Analysis of Hydrometeorological Measurements in Tuy Loan River Basin, Vietnam

- A Minor Field Study

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Abstract

Title: Analysis of Hydrometeorological Measurements in the Tuy Loan River Basin, Vietnam

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Background: The central part of Vietnam receives about 4000 mm of precipitation every year and it is common with flash floods. Flash floods are sudden floods with high discharge produced by heavy rain. They usually happen during night and can create landslides. In 1999, there was a big flooding, which spread over 200 km along the coastline and killed over 700 people. One of the areas that were damaged was Tuy Loan river basin, it consists of high mountains with steep hillsides, which makes the area vulnerable to flash floods. In the basin, hydro-meteorological measurements have been conducted in October and November 2003.

Objectives: The main objective with this study is to increase the understanding for the hydrological functions in the basin with special reference to flash floods.

Method: For analysing the hydrological processes in the area the water balance, lag-time and hydrograph were analysed. To try to simulate flash floods the unit hydrograph method and a rainfall-runoff model for flash floods (HRC-model) were used.

To investigate the rainfall pattern, a correlation analysis for the stations in Tuy Loan and in Thu Bon was done.

Conclusions: The difficulties in predicting flash floods make it hard to construct a warning system. To be able to predict flash floods a more thorough investigation has to be done. This can be done by a closer analysis of the origin and movement of the rainstorms before they enter the basin. In order to understand the functions of the catchment better, a geological investigation could be done. It would also be good if measurements could be conducted for more rain periods in order to obtain more measurements for high flow. This could improve the functionality of the models used. The results from this study are not enough for constructing a warning system.

Keywords: Flash floods, Tuy Loan, Thu Bon, Da Nang, Central Vietnam, water balance, hydrograph, unit hydrograph, loop-rating curve, correlation, HRC-model.

Sammanfattning

Titel: Analys av hydrometeorologiska mätningar i avrinningsområdet Tuy Loan, Vietnam

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Bakgrund: De centrala delarna av Vietnam har en årlig nederbörd på 4000 mm/år och det är vanligt med hastigt uppkomna översvämmningar (s.k. flash floods) här. Flash floods är plötsliga översvämmningar med ett högt flöde producerade av kraftiga regn. De sker oftast under natten och ger ofta upphov till jordskred. År 1999 skedde det en stor översvämning som spred sig 200 km längs kusten och dödade över 700 människor. Ett av områdena som drabbades var avrinningsområdet Tuy Loan. Det består av höga berg med branta sidor vilket gör det sårbart för flash floods. I avrinningsområdet har hydrometeorologiska mätningar skett under oktober och november 2003.

Syfte: Huvudsyftet med studien är att öka förståelsen för de hydrologiska funktionerna i avrinningsområdet med betoning på flash floods.

Metoder: För att analysera de hydrologiska processena i området analyserades vattenbalansen, respons tid och hydrografen. För att simulera flash floods användes enhetshydrografen och en avrinnigsmodell framtagen för flash floods (HRC-modellen).

För att undersöka om det fanns ett mönster i hur det regnade gjordes en korrelationsanalys mellan stationerna i Tuy Loan och Thu Bon.

Slutsatser: Svårigheterna med att förutse en flash flood gör att det är komplicerat att konstruera ett varningsystem. För att göra bättre prognoser behövs att en mer noggrann undersökning genomförs. Detta kan göras genom att analysera regnvärdena noggrannare genom att till exempel undersöka deras ursprung och rörelsemönster innan de når avrinningsområdet. En bättre förståelsen av avrinningsområdets funktioner skulle också uppnås genom att göra en geologisk undersökning av området. Det hade även varit önskvärt att genomföra mätningar under flera regnperioder i området för att få flera höga flöden att arbeta med. Detta hade kunnat förbättra funktionerna i modellerna som använts. Resultatet från denna rapport är inte tillräckliga för att kunna konstruera ett varningsystem

Sökord: Flash floods, Tuy Loan, Thu Bon, Da Nang, centrala Vietnam, vattenbalans, hydrograf, enhetshydrograf, loop-rating curve, korrelation, HRC-model.

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Abbreviations

MCRHS - Middle of Central Region Hydrometeorological Station
HRC - Hydrological Research Centre
CHWR- Center for Hydrology and Water Resources
SIDA - Swedish International Development cooperation Agency
IMH - Institute of Hydrology and Meteorology
EUD - Effective Uniform Depth
DWRE - Department of Water Resources Engineering
TUH - Time Unit Hydrograph
MFS - Minor Field Study
Sim - Simulated values
Obs – Directly measured values
Cal - Calculated values
MSL - Mean Sea Level

1. Introduction

1.1 Background

Most parts of Vietnam receive annually about 2000 mm of precipitation, though parts of the central highlands get as much as 4000 mm (World Bank, 2005). This can be compared with the annual values of precipitation in Sweden that varies between 600-1500 mm (Bergström, 2001). The climate in the north and central parts of Vietnam is controlled by two monsoons. The southwestern monsoon from mid May to mid September with hot air and rain and the northeastern monsoon from mid October to mid March with dry weather (World Bank, 2005). The south part of Vietnam has tropical weather.

In the central regions of Vietnam, flooding is common during the late autumn, due to the characteristic of the land. The landscape consists of mountains along the border to Laos in the west and flat plains in the east. During heavy rainfall, the runoff from the mountains is transported rapidly to the plains where it accumulates and causes flooding (Larsson, 2003). In 1999, there was a major flood that swept trough 8 provinces, spreading over 600 km along the central coastal region. During this flood 700 people died and there were material damage for over 250 million USD (Beckman et al, 2002). The maximum 24 h rainfall was measured in Hue to 1422 mm (Ali-Maher et al, 2004). Even though the flooding in 1999 was severe, there were just as heavy flooding both in 1953 and in 1983 (Ali-Maher et al, 2004). Further more there are occasions virtually every year when the flood alert in Central Vietnam reaches level three, which is the most severe (Ali-Maher et al, 2004).

The people that live in the area already live under difficult conditions, due to the frequent minor floods. Flooding may lead to spreading of diseases, decreased food production and makes the conditions for survival harder especially for poor people. Therefore, minimizing flood damage is a way to reduce poverty in the area. It is also shown that women are most affected by flooding. Because of this, flood control is also a way of improving the situation for women (Beckman et al, 2002).

In 2003, the department of Water Resources Engineering at the Lund University started a project with the Hydrological Research Centre (HRC), Institute of Meteorology and Hydrology (IMH), Vietnam sponsored by the Swedish International Development Cooperation Agency (SIDA). The project is aiming to increase the knowledge about flash floods and by doing so the result can be used for supporting an efficient implementation of a warning system for the central parts of Vietnam. One of the largest river systems in the central of Vietnam is the Thu Bon basin. A tributary to Thu Bon is Tuy Loan basin, which in that project worked as a pilot study area where precipitation and water level were measured on an hourly basis. This makes a quick change in the flow observable. The Middle of Central Region Hydrometeorological Station (MCRHS) in Da Nang conducted the measurements in October and November 2003.

This project is a Minor Field Study (MFS) sponsored by SIDA and it started in 2004. It consists of two parts: to make a field trip to the area to collect information and to analyze the data. The research was done in Vietnam and the project was then finished in Sweden.

There exist no previous data from the Tuy Loan basin but there are two nearby stations that are expected to present similar rainfall characteristics, Nong Son and Thanh My (Ali-Maher et al, 2004). The report contains analysis of the old data from nearby basins and suggestions are made that the next phase will be to examine the new data and investigate Nong Son and Thanh My further (Ali-Maher et al, 2004).

1.2 Objectives of the study

The main objective with this study is to increase the understanding for the hydrological functions in the basin and to learn more about flash floods, which in the long term will improve the condition for the inhabitants. This should be done by analysing rain measurements in the Tuy Loan basin and comparing the measurements with data from nearby rain gauges.
In detail:

- To collect data from measurements performed during October and November 2003, to collect useful information about the area.
- To evaluate the collected data.
- To analyse the water movement in the area
- To use the data for simulating flash floods.
- To compare precipitation from the stations in the Tuy Loan basin, to see if one station can represent the whole area.
- To compare the stations in the Tuy Loan basin with stations outside the basin in order to see if this stations can be used to predict the rainfall before it is entering the Tuy Loan basin.

1.3 Limitations

1.3.1 Area of the study

The measurements were conducted in Tuy Loan basin that is a part of the Thu Bon River. When the calculations were made, they were done for a small part of the area with the downstream point of Hoa Phu station. This area was in the report called Lo Dong basin, after the name of the stream where the measurements stations were located.

The stations in Tuy Loan were established in order to measure precipitation and discharge for October and November 2003 and after that, the stations were closed down and no further measurements have been conducted due to lack of funding. The Middle of Central Region Hydrometeorological Station (MCRHS) in Da Nang conducted the measurements. The measurements could be found in the *Report on hydrological measurement in Tuy Loan river basin, Flood season 2003* written by the Department of Water Resources Engineering at the Lund University and Institute of Meteorology and Hydrology, Vietnam.

1.4 Area description

1.4.1 Thu Bon

Thu Bon is together with Ba River, the largest catchments areas in the south central of Vietnam, see Figure 1.4.1. It is about 10 350 km^2 (World Bank, 2005).

Measurements have been conducted here since 1977 and there are 22 meteorological stations and 11 hydrological stations monitoring the basin, see Figure 1.4.2. Measurements are done on hourly or daily basis and are still being conducted. There is also a weather radar station in Tam Ky. Some of the stations data were used and the position for these stations can be found in appendix A.

The area consists of mountain ranges in the east and flat plains along the coast in the west. The river starts at Bach Ma Mountain, 2000 m height, and Ngoc Linh Peak, 2598 m height. The river enters the sea in two different outlets. One flows into Han River, which has it outlet through the city of Da Nang and the other outlet is through Hoi An, which is about 30 km south of Da Nang.

Figure 1.4.1: Map over Vietnam with the major river basins (World Bank, 2005).

