transports a larger amount of sediment.

5.2 Simple methods

5.2.1 Float method

Two plots have been made of the error as a function of the flow, figure 5.2.1.1 for river one and figure 5.2.1.3 for river two. It seems as if the error is generally larger at lower flows in both river one and river two. Here the values of the error plotted as absolute values, which means that a negative error of -14% is simply registered as 14% in the figure below.

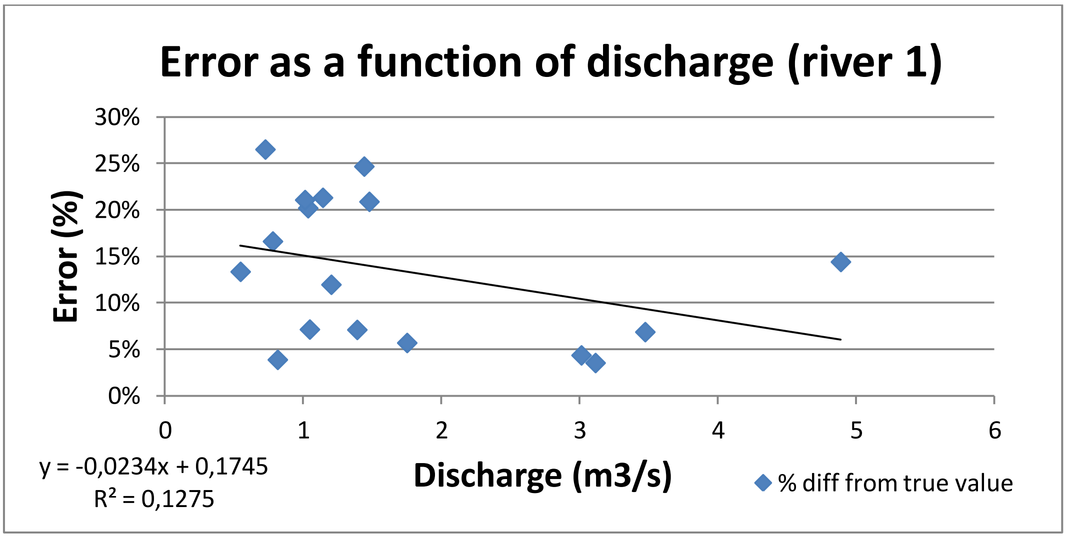


Figure 5.2.1.1 - Showing for river 1 the percent error of the float method in comparison with the "true" value obtained with the current meter. Plots are presented in absolute values.

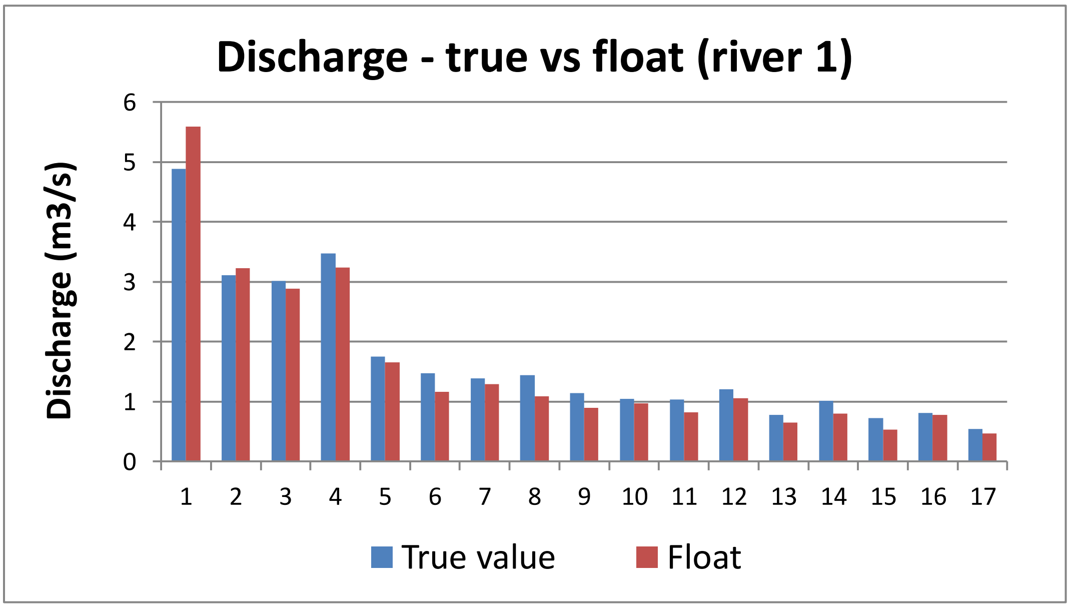


Figure 5.2.1.2 – Measurements of discharge using the float method and the corresponding "true" value presented in a staple diagram for river 1.

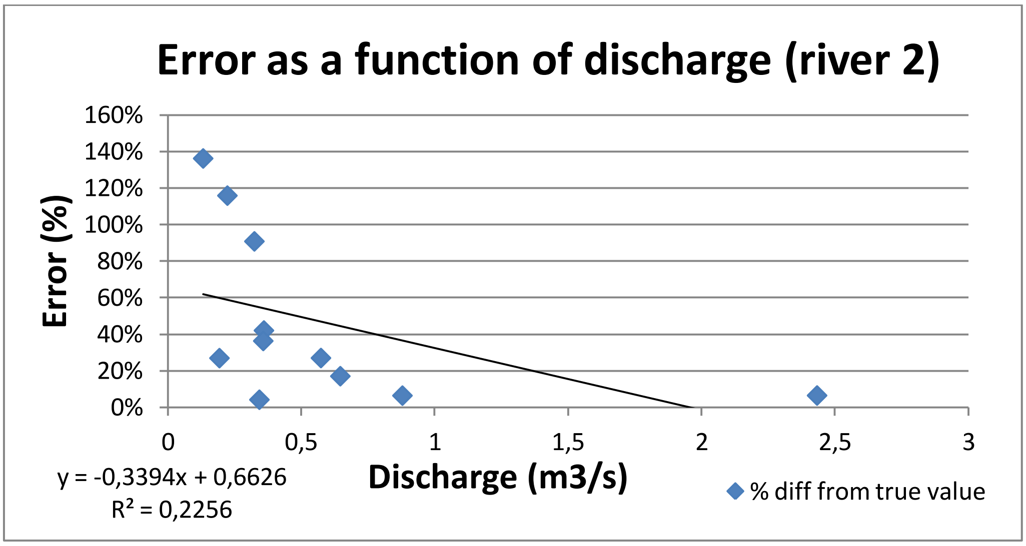


Figure 5.2.1.3 - Showing for river 2 the percent error of the float method in comparison with the "true" value obtained with the current meter. Plots are presented in absolute values.

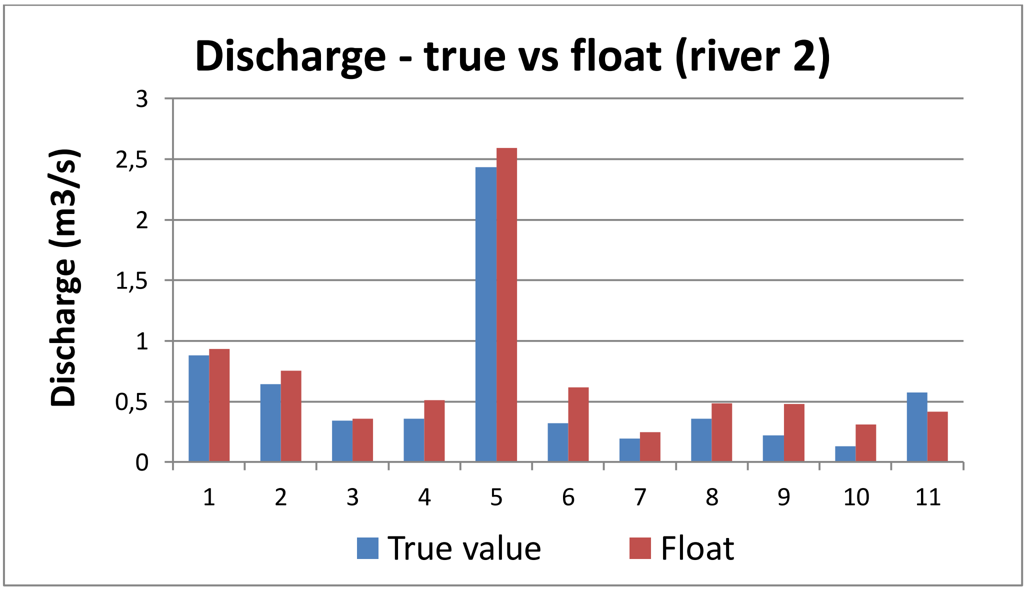


Figure 5.2.1.4 - Measurements of discharge using the float method and the corresponding "true" value presented in a staple diagram for river 2.

