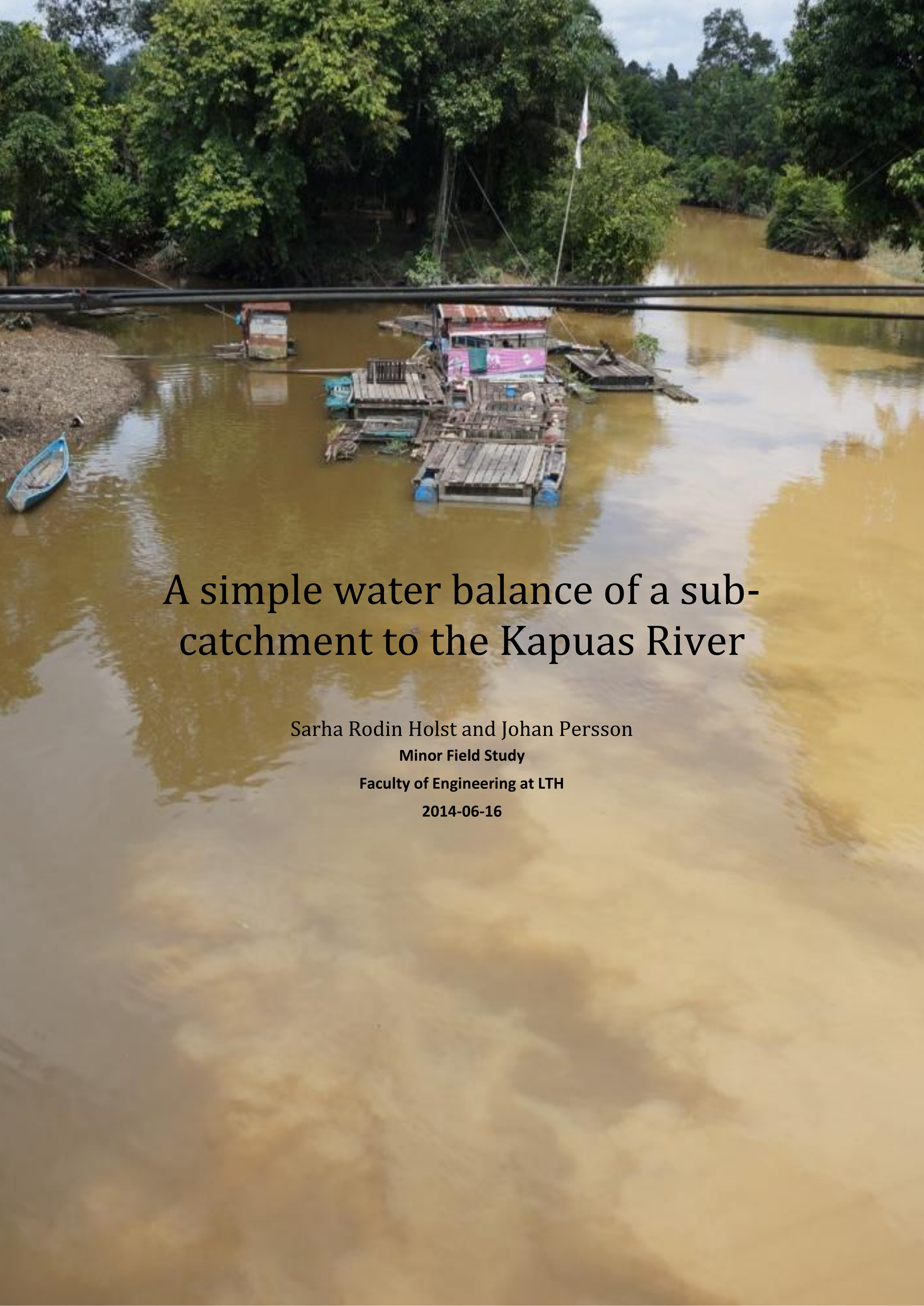

A simple water balance of a sub-catchment to the Kapuas River

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Minor Field Study

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Abstract

In developing countries across the world people are depending on rivers as a source of water for drinking, cooking and bathing. This is also the case in the Indonesian part of the island Borneo where this study was made. The largest river is the river Kapuas which, together with its tributaries, supplies the area with water. The hydrology of these rivers is changing and the quality of the water in them is deteriorating. This is due to mining industries, logging, and oil palm plantations as well as the large amounts of waste that is deposited in the water. These changes can be hard to observe since they are gradual and little to no data exists on the previous condition of these rivers.

This study was conducted to make a simple water balance model using simple methods to begin to establish an understanding of a tropical rainforest catchment. Very basic methods are a necessity when carrying out work in the region since almost no equipment is available.

The fieldwork was conducted on a sub-catchment to the Kapuas River in the village of Sosok. For five days in December from the 17th to the 21st, which is the rainy season, fieldwork was carried out. Measurements were taken of flow, depth, amount of rain, and sediment transport in the rivers in the area of investigation. Two rivers, which flow together to form one, were used as the site of this study. Three stations were established, one in each river, were measurements were taken several times a day.

This data was then put into a simple water balance model to see if the model would yield the same results as those that were observed during field work. Many assumptions had to be made regarding surface runoff, groundwater infiltration, evaporation as well as other factors. To use the water balance model one needs a basic understanding of hydrology to know which assumptions are realistic and which are not. The results of the study show that the model can yield results similar to those in the field. The accuracy is high enough that one can gain a basic understanding of the hydrological situation in a catchment by only using very simple methods.

Key words: the Kapuas River, Sosok, water balance, simple methods.

Table of Contents

1. Introduction

On the southwestern edge of Borneo lies the Indonesian province of West Kalimantan. The capitol of this province is Pontianak, a city with some 450 000 inhabitants (GeoNames, 2013). Through this city flows the Kapuas, Indonesia's largest river. Draining into it, all along the province, are the many tributaries that feed the Kapuas with water. Little is known about these catchments because there are many difficulties inherent in trying to estimate their water balance. Not only are they hard to reach, but there is little technology and few people who care. Foreign investigations that have been carried out in the area have been done by quick visits. They bring technology and engineers, do their measurements, write a report, and disappear. Local resources cannot replicate the results because they don't have the equipment or, in some cases, the education. This report aims to test a simple water balance using simple methods that should be easy to replicate. Hopefully this approach can then be used as a first step to start a basic mapping of the sub-catchments of the Kapuas to get a greater understanding of the hydrological conditions in the area.

2. Background

2. 1. The Kapuas River

The river Kapuas flows from the heart of Borneo, crisscrossing the region called West Kalimantan and ending in the Java Sea on the west coast. The river is the main source of fresh water for the people inhabiting the land around it. Its water is used for everything; drinking water, hygiene, cooking, cleaning, disposal of human and cattle feces and garbage, a way of transport and as a source of irrigation for plantations. It is the main water supply for the city of Pontianak, situated at the mouth of the Kapuas River as it drains into the ocean. The river is essential for the people in the area, however, a number of environmental problems threaten the water use, the animals in it, as well as the health of the people in the catchment.

The constantly increasing deforestation, due to oil palm plantations, is a large factor which contributes to the disturbance of the discharge of the Kapuas River (Lusiana et al, 2008). When the rainforest is cut down to make way for the oil palm industry, the protective layer of canopy and roots in the ground is removed making it easier for the soil to erode. The loss of roots also makes the ground less porous, which increases surface runoff, further aggravating the problem (Hamill, 2001). Large volumes of sediment and organic particles are washed into the Kapuas River during heavy rain falls, worsening the water quality. The increased surface runoff also raises the risk of flooding.
The land erosion is a serious issue during rain periods. There is an urgent need to study these environmental problems and to find solutions to improve the water management in the area.

Several of the catchments that drain into the Kapuas River are contaminated by mercury which springs from illegal small scale gold mining, see figure 2.1.1. Mercury is used to produce amalgam which is applied when separating gold from unwanted organic materials. The local inhabitants consider the mining industry to be a promising source of income and employment. This type of business has increased since the economical crisis in 1998 (Adijaya and Yamashita, 2004). The process of mining also produces large amounts of sediment making the water murky. Sunlight cannot penetrate the water killing plants and in turn fishes and other animals in the rivers and disrupting the ecosystem, (Brönmark and Hansson, 2005).

Figure 2.1.1. – Picture illustrating the process of mining. Used waste water is washed out into a nearby river resulting in large amounts of sediment transport. (Picture taken by lecturer at Linkungan faculty, Tanjungpura University.)

The starting point for any water management or environmental study of the catchment has to be a better understanding of its hydrology. When the hydrology is better known plans for the river's management can start to form. The Kapuas catchment covers close to 70% of West Kalimantan and the river has a mean annual discharge of about six to seven thousand m^3/s (Unesco, 2004). It is extremely hard to get an overview of the catchments tributaries, the sub-catchments, and all their functions. This report focuses on one of the sub-catchments of the Kapuas; Sosok. Here, a simple water balance model can be tested to see if it is reliable enough to use as a tool when studying other such sub-catchments. It will also serve as a base for further studies.

2. 2. Difficulties

West Kalimantan is one of the poorest provinces in Indonesia (OECD, 2013). Many roads are in poor repair and there is little to no public transport. Getting out in the terrain to do fieldwork can be extremely difficult and there is almost no modern equipment available. There is also a lack of data since there are precious few stations that measure precipitation and even less that measure river depth. Not to mention that certain remote areas of the Kapuas and its tributaries contain crocodiles, anacondas and other dangerous animals.

In this report we have, by necessity, had to use very simple methods to carry out our measurements. These methods accuracy are not as great as those of modern equivalents but they are good enough for our purposes. The point of this report is that this kind of fieldwork should be able to be repeated for different rivers and sub-catchments in West Kalimantan. That purpose would be utterly defeated if we were to bring expensive equipment from Sweden, use it, and then bring it home with us. The methods in this report can be carried out in the poor conditions stated above and with little budget.

2. 3. Aim of project

The purpose of this project is to observe and establish a water balance for a sub-catchment to the Kapuas River basin, focusing on the surface layers. The intension is to establish a basic understanding of how water moves in a typical rainforest catchment in the regions of Kapuas. Thus rainfall, discharge, infiltration and evaporation must be studied in order to understand the hydrology of a chosen sub-catchment.

We will create a simulation of a very simple water balance fit for a chosen catchment and examine if it works by collecting input data with simple methods. It is of great importance that the methods used for collecting data are very basic, inexpensive and easy to carry out. Our hope is that in the future, measured data and analyses carried out throughout this project can be used as a tool or template for future work with understanding the catchments around the Kapuas River and for developing a plan for water management.

Our objectives can be summarized as:

- Establish a rudimentary surface layer water balance for a small sub-catchment to the Kapuas River.
- Establish stage-discharge and stage-sediment curves for chosen stations at field site.
- Use simple and inexpensive methods for measuring input data to the water balance.
- Make our report available for further analysis and study at Tanjungpura University.
- Strengthen the cooperation between Lund University and Tanjungpura University.

3. Theory

3. 1. Area-velocity method

The area-velocity method is a simple the velocity of the water flowing through the cross-sectional area of that river (Subramanya, 2008). The chosen site, often called the gauging site, is preferably situated where the river flow is relatively constant and the riverbanks are stable. To be able to calculate flows for a long period of time from the same location, the following criteria should be considered when choosing the gauging site:

- The stream should have a well-defined cross-section which does not change in various seasons.
- The depth should be greater than 0.3 m.
- The velocities should all be higher than 0.15 m/s.
- The distribution curve for velocity should be regular in the vertical and horizontal plane.
- The gauging site should be in a straight, stable reach.
- The site should be free from backwater effects in the channel.
- The stream should be easily accessible all through the year.

The cross-section is measured by dividing the river into several smaller vertical rectangle subsections. The accuracy increases with the amount of vertical sections made. The depth, D_i, from river surface to bottom is measured for each subsection and multiplied with the width, W, of the segment. Consequently the area for each subsection is given by equation (1).

$$A_i = D_i * W \qquad (1)$$

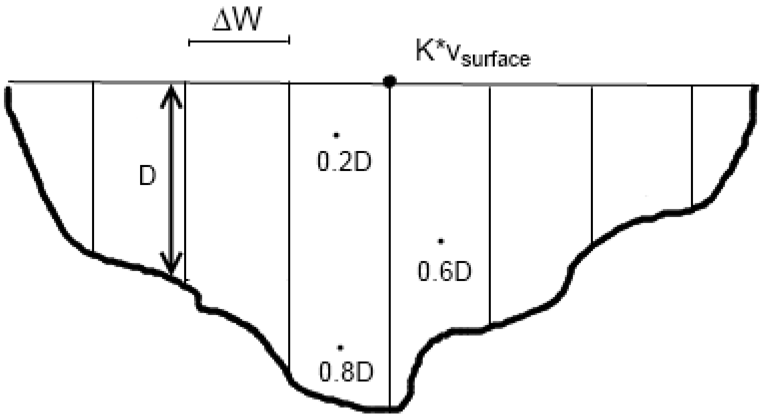


Figure 3.1.1. – Cross-sectional picture of a river showing at what depths and width intervals that the velocity measurements can be performed in order to compute discharge.

The speed over the cross-section is measured by a velocity apparatus such as a current meter or a floating device. When using a current meter, the *two point method* is often used. Two velocities are then measured at a depth of 0.2*D and 0.8*D respectively from surface to the bottom, in order to calculate an average velocity in each subsection of the river profile (Shaw, 1994), eq (2). However if the river is no deeper than 3 meters one can use the *single-point method* by measuring the velocity at a depth of 0.6*D below the water surface, eq (3). In shallow rivers or rivers prone to flooding the velocity may be measured as the surface velocity and at a depth of 0.5 meters below the water surface. The average velocity is thus obtained by using a reduction factor, K (Subramanya, 2008), eq (4).

$$v_i = (v_{0.2} + v_{0.8})/2 \qquad (2)$$

$$v_i = v_{0.6} \qquad (3)$$

$$v_i = K * v_{surface} \qquad (4)$$

Discharge is calculated by $Q = A * v$, hence the river flow is given by equation (5), depending on the method used for measuring the velocity of the river.

$$Q = \sum A_i * v_i \qquad (5)$$

The discharge measurements do not need to be collected in the exact same location as the depth measurements if a stage/discharge relationship is to be established. The discharge is normally consistent for some distance of the channel nearby to the site where depth is measured (WMO, 1994).

3. 2. Float method

The float method is a simple way of measuring velocity in a river under primitive circumstances. In order to receive relatively accurate measurements when using this method one should apply it on small rivers, but with a flow above 1m^3/s and a depth of more than 0.5m (Carlman Bydén and Hallerth, 2013). The velocity is estimated by timing the movement of a float over a known distance. The distance is then divided by time, giving the velocity of the surface water. The velocity profile of water varies with depth as a result of friction against the bottom of the river bed. Consequently a reduction factor must be multiplied with the observed surface velocity in order to calculate the average velocity over the depth, as mentioned in section 1.2 eq (4). For rivers of 1-5 meters depth, a factor of 0.7 is recommended (Shaw, 1994).