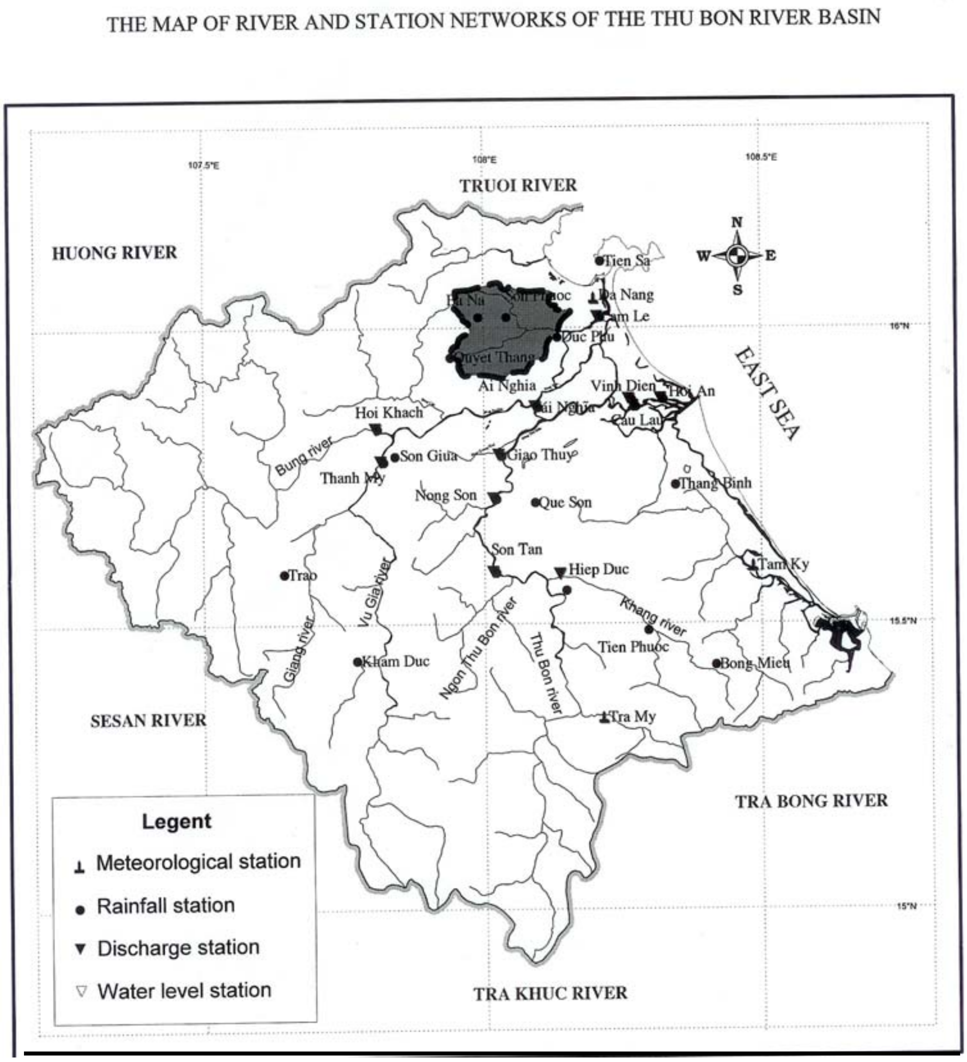


Figure 1.4.2: Map over Thu Bon river basin with precipitation stations and the shaded area is Tuy Loan river basin (Nguyen Van Dai, 2004).

1.4.2 Tuy Loan

The River basin of Tuy Loan, see Figure 1.4.3, is situated in the district of Hoa Vang in the central of Vietnam. The size of the river basin is about 250 km^2 (Ali-Maher et al, 2004). It is a tributary to Thu Bon and lies in the northern part of the basin. The length of the river is about 27 km and the average slope is about 3.20%, but varying largely between the hillside and the plains. The river starts at Ba Na or Nui Chua mountains and proceeds through a narrow valley towards the Han River where it empties.

The hillside is very steep, but near the coast the landscape flattens out and the slope is very flat near the sea. The shape of the landscape makes it very vulnerable to flash floods. The response time of Tuy Loan is about 1-2 hours and for the whole Thu Bon 12 hours. In the flooding 1999, as much as 35 persons died only in the Tuy Loan basin (Ali-Maher et al, 2004).

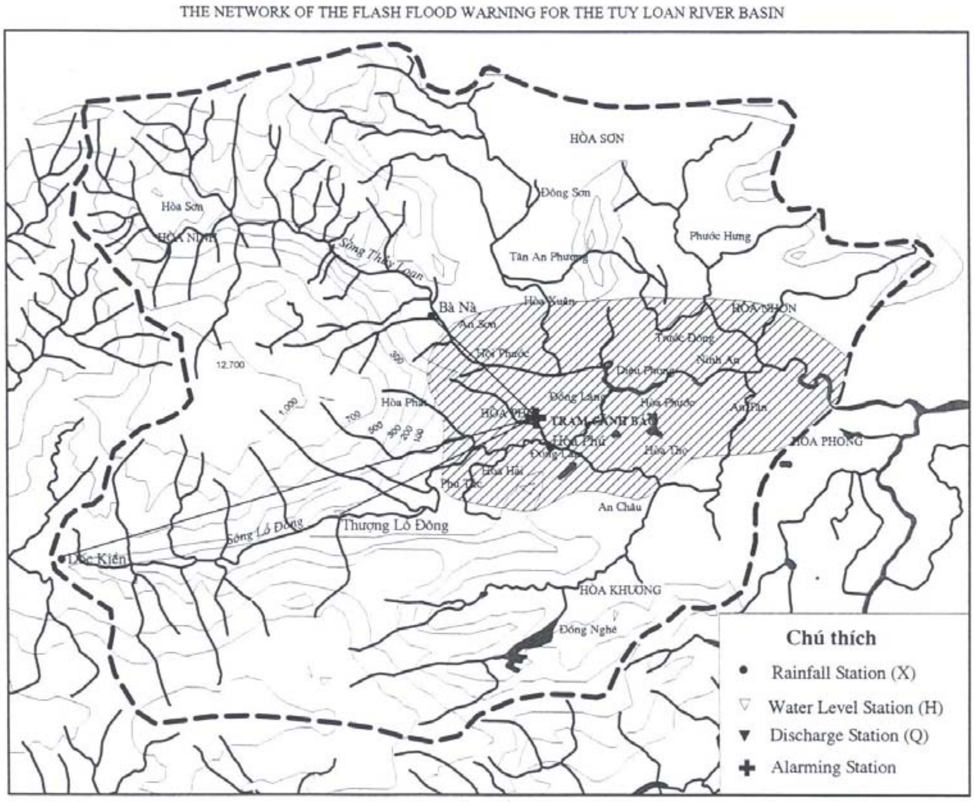


Figure 1.4.3: Map over Tuy Loan river basin with the measurement stations marked in it and also the area that was flooded in 1999 (striped area) (Nguyen Van Dai, 2004).

1.4.3 Lo Dong

The area that the measurement stations cover is not the whole Tuy Loan basin, but a small part that contains the Lo Dong River. The measurements were conducted during October and November 2003. The area of the basin is 71.6 km^2 (Nguyen Van Dai, 2004; Le Viet Xe a, 2004). The river starts just downhill of the rain gauge station of Doc Kien. The slope in the mountainous area, from Doc Kien to Hoa Phu, is about 1.7%, and on the flat plane from Hoa Phu to the sea is only about 0.25% (Pham Van Chien, 2004). The length of the river from Doc Kien to Hoa Phu is about 13 km. (Nguyen Van Dai, 2004)

In the area there is some slash and burn cultivation performed by the ethnic people living in the mountains (Tran Van Phuc, 2004; Beckman et al, 2002). Near the Doc Kien station, there is also some forest cultivation (Vo Van Minh, 2004; Ali-Maher et al, 2004). The degree of cultivated land in the area is not high, most of the land is forestland, which can be seen in Figure 1.4.4. The soil in the up-land has a red-yellow colour (World Bank, 2005).

Figure 1.4.4: A view of the landscape at Doc Kien.

1.5 Climate

Central Vietnam has a dry season and a wet season. The wet season is characterised by floods from the monsoon while the dry season consist of low flows and saltwater intrusion (World Bank, 2005). During the wet season, Vietnam is also hit by typhoons. Typhoons produce heavy rain and large floods (Le Dinh Quang, 2001).

1.5.1 Monsoon

A monsoon arises when there is a difference in temperature between land and sea, which produces a wind. There are generally two types of monsoons: the summer monsoon and the winter monsoon. The summer monsoon develops when the air over the land is much warmer than the air over the sea. The wind then blows from the sea in over land where it produces rain.

For the winter monsoon, the wind blows in the opposite direction. This happens when the land has cooled off and the air is warmer over the sea than over land. The monsoon is thereby changed regularly as the seasons change and is therefore called season winds (Ahrens, 1991).

1.5.2 Typhoons

A typhoon is an intense storm that has tropical origin. It has different names in different parts of the world, for example, it is called hurricane in USA and cyclone in India and Australia. The name typhoon is used in the western North Pacific (Ahrens, 1991).

Typhoons are formed between 5^o and 20^o latitude. They are characterised by an intense low pressure, high winds and heavy rainfall. The clouds move in a vortex towards the central eye, on the Northern hemisphere they move counter clockwise and on the southern hemisphere they move clockwise. In the central eye of the typhoon, the winds are light and the clouds are mostly broken. Just outside of the eye, the eye-wall consists of heavy thunderstorm clouds that can reach 15 km up in the air. The eye-wall produces the heaviest rainfall (Ahrens, 1991).

In the typhoon, the wind speed can be as high as 80 m/s and pressures as low as 950 hPa have been observed. The area is about 200-500 km^2, which is smaller than the low-pressure systems that are formed over Europe (Ahrens, 1991).

1.6 Flash floods

The natural phenomenon called flash flood exists worldwide. A flash flood can be distinguished from a regular storm by the timescale of the event. A flash flood happens during a very limited time, while a normal flood can occur after a long period of rain (Doswell, 1994). The definition of flash floods by IAHS-UNESCO-WMO is as follows:

> "Flash floods are sudden floods with high peak discharge, produced by severe thunderstorms that are generally of limited areal extent."
> (Gaumes et al, 2004)

In the Mediterranean area, flash floods have killed over 100 people over the last two decades (Gaumes et al, 2004). In the US, flash floods have been known as being the weather disaster that takes most lives year after year (Doswell, 1994).

Three factors that affect the flash flood is the antecedent precipitation, the terrain and the characteristics of the surface runoff. This means that a rain can give no effect at one time and the next time cause a disaster, depending on where it hit. For example, if it hits in a flash flood sensitive basin it might cause a disaster, but if it hits in an area that can cope with large amounts of water, or if it spreads over more than one basin, it might cause a much smaller effect (Doswell, 1994).

Though the awareness of the danger of flash floods increases, there is still no record of flash floods in the US, as the ones for tornados and severe thunderstorms. This might be because of the difficulties to define a flash flood (Doswell, 1994).

Flash floods also cause dangers that are related to the heavy rainfall. Heavy rainfall, especially from a typhoon, often causes landslides. It is caused by the erosion from the water and causes flows of mud and stones downstream. The landslides can be very severe and bury houses and people. They often occur without warning, which makes them very dangerous (World Bank, 2005).

1.6.1 Flash floods in Vietnam

Vietnam is frequently hit by floods both in the south, the Mekong River delta, in the north, the Red River basin, and in the central parts. In the north and central parts of the country the flow time between the flood generating parts and the flood effected areas are fairly short. This together with the characteristics of the landscape described above causes the area to be hit by flash floods frequently (Ali-Maher et al, 2004).

Recent research has concluded (Ali-Maher et al, 2004) the following characteristics of flash floods:

- It occurs high up in branched systems that have small basins and steep slopes.
- The basin where the flooding occur has usually some slash and burn cultivation, exploitation of forest or natural resources in the area that destroys the river sides and makes it more vulnerable to floods.
- The flooding occurs mostly in the beginning of the flood season.
- Flash floods occur mostly at night.
- The weather causing flash floods is low pressure pushed upwards by cold air, storms or tropical convergent strips. This causes rainfall of the magnitude of 100 mm/6 hours of 200-300 mm/12 hours.

2. The measurements in Lo Dong 2003

2.1 Descriptions of the measurement sites

2.1.1 Upper Lo Dong site

At the Upper Lo Dong water level, see map in Figure 1.4.1, measurements have been conducted. Just downstream of the measurement point, a bridge is under construction, which has been affecting the measurements at two periods, 7th November at 19.00 and the 17th of November at 10.00 to the 19th of November at 08.00.

The cross section at the site is relatively flat with a steep slope at the right side of the river. When the water level reaches 40.50 m above mean sea level (MSL) it overflows the bank on the left side. At the water level of 38.00 m above MSL, the culvert at the bridge, about 70 m downstream, is flooded. The maximum level in the 1999 flooding at this site was 41.14 m above MSL. The water level station is situated at a level of 40.5 m above MSL (Le Viet Xe b, 2005).