The float method has produced quite different results for the two rivers. It has proved to be accurate in estimating the flows for river one where the maximum error is 26% and the average error is 13%. However, for river two it has not been as successful. The maximum error in river two was 136% and the average error 46%. There is a difference in how many measurements were taken in river one and river two. There are fewer values for the flow in river two which is due to the fact that on many occasions, the flow was too low to register on the flow meter which was used in the study, hence no "true" value could be obtained.

5.2.2 Disc method

Figure 5.2.2.1 below shows the percent error in the measurements when compared to the "true" values of the current meter. Because of practical reasons, only the 0,1m diameter disc was able to be used continuously in river one. The results show an average error of 35% and a maximum error of 65%, all of which, with one exception, are larger than the “true” value. The amount of error shows that the method needs improvement in order to be a useful.

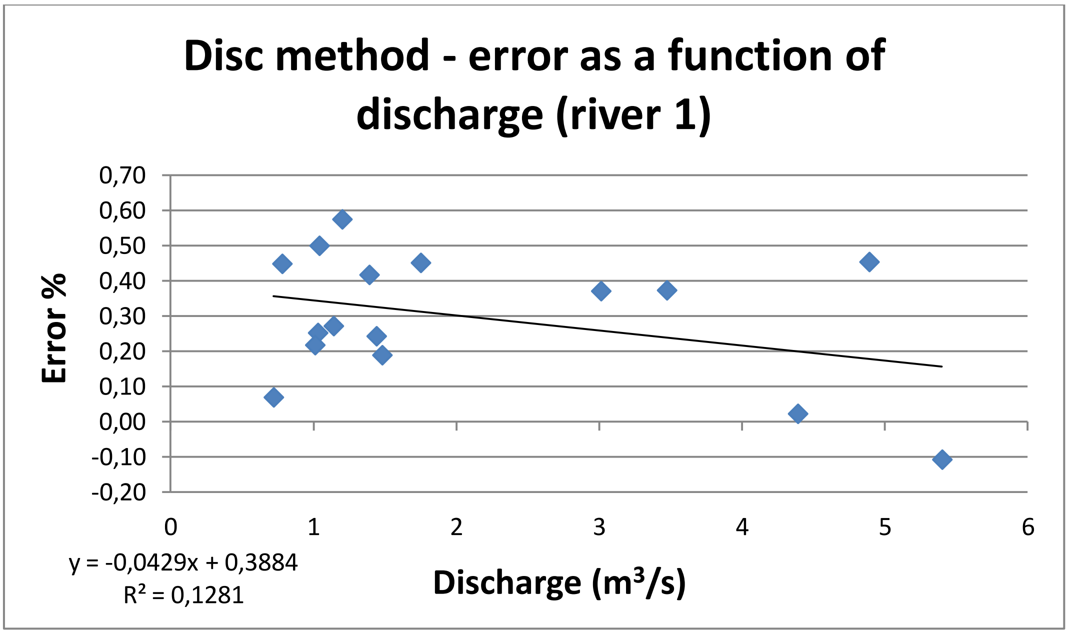


Figure 5.2.2.1 - Showing for river 1 the percent error of the 0,1m diameter disc in comparison with the “true” value obtained with the current meter. This plot is not presented in absolute values.

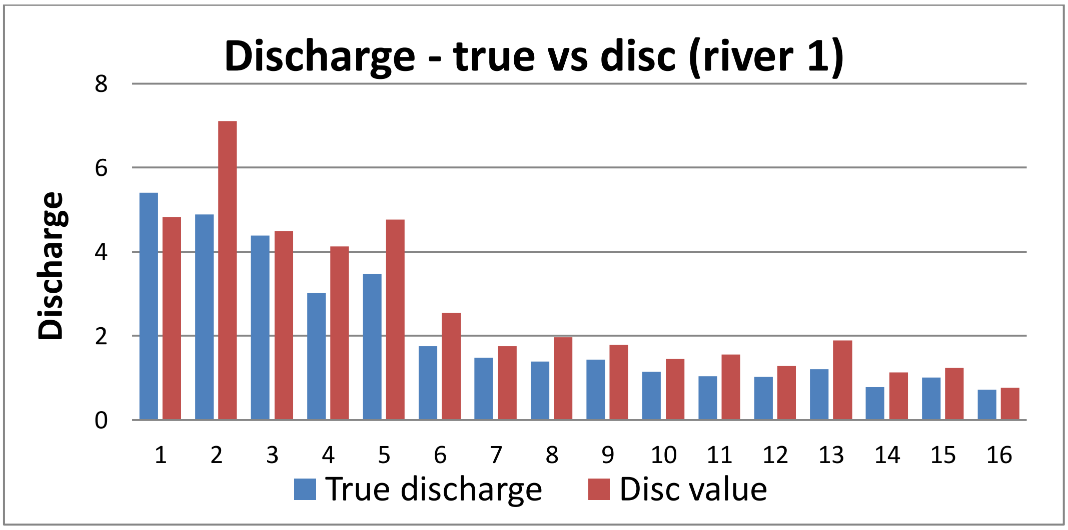


Figure 5.2.2.2 - Measurements of discharge obtained by using the 0,1m diameter disc and the corresponding “true” value presented in a staple diagram for river 1.

Figure 5.2.2.2 show the disc values and the “true” values of the flow in chronological order from earliest to latest, left to right. Both figures show the disc measuring the flow in excess of what is observed with the current meter. There is not enough data to show a pattern as to how much the error varies with flow.

Unfortunately, the middle and biggest disc with the diameters 0,2m and 0,5m were not able to be tested. The velocities of river one were too high and created instabilities when using the 0,2m disc. It was impossible to keep the equipment still enough to get an accurate reading when holding it in the river, because the force that the water generated on the disk was too great. It was often too shallow for it to be used as well. The low water velocities of river 2 were too low to generate enough force on the smaller disk in order to get an accurate reading.

The problems using the 0,5m disc were plenty. First of all it was very heavy, making it difficult to position. The channel of the slower flowing river one was often too shallow or even too narrow for the disc to be utilized. Lastly when trying to measure the velocity in the deep and wide sections of the river, where the disc could be used, the flow was often not fast enough to measure using the current meter making it impossible to find a true value.