The float may be an object of relevant size to the river, such as an orange for a small stream or a bottle of water for a larger river. It is important that the object is as submerged as possible without sinking in order to minimize the effect of wind decreasing the speed. A uniform and relatively straight part of the river with little vegetation is favorable. If the river is more than 10 meters wide, the channel profile should be divided into subsections where the velocity is measured (Gordon et. al., 1992).

3. 3. Lag time

An important factor in assessing how a catchment reacts to rainfall is lag time (Subramanya, 2008). Lag time is the time between the start of a rainfall in a catchment until one can measure a change in depth in the corresponding river. To calculate this, one notes when a heavy rain event occurs and proceeds to measure the depth in the river. As soon as a change can be seen the lag time can be estimated. It sounds simple but it can be difficult to pinpoint which rain event corresponds to the increase in depth in the river. Perhaps it has rained in an upstream catchment, not collected or noted by any measurement, which increases the depth in the river. The rain event or the depth increase can occur during the night making it hard to know when to set the time of the events.

3. 4. Sediment transport and sediment rating curve

The sediment transport in a river depends mainly on channel erosion. This erosion includes erosion in bed, sides and on flood plains of the river. A river conveys runoff produced by an entire catchment and thus also particles that have eroded from soil and bedrock due to wind or water erosion and anthropogenic processes. The dominant contributor to erosion is water because it affects soil and rock both chemically and mechanically (Gyr et al, 2006). The total sediment load that is transported from the catchment by the river is classified into wash-, bed- and suspended load (Subramanya, 2008). Wash load is sediment that originates from the land surface of the catchment and is transported to the river by means of rain, splash, rill and gully erosion. The composition of wash load is generally fine-grained soils. Bed load is the relatively rough soil material that moves on the bed surface through sliding, rolling and saltation due to river flow. Suspended load is the relatively fine bed material that is kept in suspension due to turbulence and transported in the river flow in suspended form. These particles can travel long distances before settling on the bed and sides of a river, depending on the roughness of the flow.

In general bed load forms a small part of the total load of sediment transport, usually less than 25%, and wash load forms an even smaller part of the total load (Subramanya, 2008). However, it is possible to measure the suspended load relatively easy and thus obtain a general indication of how much sediment is transported in a river. The amount of sediment transport may also indicate anthropogenic interference in the catchment, such as deforestation and mining.

When measuring sediment transport in a shallow river, one sample is taken in the vertical at 0.6 depth from water surface to river bed. It is preferable to take sediment samples corresponding to flow measurements in order to see a correlation between for example higher flows and a heavier sediment load (Shaw, 1994).

A sediment rating curve depending on time or discharge can be made as described in section 3.5. in order to investigate different relationships and characteristics of the river.

3. 5. Stage-discharge relationship

In order to execute continuous measurements of discharge at a gauging station it is of great importance to establish a relationship between the observed depth of a given river and its corresponding discharge. By assuming a relationship between stage(depth) and discharge at a gauging station, one can monitor discharge during long periods of time by observing the depth of the river. If this relationship is to be reliable, the site of the gauging station must be wisely chosen. Natural rivers are seldom stable for long periods of time, thus one can only assume that the relationship between stage and discharge is valid for a certain period of time for each gauging station. A flood could change the cross-sectional area of a channel significantly, making the relationship invalid. Thus one must investigate the cross-sectional profile from time to time in order to maintain a reliable stage-discharge relationship at each gauging station (Shaw, 1994).

To create a stage-discharge relationship one must investigate the cross-sectional area of a river and then collect numerous data of river depth and flow in order to get a wide range of possible depths and corresponding discharges occurring at the gauging site. Once enough data is collected, the depth is plotted against the discharge creating an array of points. These points are interpolated into a curve, and hence one can find the flow in a river by simply measuring the depth and reading the curve (Shaw, 1994), see figure 3.5.1 below.

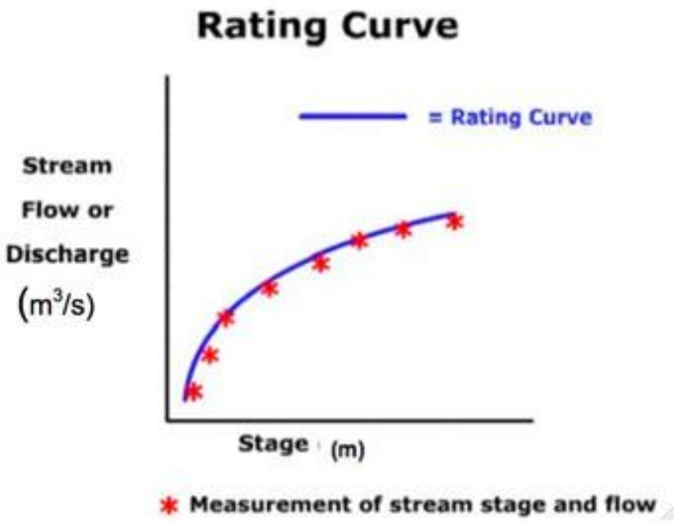


Figure 3.5.1. –The relationship between the depth of a river and the corresponding flow, (CZO, 2013).

An equation is generally fitted to the rating curve, expressing the relationship between stage and discharge, see eq (6).

$$Q = c * (H - H_0)^b \qquad (6)$$

Where *Q*=stream discharge, *H*=depth of river, H_0=a constant which represents the depth corresponding to *Q*=0, *c* and *b* are rating curve constants (Subramanya, 2008).

Since we do not know what the depth is at the rivers at our gauging sites when there is no flow, *Q*=0, the constant H_0 is assumed to be zero. Hence eq (7) express the stage-discharge relationship.

$$Q = c * H^b \qquad (7)$$

Consequently, when plotting measured data of depth against corresponding flow, one can simply use the equation given by the rating curve in the stage-discharge graph to calculate the flow of the river at observed depths.

The stage-discharge curve and its rating equation are unique for each river and often also time period. The shape of the curve tells something about the characteristics of the river since the height profile of the river bed affects the flow at different depths (Shaw, 1994).

3. 6. Water balance

A water balance can be of varied complexity and be applied to different situations. It describes the flow of water in a system. Eq (8) expresses a typical water balance.

$$Q = P - E + \Delta S \qquad (8)$$

Where Q is discharge, P is precipitation, E is evapotranspiration and ΔS is change in water storage. To build a water balance one needs to understand these parameters. The model we have established doesn’t use ΔS directly and is simply described as eq (9).

$$Q = P - E \tag{9}$$

Although, as we will see, this becomes quite complex.

3.6.1. River flow

River flow is denoted Q and measured in m^3/s. It can be measured with different types of devices for velocity measurements when the cross-sectional area of a river is known (Subramanya, 2008). This parameter is measured in field and allows us to control the parameters in a simulated version of the water balance.

3.6.2. Precipitation

Rainfall is measured in mm/time. P – E is called net precipitation (P_{net}) and is the amount of precipitation, i.e. the amount of water that ends up in the system (Shaw, 1994). The rest is evaporated from the ground or transpired by plants.

3.6.3. Evapotranspiration

The evapotranspiration is measured in mm/time. This parameter consists of two parts. Evaporation is water that evaporates from solar radiation, and transpiration which is the water transpired by plants. Evapotranspiration can refer to either *potential* evapotranspiration (E_p) or *actual* evapotranspiration (E_a). E_p is the amount of water that evaporates from a water surface, such as a lake, and the amount that plants transpire if constantly supplied with water (Hamill, 2001). E_a is the actual amount of water that leaves the system from evapotranspiration. Consequently $E_p \geq E_a$. E_p can be equal to E_a in areas with claylike soil up to a loss of 50% in available moisture (Subramanya, 2008). This would mean that in areas with claylike soil one can estimate that $E_p = E_a$ especially during the rainy season.
One should include E_a in the water balance. E_a is very difficult to measure but can be estimated through eq (10) and (11).

$$E_a = \frac{P}{(0{,}9 + (\frac{P}{L})^2)^{1/2}} \text{ (mm/year)} \tag{10}$$

$$L = 300 + 25T + 0{,}05T^3 \text{ (°C)} \tag{11}$$

Where P is the mean annual precipitation in millimeters and T is the mean annual air temperature in the area of interest.

4. Methodology

4.1. Experiment area

We tried to find a field site where two rivers were connected by a junction within a relatively small area to be able to do measurements of both rainfall and river properties each day. It is also preferable to have all measurements stations within a close range in order to easily investigate how the water in the area behaves during rain events. A village called Sosok in the middle of West

Kalimantan was chosen, since it supplies the wanted properties, see figure 4.1.1 and 4.1.2. The field experiment was carried out during five days.

Table 4.1.1. The day of field work as it is referred to in the text and corresponding date.

Day of field work	Date
Day 1	17 December 2013
Day 2	18 December 2013
Day 3	19 December 2013
Day 4	20 December 2013
Day 5	21 December 2013

Figure 4.1.1 - Map of West Kalimantan, Borneo. To the left, Pontianak lies by the sea. The A marks the village of Sosok. (Google Maps, 2013).

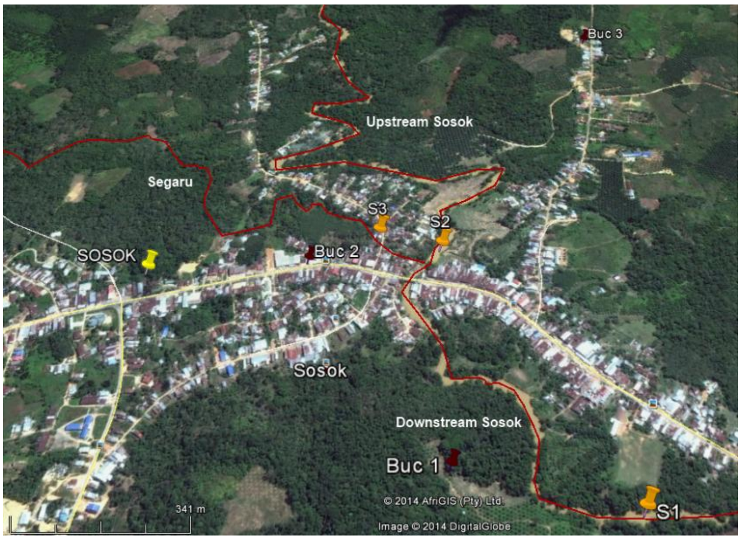


Figure 4.1.2. - Map of the locations of experiment sites and rain collecting buckets. The orange markers indicate the three different river measurement stations and the red markers indicate the buckets for rain collection. (Google Earth, 2013).

Sosok is a village with approximately 9,500 inhabitants (SI, 2010). The two rivers Segaru and Sosok, see figure 4.1.2., meet in the center of the village to form Sosok river. The water of the upstream rivers is used for the everyday needs of the villagers but also as a waste reservoir for feces and garbage.

4.1.1 Station 1

Figure 4.1.1.1. - Picture of river and measuring station downstream the junction, station 1.

The first temporary station was located downstream the junction of the two meeting rivers. This station is mostly surrounded by vegetation such as rainforest, some small houses and a small football field. The soil type is clay-like, beige-grey and red. Measurements of river velocity and sediment samples were taken from the river bank.

The coordinates for the station is 00˚17'20.00''N, 110˚14'41.00''E (N 00˚17.348’, E 110˚14.694’).

4.1.2 Station 2

The second temporary station was placed upstream the Sosok river. This station is partly surrounded by vegetation such as rainforest, artificial fields and houses. The soil type is clay-like, beige-grey and red. Upstream Sosok river illegal mining is carried out, letting out waste water into the river which causes the river to be very turbid. Measurements of velocity and sediment samples were taken from the raft on fig. 4.1.2.1.

The coordinates for the station is 00˚17'40.00''N, 110˚14'27.00''E (N 00˚17.682’, E 110˚14.452’).

Figure 4.1.2.1. - Picture of Sosok river and measuring station upstream the junction, station 2.

4.1.3 Station 3

Figure 4.1.3.1. - Picture of Segaru river and measuring station upstream the junction, station 3.

The third station was placed upstream the Segaru river. This station was located on a bridge in the urban part of the village and hence the river was mainly surrounded by houses and roads. The soil type, when not concrete, was clay-like, beige-grey and red, as in the other two stations. Boats, floating fishponds and garbage occupied large parts of the river. Measurements of river velocity and sediment samples were taken from the bridge.

The coordinates for the station is 00˚17'41.00''N, 110˚14'22.00''E (N 00˚17.684’, E 110˚14.376’).

4.2. Rainfall

In order to collect rainfall data we distributed three buckets over the total catchment of 390km^2 (BWSK 1, 2011). They were placed at locations free from overshadowing vegetation and buildings. The buckets were made of plastic and could hold 10 liters of water. Inside the bucket lay a large stone that prevented the bucket from moving or tipping over because of wind. The water levels in the buckets were measured with a ruler every day at 9 p.m. by removing the stone and placing the ruler vertically down in the middle of the bucket. The amount of water symbolizing each millimeter (mm) in the bucket was then converted into milliliter (ml) with help of a measuring beaker. The daily amount of precipitation was then converted into m^3 and divided by the area of the bucket in order to get precipitation in the unit mm/day.

A mean value for the amount of rain falling during the time of the experiment was calculated in order to calculate the average rainfall over the catchment, see eq (12) and (13).

$$P_{mean} = \frac{P_1+P_2+\cdots+P_n}{n} \qquad (12)$$

$$P_{catchment} = \frac{P_{mean,1}A_1+P_{mean,2}A_2+\cdots+P_{mean,m}A_m}{A_1+A_2+\cdots+A_m} \qquad (13)$$

Where *n* is the amount of days of the experiment and *m* the amount of buckets with an assigned catchment area.

4.2.1 Rain gauges

The three buckets was placed according to following coordinates. See also figure 4.1.2. The first bucket, buc 1 in figure 4.1.2, was placed in a field. Coordinates N 00˚17’22.00’’, E 110˚14’39.00’’ (N 00˚17.378’, E 110˚14.661’).

The second bucket, buc 2, was placed on top of a mosque. Coordinates N 00˚17’38.00’’, E 110˚14’17.00’’ (N 00˚17.649’, E 110˚14.286’).

The third bucket, buc 3, was placed in a field. Coordinates N 00˚18’07.00’’, E 110˚14’39.00’’ (N 00˚18.120’, E 110˚14.661’).

Figure 4.2.1.1. - Three pictures showing buckets and location.

4.3. Discharge

4.3.1. Cross-section

The cross-section of each gauging site was measured in the beginning of the experiment period in order to be able to calculate the cross-sectional area and consequently measure the discharge and depth in the river. Initially we sought for locations with fairly stable and straight riverbanks which were easily accessible. When an appropriate place was found a rope with knots every 1 meter was tied over the river, from one bank to the other. The depth of the river was measured at each knot with help of a bamboo stick marked as a ruler. Consequently the cross-sectional profile of each river could be estimated and drawn with Excel.