2.1.2 Hoa Phu site

At Hoa Phu the water level, discharge and rain is measured, see map in Figure 1.4.1. The river section is wide and covered with sand, which can be seen in Figure 2.1.1. On both sides, cash crops are grown. About 180 m upstream, there is a curved section with many sand bars. The sides of the river cannot cope with water levels above 9.50 m above MSL. The maximum flow in the flooding 1999 was 13.79 m above MSL (Ali-Maher et al, 2004). The rain gauge is situated in front of a house on the riverbank, at an altitude of 9 m above MSL (Le Viet Xe b, 2005).

Figure 2.1.1: The bridge at Hoa Phu.

2.1.3 Ba Na site

At Ba Na the rain was measured, see map in Figure 1.4.1. The site is at the forest fire station and the rain gauge is situated at the bank of the river on a flat land with grass, at an altitude of 30 m above MSL (Le Viet Xe b, 2005).

2.1.4 Doc Kien site

At Doc Kien the rain was measured and the rain gauge is situated at an altitude of 200 m above MSL (Le Viet Xe b, 2005), see map in Figure 1.4.1. This site was just upstream of the origins of Lo Dong River. The rain gauge was placed on an open field, where a water buffalo was grazing during the visit. There were some bushes at the open field and across the road there was a cultivated forest with high trees. A picture of the site can be seen below in Figure 2.1.2.

Figure 2.1.2: Doc Kien rain gauge site.

2.2 Descriptions of the performed measurements

Rain measurements were conducted at three of the stations: Ba Na, Doc Kien and Hoa Phu. The flow was only measured at Hoa Phu and the water level at Hoa Phu and Lo Dong.

Table 2.2.1: Measurements performed at the different sites.

Station	Rain	Flow	Water level
Ba Na	X		
Doc Kien	X		
Hoa Phu	X	X	X
Lo Dong			X

2.2.1 Precipitation measurements at Doc Kien, Ba Na and Hoa Phu stations

The measurements were conducted in the same manner at all three sites (Ali-Maher et al, 2004). One recording and one non recording rain gauge were used. They were of a tipping bucket type that is made in China (SL-1) see Figure 2.2.1. For the non-recorder rain gauge the rainfall was measured four times per day (01.00; 07.00; 13.00 and 19.00) and for the recorder the chart was replaced at 07.00 every day. The data was then interpreted and compared and the rainfall amount was defined for every hour.

Figure 2.2.1: Rain gauges used for the measurements in Lo Dong catchment area (Ali-Maher et al, 2004).

2.2.2 Flow measurements at Hoa Phu station

To conduct the discharge measurements in Hoa Phu, a bridge with a span of 40 m was used. 21 depth measurements verticals and 3 velocity measurements verticals were established. The winch was designed by the Middle of Central Regional Hydrometeorological Station, Vietnam, with iron fishes of 15, 30 and 50 kg. The automatic current meter was of the style (LS25-1A; No. 99021) and sounding head ZLS-3 made in China, see also Figure 2.2.2.The measurements were conducted with six hour intervals, except for rising and receding limb of a flood event when they were made more frequently (Ali-Maher et al, 2004).

Figure 2.2.2: Water current meter in Hoa Phu (Ali-Maher et al, 2004)

2.2.3 Water level measurements at Hoa Phu and Lo Dong stations

The water level measurements at the upper Lo Dong site were carried out on the left side of the river. It contained 14 poles and the measurements were done by a handcarried ruler with gradation in cm. The measurements were conducted at an hourly basis (Ali-Maher et al, 2004).

At Hoa Phu, the water level measurements were carried out in a similar way, but 16 poles and one staff gauge were used. See also Figure 2.2.3 (Ali-Maher et al, 2004). As at Lo Dong, the measurements were conducted on an hourly basis.

Figure 2.2.3: Water level measurement in Lo Dong (Ali-Maher et al,2004)

3. Theory and Methods

This chapter contains a short presentation of the methods that are used in this report. It starts with the water balance where the different hydrological processes are discussed and compared to each other. Then the relationship between precipitation and discharge in different rainfall-runoff methods as unit hydrograph and HRC-model are examined. Before making a unit hydrograph a hydrograph needs to be constructed, which illustrates the relationship between precipitation and discharge. It is interesting to calculate the time it takes after one rainfall event until the flow reacts and this is called lag-time or response time. A special phenomenon where the flow increase before the water level can occur when a flood is in progress. It is called Loop-rating curve and is investigated for the area. To see if the rain that falls over one station also hits other stations in the basin and outside, a correlation test was done. This was done in order to see if a station closer to the coast could be used to predict the rain in the mountains. In order to construct an effective warning system this would be desirable.

3.1 Water balance

The water balance was calculated to analyse the water movements in the area. The Water balance is a way of describing the hydrological cycle mathematically for a catchment area. The hydrological cycle is driven by solar radiation (Hamill, 2001). This is the water balance equation:

$$P - Q_{out} - E \pm G + I = \Delta S/\Delta t \qquad \text{eq. 3.1.1}$$

(Hamill, 2001)

Where P is the precipitation over the area, Q_{out} is the discharge from the area, E is the evaporation, G is the net flow of the groundwater, I is the inflow from other areas and ΔS is the change in storage over a chosen period, Δt. Over one year the change in storage is very small and almost equal to zero. The different processes that are included in the water balance are described more thoroughly in the following chapters.

3.2 Precipitation (P)

Rain can be caused by different phenomena, by which it is classified. Rain occurs when warm air is forced upwards by a barrier. When the air cools off, the vapour turns into liquid, and it starts to rain (Ward et al, 2000).

If the air is forced up by colder air the rain is called frontal rain or cyclonic precipitation. This is characterised by a long narrow front between the air masses from which the rain is coming. It is also connected to low pressure and uplifting of air. In tropical areas, the heat may cause more intense and short lived rainfall (Ward et al, 2000).

If the rain is the result of warm air that is forced up by heating and then cools off from the surrounding, the rain is called convectional or convective rain. This causes local and intense rain but with limited duration. This is a common rain in the tropical regions. In tropical cyclones, the cloud particles will circle around the centre and create a vortex or warm air rising, which may cause long lived heavy rainfall (Ward et al, 2000).

Orographic precipitation results from mechanical lifting of moist air over, for example, a mountain ridge. It is not as effective in producing rain as cyclonic precipitation, though it is the same phenomenon as when warm air is forced upwards due to cold air (Ward et al, 2000).

The flash flood in Vietnam occurs from monsoon rainfall and from typhoons. These two phenomena produce frontal rain, respectively convectional rain. The mountains in the area can also give rise to orographic rain, due to mechanical lifting (Le Dinh Quang, 2001).

3.2.1 Flash flood producing rain

Flash floods originate from high to extremely high rainfall. It is also dependent on the duration of the rainfall. Flash floods are mostly produced from convective rain because this rain type produces very heavy and intense rainfall. While a rainfall cycle of one rain parcel is only about 20 minutes, it is often needed a “train” of rain parcels to produce the needed length of the rain. A long duration of a rainfall is often associated with systems that have slow movement, large areas of high rainfall rates along the vector of movement or even both of these. The course that the rain takes over the area is also important for the duration. If the way is longer, the duration also gets longer. It has also been noted that the most important flash floods originates from quasi-stationary convective systems. These are systems of convective cells that mature and produce the heaviest rainfall over the same area (Doswell et al, 1996).

Sometimes the flash flood producing rain might also depend on supercell-storms (thunderstorms) and orographically forced rain (Doswell, 1997).

3.2.1 Measuring rainfall

When measuring rain at a point it is very important to place the gauge at a site where it is representative for the area. Because of the large area that the gauge represents, even a small error can correspond to a large amount of water when representing the whole area. (Shaw, 1994).

One of the largest problems when measuring rain is that the rain gauge is acting as an obstacle to the wind. Because of this, rain droplets that would have ended up in the gauge proceed further away and thereby give a lower result than expected. This problem is larger in temperated areas when there is more wind and smaller droplets than in tropical areas. The problem can often be reduced by placing the gauge at a proper site, not too windy and not too sheltered. An estimation of the under catch has shown that it is globally about 10%, it differs from near the poles where it is about 40% to the tropics where it is about 5% (Ward et al, 2000). If there are large obstacles in the area the distance between this and the gauge should be 2-4 times the height of the obstacle or the angle of maximum 30^o as showed in Figure 3.2.1 (Shaw, 1994).

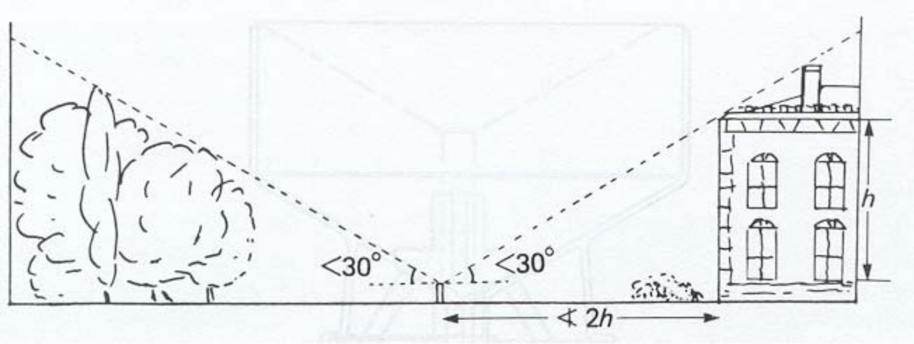


Figure 3.2.1: How to place the rain gauge properly in order to avoid errors in the measurements (Shaw, 1994).

3.2.2 Areal precipitation

Precipitation is usually only measured in some measuring points. These measurements then have to be transformed into the average precipitation in each point over the whole area. This is called the Effective Uniform Depth (EUD) of precipitation or areal precipitation and can be calculated by using as much as 15 different methods (Ward et al, 2000). Below the three most common methods are described: Arithmetic Mean Method, Thiessen Method and Isohyetal Method. The topography and climate must be taken into consideration in the choice of method. If the method can not manage to do that, an additional correction for the height has to be done.

Arithmetic mean:

The arithmetic mean is the simplest method and can be used if the rain gauge network has a uniform density. This is a plain mean value of the measurements from the different measurement points in the area.

Thiessens method:

The Thiessen method can be used if the network is not uniform. The area is divided into smaller parts, which is allocated to the nearest rain gauge, see Figure 3.2.2.
The areas are obtained as follows (Fetter, 2001):

1. Mark the measure stations in the river basin.
2. Connect the stations by drawing lines between them.
3. Draw a perpendicular line in the midpoint of the line connecting two stations.

4. Use the perpendicular lines to draw polygons around the stations to determine the area, a, that “belongs” to each station, R.
5. Determine the different areas percentage of the total area and calculate the total average rainfall.

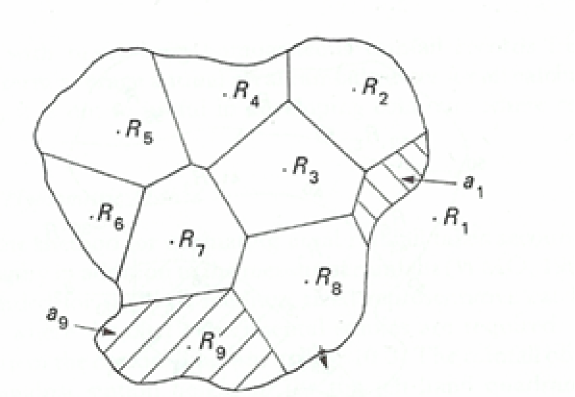


Figure 3.2.2: Figure over the polygons obtained when using Thiessens method (Shaw, 1994).