5.2.3 Turbidity tube

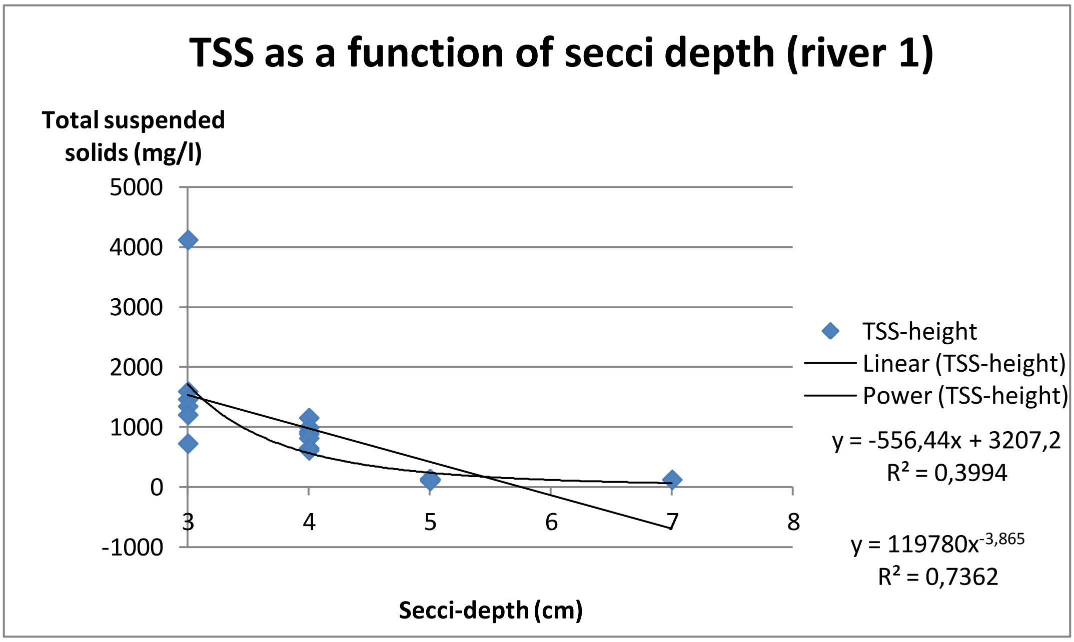


Figure 5.2.3.1 – TSS plotted against the observed secchi depth in river 1.

TSS	Secci-depth
4120	3
1594	3
1464	3
1346	3
1204	3
726	3
1154	4
996	4
924	4
886	4
814	4
650	4
614	4
136	5
135	5
119	5
104	5
123	7

Table 5.2.3.1 – The TSS-content and the corresponding observed secchi depth in river 1.

As can be seen in figure 5.2.3.1 above there is a trend of lower TSS content at larger Secchi-depths in river 1. The correlation between the linear trend-line and the line composed of the data from 5.2.3.1 is 0,3994. However, if the largest value of 4120 mg/l and the corresponding height of 3 cm is disregarded the correlation would be 0,681 which is still quite low but more promising. In table 5.2.3.1 it can be observed that the variation of corresponding TSS-content at a set secchi depth is very high, for example between 726 and 4120 (mg/l) for secchi depth 3 cm. Another equation is also fitted to the plots. When approximating the equation to $y = 119780x^{-3,86}$, the R^2 shows that it is a better fit than the linear trend suggested.

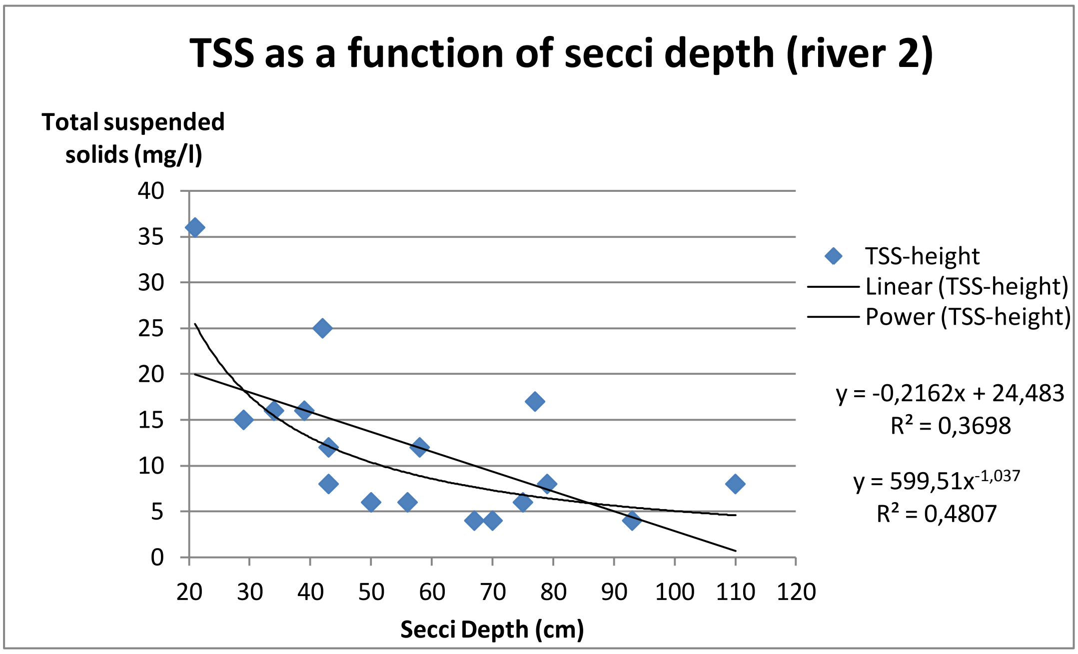


Figure 5.2.3.2 – TSS plotted against the observed secchi depth in river 2.

TSS	Secci-depth
36	21
15	29
16	34
16	39
25	42
12	43
8	43
6	50
6	56
12	58
4	67
4	70
6	75
17	77
8	79
4	93
8	110

Table 5.2.3.2 – The TSS-content and the corresponding observed secchi depth in river 2.

Figure 5.2.3.2 above show the TSS content at different Secchi-depths. There is a trend of lower TSS contents and higher Secchi-depths but the correlation between the linear trend line and the actual data is 0,3698. Even if the “extreme” values at Secchi-depths 21 cm, 42 cm and 77 cm are removed the correlation remains at 0,4214. The variation of TSS content at the same or similar depths is also apparent in this data-set. Another equation is also fitted to the plot. When approximating the equation to $y = 599{,}51x^{-1{,}037}$ the R^2 shows that it is a slightly better fit than the linear trend suggested but still low at 0,4807.

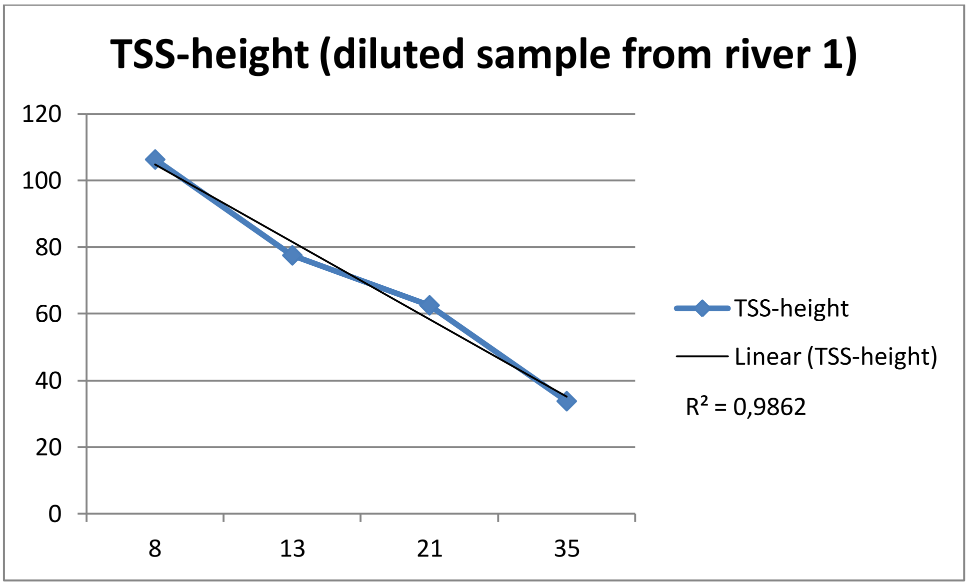


Figure 5.2.3.3 - TSS plotted against the observed height in the turbidity tube using a sample of river water diluted to 4 different concentrations.

Before the field-testing the hypothesis of a relationship between the Secchi-depth and the TSS content was investigated by diluting a sample of river water and testing the TSS-content. Four samples were made and the results are displayed in figure 5.2.3.3. The correlation between the linear trend line and the actual data set was very high, 0,9862.