Figure 4.3.1.1 - Swimming over the river at station 2 to tie the one-meter knotted rope to the other river bank.

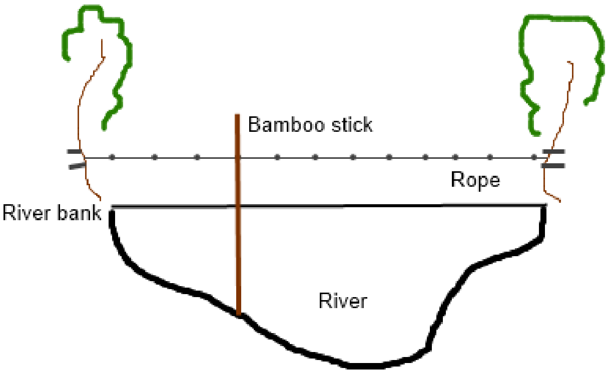


Figure 4.3.1.2. - Illustration of knotted rope tied over river while depth is measured with a bamboo stick at each knot.

4.3.2. Depth measurements

The depths of the three rivers were measured at least 4 times a day, at 10 a.m., 12 a.m., 2 p.m. and 4 p.m. during the experiment period. When rain had occurred the depth was measured every hour between 10 a.m. until 5 p.m. The depth was measured with a bamboo stick, marked as a ruler and placed at least 1 meter from the river bank into the river.

Figure 4.3.2.1. - Bamboo stick used for stage measurement, here at station 1.

4.3.3. Velocity measurements by floats

The velocity of the rivers was measured at least 4 times a day, at 10 a.m., 12 a.m., 2 p.m., and 4 p.m. during the experiment period. When rain had occurred the depth was measured every hour between 10 a.m. until 5 p.m. The velocity was measured by using the floating method described in section 3.2. We used a 0.6 liter bottle filled with 95% water so that only the cap was visible over the water surface. This method has previously proven to give a relatively good estimation of the velocity (Carlman Bydén and Hallerth, 2013). The bottle was tied to a 25 meter string which was tied to a bamboo stick or just a bamboo handle. At station 1 and 2 the bottle was tied to a bamboo handle, see figure 4.3.3.1., and a distance of 20 meters was marked on the river bank. One person threw the bottle a few meters upstream in order for the float to accelerate to the same speed as the water as it passed the observer. The progress of the float was then timed from when it passed the person who threw it until the river had carried it 20 meters down the river to the second mark where another person stopped the time. However at station 3, located on a bridge, the float was tied to a long bamboo stick, see figure 4.3.3.2. The stick was then held perpendicularly down to the river surface, the float thrown upstream and timed from passing the end of the bamboo stick until the string was stretched. Since the length of the string was known, as well as the distance of the traveled float, the average velocity could be obtained by dividing the length by the time of travel. The bottles were thrown approximately in the middle of the river. This procedure was repeated twice in order to get a mean value of the velocity.

Figure 4.3.3.1. - Float tied to short bamboo handle, used as velocity measurement at station 1 and 2.

Figure 4.3.3.2. - Float tied to a long bamboo stick, used as velocity measurement at station 3.

When carrying out velocity measurements one should try to estimate the velocity profile of the river both horizontally and vertically. The velocity profile depends on the friction of the river bed given by vegetation, rocks and the form of the river sides. These attributes create barriers on the river bed generating different forms of velocity profiles. With a fairly uniform cross-sectional profile and relatively smooth river bed we assumed that the mean velocity of the river could be calculated by eq (14). Where the constants 0.7 is approximated friction constants in the vertical and horizontal plane (Shaw, 1994).

$$v_{mean} = 0.7 * 0.7 * v_{surface} = 0.49 * v_{surface} \qquad (14)$$

However, since we noticed that the river beds at station 1 and 2 were not very uniform, the correction factor given in eq (14) was estimated to a number between 0.4-0.75 depending on where in the river the float was thrown in relation to what the bottom profile looked like.

4.3.4. Stage-discharge curve

After an experiment period of five days we calculated the discharge of the rivers by multiplying the measured velocities with the cross-sectional area of each station. The resulting flow was then plotted against the depth measured at the same time intervals as the velocities. This process is further described in section 3.5.

4. 4. Sediment measurements

Sediment samples were taken at least 4 times a day, at 10 a.m., 12 a.m., 2 p.m., and 4 p.m. during the experiment period. When rain had occurred samples were taken every hour from 10 a.m. until 5 p.m. At station 1 and 3 the samples were taken by lowering a bamboo stick with a test tube tied to the end, see figure 4.4.1. At station 2 the sample was taken by a person lowering a test tube into the river from the raft, see figure 4.4.2. The samples were taken at least 3 meters from the river bank and the sample depth was approximately 0.5 meters from the surface which was assumed to be a depth of 0.6 times the river depth where the sediment is considered to be laterally mixed (Shaw, 1994).

Figure 4.4.1. - Sediment sample taken at station 3. Test tube tied to a bamboo stick an lowered into the river.

Figure 4.4.2. - Sediment sample taken at station 2. Test tube lowered into the water at an elbows depth.

The sediment samples were then transported back to the environmental lab in Pontianak, Badan Lingkungan Hidup, for analysis by spectrophotometer.

4. 5. Rainfall event

During the first day of the experiment measurements were made every 30 minutes when a rainfall occurred. However, we soon noticed that this was too often and instead made measurements every hour during and after a rainfall event. Hence measurements were taken continuously until the depth of the river had reverted to the depth before the rainfall event. Doing this we get a stage-time curve.

This shows us how the depth of the river increases, and then decreases, over time. During rainfall events we also measured sediment and velocity as described earlier in the method. The sediment samples were then used to analyze possible anthropological processes such as different types of land use. If the sediment transport increases a lot during a rainfall event that tells us that the land erodes heavily by rain.
Velocity was measured so that we could get larger values for each rivers stage-discharge curve, thus increasing the accuracy of the curve.

Doing measurements during a rainfall event allowed us to see how the catchment reacts to rain. This gives us a better understanding of how the hydrology of the catchment works and also tells us something about possible land use and soil types in the catchment.

4. 6. Water balance

4.6.1. The model

Figure 4.6.1.1 below shows the flow of water in a system. We have based our model of water balance on this system. A system like figure 4.6.1.1 was built in Excel to simulate the water movement occurring in the catchments where our field work took place. The gray area is the root zone, from here water flows either into the river, Q, or down into groundwater storage, the brown dotted area. Our focus lies on the surface layers meaning that we did not investigate the complex groundwater processes.

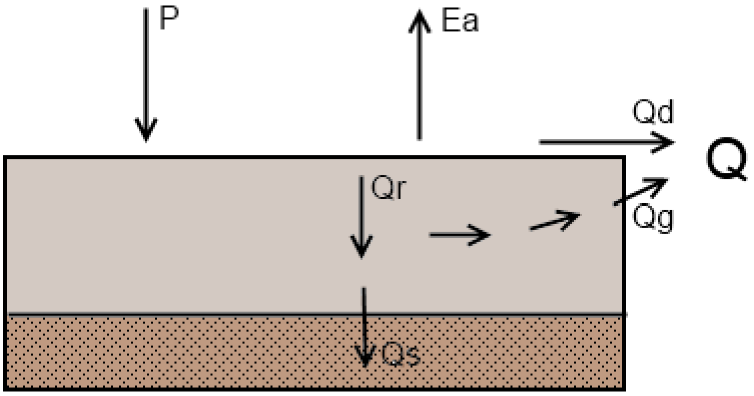


Figure 4.6.1.1. - P = Precipitation, E_a = Actual evapotranspiration, Q_D = Direct runoff, Q_R = Water infiltrating the root zone, Q_G = Root zone runoff entering river, Q_S = Water infiltrating groundwater storage, Q = River flow

As can be seen in figure 4.6.1.1 the equation must be as follows:

$$Q = Q_D + Q_G \qquad (15)$$

Where Q_D is the direct runoff; the amount of precipitation that does not infiltrate but instead runs along the surface and ends up as flow in a river. Q_D is calculated according to eq (16).

$$Q_D = P_{net} * C \tag{16}$$

Where P_{net} is $P - E_a$.

Q_G is the groundwater flow which is the amount of groundwater that does not infiltrate into groundwater storage but instead flows into the river. This process is slower than direct runoff. Q_G is calculated according to eq (17).

$$Q_G = Q_R * \alpha \tag{17}$$

Where Q_R is $P_{net} * (1 - C)$ which is to say, the amount of water that does not end up as direct runoff but instead infiltrates into the root zone. α is a fraction variable, based on the soil type and other catchment properties.
The remainder of the water,Q_S, flows into storage and leaves our model. It is calculated as:

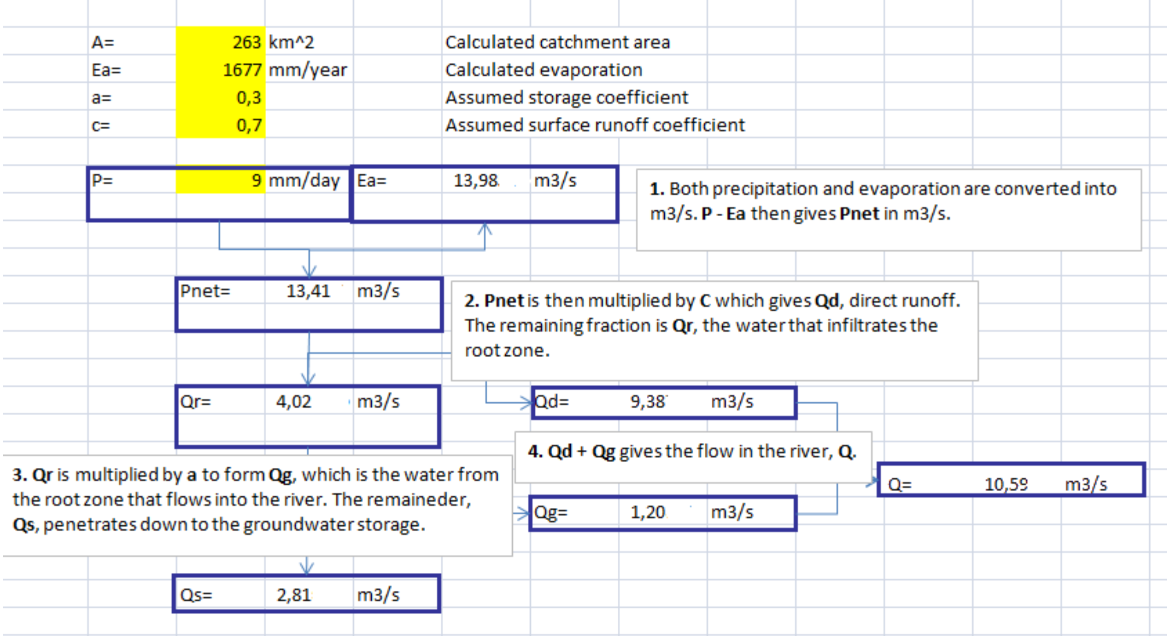
$$Q_S = (1 - \alpha) * \ Q_R \tag{18}$$

Our original equation; $Q = Q_D + \ Q_G$; eq 16, is thus derived from eq (19).

$$Q = (P - E_a) * C + (P - E_a) * (1 - C)) * \alpha \tag{19}$$

Here we can see that the only input needed for the equation is precipitation and actual evapotranspiration, not far from our original $Q = P - E$ equation but with two fraction variables that will have to be estimated.

Figure 4.6.1.2 illustrates the Excel model using the parameters explained above.



A=	263	km^2	Calculated catchment area
Ea=	1677	mm/year	Calculated evaporation
a=	0,3		Assumed storage coefficient
c=	0,7		Assumed surface runoff coefficient

P= 9 mm/day

Ea= 13,98 m3/s

1. Both precipitation and evaporation are converted into m3/s. **P - Ea** then gives **Pnet** in m3/s.

Pnet= 13,41 m3/s

2. Pnet is then multiplied by **C** which gives **Qd**, direct runoff. The remaining fraction is **Qr**, the water that infiltrates the root zone.

Qr= 4,02 m3/s

Qd= 9,38 m3/s

4. Qd + **Qg** gives the flow in the river, **Q.**

Q= 10,59 m3/s

3. Qr is multiplied by **a** to form **Qg**, which is the water from the root zone that flows into the river. The remaineder, **Qs**, penetrates down to the groundwater storage.

Qg= 1,20 m3/s

Qs= 2,81 m3/s

Figure 4.6.1.2. - An illustration of the water balance model made in Excel and used to calculate a simulated flow for each catchment to investigate its similarities with the observed flow during field work. The Q is calculated as an average for a period of five days.

4.6.2. Evapotranspiration

On the equator the climate does not vary much during the year (Kume et al, 2011). That makes evapotranspiration stable and relatively easy to estimate. We assumed E_a by looking at data of temperature and precipitation in the region of Sosok and using eq (10) presented in section 3.6.3. Evapotranspiration depends on many factors, solar radiation, wind, temperature, air humidity and soil moisture.

4.6.3. Estimating root zone coefficient - α

The root zone coefficient is the percentage of water that enters the root zone that ends up as flow in the river. The water either flows into the river or infiltrates into groundwater storage. α depends on how saturated with water the root zone is, and on the soil type. If the soil is very porous, gravel for example, then α will be small, since a lot of water infiltrates through the gravel and into groundwater storage. The less porous the soil is the larger α will be. However, if the soil has zero porosity then there will be no water in the root zone for α to work on.

4.6.4. Estimating direct runoff - C

The coefficient C is the percentage of net rainfall that results in direct runoff. It depends largely on the permeability of the soil but also on how saturated the soil is. Impermeable soil, for example asphalt (which has zero permeability), results in a C of 1, i.e. 100%. This number drops as the permeability increases. If the soil is completely saturated, water cannot infiltrate which would also result in a C of 1. When saturation decreases, i.e. the soil dries up, water can infiltrate and C decreases.

4.6.5. Estimating the discharge-time curve incline

The variables C and α both depend on the type of soil, i.e. how porous the soil is, and on how much water the root zone can contain. After investigating a soil type, one may consult a table to see how porous the soil in the catchment could be. Finally one must estimate how much water the root zone can hold. To estimate the amount of water in the soil one can use a discharge-time curve. A discharge-time curve's right hand slope gives an indication of water storage; if the slope is steep, the ground can hold little water, if it is gentle, the ground can hold more water. The gentler the right hand incline is the more water the soil can hold. This relationship between incline and root zone discharge has the following correlation: when it rains, if the soil has zero permeability and thus no root zone discharge; the discharge-time curve for the river might appear as in figure 4.6.5.1.