Isohyetal method:
The Isohyetal method can also be used in non-uniform networks. It is the most accurate method and factors known to affect the precipitation as elevation can be taken into account. The method is done by drawing isolines for measured precipitation in the area of the basin, see Figure 3.2.3. This can be done by using known factors that affect the precipitation or by using simple linear interpolation between the stations. The area that lies between two lines is measured and the average depth of the rainfall in the area is the mean of the bounding isohyetals. The EUD of precipitation is then the weighted average based on the relative size of each isohyetal area.

A drawback of this method is that the isohyetal must be redrawn for each analysis (Fetter, 2001).

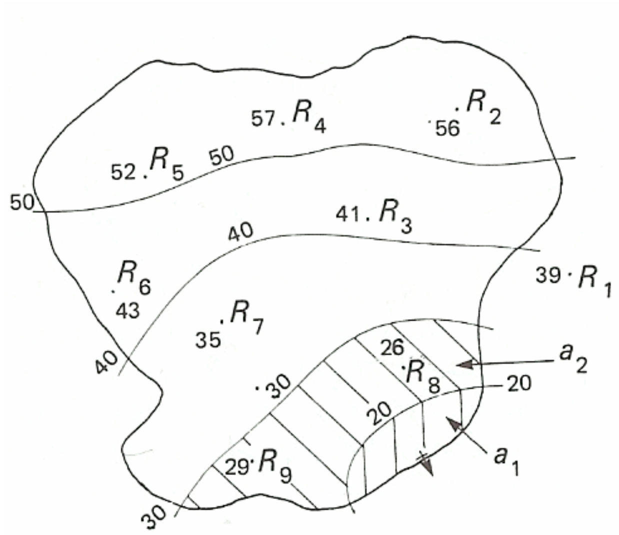


Figure 3.2.3:The priciples of the Isohyetal method (Shaw, 1994).

3.2.3 Elevation dependency

Precipitation varies with different topographic factors like elevation, slope and orientation, which for example Spreen have studied for western Colorado (Linsley et al, 1998). This study showed that the elevation difference could cause 30% of variation in the precipitation. When all the parameters above were put together, it could vary up to 85%. In the reference, there is no comment about how large the catchment areas in the studie were. In mountainous areas the correction could be even larger, if so it is usually adjusted by using the isohyetal method.

In Sweden, the height dependency has been studied above the treeline in an area called Övre Indalsälven. In the report (Niemczynowicz, 1988), the area of the catchment is not given but there is a map included so the area was estimated to 400 km^2. There were ten rain gauges with daily measurement and they were placed at an elevation from 431 m to 1005 m above MSL. This study gave the average correction factor of 9.5% every 100-meter increase of the mountain. The height dependency for heavy rainfall was not larger than for lighter rainfall. The precipitation of frontal rain showed more height dependency then other kinds of rain. The distance from the ocean was a factor where more rain was found closer to the ocean. The wind direction in this area was from the west and the largest amount of precipitation was found on the leeside of the mountain, which is called “carry over” effect (Niemczynowicz, 1988).

In the study, it is also mentioned that in general the rain gauges are situated at the low levels in an area where the population live. This correction method is an uncertain method but has to be done if the water balance in the area should be correct (Bergström, 2001).

Da Nang station had made some measurements of the elevation dependency at Ba Na Mountain. The three rain gauges (Hoa Phu, Ba Na and Doc Kien) are situated at the foot of mountains where the highest peak is the peak of Ba Na Mountain that is 1279 m above MSL. Because Tuy Loan is the first area with high altitude from the coast, the effect of the elevation is very important to consider.

3.2.4 Method for the calculation of areal precipitation

The areal precipitation with elevation dependency was calculated from the precipitation data in October and in November 2003, using the different period of one hour, one day and one month. The calculations were done with Thiessens Method. Because the rainfall was not uniform over the area the Arithmetic mean method was not used, nor was the Isohyetal method since there was not enough data for this method.

The catchment area was set to 71.6 km^2 (Nguyen Van Dai, 2004; Le Viet Xe a, 2004). The area of influence of the different stations, when using Thiessen, was calculated manually by using a paper map.

The areal precipitation was then corrected by the elevation dependency of the rainfall. The measurements for Ba Na Mountain showed that it rains 100-200 mm/year more per 100 m increase of altitude (Le Viet Xe a, 2004). For the calculations 150 mm/year were chosen and from statistics it was found that 25% of the annual precipitation occurred in October and 25% in November (Ed. Ban Biên Tâp, 2001).

When calculating the increase/decrease of the rain due to elevation, the area was divided into 25 smaller parts where the altitude contours were the boundaries, together with the borders from Thiessen method. This was done with software program MapInfo, which also calculated the area of the different parts. The value in the middle of two curves is chosen to be the altitude for that area. The precipitation is then corrected for the altitude of the area. Consideration was taken to which altitude the rain gauge was situated at and the increase or decrease in rain was calculated from that level.

3.3 Discharge (Q)

The discharge from the area is the amount of water going out from the area by the river. Because it is easier to measure the water level than it is to measure the flow, it is desirable to be able to calculate the flow from the water level.
This can be done by using the level and stage-discharge relationship:

$$Q = a(H - H_0)^n \qquad (\mathrm{m}^3/\mathrm{s}) \qquad \text{eq. 3.3.1} \qquad \text{(Gordon et al, 1996)}$$

where a and n are constants that can be found by calibration against observed discharge measurements. H is the observed water level and H_0 is the lowest level of the bottom of the river at the measurement point. During a flash flood event, this relationship is not valid because the high velocity of the water makes the flow unsteady. The high velocity of the water also brings sediment and debris that can cause problems with the measurements of the water level (Gaume et al, 2004).

If direct measurements of the flow have been done, interpolation can be used. The measurements should not be to far apart in time, especially during periods when the flow changes quickly (Hoybye, 2004).

3.3.1 Method for calculating discharge

The flow measurements were done with approximately six hours intervals when the flow was not changing very much. When it started to rain and the flow started to increase, the measurements were made much more often, sometimes more than once every hour. Because of the high frequency of the measurements, interpolation was used for calculating the hourly flow.

3.4 Evaporation (E)

Evaporation means liquid that is transferred from its liquid phase into a gaseous phase (Ward et al, 2000). The potential evaporation, denoted E_p, is the evaporation that would have taken place if there were no limitation in the water supply, i.e. the atmospheric demand of water is satisfied. It is not the same as the evaporation that takes place, called the actual evaporation ,denoted E_{ac} (Ward et al, 2000).

3.4.1 Estimation of potential evaporation

This can be estimated in different ways. A common way of estimating the potential evaporation is to use a so called evaporation pan. The most commonly used is called a “Class A” pan and this type is situated above the ground while other types are dug into the soil. The pan is filled with water and is open to the air so the water can evaporate. As the water evaporates new water is added. The amount of water added is monitored (also precipitation) and by knowing the level of the water in the pan and the amount of water added or removed, the evaporation can be derived (Ward et al, 2000).

It is also possible to make models to estimate the evaporation. Although the parameters that the evaporation depends on (amongst other humidity, windspeed and radiation) are relatively easy to measure, it is hard to estimate the evaporation both by measuring and by modelling. This is due to the interaction between the demand from the atmosphere and the control from the soil of how much water that is available.

The two most common models to use is the purely empirical model developed by Warren Thornthwait, called the Thornthwait model, and the physically based model developed by Howard Pennman, and modified and further developed by John Monteith, called the Pennman-Monteith-method. In this project a model which is a combination of Penman-Monteith and a Russian model is used and explained below.

3.4.2 Calculating evaporation with the method used by Hydrological Research Centre (HRC)

This method is a combination method where the potential evaporation is calculated and then adjusted to be the actual evaporation. The method can be described as follows:

$$E_p = \frac{\Delta}{\Delta + \gamma} E_r + \frac{\gamma}{\Delta + \gamma} E_a \qquad \text{(mm/day)} \qquad \text{eq. 3.4.1} \qquad \text{(Chow et al, 1988)}$$

-E_r = the evaporation due to radiation
-E_a = the evaporation due to advection
-Δ = the gradient of the saturated vapour pressure
-γ = the psychometric constant

These two make up the weighting factors of the radiation and advection and is calculated by using:

$$\Delta = \frac{de_s}{dT} = \frac{4098 e_s}{(273.3 + T)^2} \qquad \text{(Pa/}^{o}\text{C)} \qquad \text{eq. 3.4.2} \qquad \text{(Chow et al, 1988)}$$

-e_s = the saturation vapour pressure

γ is defined by:

$$\gamma = \frac{C_p K_h P}{0.622 l_v K_w} \qquad \text{(Pa/ }^{o}\text{C)} \qquad \text{eq.3.4.3} \qquad \text{(Chow et al, 1988)}$$

-K_h/K_w = the ratio between heat and diffusive coefficients (=1.0)

C_p is defined by:

$$C_p = \frac{de_u}{dT} \qquad \text{(J/(kg*°C))} \qquad \text{eq. 3.4.4} \qquad \text{(Chow et al, 1988)}$$

-P = the air pressure
-l_v = the latent heat of vaporization

l_v varies slightly with the air temperature and can be estimated by:

$$l_v = 2.501 \times 10^6 - 2307T \qquad \text{(J/kg)} \qquad \text{eq. 3.4.5} \qquad \text{(Chow et al, 1988)}$$

E_R is computed by:

$$E_R = \frac{R_n}{l_v \rho_W}$$ (mm/day) eq. 3.4.6 (Chow et al, 1988)

-R_n = the net radiation
-ρ_w = the density of vapour pressure

E_a can then be calculated using:

$$E_a = B(e_s - e_a)$$ (mm/day) eq. 3.4.7 (Chow et al, 1988)

-e_a = the air vapour pressure

B is the vapour transfer coefficient determined by:

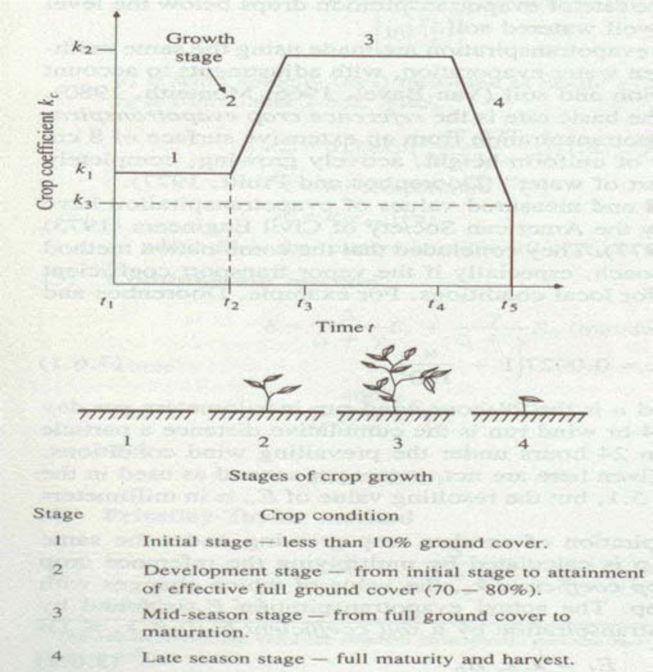
$$B = \frac{0.622 k^2 \rho u_2}{P \rho_W \left[\ln(Z_2 / Z_0)\right]^2}$$ (m/(Pa*s)) eq. 3.4.8 (Chow et al, 1988)

-k = the von Karman constant
-ρ_a = the density of moist air
-u_2 = the wind velocity at the elevation Z_2 (cm) and Z_0 is the roughness height (cm).