Picture 5.2.3.1 – Three dilutions of river water used for the testing of the turbidity tube method, resulting in figure 5.2.3.3

5.2.4 Turbidity by photos

The NTU value of each picture, calculated using the databases created for the two rivers, is plotted against the corresponding TSS-value. The results are presented in figures 5.2.4.1 and 5.2.4.2. They show little to suggest a relationship between NTU values calculated using the photographs and the TSS content measured in the laboratory. The plots are scattered idiosyncratically, making it impossible to distinguish a curve or line to represent a relationship between the values. The database and calibration values are available in Appendix 2.

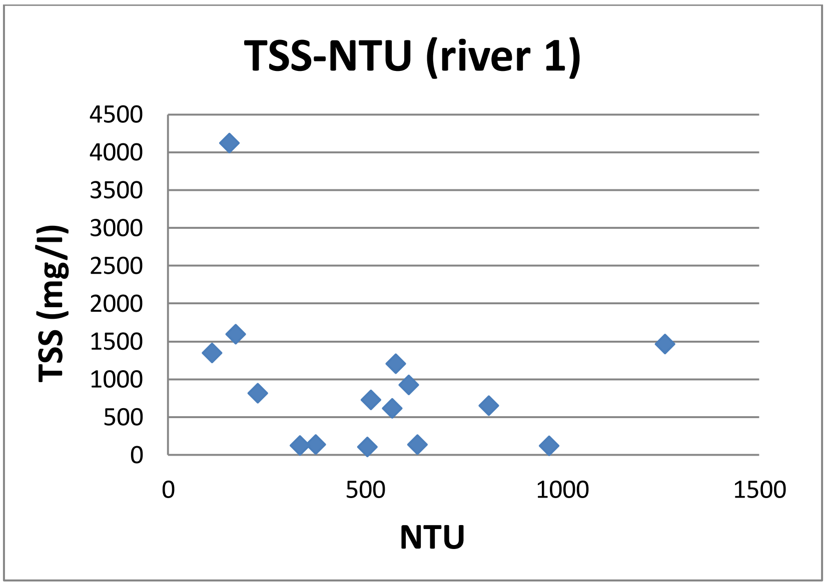


Figure 5.2.4.1 - Obtained values of TSS plotted against the NTU value calculated from the photo of the same water for river one.

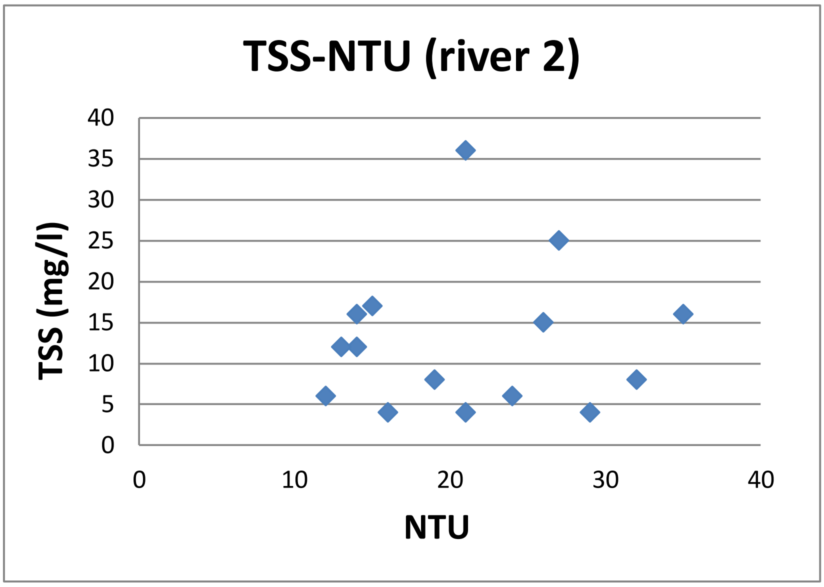


Figure 5.2.4.2 - Obtained values of TSS plotted against the NTU value calculated from the photo of the same water for river two.

6. Discussion

6.1 Stage discharge and stage sediment transport

6.1.1 Stage discharge

The rating curves in figures 5.1.1.5 and 5.1.1.6 of depth correlation show varying results. In an Ideal situation with a stable river bed, the depth of the river from surface to bottom should sink as much as the depth from the bridge to the surface of the water increases. The bridge is a geographically fixed object, which makes observations of water height simple. Unfortunately, this does not mean that the depth under the bridge will be completely proportional to the flow. The banks and riverbed of a river are under constant remodeling due to erosion, sedimentation and other processes, all which affect the height of the water surface. This means that the height of the water might increase or decrease from day to day, even though the flow is the same. The banks of river 1 have been observed to undergo large changes during the span of the project. This might partly explain the somewhat poor correlation (R^2=0,77)in 5.1.1.5, and the less coupled plots when using Manning's depth (see figures 5.1.1.1 and 5.1.1.2). Just a few years ago, the riverbed of river one is known to have been rocky as opposed to its present state; completely composed of sand. This raises the question as to how long the rating curves can be assumed to be valid. Noteworthy is that the cross section at our gauging site was largely changed between the first and second field trip, due to heavy rain during our absence.

The two figures 5.1.1.5 and 5.1.1.6 show the correlation between stage from bridge and depth. The object was to see how well the depth in the river correlated to the measurement method of looking at the stage under the bridge. The comparison was meant to give an idea of how much influence on our results the measurements of stage might have from the changes in the river bed. The deviance of the two rivers seems to be around equally large, with a difference of around 5-10cm. The deviation from the true value of the height from the water surface to the bridge might at the most be plus minus 2cm using a metal measuring tape (appreciatively), which makes the Manning's depth seem relatively poor in accuracy. Conclusively a fixed geographical object is to be preferred when measuring stage to avoid the problems with a shifting bottom profile.

No observations were made of very high stages of the river. The first of the measurements were done right at the end of wet season and only four of the higher flows were observed. Unfortunately, the stage under the bridge was not observed in river one during the two highest floods. This might be the reason for the values of figure 5.1.1.1 to have more of a linear relationship. Looking at figure 5.1.1.2, the figure is more akin to that of a rating curve with a logarithmic relationship than figure 5.1.1.1. One or two exceptionally large flows are nonetheless needed to complete the rating curves. Figure 5.1.1.1 looks to have a more clear relationship, with more closely coupled measurements (R^2=0,91) than in Figure 5.1.1.2 (R^2=0,80). The more linear and apparent relationship of figure 5.1.1.1 is likely due to a more accurate method of measuring and the fact that it is lacking the two biggest flows and even larger flows for that matter.

River number two has proved difficult to measure. The exceptionally low flows observed during almost a fourth of the field days proved impossible to measure with the flow meters and are because of that absent from our results. Some days the velocity was very low, just barely enough to measure the discharge, which question the accuracy of the flow meter at these low velocities. Holding the meter correctly without movement or contact with physical objects in the river has also proved difficult. The stage-discharge plots in figures 5.1.1.3 and 5.1.1.4 for river 2 show no clear relationship. Unfortunately only one large flow has been observed, but it is enough, together with the other plots seen in figures 5.1.1.3 and 5.1.1.4, to suggest that a high discharge will be observed at a high stage. Disregarding the highest plot in both figures the river is almost constant in flow as the depth of the river varies, not at all as to be expected of a more or less natural lowland river.

It was not until the end of the project that information was provided that there was a large dam a kilometer downstream of the gauging station. There the river water is able to be regulated and redirected over large rice fields. This obstacle may very well be the reason that the observations of discharge have been more or less the same every day for two weeks. Because the topography is very flat both up and downstream, the dam will likely affect the stage of the water even 1,5 kilometers from its position at our gauging site. In a situation where flow is constant and the dam closed, we might observe high stage, but the same overall flow the same, or even less than when the dam is open. Parts of the river water in a cross section at the gauging site has despite a middle high stage, been observed to flow backwards in the river.