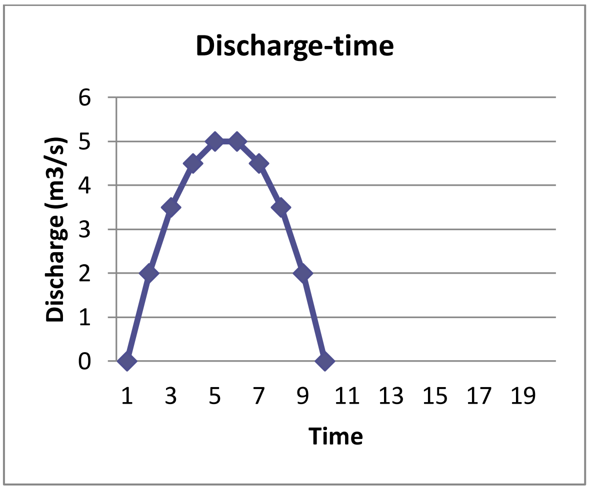


Figure 4.6.5.1- A steep discharge time curve where y=0 indicates the base flow of the river.

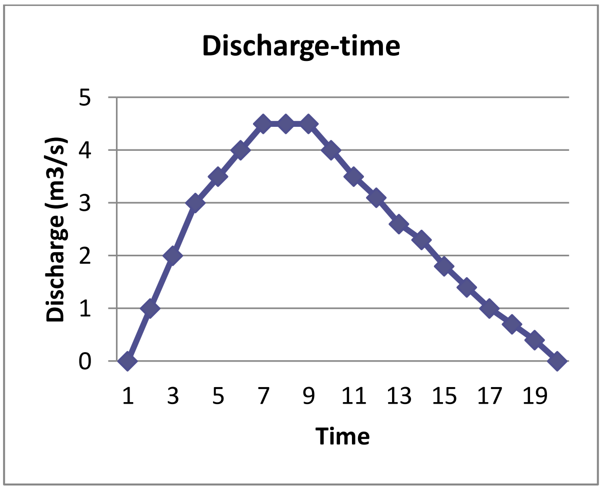


Figure 4.6.5.2- A gentle discharge time curve where y=0 indicates the base flow of the river.

The discharge from the surface runoff reaches the river fast, resulting in an increase in discharge. This change is fast and once it stops raining the river will soon go back to its normal base flow, see figure 4.6.5.1 where y=0.
If instead the rain infiltrates the root zone and travels through it, it will take a longer time for the water to reach the river. This is because the water travels slowly in the root zone. In this case the peak of the discharge-time curve might be lower but the rainwater will be fed into the river for a longer period. The discharge-time curve might appear as in figure 4.6.5.2.

Depending on how the discharge-time curve looks for the investigated catchment and on what type of soil the area is composed of, assumptions can be made as to what values α and C have.

4.7. Practical issues with field work

This paragraph describes some practical difficulties with carrying out field work in Indonesia and how we solved these issues. If the reader is simply interested in the results of this study, one may skip down to the results, section 5.

As described earlier in this report, proper equipment is hard to find in West Kalimantan. Therefore we bought cheap material and created instruments for measurement before we went out into field, such as bottles, buckets, ropes, inflatable tubes etc. Some material, such as bamboo sticks and markers we could find at the village of our field site.

Figure 4.7.1. – Johan and Sarha making knots on the rope that will be tied across the river.

We rented a car with a driver to travel the 5 hour distance between Pontianak and Sosok with bags and equipment. Borneo has left hand traffic, which is why we would not recommend one to drive a car or a motorcycle by themselves for such long distances. The conditions of the roads are mostly bad, the traffic is very hectic and heavy rainfalls will impair sight and make the road slippery.

To be able to carry out our measurements in Sosok at the three rivers we needed assistance. Four Indonesian students from the Tanjungpura University, which we were acquainted with, offered to help us with our field work. Three of them traveled to Sosok by motorcycle in order for us to use these as a means of transport in the small village.

Figure 4.7.1. – Team Sosok; in the back are our four friends from Tanjungpura University and in front the host family.

Our accommodation was arranged by one of the university students with contacts in Sosok. The six of us stayed in the house of an Indonesian family and paid them for two cooked meals per day.

In order to carry out work outside of Pontianak we needed permission from the Police in Pontianak. Our Indonesian supervisor helped us issue these papers of permission. When arriving in Sosok we had to meet no less than four city officials. The Head of Neighborhood of both the neighborhood we lived in and the one we worked in. The Head of the Village of Sosok and the Head of the Sosok Police department. Upon departure we had to officially say goodbye to these important men.

Had it not been for our Indonesian contacts, both students and supervisor, we would not have known to do any of these things.

5. Results

5. 1. Rain

Table 5.1.1. presents the measured amount of rainfall collected in the three buckets placed in the catchment during the time of the experiment. Each bucket represents a part of the total catchment of Sosok. See figure 4.1.2 for bucket locations.

Table 5.1.1. - Measured rainfall data in the three buckets distributed in the catchment. The measured amount of rain in each bucket is recalculated to mm/m^2/day.

	Buc 1			**Buc 2**			**Buc 3**		
	mm/day	ml/day	mm/m^2/day	mm/day	ml/day	mm/m^2/day	mm/day	ml/day	mm/m^2/day
Day 1	11	445	8,4	6	195	3,7	2	80	1,5
Day 2	7	317	6,0	5	117	2,2	8	245	4,6
Day 3	7	317	6,0	2	80	1,5	1	50	0,9
Day 4	20	917	17,3	23	1017	19,2	32	1417	26,7
Day 5	0	0	0	0	0	0	1	50	0,9
Mean/ 5 days			7,5			5,3			7

The area of the catchment of Sosok is 390km^2 (BWSK 1, 2011). Station 1 lies just at the edge of this catchment and from maps it was estimated that approximately 30km^2 of the total catchment area drained straight into the location of station 1. That leaves 360km^2 that needs to be divided between the two remaining rivers at station 2 and 3. This division was done by looking at the observed flow in the rivers. It was assumed that discharge is linearly proportional to the size of the river's corresponding catchment. This assumption leads to eq (20):

$$\frac{3{,}9}{14{,}5} = 0{,}27 \qquad (20)$$

Where 3,9m^3/s is the average discharge over five days observed at station 3 and 14,5 m^3/s is the average discharge observed at station 2. This means that 27% of 360km^2 (97km^2) drains into Segaru river at station 3 and the rest (263km^2) drain into Sosok river at station 2.

Bucket 1 representing a catchment of size: 30km^2
Bucket 2 represents a catchment of size: 97km^2

Bucket 3 represents a catchment of size: 263km^2
Average rainfall over total catchment: 6,6mm/day/km^2 over a catchment of 390km^2.

5. 2. Cross-section

The following three figures display the profile of the rivers at each station. They are calculated from the measurements done in the field and explained in section 3.1. The starting point (depth=0) is where the water level was at the time of measurement.

The area of the river profile at each station is as follows;
station 1: 66,30m^2, station 2: 72,00m^2 and station 3: 26,15m^2.

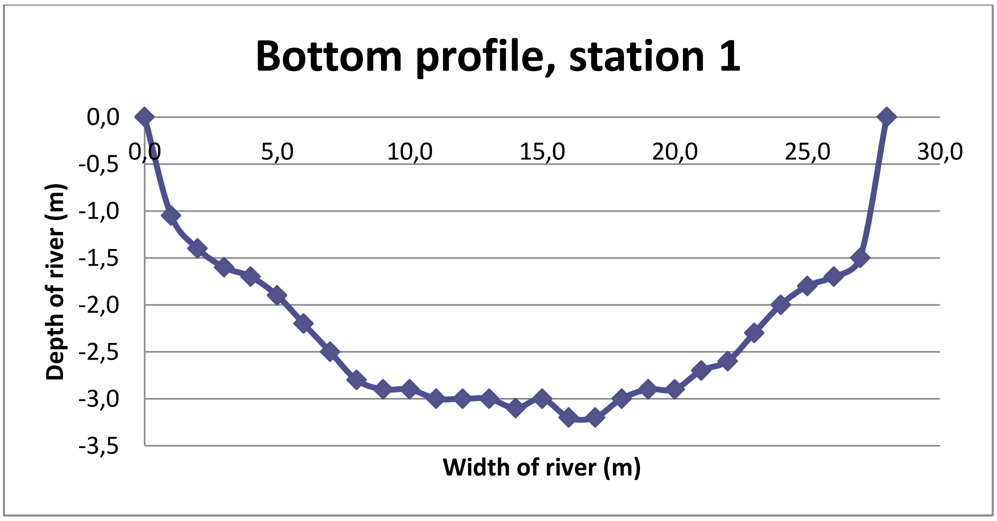


Figure 5.2.1. - Bottom profile of station 1. The measurements are taken for every meter.

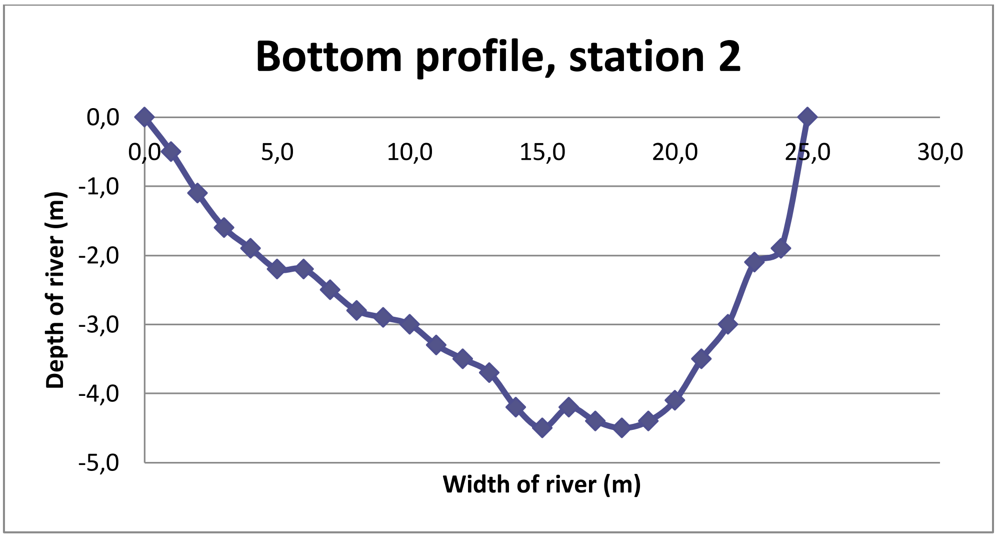


Figure 5.2.2. - Bottom profile of station 2. The measurements are taken for every meter.

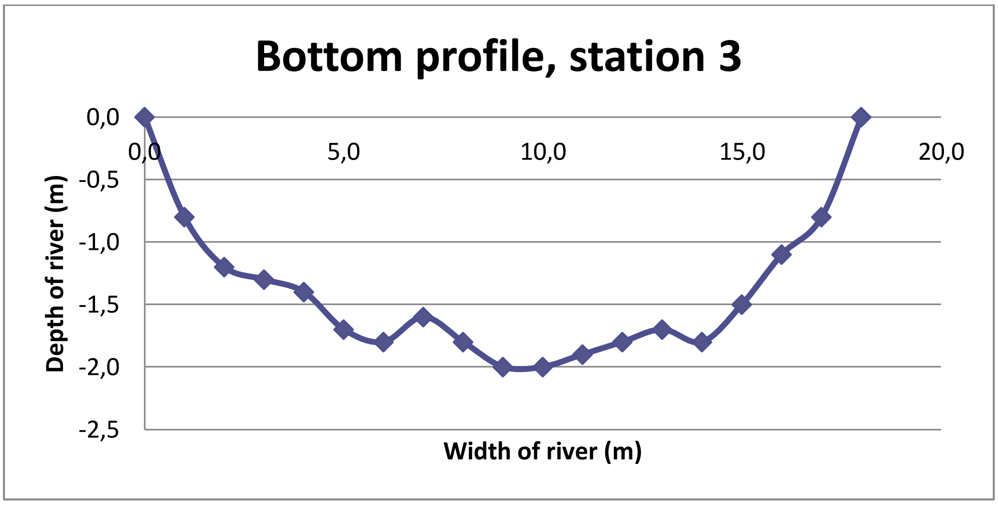


Figure 5.2.3. - Bottom profile of station 3. The measurements are taken for every meter.

5. 3. Lag time

Table 5.3.1 shows when rain occurred during the time of the experiment. However, only three rain events were heavy and seem to have had an impact on the water system in the catchment.

Table 5.3.1. - Time and type of occurring rain events during the experiment time.

Time of experiment	Time for start of rain	Type of rain
Day 1	14^{00}	Drizzle
Day 2	17^{30}	Heavy rain
Day 3	8^{30}	Drizzle
Day 4	13^{00}	Heavy rain
Day 4	3^{30}	Heavy rain
Day 5	13^{20}	Drizzle

Following charts displays how the depth changed during the time of the experiments according to when events of heavy rain took place. Rain that occurred only as drizzle did not show any change in either depth nor discharge and are thus not taken into consideration.

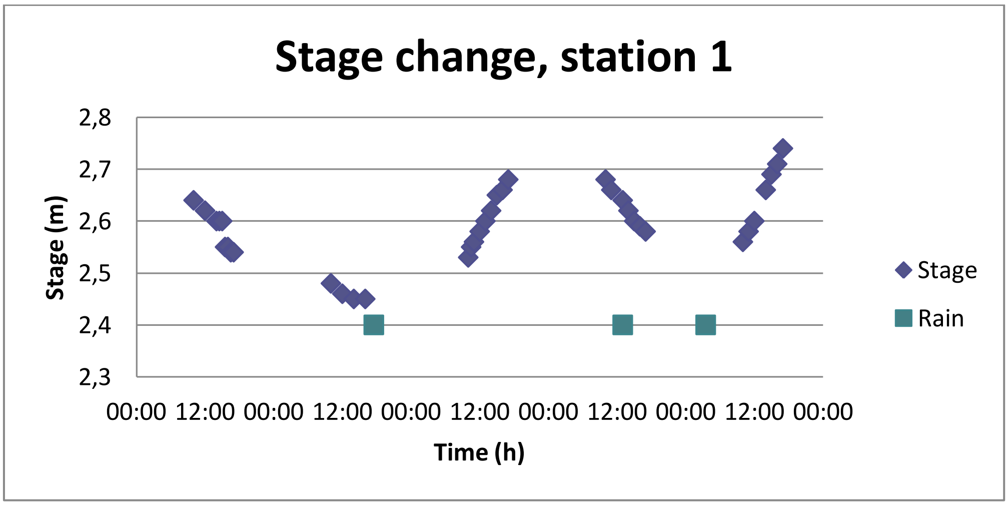


Figure 5.3.1. - Change in river depth in relation to time and occurring heavy rain events at station 1.