E_{ac} is the actual evaporation that occurs from the soil and from the transpiration from plants. This can be estimated by correcting the potential evaporation. This can be done using the equation:

$E_{ac}=K_sK_cE_p$ (mm/day) eq. 3.4.9 (Chow et al, 1988)

Where K_c ($0.2 \leq K_c \leq 1.3$) is the crop coefficient that is based on the growth stage of the crops in the area, and the K_s ($0 \leq K_s \leq 1$) is the soil coefficient. If the soil is well watered, the soil coefficient is equal to one. The crop coefficient can vary over the year, as showed in Figure 3.4.1. It is dependent on the degree of cover from the crop on the soil. If the coverage is large the coefficient can be as high as 1.3.



Stage	Crop condition
1	Initial stage — less than 10% ground cover.
2	Development stage — from initial stage to attainment of effective full ground cover (70 — 80%).
3	Mid-season stage — from full ground cover to maturation.
4	Late season stage — full maturity and harvest.

Figure 3.4.1: Figure to help estimating the crop coefficient K_c (Chow et al, 1988).

3.4.3 Method for calculations of actual evaporation

The evaporation was, in this project, calculated using the HRC method and computed for daily values. The data of temperature, relative humidity, air pressure and wind speed are daily values measured at the Middle of Central Region Hydrometeorological Station (MCRHS) in Da Nang. The net radiation and the two correction coefficients were estimated.

3.5 Groundwater (G), Inflow (I) and change in Storage (ΔS)

Groundwater flow is an essential part when calculating the water balance in a long term, one year or longer. The process of infiltration and percolation contributes to the groundwater. Infiltration is the process where the water penetrates the surface and percolation is the process where the water is moving vertically in the ground towards the groundwater. The soil consists of different layers with different soil types where some are more permeable than others. If the water reaches an impermeable layer, it starts to move horizontally and this is called interflow. The interflow discharges to streams and is part of the baseflow. Percolation is a slow process where the water moves with a velocity of about 1 m/year. The velocity is depending on three factors: type of soil, the moisture condition in the soil and rainfall intensity (Hamill, 2001). Because of the slow movement, this process does not have such a large impact over shorter periods. The groundwater flow can be hard to determine if there are no measurements. For rough calculations and shorter periods, the groundwater flow can be treated as a part of the change in storage.

Inflow is water that is not precipitation and enters the river catchment by a watercourse. This does not usually happen, but there are cases when humans make a construction that leads the water between different catchment areas.

The change in storage can be water retained in the soil, a lake or snow. If the change in storage is calculated over a number of years, it should be equal to zero and for a year the change should be small (Ward et al, 2000). When doing a rough calculation the groundwater term is sometimes ignored and put into the change in storage.

3.6 Method for calculating the water balance

The water balance of the area was calculated using the data of the precipitation and water level measurements done in the Tuy Loan during October and November 2003. The areal precipitation with elevation correction was used. The discharge was calculated from the interpolated water level measurements from Hoa Phu, transformed into mm/h by dividing the flow measured with the area of the river basin. The groundwater term was ignored, because the water balance was made on a short period. It would have been difficult to estimate groundwater flow when the geological condition in the area is unknown. There was no inflow of water from other river basins around Tuy Loan.

3.7 Hydrograph and Hyetograph

A hydrograph shows the changes of flow in the river during a period due to a rainfall event. A hyetograph shows the change in intensity of the rainfall event. The rainfall is measured at precipitation stations in the area and then the areal precipitation is calculated. The discharge is measured in the river, where the water leaves the catchment area. The period can be chosen depending on what is interesting, and could be year, month, day, hour or event. The period also depends on the frequency of the rain measurements (Shaw, 1994). Below a hydrograph is displayed together with a hyetograph, Figure 3.7.1.

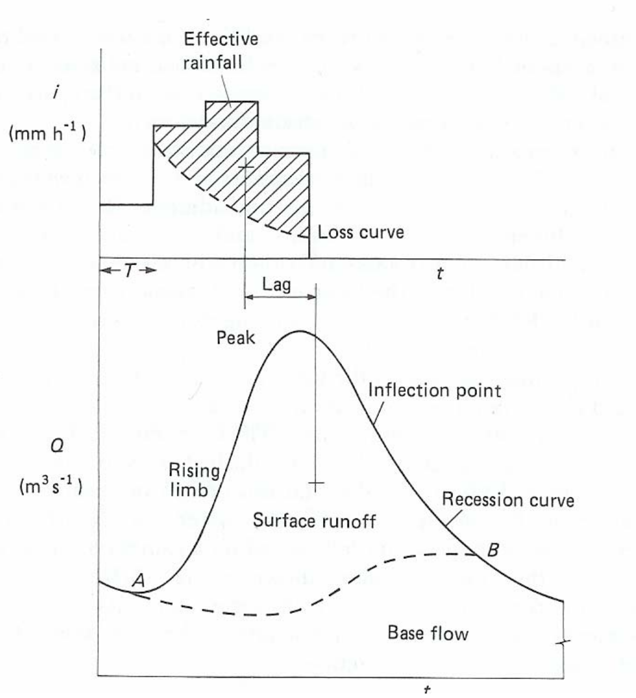


Figure 3.7.1: Hyetograph and a hydrograph with the different terms used when constructing a hydrograph, marked and described (Shaw, 1994).

The water in the river comes partly from the groundwater and partly from precipitation. Groundwater is called baseflow in the Figure 3.7.1 and has a natural variation over a year due to climate in the area. Baseflow tends to be low when there has been a drought and high after a long period of wet weather. The part from precipitation is named surface runoff in Figure 3.7.1 and varies a lot during the event. The figure shows a single event but precipitation could be much more complex with a longer period and varies in intensity and then a hydrograph could consist of more peaks.

The water level does not start to rise immediately when there is a rain. There is always a delay due to that the water first has to fill up the catchments area negative storage (if there is one) and make the surface and soil saturated. The delay, also called lag-time or response time, could vary from a couple of hours to some days depending on the characteristic of the catchment: soil type, bedrock, crops etc. The water level then rises to the peak of the curve and rainfall still contributes to the surface runoff until the curve reaches the inflection point. After this point, it is only water that is temporarily stored in soil, which contributes to the hydrograph. When that water decays, the curve has reached the recession curve and then baseflow takes over. This point between the surface runoff and baseflow is hard to define, see point B in Figure 3.7.1. The boundary depends on geological factors and the composition of the catchment area (Shaw, 1994).

The rainfall can be divided into two different parts: the effective rainfall and rainfall losses. The rainfall losses are water that evaporates, are stored above surface or in the soil and are larger in the beginning of the rain, see Figure 3.7.1.

3.7.1 Method for constructing hydrograph and hyetograph

The hydrograph and hyetograph for the October and November 2003 were constructed by using the areal precipitation with height corrections and direct discharge measurements from Hoa Phu. During this period, five lager events occurred and these are going to be more discussed in chapter 3.8 and chapter 3.9.

3.8 Unit hydrograph

This method was used to be able to predict the relationship between different storm events and it can be used as a simple model to see how the catchment area responds to rainfall. The unit hydrograph was introduced by Sherman in 1932 and is based on three assumptions:

1. Any uniform net rainfall with a given duration will produce a runoff of the same duration, regardless of the intensity.
2. The ratio of the runoff is equal to the ratio of the intensity of the rainfall, if the rainfalls have the same duration.
3. If a hydrograph represented by a number of runoff events the sum of the individual contributory events is the hydrograph, i.e. the principle of superpositioning can be applied.
   (Chadwick, 1998)

These assumptions imply that the response of the rainfall in the basin should be linear, but this is not true. However, the unit hydrograph has been found to be a useful tool in predicting the effects of a rain and is often used for design flood prediction. If a unit hydrograph is derived then the effect of every rain in the basin can be predicted (Chadwick, 1998). The unit hydrograph is constructed from the hydrograph and the hyetograph. The baseflow and rainfall losses are then removed, by methods described in chapter 3.8.1, so that the effective rain is equal to the direct runoff. The unit hydrograph is then constructed and the area under the graph represents 1 mm of precipitation in the catchment area.

3.8.1 Baseflow and rainfall separation

There are many different techniques for separation of the base flow. Some of them are developed for specific regions. Here are three general methods explained and displayed in figure 3.8.1 and a, b and c stands for the first, second and third method (Shaw, 1994).

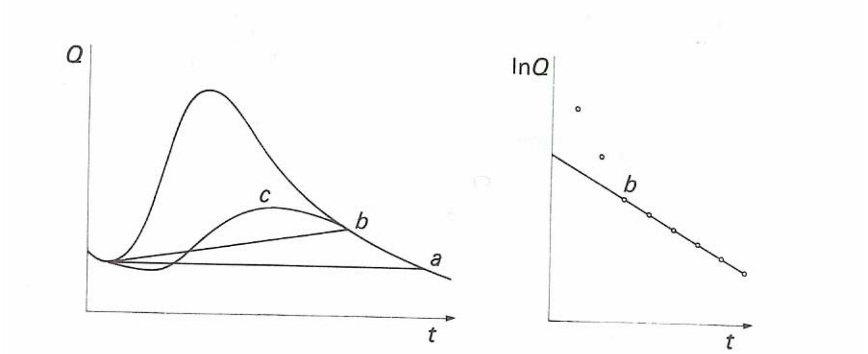


Figure 3.8.1:In the first figure three different methods for separation of the baseflow can be seen. The second figure shows the method for deciding point b (Shaw, 1994).

The first method (a) assumes that the baseflow is constant and equal to the flow before the start of the storm. This assumption means that the rainfall event has no effect on the groundwater and is not contributing to the groundwater. The second method is that after point b in Figure 3.8.1 the curve is exponential. If the curve is plotted semilogaritmic, the curve then will be linear, as in Figure 3.8.1 and point b can be found. The third method (c), which probably is the most realistic one, but it has to be estimated for each hydrograph.

For calculating the effective precipitation, there are two different methods available, Φ index method and "initial and continuing loss"-method (Shaw, 1994). The two different methods are showed below, Figure 3.8.2.

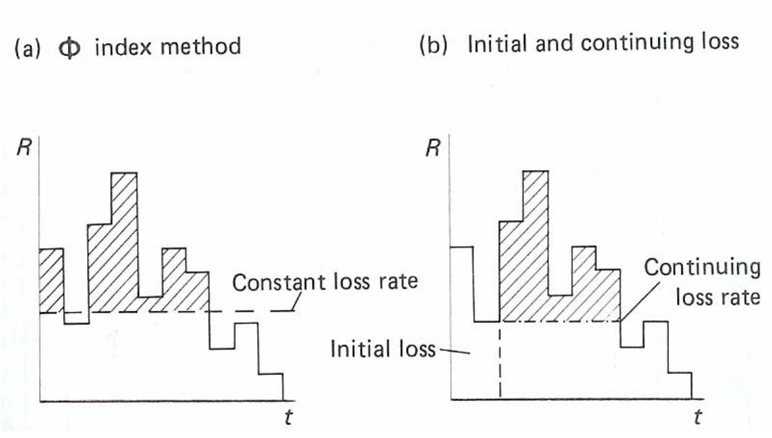


Figure 3.8.2: Two methods for calculating the rainfall losses. The first figure (a) shows the Φ index method and the second (b) shows the "initial and continues losses"-method (Shaw, 1994).

For the Φ index method there is a constant loss rate for the event. First the theoretical precipitation depth is calculated from the surface runoff, which is the effective rainfall. This is done by calculating the area under the hydrograph, which gives the volume of the surface runoff. The surface runoff is divided by the area of the catchment, and the rainfall losses are then obtained by taking the total rainfall minus the effective rainfall. For calculating the Φ index the rainfall losses is divided by the number of measurements when it has been raining.