6.1.2 Stage sediment

The sediment rating curves have not been successful. It is expected that a higher flow would result in a higher transportation of material in the river as figure 5.1.2.2 suggests for river 2. Figure 5.1.2.1 on the other hand, shows rather the opposite for river 1, except for the extreme value of 5000g/s. This is an interesting observation, as it contradicts our expectations. One possible contributor to this trend in river 1 is the dry and hot weather in the later field work which might have caused much of the water to evaporate from the river, leaving higher concentrations of sediment and other debris. It is known that the rivers of West Kalimantan undergo great changes in flow during the seasons. Stage and discharge measurements of the Sunggai River nearby, show that it in the wet season is 10m in depth and close to dried out in the dry season. Gold mining is practiced all year round, using the water from the river. The waste water of the process is extremely high in sediment content and is returned to the river once utilized. With little or no other base flow of clean water in the dry season, most will consist of the waste water from the mining. This might at least explain the increasing concentrations of sediment. Another source of error, which has not been taken into account, is that the propeller of the current meter was not able to be completely submerged at the lowest stages of the river in the more shallow parts. How this might affect the results, is anyone's guess, but it seems reasonable that the faster flowing surface water along with the reduced friction in the part of the propeller which is in the air might have caused the propeller to spin faster, giving a higher observed velocity. This would imply a larger observed flow and hence higher amount of transported solids in the lower stages of figure figure 5.1.2.1.

The fact that the amount of observed transport of material in river 1 is about 100 times larger than in river 2 is extreme, but plausible. The difference is painfully obvious in picture 6.1.2.1 to the right. The water of the smaller catchment flowing in to river one as seen in the picture is similar in color and turbidity to water in river 2. Some water samples of river 1 have been observed to remain yellow in tone for weeks, while particle loads of other samples are completely sedimented in a matter of days. This suggests big variations of the particle distribution.

Picture 6.1.2.1 – Water originating from small catchment consisting of domestic- and forest-areas meets the sediment saturated water of river 1. The picture is taken in a downward angle and the depth is around 7cm.

The non consistent TSS values of river one (and poor correlation with Secchi depth in section 5.2.3) might have many explanations such as:

- The lab analysis of TSS-content, conducted by a third party at the agricultural department using a standard procedure filtration method, might not be accurate. As far as the procedures go they are well laid out and not likely to cause error. The procedures not being followed correctly by the individual performing the test is a likely source of error. It is however hard to determine whether this is the case.
- Mistakes might have been made when collecting the samples. When collecting samples care was taken to no disturb the bottom and to draw the samples from the middle of the water, but it is possible that this was not done correctly. This might result in larger or lower sediment content in the sample than the average for the water that day.
- The analysis of the samples was carried out at different lengths of time after their collection. In some cases, more than two weeks passed before the samples were analysed. Leaving the samples to settle makes the solids in the water cohere and sediment. If the tests cannot be carried out as recommended, immediately after sampling, great care must be taken to shake the samples to homogeneity before filtration.

- The overall biggest contributor to the properties of the water the human activities upstream. It is safe to say that the land use practiced in the area such as gold mining and deforestation will affect the sediment content not only in the long term, but also cause large oscillations in the composition and amount of material in the river from day to day. This might explain, at least in river 1 the large variations in TSS.

Picture 6.1.2.2 – The effects of gold mining practices. Seen in the background is natural forest and a pond. The white, coarse sand in the foreground is what is left after deforestation followed by mining of gold in the first few meters of soil. Most fine sediment and all soil is washed away in the process.

6.2 Simple methods

6.2.1 Float method

The float method was the most successful method for measuring the flow in river one. Both the maximum error and the average error were within an acceptable range of the value achieved using the flow meter. The method was much less successful at river two where the error is larger than what can be accepted.

It seems that the method was more successful at higher discharge which probably stems from two main reasons.

- At lower discharge, the velocity is lower and disturbances such as wind, resistance in the line or flowing debris will affect the velocity to a larger extent. This was especially evident in river number two where the velocity was very low at low discharges. That leads to resistance in the line and wind affecting the velocity to a large degree than at higher discharges.
- When the discharge is lower, the depth of the water is lower causing the bottle to hit or drag on the bottom. This was especially evident at low discharges in river one where the water depth sometimes went below 10 cm at low discharges.

6.2.2 Disc method

Using the disc method to calculate the total flow in a river has not proven to be accurate. As uncertainties are large, even with proper measuring equipment, an error of approximately 20% is still acceptable for this method. 50 or 60 percent as shown in figure 5.2.2.1, is simply too large an error to consider useful. However, as seen in figure 5.2.2.2, the method does show that it to some extent mirrors the “true” values, at an average of 30% too large on the readings. The method might need a calibration coefficient to compensate for the enlarged reading. In order to properly calibrate the method, it is necessary to test the disc(s) at different water speeds, to show how the readings correlate to the actual flow. The method used in this study was primarily designed to test the apparatus to see if it is practically applicable. As of now, we can only guess as to how accurate the apparatus really is in determining the actual speed of water.

This method was however only a prototype, for which many adjustments are needed in order to make a useful piece of equipment. As of today the equipment is heavy and unwieldy, making measurements are hard to read. Several practical issues and suggestions for improvements have been identified:

- The staff needs to be able to be held still, suggestively by lengthening it so that it can stand on the bottom and thus also function as a staff gauge.
- The height of the disc needs to be adjustable by other than by holding it still at one height. This would be accomplished by introducing some way of positioning the wheel which the string runs on at different heights on the staff.
- Ideally the disc is constructed in such a way that it is neutral in buoyancy. This would eliminate the need for a float or holding the string which suspends the disc in the water.
- Three instead of four strings attached to the disc will likely make adjustments of their lengths easier. Having then welded to the disc would also be a good idea, since they tend to dislodge.
- The Newtonmeters used were on a scale from 0-2 N and 0-24N and were visibly worn down. The design and size of the discs are optimized for forces of 0-10N. Two well functioning newton meters, one from 0-2 and one from 0-10 would improve the accuracy of the test.

6.2.3 Turbidity tube

There is a trend of lower turbidity at higher TSS-contents as expected. However in order for this method to work there must be a strong connection between the TSS-content and the Secchi-depth. The variations of TSS-content are too great at the same or similar Secchi-depths to give an accurate measurement of the sediment content in the water.

One explanation as to why the results were poor is that there is no relationship between the turbidity and TSS-content. This does not seem likely since a higher particle content will mean more particles scattering light. Thus decreasing the light penetration and in turn decreasing the Secchi-depth.

Four possible sources of error are the following:

- As explained in section 6.1.2 of the sediment rating curves, the laboratory analysis might be poorly conducted.

- Our reading of the turbidity in the field might not have been accurate in the field. When performing the reading of the Secchi-depth, care was taken to create similar lighting conditions etc. to ensure that the readings were accurate. Measurements were done in the same spot each day, but some days were overcast and some sunny, making for differing light conditions. Also, the readings were performed by the authors and therefore introducing the distinct possibility of human error as personal judgment was used in order to determine when the disc was no longer visible.
- The sampling of water as explained in section 6.1.2 might not have been conducted properly.
- The relationship between the TSS-content and the turbidity is more complex than a simple direct relationship. Perhaps the sediment content of the river is different on different days, depending on which activities are done upstream, and different particles are affecting the turbidity in different degrees. Therefore depending on the particles in the river, the same Secchi-depth could have varying corresponding TSS-contents.
- Flux in nutrients or carbon particles from farming or other processes could affect the visibility to a greater extent than the sediment in the water. The biological processes such as growth of algae or bacterial degradation could have effects of the results.

6.2.4 Turbidity by photos

This method of measuring sediment content in water is as of now just a prototype and the data that has been gathered is so far the only data from actual field work yet to be analyzed using it. As mentioned in the result section of this method, there are no signs of correlation between the measured color and TSS. There are many aspects of this method which contribute to uncertainty of the results.