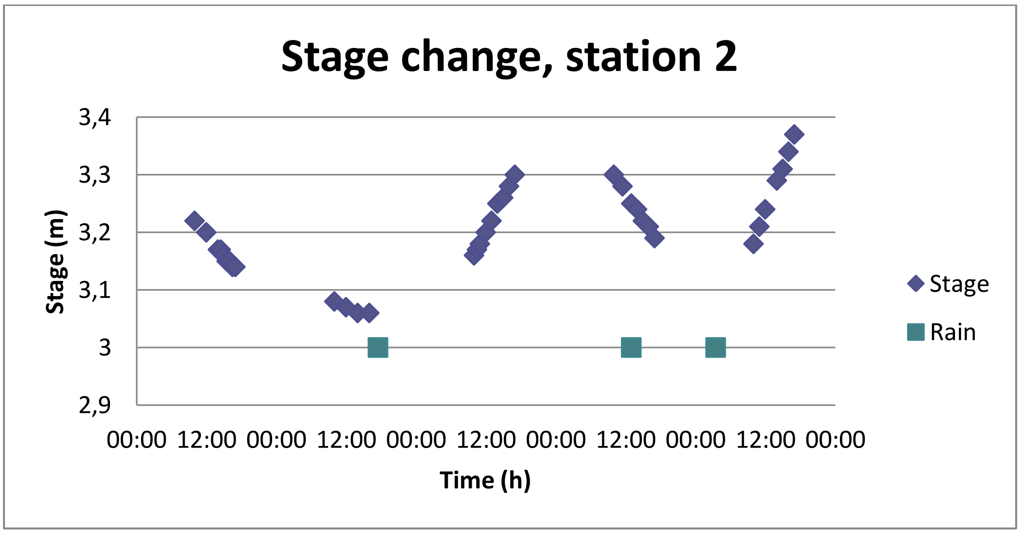


Figure 5.3.2. - Change in river depth in relation to time and occurring heavy rain events at station 2.

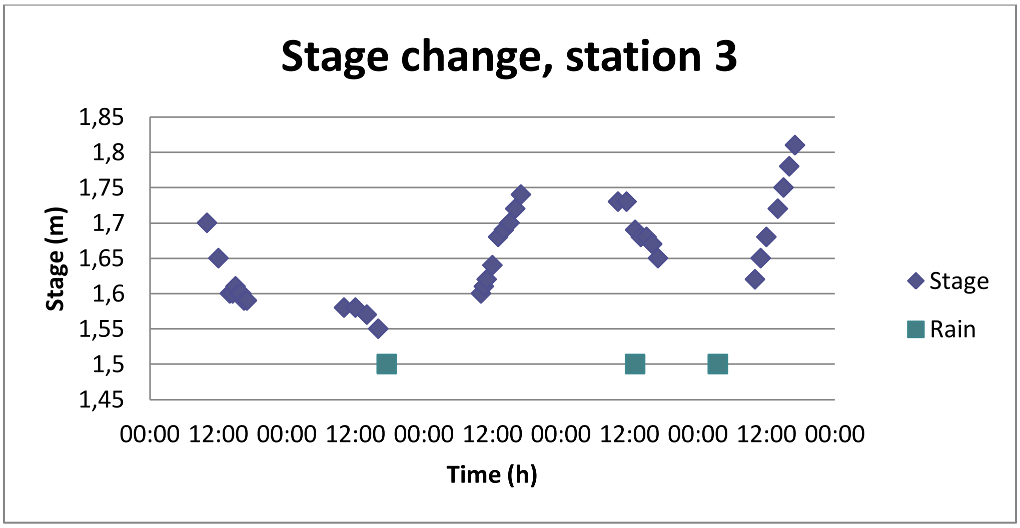


Figure 5.3.3. - Change in river depth in relation to time and occurring heavy rain events at station 3.

Since measurements were made between 10 a.m. and 5 p.m. each day, we cannot see the complete response of the change of water level depending on time of rainfall. However we may estimate how these would appear.

For the first heavy rain at 17.30, day 2, the depth increases by 2cm/h from 10 a.m. to 5 p.m during day 3 at all three stations. We may assume that the increase of 2cm/h start from the lowest value of the previous day. At station 1 this is a step of 8cm, giving that the increase of the depth starts at 6 a.m. At station 2 and 3 the step is 10cm and 5cm, indicating a start for the increase at 5 a.m. respectively 8 a.m. The lag time, i.e. the time between a rain event and the corresponding depth increase in the river, is then 11,5-14,5 hours.

For the second and third event of heavy rainfall at 13.00 respectively 3.30 in day 4, we see an increase in depth of 2,7cm/h from 10 a.m. to 5 p.m in day 5. Since the last measured depth of day 4 is very similar to the first measured depth of day 5 we assume that the increase in depth due to rain starts at 10 a.m. From the rain at 13.00, day 4, this gives a lag time of 21 hours. From the rain at 3.30, day 4, the lag time is 6,5 hours. However the increase in depth during day 5 is most likely a result of both the two heavy rain events of day 4, hence a mean value of the two lag times gives a more proper estimation; 13,7 hours.

From the three occurring heavy rainfalls we have estimated a lag time of approximately 13 hours.

5. 4. Stage-discharge curve

The results of the calculated discharge from the velocity measurements are plotted against the registered depth for each time measured during the experiment period. The depths of the rivers were measured approximately one meter from the riverbanks. However since this distance may change during flood or drought the depth of the figures are changed so that they represent the middle of each river.

The results are presented in figures 5.4.1, 5.4.2 and 5.4.3. An approximated logarithmic relationship has been extrapolated in each figure, shown along with its equation.

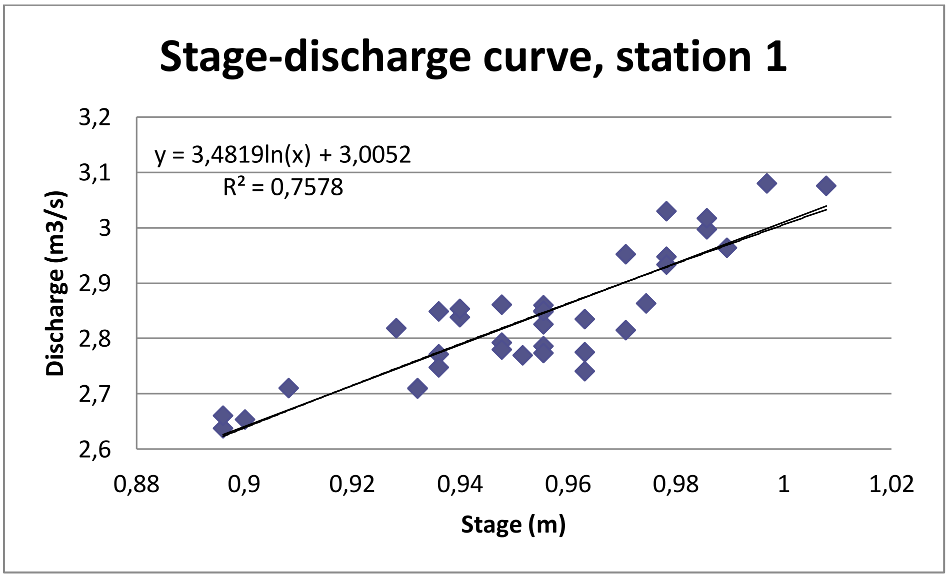


Figure 5.4.1. - Rating curve of Sosok river at station 1.

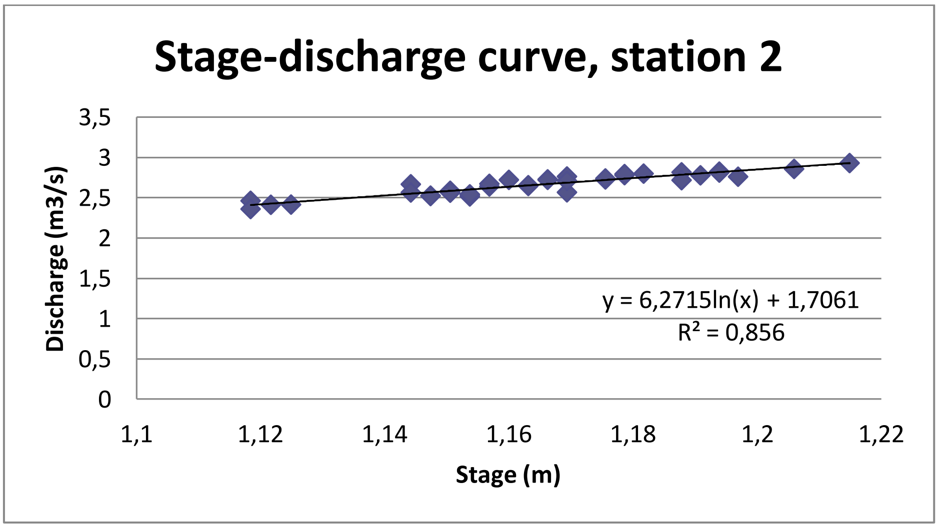


Figure 1.4.2. - Rating curve of Sosok river at station 2.

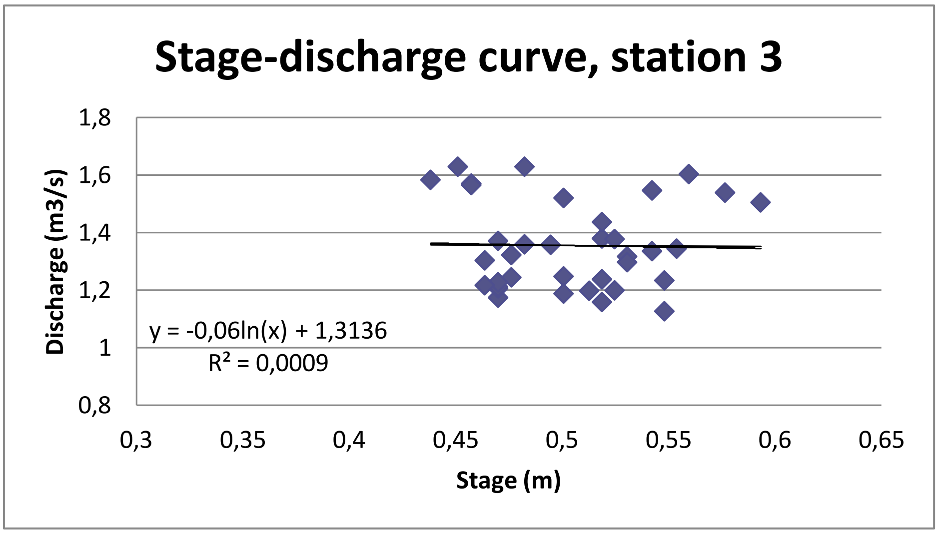


Figure 5.4.3. - Rating curve of Segaru river at station 3.

The rating curves for the two first stations show a fairly good correlation between increase in depth and responding discharge. However, the third station shows no correlation whatsoever. The reason to this will be discussed in section 6.4.

5. 5. Stage-sediment curve

The total amount of transported material per second, TSS, is plotted as a function of depth in the middle of the three rivers. A linear function is approximated to represent a relationship between the total amounts of material transported depending on the depth in the river. Results are shown in figures 5.5.1, 5.5.2 and 5.5.3.

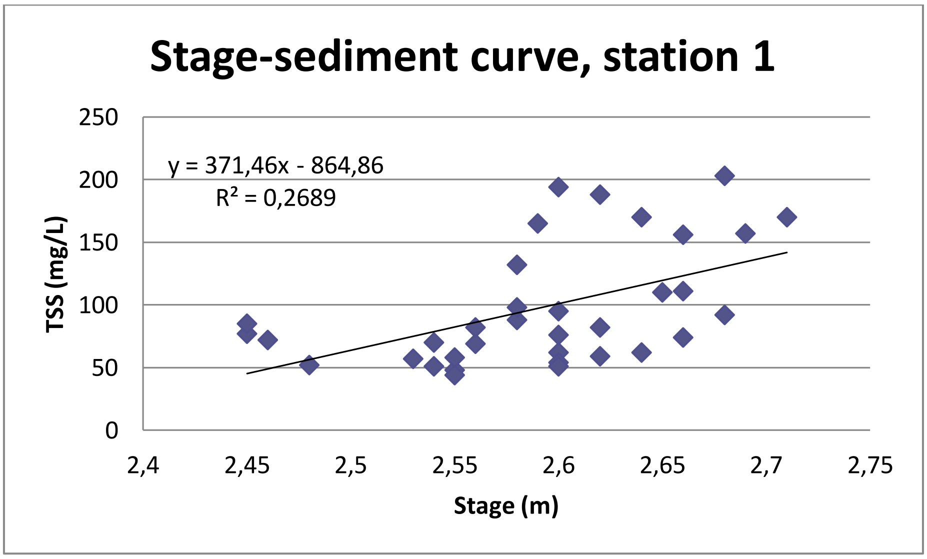


Figure 5.5.1. - Stage-sediment rating curve for Sosok river at station 1.

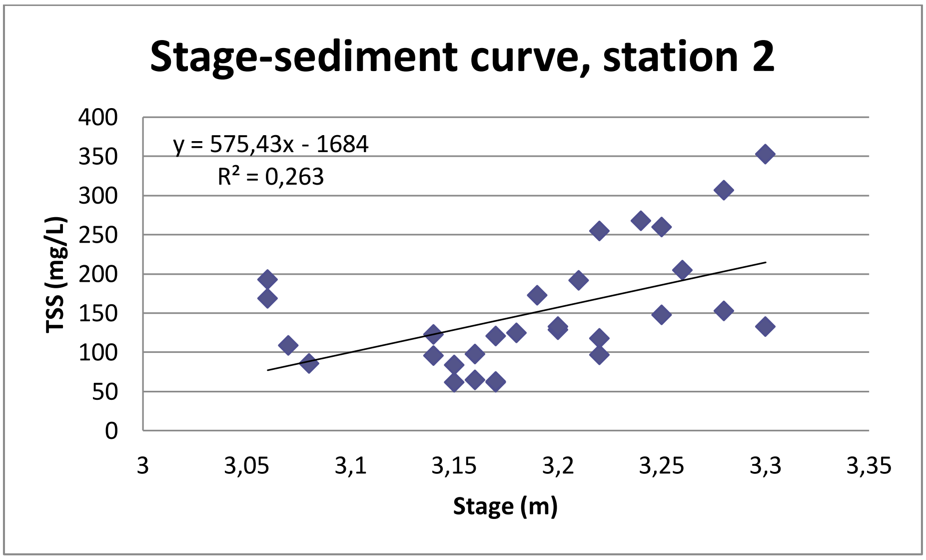


Figure 5.5.2. - Stage-sediment rating curve for Sosok river at station 2.