For the second method initial and continuing loss it is assumed that there are one period in the beginning of every rainfall event where every thing is lost. After this time, the loss is constant as in the first method (Shaw, 1994).

3.8.2 Derivation of the unit hydrograph

The unit hydrograph is derived from the expression

$$Q_j = \sum_{i=0}^{j-1} R_i U_{j-1} \qquad \text{eq. 3.8.1} \qquad \text{(Shaw, 1994)}$$

-Q = the surface runoff
-R = the effective rainfall
-U = the unit hydrograph.
-j=1, 2, 3…

The number of effective rainfall is m, and the number of non-zero ordinates in the Time Unit Hydrograph (TUH) is n which gives m+n-1 number of equations. The matrix can be seen below:

$$\begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ \vdots \\ Q_m \\ Q_{m+1} \\ \vdots \\ Q_{m+n-2} \\ Q_{m+n-1} \end{bmatrix} = \begin{bmatrix} R_0 & 0 & & \cdots & & & & 0 \\ R_1 & R_0 & 0 & \cdots & & & & 0 \\ R_2 & R_1 & R_0 & \cdots & & & & 0 \\ \vdots & & & & & & \vdots & \vdots \\ R_{m-1} & R_{m-2} & R_{m-3} & \cdots & R_0 & 0 & \cdots & 0 \\ 0 & R_{m-1} & R_{m-2} & \cdots & R_1 & R_0 & 0\ \cdots & 0 \\ \vdots & & & & R_2 & & \vdots & \vdots \\ 0 & 0 & & \cdots & & & R_{m-1} & R_{m-2} \\ 0 & 0 & & \cdots & & & 0 & R_{m-1} \end{bmatrix} \times \begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ \\ \vdots \\ \\ \\ \\ U_n \end{bmatrix}$$

eq. 3.8.2 (Shaw, 1994)

The matrix can also be expressed

$$\underline{Q} = \underline{R} \times \underline{U}$$

eq. 3.8.3 (Shaw, 1994)

The rain matrix is first transferred into a square matrix by multiplying it with its transponent (R^T). The unit hydrograph is then obtained by solving the matrix system for $\underline{U}$, the expression then becomes:

$$U = \left(\underline{R}^T \cdot \underline{R}\right)^{-1} \cdot \underline{R}^T \cdot \underline{Q}$$

eq. 3.8.4 (Shaw, 1994)

It is best to construct a few unit hydrographs for different rainfall events and then construct one average unit hydrograph. The average unit hydrograph could be used in order to simulate discharge from an event by using eq. 3.8.4. The effective rainfall and the unit hydrograph will give the discharge.

3.8.3 Method for constructing unit hydrographs

From the hydrograph and hyetograph for the period of October and November 2003, five larger events could be found. These five events were used for constructing the unit hydrograph. The starting point of each event was found by deciding which rain that made the water level in the river to start to rise. The end of each event was found by using the baseflow method b, described in chapter 3.8.1. The effective precipitation was calculated by using Φ index method for each event.

The unit hydrograph was calculated by using the computer software called MatLab. The software can do large calculations with matrixes and was therefore used. The discharge was made into a vector and the effective rainfall was made into a matrix with a size of the length of the discharge vector times the number of the unit hydrograph.. Then an average unit hydrograph was constructed using the mean value of the remaining four events. In order to be able to use the unit hydrograph for simulating rainfall an average Φ index was calculated. The events were then simulated and compared with the direct measured flow.

3.9 Lag-time

The definition for lag-time (also called response-time) used in this paper is the time from the centroid of rainfall to the centroid of discharge (Shaw, 1994), see also Figure 3.7.1.

The response time can be calculated, using the definition mentioned above, by finding the centroid of the rain by calculating the moments as follows:

$$\bar{x} = \frac{\bar{P}_1 \times t_1 + \bar{P}_2 \times t_2 + \ldots + \bar{P}_n \times t_n}{\bar{P}_1 + \bar{P}_2 + \ldots + \bar{P}_n}$$

eq. 3.9.1 (Chadwick et al, 1998)

- $\bar{P}$ = the mean rainfall of the period
-t = the time elapsed from the start of the rain until the middle of the period of the each rain measurement.

- $\bar{P}_1$ = the rainfall measured during the first period

- $\bar{P}_2$ = the rainfall measured during the second period and so forth
-$t_1, t_2, \ldots, t_n$ = the corresponding time.

From this, the hour of the centroid was found. The centroid of discharge was found in the similar way, only $\bar{P}$ was exchanged for $\bar{Q}$.

$$\bar{y} = \frac{\bar{Q}_1 \times t_1 + \bar{Q}_2 \times t_2 + \ldots + \bar{Q}_n \times t_n}{\bar{Q}_1 + \bar{Q}_2 + \ldots + \bar{Q}_n} \qquad \text{eq. 3.9.2} \qquad \text{(Shaw, 1994)}$$

The response time is then found by:

Response time= $\bar{y} - \bar{x}$ eq. 3.9.3 (Shaw, 1994)

3.9.1 Method for calculating Lag-time

First, the lag time was calculated using the same periods as for the hydrograph. When this was done, the lag-time became very high. In order to calculate the lag time in an accurate way the directly measured data had to be divided into new periods. These periods were narrower in time and consists only of one rain peak and the corresponding increase in discharge.

For calculating the lag-time, the method described in chapter 3.9 was used.

3.10 Correlation

By using statistical tools, it is possible to understand more about the rainfall pattern over a catchment area. The correlation can also be used for establish the most likely path of the weather systems.

To measure the agreement of two sets of variables (X and Y) the correlation coefficient and the covariance can be calculated. These two measures are often used because they give one value of how well the data series agree with each other (in distinction of probability) (Körner, 1987).

3.10.1 Covariance

The covariance is a measure of the degree of linear relation between the two variables. If it is positive, there is a tendency for the variables to diverge at the same time from their expected value. If it is negative, the tendency is that the values diverge in the opposite direction. If the covariance is equal to zero the samples are said to be uncorrelated. The covariance between X and Y is defined as:

$$COV(X,Y) = \Sigma\Sigma p(x,y)(x-\mu_X)(y-\mu_Y)$$ eq. 3.10.1 (Körner, 1987)

-p(x,y) = the probability
-μ_X and μ_Y = the expected values for X respectively Y
-x and y = the values of the observations.

3.10.2 Correlation coefficient

The correlation coefficient varies from -1 to +1. The value +1 is a perfect positive linear dependency, whereas -1 is a perfect negative. If the value of the correlation coefficient is equal to zero, it only means that there is no linear correlation. There can still be a non-linear relation (Andersson et al, 1994).

The correlation coefficient for X and Y is defined as follows:

$$\frac{COV(X,Y)}{\sqrt{\text{var}(X)\cdot\text{var}(Y)}} = \frac{COV(X,Y)}{s_X s_Y}$$ eq. 3.10.6 (Körner, 1987)

-var(X) = the variance of X
-var(Y) = the variance of Y
-s_x = the standard deviation of the x data set
-s_y = the standard deviation of the y data set

3.10.3 Method for calculating correlation

The coefficient of correlation was calculated for precipitation measurements conducted inside and outside Lo Dong basin. The values used were without any correction for elevation, because point measurements were compared. For the correlation inside Lo Dong and for Da Nang station hourly values could be used and here the values also were shifted by one and two hours. Unfortunately only daily values were available from the other stations in Thu Bon basin, so no shifting was done for these measurements. The calculations was made in Excel, which has a statistic tool called correlation.

3.11 Loop-rating curve

If the water level is plotted as a function of the discharge, the graph obtained is called a rating curve. Sometimes when this is done, a loop can be seen. This happens sometimes when the surface runoff is very fast and the water level is rising before the discharge.

When the flow is uniform the relationship Q=Q(H) is valid and if plotted, a straight line is obtained. The looping rating curve can occur when a flood wave is in progress or because of a sudden change of slope in the riverbed, which makes the flow not uniform. The relationship between flow and water level is only valid for uniform flow and therefore not valid in the cases above. When this occurs, it can be useful for the interpretation of the data to find a model for the theoretical wave. This can be done in two ways, depending on which of the terms that is considered for S_f (the slope of the energy line). In the first case only S_0 (the slope of the river bed) and $\frac{\partial y}{\partial x}$ is considered (Henderson, 1966)

The basic equation is:

$$Q = CA\sqrt{R\left(S_0 - \frac{\partial y}{\partial x} - \frac{v}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t}\right)} \qquad \text{eq. 3.11.1} \qquad \text{(Henderson, 1966)}$$

-C = the Chézy constant
-A = the cross section area of the river
-R = the hydraulic radius of the river
-S_0 = the slope of the riverbed
-v = the velocity
-g = the gravitation

In this equation, the slope of the energy line, S_f, is equal to the expression within the parenthesis in the equation 3.11.1, and is written below:

$$S_f = \left(S_0 - \frac{\partial y}{\partial x} - \frac{v}{g}\frac{\partial v}{\partial x} - \frac{1}{g}\frac{\partial v}{\partial t}\right) \qquad \text{eq. 3.11.2} \qquad \text{(Henderson, 1966)}$$

In the first case studied only S_0 and $\frac{\partial y}{\partial x}$ is considered. This gives the following first equation:

$$Q = BCy\sqrt{y\left(S_0 - \frac{\partial y}{\partial x}\right)} \qquad \text{eq. 3.11.3} \qquad \text{(Henderson, 1966)}$$

-B = the width of the river
-y = the water depth

If the normal flow of the river is set to the uniform flow, Q_0, this equation can be used.

$$Q_0 = BCy\sqrt{yS_0}$$ eq. 3.11.4 (Henderson, 1966)

If equation.3.11.3 is divided by equation 3.11.4 then it results in the following expression:

$$\frac{Q}{Q_0} = \sqrt{1 - \frac{1}{S_0}\frac{\partial y}{\partial x}}$$ eq. 3.11.5 (Henderson, 1966)

Now the term $\frac{\partial y}{\partial x}$ has to be replaced by a term that can be obtained from the water level records. If subsidence is neglected this can be done by:

$$\frac{\partial y}{\partial x} = -\frac{1}{c}\frac{\partial y}{\partial t}$$ eq. 3.11.6 (Henderson, 1966)

-c = the wave velocity

If this is put into the equation, it becomes:

$$\frac{Q}{Q_0} = \sqrt{1 + \frac{1}{S_0 c}\frac{\partial y}{\partial t}}$$ eq. 3.11.7 (Henderson, 1966)

This equation is also known as the Jones formula. Subsidence is a vital part of the loop-rating phenomenon and it should be considered. This can be done by:

$$\frac{\partial y}{\partial x} = -\frac{1}{c}\frac{\partial y}{\partial t} + \frac{dy}{dx} = -\frac{1}{c}\frac{\partial y}{\partial t} - \frac{2S_0}{3r^3}$$ eq. 3.11.8 (Henderson, 1966)

-r = the ratio S_0/S_w eq. 3.11.9 (Henderson, 1966)

-S_w = the ratio y_0/x_0 eq. 3.11.10 (Henderson, 1966)

In natural rivers, the value of r is usually larger than 10^2 and the term $1/r^2$ can therefore be treated as relatively small. If this is put in to the equation 3.11.7 it will become:

$$\frac{Q}{Q_0} = \sqrt{1 + \frac{1}{S_0 c}\frac{\partial y}{\partial t} + \frac{2}{3r^3}}$$ eq. 3.11.11 (Henderson, 1966)

The term $\frac{2}{3r^3}$ is negligible at the flanks of the wave, due to that the term $\frac{\partial y}{\partial x}$ applies on the crest of the wave. The distance between the flanks and the crest is given by:

$$x = \pm 2y_0 / S_0$$ eq. 3.11.12 (Henderson, 1966)

The second way is to consider the whole S_f-term. To do this the following assumptions must be valid (Henderson, 1966):

1. The Froude number (Fr) is small enough to neglect Fr^4 and higher powers.
2. The two last terms of the slope term in the basic equation (eq. nr 3.11.2) is small enough to be estimated from the resistance equation by only including the first two slope terms.
3. Over the crest region, the distance between y and y_0 and the ratio $\frac{\partial y}{\partial x}/S_0$ is small. At this point Fr is almost constant.