- The TSS-analysis performed by the Agricultural lab, as mentioned in section 6,1, may not be reliable.
- Only one sample of water from each river is used for the calibration and is assumed to be representative at any stage of the river. Higher or lower floods will carry sediment with different particle distributions.
- The calibration of the databases for the two rivers was performed around two weeks after the last sample was collected. The samples have been observed to alter their color after only a week, probably due to oxidation processes of the waters contents. This will affect the observed amount of colors in the photographs taken of the solutions for the database.
- Light conditions, time of day, weather etc. when photographs were taken have varied significantly from day to day. Shadows, reflections and direct sunlight on the beaker made photographing under monotone conditions difficult.

7.1 Conclusion

7.1.1 Stage discharge

Measuring Stage and discharge during a limited period of time has proved to be difficult and somewhat inefficient. Many of the same flows have been recorded and the actual fieldwork is expensive and logistically challenging. In order to collect data from a region as big as the Kapuas with limited resources, the equipment needs to be much cheaper and easy to repair and replace. Sporadic excursions at different times of the year in order to establish a rating curve is likely to give more conclusive and useful results, as more differing values are able to be collected to get a relationship in a larger span.

7.1.1 Sediment transport

This study has yet to find a simple method able to cope with the extreme sediment loads of river 1. Not even for the cleaner river 2 does the turbidity tube seem to provide useful results. Neither has the turbidity by photos method produced any viable results at this moment. As the sediment load of river 1 has been observed to undergo large variations in both amount and content, maybe a more crude way of measuring the sediment content is all that is needed, or for that matter useful, for future monitoring. Better routines for testing sediment content shortly after sampling are also necessary. It is not certain that the procedures of the TSS analysis have been poorly conducted. The rivers might be as extreme in the fluctuation of sediment content as the results predict. It is however necessary to thoroughly ensure that the lab work is performed correctly if the work is outsourced.

7.2 Simple methods

7.2.1 Float method

By far the cheapest and so far best alternative to conventional flow measurements with a current meter found in this study. The measurements take in total 30 minutes, tying rope over the river and measuring depth every two meters in order to get a profile included. For this minimal effort and at almost no cost, this has so far proved adequately accurate at higher discharge. Letting the fishing line first flow downstream while holding its end reduces the risk of tangling and reduces the friction in and on the line during slow flows, which has been observed to affect the results. By using the line, the same bottle can be utilized numerous times rather than letting the bottle flow off downstream which in itself pollutes the river. It also makes it possible for one single person to perform the testing. Measuring velocities lower than circa 0,5m/s has not been successful. The method is simple enough to be used by anyone and easy to explain.

7.2.1 Disc method

This method has potential to be used for measuring water velocity if it is further refined. As opposed to conventional current meters the cost and maintenance of the equipment is cheap and easy. The current meter used for the true value costs ca 6200 US dollars whilst manufacturing all the equipment for the disc method in Indonesia is at around 30 US dollars. Repairs are several times cheaper and easier, carried out with a few basic tools. It has the benefit of also functioning as a gauging stick for cross sectional analysis if redesigned as described in the discussion section 6.2.2. This method is slightly more complicated than the float method, but has several advantages. It takes only about five seconds to get a reading, it does not tangle as much as the float and you can use it at different heights is so desired. It can also be used in channels which are very narrow or filled with obstacles where the float method might not be suitable. It has proven easier to work with smaller discs. A more sensitive apparatus using smaller lighter discs might be more practical. Wielding an eight kilo disc at a diameter of 0,5m is not convenient in any way.

7.2.3 Turbidity tube

This method is a well documented way to record turbidity but this study has not been successful in finding a strong correlation between the turbidity and the sediment content. However, testing it by simply diluting one single sample proved very successful, suggesting that the method might be more successful in a different setting. The fact that it is recommended for turbidity testing by several reputable organizations speak for it. Conclusively our studies suggest that another way of measuring or further refining of the method is needed in order to cope with the extreme conditions of river 1 and the less polluted river 2.

7.2.4 Turbidity by photos

Looking at the pictures it is clear that the color and lighting of the beaker from day to day varies profoundly. The field work needs standardization of the method for photographing in order to be able to compare the photos. A high quality camera is simply not enough to cope with the varying light conditions, or maybe the method is just not sufficiently accurate. Several aspects of the method have to be overlooked and refined in order to achieve a useful tool for measuring sediment content in river water. Something is needed in order to standardize lighting conditions. Suggestively a boxed fixed with a light bulb with a certain amount of watts fixed in the roof of a box in which the beaker is placed in at a specified place. Using the same camera with the same settings every time, from the same angle, will likely help improve the results.

7.3 Overall conclusion

Overall there is a need for more data, both concerning the methods and to complete the stage-discharge and stage-sediment curves for a larger range of stages. Stage-discharge and stage-sediment curves have been created and might prove useful in the future if extended. Some of the methods that have been tested in this report have been successful and some have not been. The methods have also only been tested during the dry season and considering the huge changes in precipitation the discharge is expected to be much higher during the wet season. This might make it difficult to use the methods in the way described in this report. Also, these rivers in which the methods have been tested are quite small. It is of course desirable to monitor all rivers in the Kapuas catchment area but initially it is probably of more interest to map bigger rivers since the changes in them have greater effects on the citizens of west Kalimantan. Some of the methods might adapted to suit bigger rivers which is also something to consider for anyone interested in testing any of these methods further.

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Appendix 1

0-24 Newton			
weight (kg)	actuall (N)	reading (N)	difference (N)
2,05	20,131	20,2	-0,069
1,55	15,221	15	0,221
1	9,82	10,4	-0,58
0,5	4,91	5,2	-0,29
0,25	2,455	2,8	-0,345
		avarage=	-0,2126
correction coefficient negligable			
0-2 Newton			
weight (kg)	actual (N)	reading (N)	difference (N)
0,0496	0,487072	0,662	-0,174928
0,097	0,95254	1,08	-0,12746
0,153	1,50246	1,68	-0,17754
0,1997	1,961054	2,17	-0,208946
0,2253	2,212446	2,3	-0,087554
		avarage=	-0,1552856
correction coefficient = -0,16N			

Table A.1 - Calibration of Newton meters for disc method. “weight” is the weight used for the calibration.

Disc method calibration calibration (a bottle filled with water), “actual” refers to the theoretical reading produced by the particular weight according to F=m*a, “reading” is the observed value on the meter and “difference” is the difference between the two values. The difference is averaged and used as a correction.

Appendix 2

Calibration of photo method (river 1)

No	Sample	NTU	Pt-Co	RGB		
				Red	Green	Blue
1	10 ml S + 90 ml A	123	92	**232**	**218**	**183**
2	20 ml S + 80 ml A	259	185	**224**	**209**	**174**
3	30 ml S + 70 ml A	415	287	**213**	**194**	**158**
4	40 ml S + 60 ml A	582	419	**229**	**210**	**175**
5	50 ml S + 50 ml A	753	491	**214**	**194**	**155**
6	60 ml S + 40 ml A	893	700	**200**	**178**	**135**
7	70 ml S + 30 ml A	1060	830	**199**	**171**	**130**
8	80 ml S + 20 ml A	1150	870	**189**	**162**	**119**
9	90 ml S + 10 A	1330	940	201	174	135
10	100 ml S	1470	1140	211	186	146

Table A.2.1 - Calibration of water colour in River 1. A is distilled water used to dilute the sample (S).