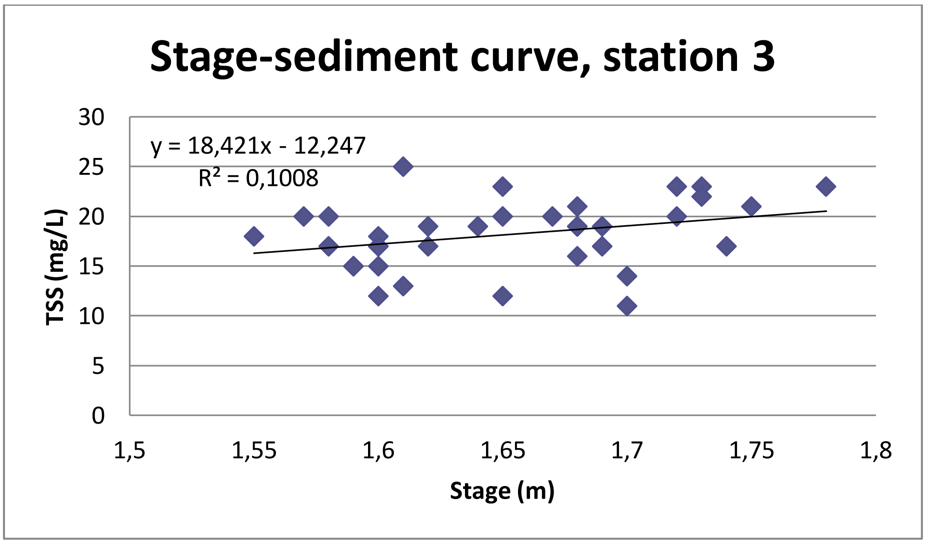


Figure 5.5.3. - Stage-sediment rating curve for Segaru river at station 3.

The three figures show no clear correlation between depth and total amount of transported sediment. For station 1 and 2, figure 5.5.1 and 5.5.2, show some indication of an increased amount of transported sediment due to increased river depth and consequently increased flow. However, the results of station 3, figure 5.5.3, show no correlation at all between increased amount of transported sediment and larger river depth.

The three figures 5.5.4, 5.5.5 and 5.5.6, below show the transport of suspended solids in relation to time of the field experiment. The three events of heavy rain is also marked in the figures to investigate if there is any correlation between occurring rain and an increased amount of sediment transport.

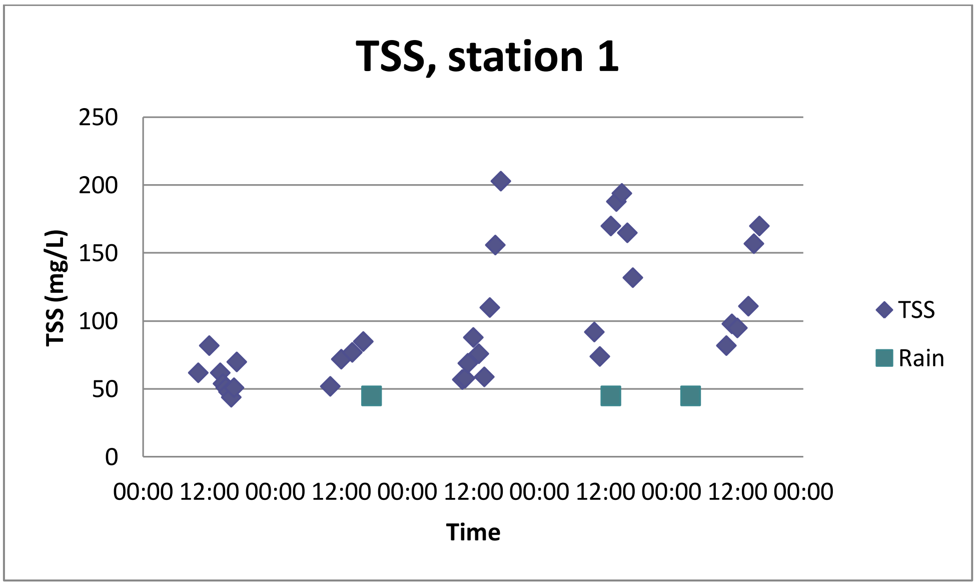


Figure 5.5.4. - Total suspended solids in relation to time of experiment and occurring heavy rainfalls at station 1.

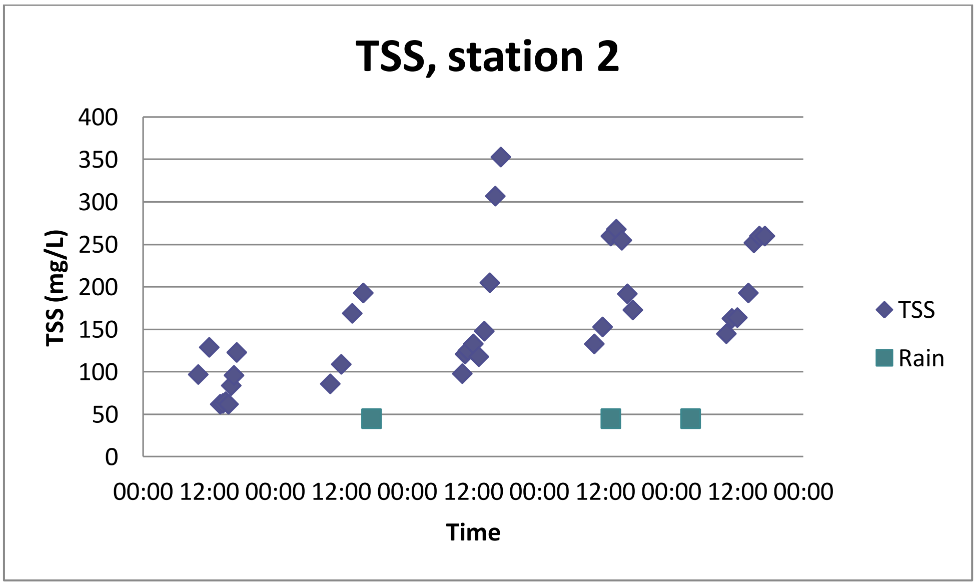


Figure 5.5.5. - Total suspended solids in relation to time of experiment and occurring heavy rainfalls at station 2.

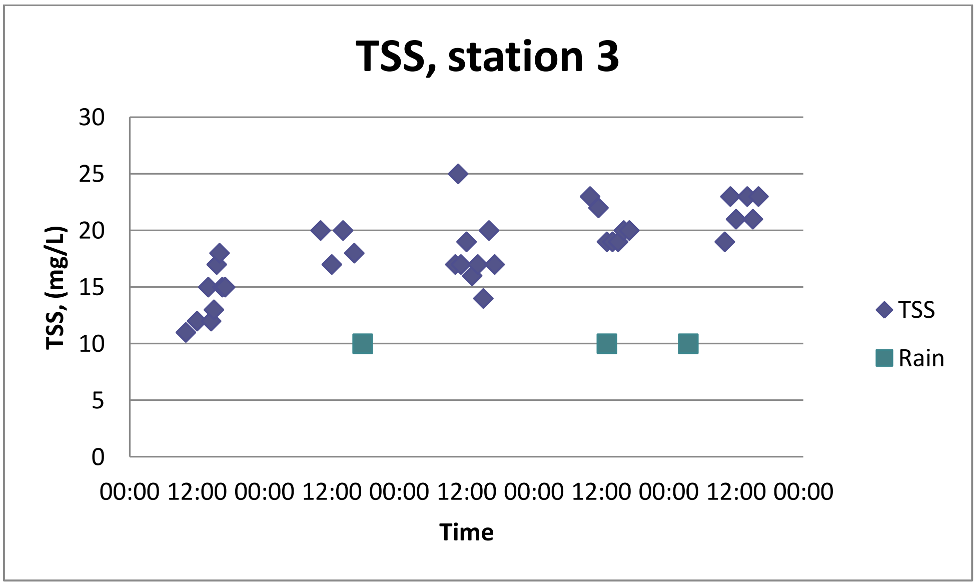


Figure 5.5.6. - Total suspended solids in relation to time of experiment and occurring heavy rainfalls at station 3.

In figure 5.5.4 and 5.5.5, results of station 1 and 2, we can see some correlation between an increased amount of transported sediment in relation to when a heavier rainfall occurred. However, during the fourth day we see an increase in sediment transport during the day even though no rainfall occurred, an assumed reason to this is further discussed in section 6.5.

For station 3, figure 5.5.6, we see no correlation between rainfall and increased amount of sediment transport. The values vary within a very small range, indicating that the change in transport may only be due to human interference.

5. 6. Water balance

5.6.1. Evaporation

The actual evaporation occurring in the catchment was calculated using rain data from Sosok and air temperatures from a station in Kembayan, not far from Sosok. The number was estimated from data of monthly measurements during four years from 2007-2011 using eq (10) and (11) presented in section 3.6.3.

The actual evaporation, E_a= 1677mm/year.

5.6.2. Root zone coefficient – α

We assumed the root zone coefficient to be α = 0,4. Based on observations in field, soil type and estimated catchment properties. The assumption of this number is further discussed in section 6.6.2.

5.6.3. Direct runoff – *C*

The amount of rain that becomes direct runoff, never penetrating the soil surface, was estimated to be 0,7 of net precipitation. The coefficient *C* should lie within a range of 0,6-0,8 since the soil in the catchment is mainly composed of silt and clay with a porosity of 0,30-0,50 resulting in a ground that is not very permeable (PCW, 2008). The land use in the catchment is mainly oil palm plantations, mining areas and some small villages resulting in less ground vegetation and roots that can take care of the precipitation making the amount of direct runoff to the river higher.

5.6.4. Water balance – the model

The weighted catchment area, observed precipitation in each of these areas and the assumed parameters of evaporation, root zone coefficient and direct runoff were inserted into the water balance model. The time step in the model is for five days and all time dependent values were entered as an average over this period. The model is presented in section 4.6.1. Table 5.6.4.1 illustrates the main result of this water balance model using observed precipitation.

Table 5.6.4.1. - A water balance over two sub-catchments resulting in the total catchment of station 1, with observed precipitation.

	Area (km^2)	P (mm/day)	E_a (m^3/s)	Q (m^3/s)
Station 3	97	5,3	5,2	0,7
Station 2	263	7	14,0	6,0
Station 1	390	6,6	20,7	7,4

However, there are a lot of uncertainties with the rain we observed during our field experiment. According to data from December rain from previous years our measurements are very low and 24 hours of evaporation between the daily rain measurements affect the amount of observed rain substantially. Therefore we have assumed an increased amount of rain of 2mm in each bucket in order to simulate a more reasonable guess regarding the behavior of the catchment, results in table 5.6.4.2. The reason for this 2mm increase is discussed further in section 6.6.

Table 5.6.4.2. - A water balance over two sub-catchments resulting in the total catchment of station 1, with 2 mm more rain then what was observed in field.

	Area (km^2)	P (mm/day)	E_a (m^3/s)	Q (m^3/s)
Station 3	97	7,3	5,2	**2,5**
Station 2	263	9	14,0	**11,0**
Station 1	390	8,6	20,7	**14,8**

The average observed flow at the three stations during the five days of experiment can be seen below.

Observed mean flow over 5 days, station 3: **3,9** m^3/s
Observed mean flow over 5 days, station 2: **14,5** m^3/s
Observed mean flow over 5 days, station 1: **17,2** m^3/s

The values of the observed flow are somewhat larger than the values obtained by the water balance model with a 2mm increase in precipitation, table 5.6.4.2. However, the model does not account for the river base flow, i.e. the amount of water that is fed into the river by the groundwater independent of rain. A river base flow will exist and be relatively constant until the catchment is completely dried out. Thus the results of the Excel model, displayed in table 5.6.4.2, are relatively similar with what was observed in field considering a base flow of approximately 2-3m^3/s.

6. Discussion

6. 1. Rain

Before we started our five day experiment period there had been a few days without rain. This could explain why the depth kept going down, see figure 5.3.1, 5.3.2.and 5.3.3., even though we recorded days of rainfall, table 5.1.1. The soil was so dry that it absorbed most of the rain minimizing the effects of surface runoff to start with. The soil was then saturated with water, thus the high value for C (0.7).

During our field work we noticed that, although our buckets were fairly close together, they never recorded the same amount of rain. A previous exchange student at Tanjungpura University (Haag, 2014, in prep.) has been examining the correlation of rainfall events to see how evenly the rain is dispersed over a catchment in West Kalimantan. He found that there is very little correlation, in other words, the rain is extremely local. This affects a lot of our assumptions and calculations regarding the rain. When recording the amount of rain in a certain spot, it is just that, data for a single spot. To extrapolate data from one bucket to cover the entire catchment is a source of error. It is hard for us to say anything about what happens further upstream. To minimize this error one should place as many buckets as possible and try to spread them evenly across the catchment. Unfortunately this would make it impossible to control all buckets within a reasonable time interval in one day. The roads in the catchment are bad and some areas can only be reached by hiring a boat and paddle upstream (there are no motorboats in Sosok). The foremost consideration has to be the possibility to carry out the fieldwork, as such, the buckets we placed and the extrapolations from their data is a necessary compromise.

The area we used for our catchment is 390km^2 (BWSK 1, 2011). Before arriving at this area there were several other values for the area that were considered. Different maps gave different results but 390km^2 came up more than once and was thus chosen as our area. We then used Google Earth to look at our catchment to see if 390km^2 seemed reasonable, which it did.
When weighting the area we have not looked at any maps, nor have we seen any data that supports the division of the area between the Segaru and the Sosok river. We have looked at the flows as described in section 5.1 and assumed that the flows are strongly correlated to their respective catchment area. Dividing the area based only on the flow of the two rivers, especially since we have seen that one of these rivers is heavily affected by human interference, is a large assumption. This assumption, however, works well in our water balance which we feel strengthens its plausibility.

6. 2. Cross-section

It is our belief that the cross-section is accurate enough for our purposes although it proved harder to measure than we thought. Segaru river at station 3 could be profiled from a bridge but the remaining two had to be made by going into the water. Since it was the middle of rain season the river depth was high, it had a very fast flow and was much wider than we had anticipated. The profile was measured by swimming perpendicular to the stream with inflatable tubes to tie a rope across the river. This rope made it possible to move back to the main riverbank, one meter at a time, while measuring the depth. Without doubt one would have been swept away with the current if there was nothing to hold on to. It was also hard to force the buoyant bamboo stick to the bottom while keeping it straight at 4,5 meters depth. When measuring at station 2 one person had to dive down and push the stick while two others (floating with the help of inflatable tubes) forced it upright. This made the work less accurate than we would have hoped but the errors in the measurements are believed to be minor. The difficulty chiefly inhibits the repeatability of our method. Had not the previous two days been sunny and dry the water level would have been too high for us to carry out the measurements without a boat. However, there are no motorboats in Sosok, and to paddle against a current like those we experienced whilst struggling with a 6 meter long bamboo stick might not have been easier. There were also snakes swimming across the river on more than one occasion. When taking the high flow, the deep water, and the snakes into consideration we must admit that doing the cross-section by hand, without a boat, takes some determination.