The surface slope is equal to:

$$S_f = S_0\left(1+\frac{Fr^2}{r^2}\right)-\frac{\partial y}{\partial x}\left(1-\frac{Fr^2}{4}\right)$$ eq. 3.11.13 (Henderson,1966)

This leads to the equation:

$$\frac{Q}{Q_0} = \sqrt{1+\frac{2}{3r^2}+\frac{5Fr^2}{6r^2}+\frac{1}{S_0 c}\frac{\partial y}{\partial t}\left(1-\frac{Fr^2}{4}\right)}$$ eq. 3.11.14

(Henderson, 1966)

And for the flanks:

$$\frac{Q}{Q_0} = \sqrt{1+\frac{Fr^2}{2r^2}+\frac{1}{S_0 c}\frac{\partial y}{\partial t}\left(1-\frac{Fr^2}{4}\right)}$$ eq. 3.11.15

(Henderson, 1966)

3.11.1 Method for calculating a loop-rating curve

To see if any loops could be seen a rating curve was constructed. The calculation of the loop was done only for the largest loop because the phenomenon was most pronounced there. The value of Q/Q_0 was calculated using eq 3.11.14.

3.12 Hydrological Research Centre Rainfall-Runoff-model (HRC-model)

Flash floods come very suddenly and it is important to understand how the relationship between precipitation and the resulting flow works. To understand the relationship a rainfall runoff model, as HRC model, could be used in order to simulate floods. This method was produced especially for flash flood conditions (Ali-Maher et al, 2004) and functions on an hourly time step basis. It consists of eight parameters, see table 3.12.1, which describes the hydrological condition in the river basin.

Table 3.12.1: The eight parameters with description used in HRC-model.

Parameter	Description
K_1	For overland runoff routing
P_1	For overland runoff routing
K_2	For underground runoff routing
P_2	For underground runoff routing
C_1	Moisture condition
C_2	Determines how much of the precipitation becomes overland flow
C_3	Determines how much precipitation becomes underground flow
C_4	The decreasing factor for C_3

The HCR model for rainfall runoff considers the following processes:
-Routing process
-Estimation of effective rainfall and overland runoff
-Underground (based) runoff
(Luong Tuan Ahn, 2004)

3.12.1 Routing process

The routing process is describing how the flow changes through its way in the river. At a point high up in the river, the peak on the hydrograph is larger and comes earlier compared to a lower point, because of energy losses. The routing process is based on the following equations:

The continuity equation: $R(t) - Q(t+\tau_1) = \frac{dS(t+\tau_1)}{dt}$ eq. 3.12.1

(Luong Tuan Ahn, 2004)

The water stored in the river basin is described by the expression:

$S(t+\tau_1) = KQ^P(t+\tau_1)$ eq. 3.12.2 (Luong Tuan Ahn, 2004)

-R(t) = the effective rainfall in cm/hour
-$Q(t+\tau_1)$ = the concentration of the runoff (cm/hour) in time τ_1
-$S(t+\tau_1)$ = the water storage of the river basin in cm.
-K_1 = parameters for overland runoff routing

-P_1 = parameters for overland runoff routing
-K_2 = parameters for underground runoff routing
-P_2 = parameters for underground runoff routing

3.12.2 Effective rainfall and overland runoff

This is a process that calculates the precipitation to become runoff, which will be divided in overland and underground flow. In order to do that characteristic in the basin has to be determined, which in this case is made by using different parameters. To estimate the effective rainfall the rainfall index has been used. This can be expressed as follows:

$$IM(t) = a_0 X(t) + a_1 X(t-\Delta t) + a_2 X(t-2\Delta t) + ... + a_n X(t-n\Delta t)$$

eq. 3.12.3 (Luong Tuan Ahn, 2004)

-IM(t) = the rainfall index at time t
-X(t) = the average rainfall over the basin at time step Δt
-a_i = parameters that satisfy the moisture condition $a_0 > a_1 > \ldots > a_n$.

The equation is rearranged to replace a_0 to a_n in order to use only one moisture condition parameter, which is called C_1:

$$IM(t) = C_1 IM(t-\Delta t) + [1 + a(t-\Delta t)]X(t)$$

eq. 3.12.4
(Luong Tuan Ahn, 2004)

-a(t-Δt) is the runoff coefficient

The moisture condition should be less then one, $C_1<1$. If it is raining, $X(t)>0$, the rainfall index, IM(t), will increase otherwise it will decrease. The overland runoff coefficient is determined by this expression:

$$a(t) = 1 - \exp\left[-(IM(t)/C_2)^2\right]$$

eq. 3.12.5
(Luong Tuan Ahn, 2004)

-C_2 = parameter that determines how much of the precipitation becomes overland flow

3.12.3 Underground runoff

The underground runoff coefficient is used to simulate the underground runoff. The coefficient is estimated by using the following relationship:

$$a_N(t) = C_3 \exp(-R(t)/C_4)$$

eq. 3.12.6 (Luong Tuan Ahn, 2004)

-$a_N(t)$ = the underground coefficient
-R(t) = the effective rainfall

-C_3 = parameter which determines how much precipitation becomes underground flow
-C_4 = parameter which is the decreasing factor for C_3
The parameters that satisfy the conditions is $0<C_3<1$ and $C_4>0$

3.12.4 Method for calculating HRC-model

The model uses two input files, one with the information about the stations and one with the parameters, C_1, C_2, C_3, C_4 K_1, P_1, K_2 and P_2,. How the input file with the information of the stations is constructed can be seen in Table 3.12.1. The stations can have different weighting where the weighting 1-1-1 is the same as using Arithmetic mean method. The measured precipitation with corrections for elevation of all the rainfall station should be added below all information. After the rainfall data is the discharge placed with the same timescale as for the rainfall. The discharge used in the calculations is interpolated values.

Table 3.12.1: The information about the basin needed for constructing the first input file. After these values follows the measured precipitation and discharge, using hourly values.

‘name’				
Number of stations	Number of measurements	Initial runoff Q_{0s}	Initial underground coefficient Q_{0u}	The ratio Q_{0s}/Q_{0u}
Area of the basin	Iteration step	Initial moisture	Time step	
Year				
Weight of station 1	Weight of station 2	Weight of station…	Weight of station n	

The second input file contains the eight parameters. These are placed in three rows, in the order mentioned above, where the first row is the initial values of the eight parameters, the second is the maximum values and the third is the minimum values.

When running the model, an output file is constructed which contains a new set of parameters and the Nash coefficient. The Nash coefficient is used to evaluate the accuracy of the different weightings and parameters by comparing the interpolated flow and the simulated flow. The Nash coefficient is defined as:

$$F^2 = \left(1 - \frac{F_1^2}{F_0^2}\right) \times 100 \qquad \text{eq. 3.12.7} \quad \text{(Luong Tuan Ahn, 2004)}$$

where

$$F_1^2 = \frac{\left(Q_{obs} - Q_{sim}\right)^2}{n-1}$$ eq. 3.12.8 (Luong Tuan Ahn, 2004)

and

$$F_0^2 = \frac{\left(Q_{obs} - \bar{Q}_{obs}\right)^2}{n-1}$$ eq. 3.12.9 (Luong Tuan Ahn, 2004)

The higher the Nash coefficient is, the better the model agrees with the input data and the highest value is 100%. The model was calibrated for October 2003 and validated for November 2003.

4. Results

4.1 Areal precipitation and elevation dependency

The area of influence of the different stations when using Thiessens method was calculated manually and the result is showed below in Table 4.1.1. The map that the calculation is based on can be seen in appendix B.

Table 4.1.1: Area and percentage of the three rain gauges in Tuy Loan.

Station	**Area (total 71.6 km^2)**	**Percentage of the basin**
Doc Kien	41.5	57.96
Hoa Phu	17.6	24.58
Ba Na	12.6	17.60

The areal precipitation was then calculated and the monthly values are displayed in Table 4.1.2 below.

Table 4.1.2: Monthly values of areal precipitation with Thiessens method in Tuy Loan river basin.

Month	**Doc Kien** (mm/month)	**Hoa Phu** (mm/month)	**Ba Na** (mm/month)	**Total** (mm/month)
Oct 2003	605.7	547.8	492.4	548.6
Nov 2003	488.8	439.7	410.9	446.5

For calculating the elevation dependency, the areas were divided into smaller sub areas with the altitude contours and Thiessen areas as borders. The different sub areas are displayed in Table 4.1.3, together with the percentage of increased or decreased precipitation for each month.

Table 4.1.3: Correction values of the precipitation due to elevation for the different areas in Tuy Loan river basin.

Station	**Sub-area**	**area** (km^2)	**altitude contour** (m)	**average altitude** (m)	**October** (%)	**November** (%)
Doc Kien	1	2.91	1200-1000	1100	59	74
	2	3.24	1000-700	850	43	53
	3	4.36	700-500	600	26	33
	4	9.27	500-300	400	13	16
	5	3.71	300-200	250	3	4
	6	3.12	200-100	150	-3	-4
	7	4.20	700-500	600	26	33
	8	6.78	1000-700	850	43	53
	9	2.84	1200-1000	1100	59	74
Hoa Phu	10	0.23	1000-700	850	62	77
	11	0.38	700-500	600	43	54
	12	2.32	500-300	400	29	36
	13	1.38	300-200	250	18	22
	14	1.77	200-100	150	10	13
	15	10.21	100-0	50	3	4
	16	0.03	300-200	150	10	13
	17	0.34	100-200	100	7	8
Ba Na	18	0.17	100-0	50	2	2
	19	0.84	100-0	50	2	2
	20	1.91	200-100	150	10	12
	21	1.28	300-200	250	18	21
	22	2.27	500-300	400	30	36
	23	2.08	700-500	600	46	55
	24	3.18	1000-700	850	67	80
	25	1.96	1200-1000	1100	87	104

The correction of the precipitation due to elevation for the three stations varies between 10-52%, see Table 4.1.4 below. The highest increase of precipitation, 43% and 52%, is from Ba Na area, which also had the largest area of high altitude and largest contribution. Hoa Phu had the smallest increase, 10% and 13%, due to low elevation in the area. The negative values for some areas depend on that the rainfall station is situated higher than that area. For the whole basin, the precipitation increase was 720 mm in October and 612 mm in November, which makes an increase of 26% for October and 32% for November. These values were used for calculating the corrected hourly values of precipitation.

Table 4.1.4: The areal precipitation (P) and the increase (I) due to elevation for the rain stations in Tuy Loan river basin..

	Doc Kien		**Hoa Phu**		**Ba Na**	
	P (mm/month)	**I** (%)	**P** (mm/month)	**I** (%)	**P** (mm/month)	**I** (%)
Oct 2003	774	28	605	10	705	43
Nov 2003	657	34	497	13	623	52

4.2 Evaporation

The parameters used for calculating the evaporation can be seen in Table 4.2.1. Most of the parameters were obtained from measurements done by MCRHS in Da Nang. For calculating the actual evaporation, the value for K_c was estimated to 0.6 because the growth stage is in its final state and the vegetation is covering about 70%. The vegetation in the area is mostly forest, but also some open grass plains. There is also some slash and burn agriculture in the area, which increase the amount of open soil. The soil coefficient, K_s, is set to 1.0 in this calculation because the soil can be said to be well watered in the rainy season of October and November

Table 4.2.1: The value and input data used for calculating the evaporation in the Lo Dong river basin for October and November 2003.