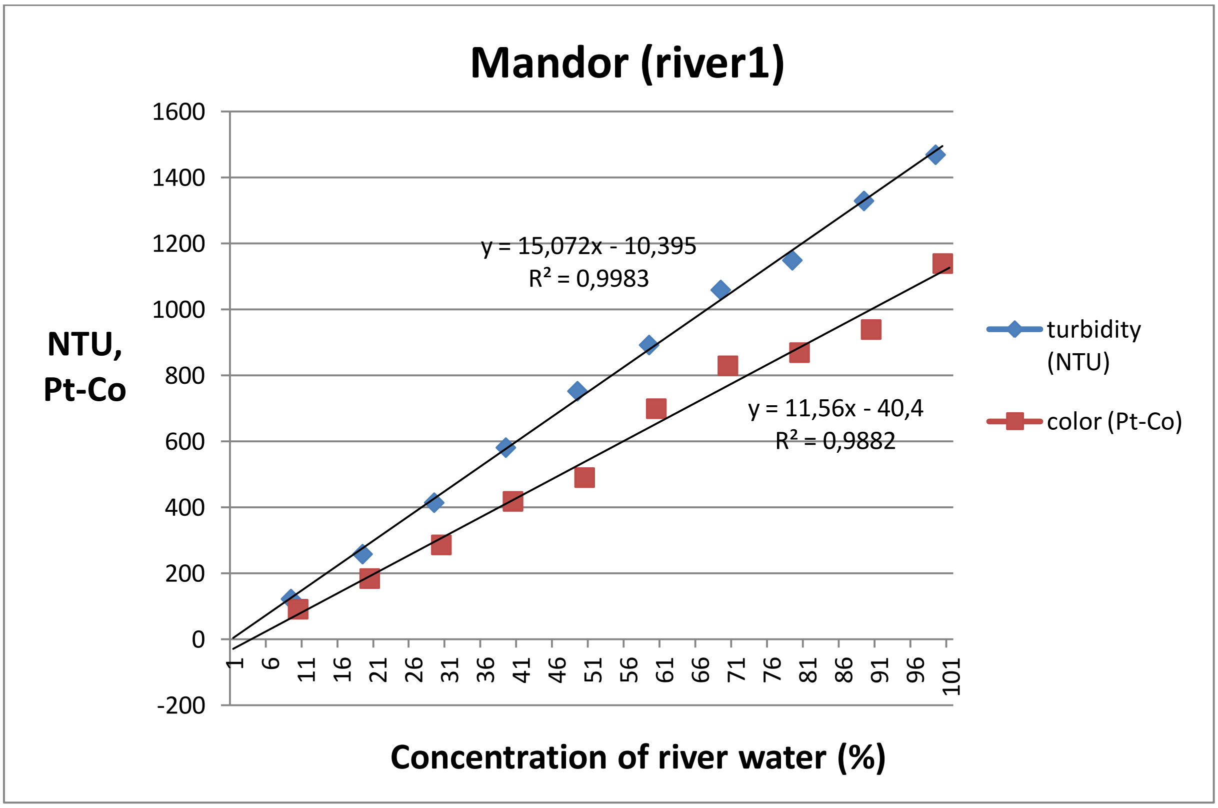

Figure A.2.1 – Calibration of photo method. Water from river 1 diluted several times plotted against measured NTU and Pt-Co relationship

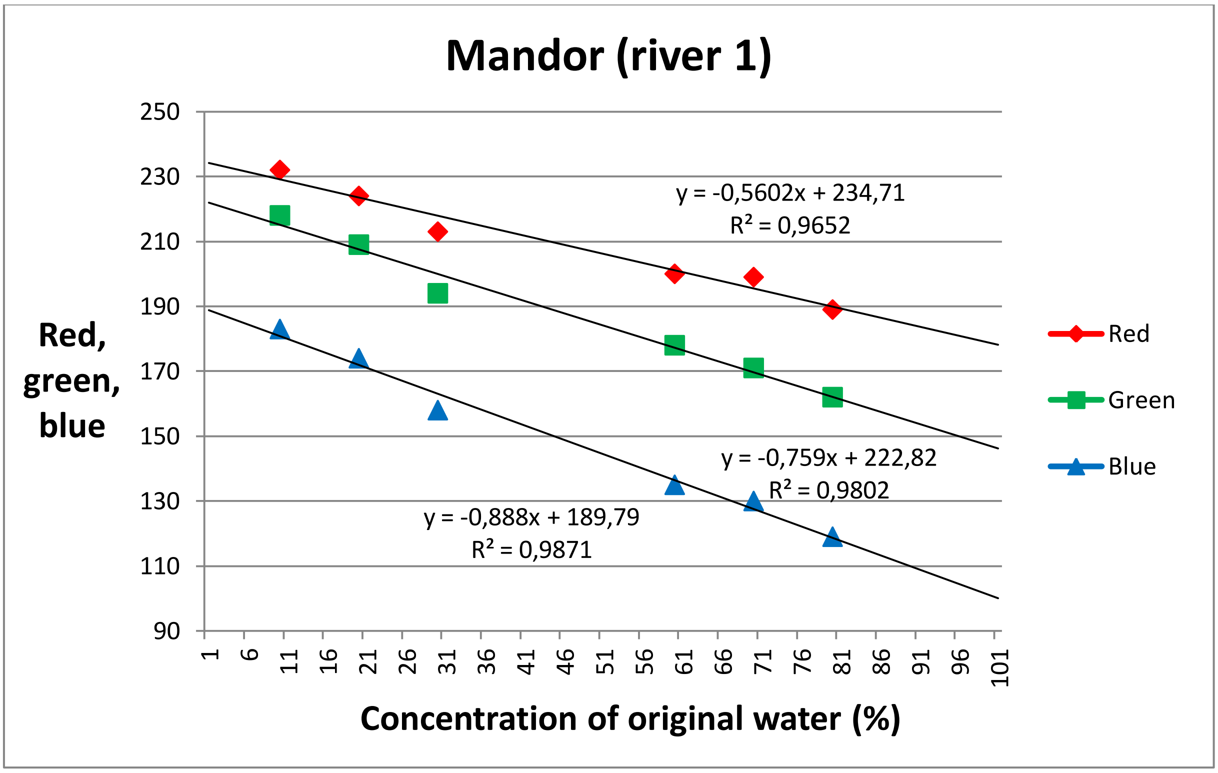

Figure A.2.2 - Detected amounts of color in calibration photo of dilutions of water from river 1.

Calibration of photo method (river 2)

No	Sampel	NTU	Pt-Co	RGB		
				Red	Green	Blue
1	10 ml S + 90 ml A	3,15	20	232	240	240
2	20 ml S + 80 ml A	6	39	**240**	**247**	**243**
3	30 ml S + 70 ml A	8,34	65	**236**	**241**	**233**
4	40 ml S + 60 ml A	10,3	78	238	242	229
5	50 ml S + 50 ml A	12,8	104	**232**	**235**	**222**
6	60 ml S + 40 ml A	13	124	**228**	**230**	**212**
7	70 ml S + 30 ml A	16,7	138	233	235	215
8	80 ml S + 20 ml A	22,5	152	235	231	211
9	90 ml S + 10 A	23,8	163	235	231	209
10	100 ml S	28	165	234	233	207

Table A.2.2 - Calibration of water colour in river 2. A is distilled water used to dilute the sample (S).