6. 3. Lag time

During the five day period that we measured we recorded three substantial rainfall events. From these we have approximated the lag time of the catchment. Unfortunately we were limited to measuring during the day. This meant that we were unable to pinpoint the time in which the river depth started to change due to the rain. The assumptions in our calculations are hopefully close to the mark but there is no way for us to know how the river depth changed during the night. The second and third heavy rainfall event occurred in proximity to one another. This overlapping event makes it hard to know what time to set from the rain start to the depth increase. However, we did calculations for both these rain events and tried to assume a mean lag time from how they seem to have affected the increase of the depth.

6. 4. Stage-discharge curve

The established stage-discharge curves for station 1 (R^2=0,76) and 2 (R^2=0,86), figure 5.4.1 and 5.4.2, show a fairly good correlation considering that the methods used in our fieldwork are very basic. During the experiment period the depth of the rivers changed less than we had accounted for, only 29cm, 31cm respectively 26cm at the three stations. This of course gives us rating curves that include quite small ranges of possible depths and corresponding discharges. It would be preferable to do the same measurements a second or even third time in order to establish rating curves that include a large range of depths and flows.

The banks of each river are under constant remodeling due to erosion and sedimentation which may change the depth of the water from day to day even though the flow is constant. The riverbanks of the three chosen stations seemed fairly stable, not changing visibly between the first examinations until the last experiment day. However it is hard to tell how they would change if a really heavy rainfall would occur.

At station 1 and 2 the rivers were meandering, and even though the sites of measurement were composed of a straight stretch of land, the riverbeds show significant signs of being hollowed due to discharge created by a meandering flow. The cross-sections, figure 5.2.1 and 5.2.2, for station 1 and 2 are visibly deeper on one side due to the water force in a meandering river. This creates an uneven velocity profile and the highest velocity can no longer be assumed to be found in the middle of the river. When carrying out the field work we repeatedly noticed that the time of the float changed substantially depending on where in the river it was thrown. Consequently we corrected the values of velocity with a correction factor, described in section 4.3.3, depending on where in the river cross-section the float was thrown at station 1 and 2.

The established stage-discharge curve for station 3 shows no correlation between river depth and flow at all (R^2=0,0009), see figure 5.4.3. Measurements were taken from a bridge in the middle of the river at this station and the riverbanks seemed relatively stable. However, in the river lay several rafts used for fish farming, boats and outhouses. Figure 6.4.1 below shows the difference between the discharges measured at different depths. During the five day period of the experiment the same depth was recorded more than once. In the other two stations we saw that when the same depth was measured several times the discharge would be almost the same. At station 3 however we found that some depths have close to, or even above, 1 m^3/s in difference. This significantly contributes to the nonexistent correlation in the stage-discharge curve for station 3. Another thing we can see in figure 6.4.1 is that the highest values for the discharge occurred when the depth was the lowest. These values were all taken during day 2. When observing the water during day 2 we could see that it was very turbulent. This could be due to the large number of floating rafts in the river just upstream of our measuring location. When the depth is low, the rafts sink closer to the bottom of the river. This could force the water to flow through narrow openings which would increase its velocity and the turbulence downstream of the rafts.

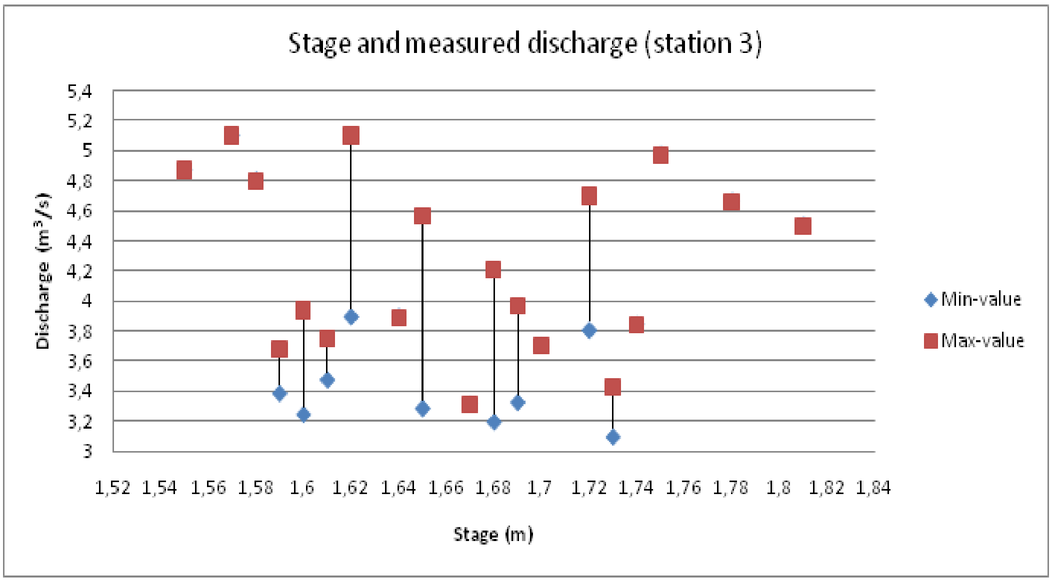


Figure 6.4.1. - The maximum value and (when available) the minimum value of the discharge for all the recorded depths of station 3.

In retrospect we should have known that the location of this station was not optimal. The bridge gave us good access to the river and allowed us to do our measurements in the exact same spot in the river every time. This eliminates many of the factors of error that the other stations were subject to. The way in which the river reacted to increases and decreases of depth shows that it is heavily affected by anthropomorphic factors.

Possible sources of error affecting the rating curves at all three stations are the uncertainty of the float method. In a previous field study concerning a sub-catchment to the Kapuas River it is suggested that the float method gives a fairly good estimation of the real flow in a river (Carlman Bydén and Hallerth, 2013). The result of this study suggests that the margin of error increases when discharge is low, sometimes with an error up to 46% from measurements taken by a current meter. However for higher flows, the float method give an average error of only 14%. The results from our observations on station 3, which shows relatively low flows, might have a large margin of error considering the result of the study mentioned above. Reasons for these error margins are that the float is easily carried away by sudden currents or may be slowed down by obstacles in the water. Such disruptions might not affect the result of a current meter equally much.

The measurements were made by six persons divided into three teams, one at each station. The result of human error as persons do measurements slightly differently may also cause discrepancies in the measurements of depth and discharge. The locations of the three stations could have been better, concerning straightness of riverbanks and human interference. However, then they would have been much harder to access since no roads were found to penetrate the rivers from other directions.

6. 5. Stage-sediment curve

When observing the three rivers it was clear that the river by station 2 was the one that had the highest sediment transport. At station 3 the water was much clearer. Locals living in the area confirmed that an illegal mining operation was taking place upstream from station 2. At these mining sites, water is pumped out of the river and flung into sandbanks. The mass of eroded sand and water is filtrated a couple of times in search of valued minerals and then let out into the river again. This causes large amounts of fine particles and suspended solids to disperse in the river water and being transported downstream from the mining (Adijaya and Yamashita, 2004).
In figure 6.5.1 we can see the rivers from station 2 and 3 mix. The cloudy colored one on the right is the river from station 2 and the darker one on the left is the river from station 3. The rivers flow together to form the river at station 1. This river was less murky than river 2 because the sediment-rich water has been diluted by river 3.

Figure 6.5.1. – The junction between Segaru river (station 3) and Sosok river (station 2). Sosok river carrying a great deal of sediment due to mining located upstream.

The results from the spectrophotometer, see appendix 9.1, confirms what figure 6.5.1 shows. Sosok river, used for disposing mining waste water has a sediment concentration that varies between 62-353mg/L water. Segaru river passing station 3 has a sediment transport that varies between 11-25mg/L and the downstream of Sosok river has a sediment transport that is lower than upstream at station 2 and varies between 44-203mg/L.

In figures 5.5.4 and 5.5.5 which show rain events in relation to transported sediment at station 1 and 2 we can see that when a heavy rain occurs, the sediment transport increases. This correlation between increased sediment transport when rainfalls occur is suggested again when plotting depth, which depends on rain, against sediment transport, figure 5.5.1 and 5.5.2. The correlations are R^2= 0,27 for station 1 and R^2=0,26 for station 2. Such low numbers of R^2 does not show much of a correlation between a rain event and increased amount of sediment transport but it might indicate that there is some connection.

Figures 5.5.3 and 5.5.6 show us that the measured parameters on station 3, yet again, have no correlation at all. We believe that this is due to the many floating fish farms that were observed in the river and a lot of human activity in the water. These fish farms would contribute to the sediment transport with fish scales, excrement and so on. However the fish could also decrease the sediment transport by eating the suspended organic particles that are transported in the river. This sediment disruption caused by the fishes is independent of the amount of rain and thus depth increase which is why the correlation is nonexistent.

The sediment transport should increase during rain events because the rain erodes the unprotected land. Much of the land use in the catchment consists of oil palm plantations. These palms have large canopies and inhibit the growth of plants at ground level. Between the palms trees the vegetation consists of low growing, leafy vegetation. No bushes or other trees, that bind the soil, can survive underneath the shadow of the palm trees.

We also observed that for the Sosok river at station 2 the sediment transport increases during the day and then decreases during the night, see figure 5.5.5. This could be due to the mining operation upstream the Sosok river. This mining operation is probably not active during the night which is why the sediment transport decreases. During the day the mining starts again and the sediment transport increases. This is mere speculation, though, since we do not know when the mining operation starts or stops.

The study referred to previously in the discussion, (Carlman Bydén and Hallerth, 2013), suggests some methods for investigating total suspended solids in a river. They investigated methods using turbidity tube and measuring turbidity by photos. However neither of these methods gave reliable results compared to investigating samples in an established laboratory. Consequently we chose not to investigate any of the methods Carlman Bydén and Hallerth tested.

6. 6. Water balance

6.6.1. Evaporation

The evaporation used in the water model was calculated from an equation that relies on mean annual temperature and mean annual rainfall. The rainfall and temperature vary little from year to year and we see no extremes that we think could have influenced our evaporation value. However, our evaporation calculation rely on data from only four previous years, 2011, 2009, 2008, and 2007. For a higher accuracy, data from more years should be used. In our case we did not have access to more data and the four years will have to suffice.

The equation we have used, Turc eq (10) and (11) in section 3.6.3, does not take many factors into account. It relies on empirical values and leaves out such factors as air and soil moisture to name a few. It is, as all such equations, an approximation of reality. Since measuring evaporation accurately is difficult we opted to rely on Turc's equation.

6.6.2. Root zone coefficient

The root zone coefficient for the investigated catchment of Sosok is very hard to estimate. We have not done any hydrological studies of the groundwater in the catchment and can therefore not draw any conclusions of how much rain water that finally drains into the groundwater storage. Soils in rainforest seldom contain aquifers in which water can be stored and consequently form a proper groundwater flow. Neither does it contain any bedrock that may form an impermeable layer on which groundwater can be stored. Instead the soil situated deep under the ground drains small amount of stored water continuously to watersheds and rivers (Mr. Kiki Prio Utomo). The scope of this study would have been too great if we had included a study that would have investigated groundwater.

Since we observed a very small incline of the catchment and the soil is relatively impermeable with a soil porosity of 30-50% we assumed the root zone coefficient to be $\alpha=0,4$. This means that 40% of the water that penetrates into the root zone will drain back to the river.

6.6.3. Direct runoff

The soil in the catchment consists of silt and clay which are not very porous. This means that the ground is impermeable which in turn results in a high C. Further increasing C is the land use in the catchment which mainly consists of oil palm plantations, mining areas and some small villages. There is little rainforest and thus roots that can take care of the precipitation. These factors together is why we estimated that the value for C is 0,7.

Our field work was carried out a couple of weeks after dry season. During dry season, the soils in rainforest catchments are in theory totally drained from water. When rainy season begins, it takes some time before rain water is able to penetrate the soil. This is because the dry top soil is washed into the pores of the soil, blocking the rain water from penetrating (Arsyad, 2010). This causes high surface runoff and is one reason as to why we have chosen such a high value for C.

6.6.4. Water balance- the model

When entering the measured rainfall into our Excel model we get a flow that is significantly lower than the measured discharge in the rivers. This could either indicate that our model is at fault or that our rain data is at fault. If we assume that the rainfall data is in error there are several factors to support this.

We received data from a rainfall station in our catchment in Sosok. If we look at the rainfall data for 2007, 2008, 2009, 2011, (the years that have recorded rainfall data for December) we get an average of 10,3 mm/day, see appendix 9.3. If we eliminate the data for 2011, which is extremely high with more than twice the precipitation compared to the other years, we get an average of 8,2mm/day. These values are both higher than our average of 6,6mm/day. This could suggest that our recorded data is too low.

Another factor that decreases measured data is evaporation. The rainfall collectors were checked every morning at 9a.m. This means that the buckets were subject to evaporation for a full 24 hours. The evaporation was calculated to be 1677mm/year, section 5.6.1. If we transform this to act for 24 hours on an area of 0,053m^2 (the bucket area) we see that up to 5,9 mm could have evaporated from the buckets during a day, see appendix 9.3 for calculations. Of course not all rain spends the full 24 hours in the bucket and during the night or cloudy weather the evaporation decreases. Still, a significant error in measured rainfall could be due to evaporation.

Since our model outputs such low numbers for the discharge this could indicate that upstream in our catchment there has been heavy rainfall events that we have not recorded. Our buckets were placed over a relatively small area and do not account for all of the catchment. Also, as has been mentioned, rainfall here is extremely local, which further strengthens the theory that there are rain events unaccounted for.

Our Excel model does not account for river base flow, it only accounts for the water in the catchment that is a result of rain and evaporation. Therefore it is impossible to get as high values as observed in the field in our model. We get a difference between observed flow and simulated flow of 2-3m^3/s which we assume to be the river base flow. There are of course a lot of possible sources of error behind the results gained from the water balance model; such as methods used for flow and rain measurements, assumptions of coefficients and estimations regarding the catchment areas.

7. Conclusion

7. 1. Rain

The rain is hard to measure accurately since every rainfall event is very local. The placement of rain collecting buckets should be made with this in consideration. In order to get more accurate results we should have allocated more time to the scouting of areas for the buckets and distributed a larger amount of rain collectors. Ideally one could place buckets with some family in a remote area, paying them to do measurements each day. This would allow for a wider dispersion of buckets and being able to collect more rain data. However, one must also take into consideration that work might not be carried out properly when not doing it yourself.

The catchment area is a large source of error as changing this area changes many of the results we have calculated and gained in the simulation of a water balance. It is therefore important that the area is something to be relied on. In our case we feel that the area is uncertain. Both the number for the area 390km^2 and our method of weighting the area between the catchment for stations 2 and 3 are in dispute, as mentioned in the discussion. If there is any possibility of measuring the catchment by oneself or calculating it in a manner that one can be sure of the results, it should be done.

7. 2. Cross-section

As we experienced, the cross-section might be very hard to measure. However, the accuracy in our case must not be extremely high since the aim of this project is to use basic methods and see if they can give okay results. Hence, five to ten centimeters depth inaccuracy at each meters measurement will not make that big of a difference. If the river flow is too fast one could use a boat when doing measurements in the middle of the river and use a line with weights tied to it as an alternative to the bamboo stick as a measuring device. This would be less cost effective but could be faster and more accurate. If however the river allows it, the method we used for measuring the cross-section is cheap and easy. To be really accurate one would have to employ a teodolite.