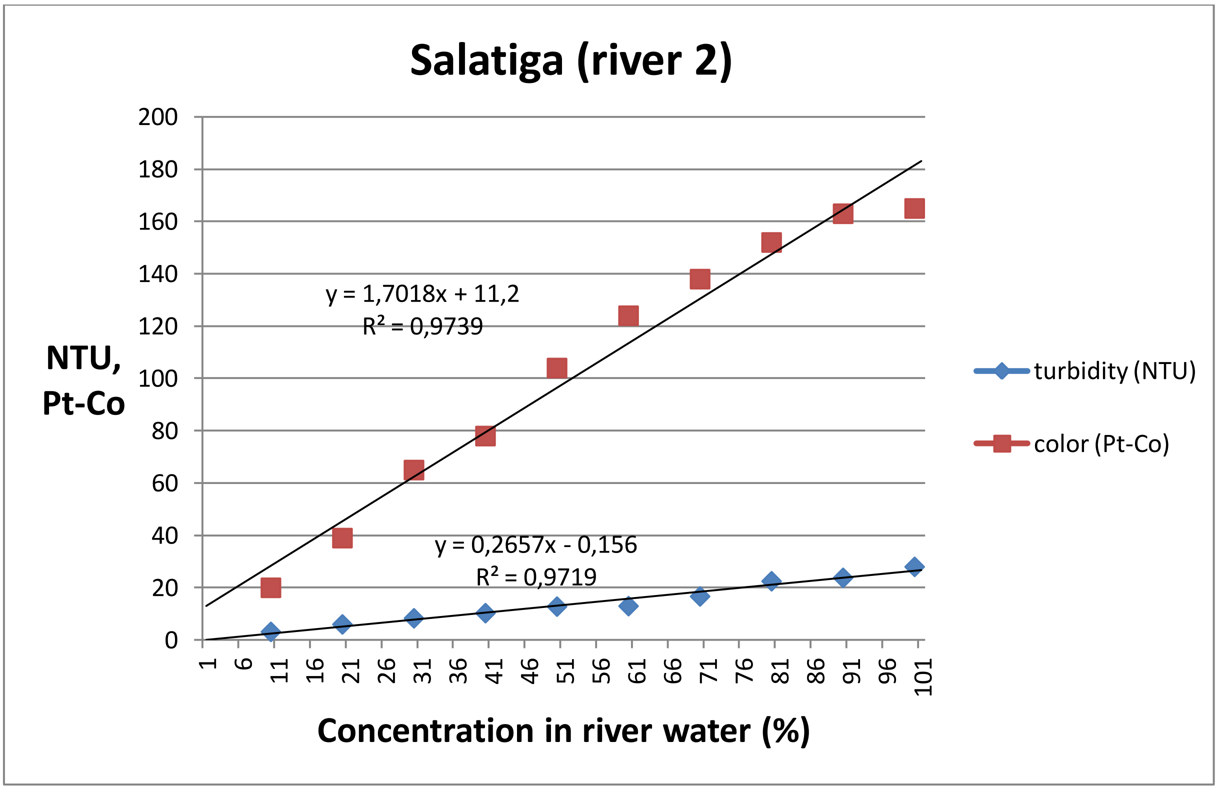

Figure A.2.3 - Calibration of photo method. Water from river 2 diluted several times plotted against measured NTU and Pt-Co relationship

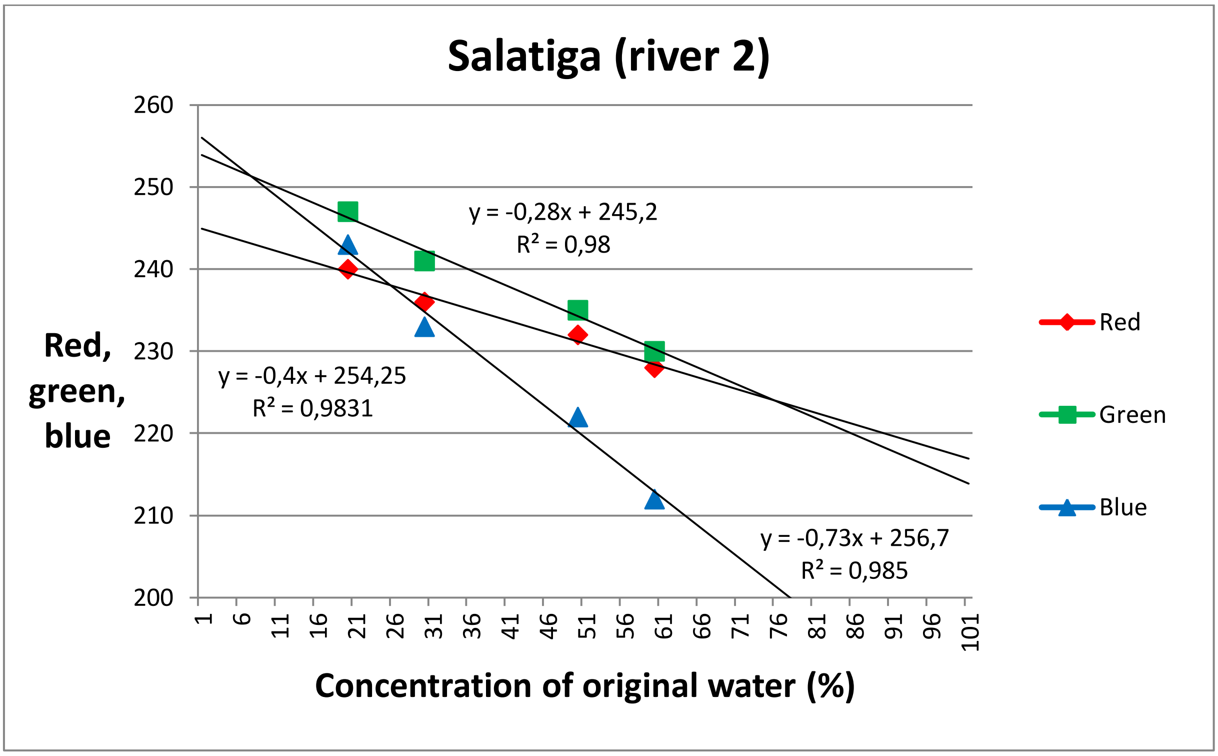

Figure A.2.4 – Detected amounts of color in calibration photo of dilutions of water from river 2.

Appendix 3

River 1

Date	Q (m3/s)	D bridge (m)	D river (m)	TSS (mg/l)	T. tube (cm)	Float (m3/s)	Photo (NTU)	Disc 0,1 (m3/s)	Disc 0,2 (m3/s)
21-maj	5,4		0,68		4			4,82	
22-maj	4,89		0,48	135	5	5,59	632	7,11	
23-maj	4,39	2,77	0,33	136	5	3,22	374	4,49	
24-maj	3,012	2,81	0,35	104	5	2,88	505	4,13	4,36
25-maj	3,473	2,92	0,37	119	5	3,24	966	4,77	
26-maj		2,82	0,43	123	7		334		
15-jun	1,75	3,00	0,243	886	4	1,65		2,54	
16-jun	1,47	3,03	0,23	814	4	1,17	227	1,76	
17-jun	1,39	3,00	0,27	650	4	1,29	813	1,97	
18-jun	1,44	3,03	0,18	614	4	1,09	568	1,79	
19-jun	1,14	3,05	0,12	924	4	0,90	610	1,45	
20-jun	1,04	3,05	0,16	996	4	0,97		1,56	
21-jun	1,03	3,08	0,17	1154	4	0,83		1,29	
22-jun	1,2	3,07	0,22	4120	3	1,06	155	1,89	
23-jun	0,78		0,2	1464	3	0,65	1260	1,13	
24-jun	1,01	3,08	0,18	726	3	0,80	514	1,23	
25-jun	0,72	3,10	0,13	1204	3	0,53	577	0,77	
26-jun	0,81	3,11	0,11	1346	3	0,78	111		
27-jun	0,54	3,11	0,18	1594	3	0,47	171		

Table A.3.3 – All data collected from river 1.

River 2

Date	Q (m3/s)	D bridge (m)	D river (m)	TSS (mg/l)	T. tube (cm)	Float (m3/s)	Photo (NTU)
21-maj	0,88					0,9351	
22-maj	0,65		0,68	12	58	0,7558	14
23-maj	0,34	4	0,45	6	75	0,3565	12
24-maj	0,36	4,07	0,45	17	77	0,5102	15
25-maj	2,43	3,58	0,97	15	29	2,5908	26
26-maj		3,62	0,98	25	42		27
15-jun		4,04		16	39		
16-jun							35
17-jun	0,32	3,75	0,75	36	21	0,6172	21
18-jun	0,19	4,25	0,36	6	50	0,2443	24
19-jun	0,36	4,25	0,36	12	43	0,4863	13
20-jun	0,22	3,90	0,60	8	43	0,4797	
21-jun	0,13	4,08	0,55	6	56	0,3104	
22-jun		4,15		4	70		21
23-jun		4,14		4	67		16
24-jun	0,57	3,97	0,57	16	34	0,418	14
25-jun		4,14		8	110		32
26-jun		4,14	0,38	4	93		29
27-jun		4,10	0,41	8	79		19

Table A.3.4 – All data collected from river 2.