7. 3. Lag time

The time it takes for water to travel from the first drop of rain until a change in river depth is visible, i.e. the lag time, is very difficult to measure properly. It is a value based on assumptions and estimations of how the catchment responds to rain. We had to extrapolate our measured data in order to calculate the lag time. However, since the lag time is about 13 hours we believe that an hour in either direction is an okay margin of error. It is impossible to capture the entire event since there is only 12 hours of daylight and the lag time ranges from 12-14 hours. To arrive at the exact lag time one would have to measure during the night or have some way of measuring automatically.

7. 4. Stage-discharge curves

Measuring depth and discharge during a limited period of time seems to be somewhat inefficient. During our period of experiment many of the same flows and depths were recorded since there was no rain event that was large enough to change the depth sufficiently. The actual fieldwork and process of hiring people to do measurements on all stations is expensive and might be logistically challenging if it were to be for a longer time. If sporadic excursions at different times of the year would be carried out one could fairly easily establish a rating curve with stage-discharge relations over a larger span. Thus the cross-section of the rivers ought to be controlled a few times a year to control how the riverbanks and riverbeds are affected over time.

7. 5. Stage-sediment curves

Based on the results gained from the spectrophotometry done by the environmental lab in Pontianak, the results from the sediment samples taken in field seem very probable. As we expected, the little sediment load from station 3 dilutes the heavy sediment load from station 2 resulting in less sediment transport after the river junction at station 1. Since there is knowledge about an industry of illegal mining upstream of Sosok river and station 2 it seems reasonable to argue that the high amount of sediment transport at station 2 is a result of this. However, as expressed in the discussion, we do not find an obvious correlation between increased amounts of sediment transport and heavy rainfall. On station 3 there are fish farms and human activity interfering with the result of the total amount of suspended solids. Station 2 is affected by an upstream mining industry which seems to influence the sediment transport in the river different depending on the time of the day. Due to these variables of interference at station 2 and 3 we may suggest that the little correlation that is indicated by the stage-sediment curves are affected by factors such as fish farms and mining. To strengthen the correlation between rain event and increased amount of sediment transport one must choose another sample site for station 3 and investigate how the mining upstream Sosok is carried out. Consequently, more samples and a deeper knowledge of the area are needed to draw further conclusions.

7. 6. Water balance

Much of this report is based on our simulated water balance which is why it is important that the model is as correct as possible. Of course it will only be an approximation of reality, and a simple one at that. We have tried to have a solid base in established literature when devising our model. As far as we can tell none of the assumptions made are in dispute. That being said, the variables α and C that we have estimated are a large uncertainty. No direct measurements have been made that allows us to calculate these numbers. Instead we have looked at our catchment in several different ways and tried to estimate α and C from this information. The limiting factor here is our lack of experience in doing hydrological fieldwork. To gain more knowledge about these coefficients one must investigate the workings of groundwater in a rainforest catchment, which we believe, would be a very difficult task. However, based on the assumptions we have made when simulating a water balance model for our catchment, we get relatively similar results to those we observed in the field.

7.7. Difficulties with assumptions and measurements

- The estimation of a catchment area when no reliable sources are available.
- Deciding an appropriate time period to carry out investigations. We thought that two weeks would be enough, doing measurements for one week and then testing their reliability during a second week. However, even though our project was carried out during rainy season we had trouble with little rain during our first week and since there was barely any more rain after the first week, we never did a second follow up.
- The location of rain gauges. Since it is very hard to find suitable locations for rain gauges dispatched over a large catchment area and then being able to control them every day.
- There are difficulties with measuring the occurring rain to proper values since the evaporation is very high, up to 5,9mm during 24 hours.
- Understanding the movements and workings of groundwater in rainforests and how to investigate how the deep soil water i.e. groundwater is affected by rain. Consequently, how to estimate a proper value for the root zone coefficient α.
- Estimations regarding the direct runoff, C. This coefficient should not be so difficult to calculate, dividing the amount of rain that is observed in the river with the net precipitation, i.e. the amount of rain that is left after evaporation. Since the evaporation is very high, and it is hard to get a proper value of the actual amount of rain, we did not manage to calculate the number of C, but had to estimate it instead.

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Stage-discharge curve, Boulder Creek Critical Zone Observatory (CZO), 2013, Digital Image, Available: http://czo.colorado.edu/inter/hydrology.shtml,(2013-11-27)

9. Appendix

9.1. Field data

Table 9.1.1, 9.1.2 and 9.1.3 contains collected data in field during five days of experiment.

Table 9.1.1. Measured data for Sosok river at station 1.

Date and time	Depth (m)	Mean time of bottle (s)	Velocity (m/s)	Discharge (m3/s)	TSS (mg/L)
Day 1					
13-12-17 10:00	2,64	41,9	0,36	19,1	62
13-12-17 12:00	2,62	40,4	0,32	17,0	82
13-12-17 14:00	2,6	32,3	0,31	16,2	62
13-12-17 14:30	2,6	32,7	0,31	16,0	54
13-12-17 15:00	2,6	30,3	0,33	17,3	51
13-12-17 15:30	2,55	31,9	0,31	16,0	48
13-12-17 16:00	2,55	29,4	0,31	15,6	44
13-12-17 16:30	2,54	30,3	0,30	15,0	51
13-12-17 17:00	2,54	33,7	0,30	15,0	70
Day 2					
13-12-18 10:00	2,48	32,6	0,31	15,0	52
13-12-18 12:00	2,46	30,7	0,29	14,2	72
13-12-18 14:00	2,45	34,4	0,29	14,0	77
13-12-18 16:00	2,45	26,9	0,30	14,3	85
Day 3					
13-12-19 10:00	2,53	30,1	0,33	16,8	57
13-12-19 10:30	2,55	36,6	0,34	17,3	58
13-12-19 11:00	2,56	30,0	0,33	17,1	69
13-12-19 12:00	2,58	29,6	0,34	17,5	88
13-12-19 13:00	2,6	30,0	0,33	17,5	76
13-12-19 14:00	2,62	33,0	0,30	16,0	59
13-12-19 15:00	2,65	30,7	0,33	17,5	110
13-12-19 16:00	2,66	31,3	0,38	20,7	156
13-12-19 17:00	2,68	35,4	0,37	20,0	203
Day 4					
13-12-20 10:00	2,68	34,7	0,37	20,4	92
13-12-20 11:00	2,66	31,2	0,35	19,1	74
13-12-20 13:00	2,64	32,0	0,31	16,7	170
13-12-20 14:00	2,62	34,1	0,29	15,5	188
13-12-20 15:00	2,6	27,9	0,32	16,9	194
13-12-20 16:00	2,59	29,4	0,31	16,0	165
13-12-20 17:00	2,58	31,7	0,32	16,3	132
Day 5					
13-12-21 10:00	2,56	29,5	0,34	17,3	82
13-12-21 11:00	2,58	32,1	0,31	16,1	98
13-12-21 12:00	2,6	30,3	0,33	17,3	
13-12-21 14:00	2,66	25,9	0,35	18,8	95
13-12-21 15:00	2,69	28,3	0,35	19,4	111
13-12-21 16:00	2,71	25,5	0,39	21,8	157
13-12-21 17:00	2,74	26,0	0,39	21,7	170

Table 9.1.2. Measured data for Sosok river at station 2.

Date and time	Depth (m)	Mean time of bottle (s)	Velocity (m/s)	Discharge (m3/s)	TSS (mg/L)
Day 1					
13-12-17 10:00	3,22	48,0	0,21	13,0	97
13-12-17 12:00	3,2	44,0	0,23	14,1	129
13-12-17 14:00	3,17	43,7	0,21	12,6	62
13-12-17 14:30	3,17	49,5	0,20	12,4	63
13-12-17 15:00	3,16	46,0	0,22	13,3	65
13-12-17 15:30	3,15	48,6	0,21	12,5	62
13-12-17 16:00	3,15	48,9	0,20	12,4	84
13-12-17 16:30	3,14	42,1	0,24	14,4	96
13-12-17 17:00	3,14	46,6	0,21	13,0	123
Day 2					
13-12-18 10:00	3,08	52,8	0,19	11,2	86
13-12-18 12:00	3,07	52,7	0,19	11,2	109
13-12-18 14:00	3,06	49,9	0,20	11,7	169
13-12-18 16:00	3,06	55,3	0,18	10,6	193
Day 3					
13-12-19 10:00	3,16	37,6	0,21	13,0	98
13-12-19 10:30	3,17	38,6	0,21	12,7	121
13-12-19 11:00	3,18	35,1	0,23	14,0	125
13-12-19 12:00	3,2	34,9	0,23	14,2	133
13-12-19 13:00	3,22	31,6	0,25	15,8	118
13-12-19 14:00	3,25	31,4	0,25	16,1	148
13-12-19 15:00	3,26	30,9	0,26	16,4	205
13-12-19 16:00	3,28	30,7	0,26	16,7	307
13-12-19 17:00	3,3	30,7	0,26	16,8	353
Day 4					
13-12-20 10:00	3,3	34,9	0,26	16,6	133
13-12-20 11:30	3,28	33,8	0,24	15,1	153
13-12-20 13:00	3,25	31,0	0,26	16,3	260
13-12-20 14:00	3,24	33,0	0,24	15,3	268
13-12-20 15:00	3,22	33,3	0,24	15,0	255
13-12-20 16:00	3,21	32,6	0,25	15,3	192
13-12-20 17:00	3,19	32,5	0,25	15,2	173
Day 5					
13-12-21 10:00	3,18	34,0	0,24	14,5	145
13-12-21 11:00	3,21	36,9	0,24	15,2	163
13-12-21 12:00	3,24	32,6	0,25	15,5	164
13-12-21 14:00	3,29	32,0	0,25	16,1	193
13-12-21 15:00	3,31	32,8	0,24	15,8	252
13-12-21 16:00	3,34	30,1	0,27	17,4	260
13-12-21 17:00	3,37	31,8	0,28	18,7	260

Table 9.1.3. Measured data for Segaru river at station 3.

Date and time	Depth (m)	Mean time of bottle (s)	Velocity (m/s)	Discharge (m3/s)	TSS (mg/L)
Day 1					
13-12-17 10:00	1,7	55,6	0,18	3,7	11
13-12-17 12:00	1,65	57	0,18	3,5	12
13-12-17 14:00	1,6	58,6	0,17	3,2	15
13-12-17 14:30	1,6	56,7	0,18	3,3	12
13-12-17 15:00	1,61	55,1	0,18	3,5	13
13-12-17 15:30	1,6	56,4	0,18	3,4	17
13-12-17 16:00	1,6	55,5	0,18	3,4	18
13-12-17 16:30	1,59	55,6	0,18	3,4	15
13-12-17 17:00	1,59	51,0	0,20	3,7	15
Day 2					
13-12-18 10:00	1,58	38,7	0,26	4,8	20
13-12-18 12:00	1,58	38,9	0,26	4,8	17
13-12-18 14:00	1,57	36,1	0,28	5,1	20
13-12-18 16:00	1,55	37,1	0,27	4,9	18
Day 3					
13-12-19 10:00	1,6	48,1	0,21	3,9	17
13-12-19 10:30	1,61	51,0	0,20	3,8	25
13-12-19 11:00	1,62	49,6	0,20	3,9	17
13-12-19 12:00	1,64	50,6	0,20	3,9	19
13-12-19 13:00	1,68	51,3	0,19	4,0	16
13-12-19 14:00	1,69	51,9	0,19	4,0	
13-12-19 15:00	1,7	56,7	0,18	3,7	17
13-12-19 16:00	1,72	55,5	0,18	3,8	14
13-12-19 17:00	1,74	56,0	0,18	3,8	20
Day 4					
13-12-20 10:00	1,73	62,0	0,16	3,4	17
13-12-20 11:30	1,73	69,0	0,14	3,1	23
13-12-20 13:00	1,69	62,0	0,16	3,3	22
13-12-20 14:00	1,68	64,0	0,16	3,2	19
13-12-20 15:00	1,68	59,1	0,17	3,4	19
13-12-20 16:00	1,67	61,0	0,16	3,3	19
13-12-20 17:00	1,65	60,5	0,17	3,3	20
Day 5					
13-12-21 10:00	1,62	37,9	0,26	5,1	20
13-12-21 11:00	1,65	43,4	0,23	4,6	19
13-12-21 12:00	1,68	48,5	0,21	4,2	23
13-12-21 14:00	1,72	45,0	0,22	4,7	21
13-12-21 15:00	1,75	43,6	0,23	5,0	23
13-12-21 16:00	1,78	47,6	0,21	4,7	21
13-12-21 17:00	1,81	50,5	0,20	4,5	23

9.2. Evaporation data

Table 9.2.1 contains data used to calculate an average actual evaporation working in the area of Sosok from year 2007-2011. The choice of years listed below is due to non adequate registers of data regarding rain and temperatures.

Table 9.1. Data of precipitation at gauging station in Sosok and temperatures at gauging station in Kembayan. The data was used to estimate a value for actual evaporation in the region of Sosok during the last few years.

Rain in Sosok	mm	mm	mm	mm	**Temperature in Kembayan**	℃	℃	℃	℃
	2011	**2009**	**2008**	**2007**		**2011**	**2009**	**2008**	**2007**
January	225	236	252	285		28,4	25,8	26,6	26,6
February	45	103	214	196		28,9	26,3	26,2	26,7
March	145	162	151	168		29,3	26,5	26,3	27,2
April	285	309	0	502		28,9	27	26,8	27,4
May	368	306	123	181		29,6	27,6	27,4	27,2
June	430	239	256	181			29,3	28,7	29,2
July	34	263	284	87			26,9	26,8	26,8
August	81	312	159	238			27,2	26,9	27
September	95	298	121	330			28,1	27,2	27,2
October	240	191	206	321			27	26,8	27,3
November	454	306	389	286			26,4	27,1	26,4
December	524	252	256	250			26,4	26,4	26,6
mean	244	248	201	252		29,0	27,0	26,9	27,1
E_a	1813	1665	1547	1680					

9.3. Assumptions regarding evaporation from buckets

Average rainfall per day in December for 2011, 2009, 2008, 2007

$$\frac{524+252+256+250}{4*31} = 10{,}3\text{mm/day}$$

Average rainfall per day in December for 2009, 2008, 2007

$$\frac{252+256+250}{3*31} = 8{,}2\text{mm/day}$$

Evaporation acting for a day on a single bucket

$$\frac{1677}{365} = \frac{4{,}59mm}{day} \rightarrow 4{,}59*10^{-3}*0{,}53\ (bucket\ area) = 0{,}0024\frac{m^3}{day}$$

0,0024m^3 per day corresponds to a height of 5,9 mm per day, as measured in our buckets.