Month	**T (^oC)**	**Relative humidity (%)**	**Net radiation (W/m^2)**	**C_p $J/(kg^oC)$**	**K_c**	**K_s**
October 2003	25.9	85	250	1005	0.6	1.0
November 2003	24.5	85	250	1005	0.6	1.0

The actual evaporation was calculated and the mean values can be seen in Table 4.2.2. The monthly values for October was 107 mm/month and for November 101 mm/month

Table 4.2.2: The calculated actual evaporation in Lo Dong river basin for October and November 2003.

Month	**Mean value** (mm/day)	**Min value** (mm/day)	**Max value** (mm/day)	**Total** (mm/month)
Oct 2003	3.5	3.3	3.6	107
Nov 2003	3.4	3.1	3.5	101

4.3 Discharge

The level and stage-discharge relationship method described in chapter 3.2 is valid for steady flow. During a flash flood, the flow is unsteady and when using the equation for the stage-discharge relationship, the peaks of the simulated flow did not reach the peaks of the directly measured flow. Instead, interpolation was used and the hourly result can be seen in Figure 4.5. The largest discharge during the period was 277 m^3/s and it occurred the 24th of November. At this time, the water level was at a point of 7.76 m above MSL. In the flood in 1999, the maximum water level was as high as 13.79 m above MSL.

4.4 Water balance

The result from the water balance calculations are based on hourly values, except for evaporation, which originate from daily values. The five events, which were chosen from Figure 4.3.1, occur during different lengths of time, from one and a half day to five or six days. The unit used for the water balance is mm/event and the result is displayed in Table 4.4.1. The highest amount of precipitation occurs at event number three and the discharge for this event is also the largest. Event number four and five have about the same values for precipitation, discharge and storage. For event four, the period is long with a few peaks, but event number five has one large peak and short duration. The short duration leads to a low value of the evaporation.

Table 4.4.1: The water balance for Hoa Phu for the five different events visible in the hydrograph (Figure 4.5.1) for the period of October and November 2003. P is precipitation, E is evaporation, Q is the discharge and ΔS is the change in storage. The unit for these are mm/event.

Event	**Start** (date hour)	**End** (date hour)	**P** (mm/event)	**E** (mm/event)	**Q** (mm/event)	**ΔS** (mm/event)
1	02.10.03 23:00	04.10.03 18:00	129	5.7	55	68
2	05.10.03 15:00	06.10.03 23:00	103	4.7	42	56
3	15.10.03 10:00	21.10.03 17:00	292	22	204	66
4	10.11.03 05:00	15.11.03 17:00	273	19	146	109
5	23.11.03 05:00	25.11.03 14:00	259	8	140	112

A graph were constructed to see if a relationship between discharge/precipitation and precipitation could be found. The graph can bee seen in Figure 4.4.1. As can be seen, the relative discharge increases with precipitation. Because of the few measurements, the relationship is though uncertain.

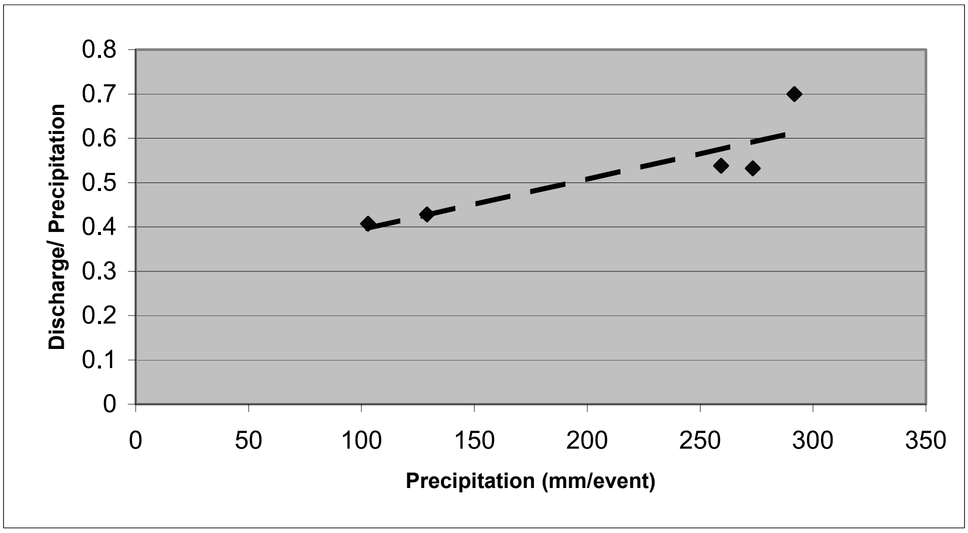


Figure 4.4.1: The relationship between precipitation and the ratio discharge/precipitation for the five events in October and November 2003.

For monthly values, the result is displayed in Table 4.4.2. The precipitation is larger in October compared to November, but the value for discharge is the opposite with higher value in November. The evaporation is about the same for the two months. This gives a positive storage for October and a negative storage for November.

Table 4.4.2: The Water balance for Hoa Phu, monthly values.

Month	**Precipitation** (mm/month)	**Evaporation** (mm/month)	**Discharge** (mm/month)	**Storage** (mm/month)
Oct 2003	720	107	510	103
Nov 2003	612	101	528	-18

4.5 Hydrograph and Hyetograph

The constructed hydrograph and hyetograph is shown below, Figure 4.5.1 and are based on hourly data. From the figure, five larger events can be seen, three in October and two in November. During an event, the intensity in the precipitation varies which causes the discharge to have more than one peak. The largest event is in the end of November with the highest intensity 39.1 mm/h and largest discharge of 277 m^3/s. None of the events of 2003 caused flooding in the area.

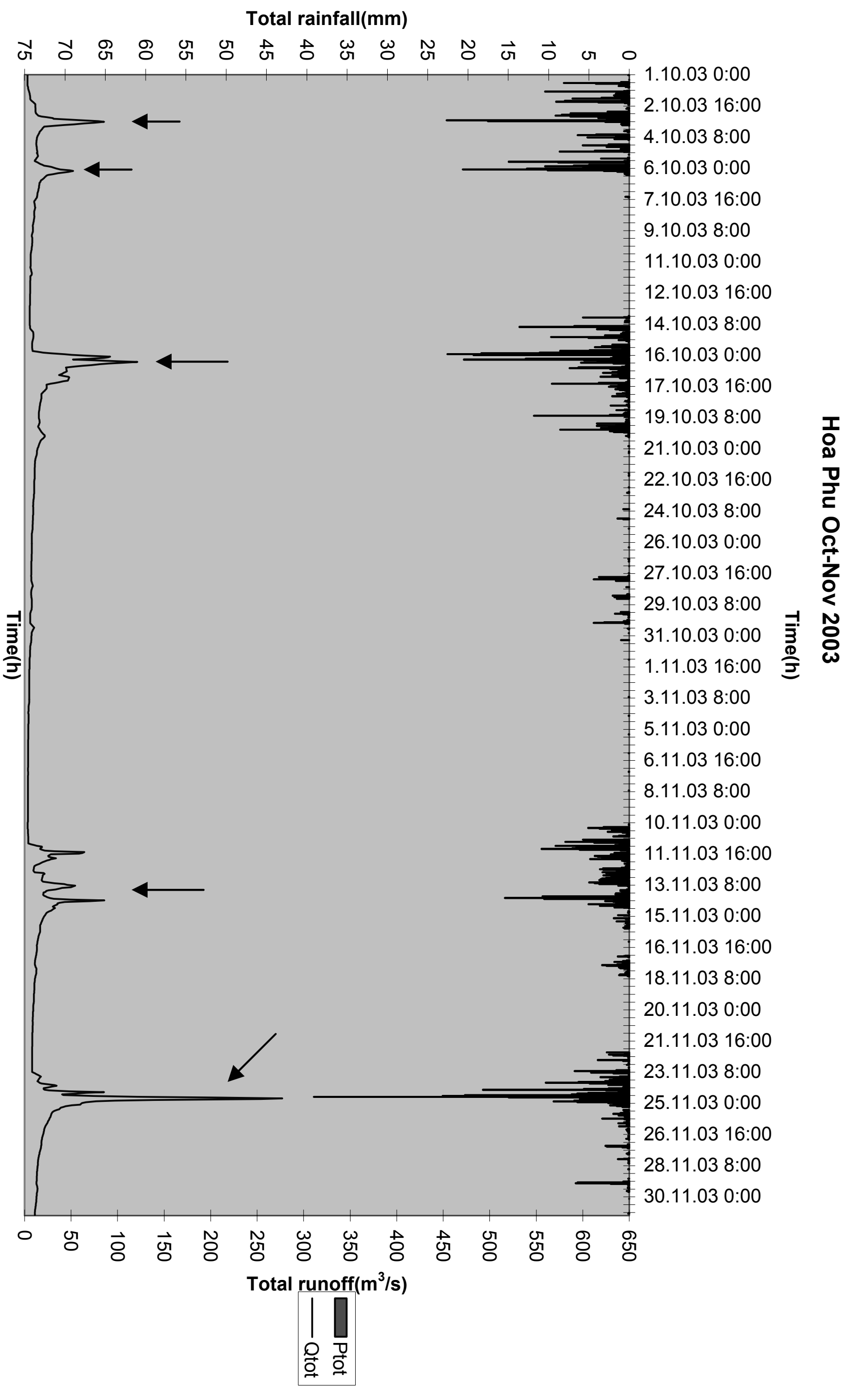


Figure 4.5.1: The areal precipitation with correction for altitude and total measured discharge for October and November 2003 for Lo Dong basin. The five events are marked with arrows.

4.6 Unit Hydrograph

When constructing the unit hydrograph the volume of the effective rain over the area and the surface runoff should be equal. If the Φ index method, described in chapter 3.8.1, was used the volumes of the effective rainfall and the direct runoff did not agree. To correct this, the Φ index had to be adjusted. The corrected Φ index became about twice as high as the calculated one. The different periods and Φ index that was used for calculating the unit hydrograph can be seen in Table 4.6.1.

Table 4.6.1: Φ index before and after correction that had to be done when comparing the amount of effective rain and the amount of direct runoff. The modified values were used for calculating the unit hydrographs for Lo Dong river basin in October and November 2003.

Event	**Start**	**End**	**Φ index, uncorrected** (mm/h)	**Φ index, corrected** (mm/h)
1	02.10.03 09:00	04.10.03 18:00	3.1	7.4
2	05.10.03 15:00	06.10.03 23:00	5.3	10.3
3	15.10.03 12:00	21.10.03 17:00	1.4	3.3
4	10.11.03 21:00	15.11.03 09:00	1.8	3.2
5	23.11.03 19:00	25.11.03 14:00	3.2	7.1

The effective rain and the surface runoff are displayed in Figure 4.6.1-4.6.5.

The first event can be seen in Figure 4.6.1. In the night of the 3rd October, a small rain falls and the flow in Lo Dong starts to rise. During a few hours, there is no rain and the flow stagnates. At 10.00 it starts to rain again for two hours. The flow starts to rise again and reaches its peak at 12.00. The flow is then 73 m^3/s. After that, the flow decreases slowly and reaches the baseflow the 4th October at 18.00.

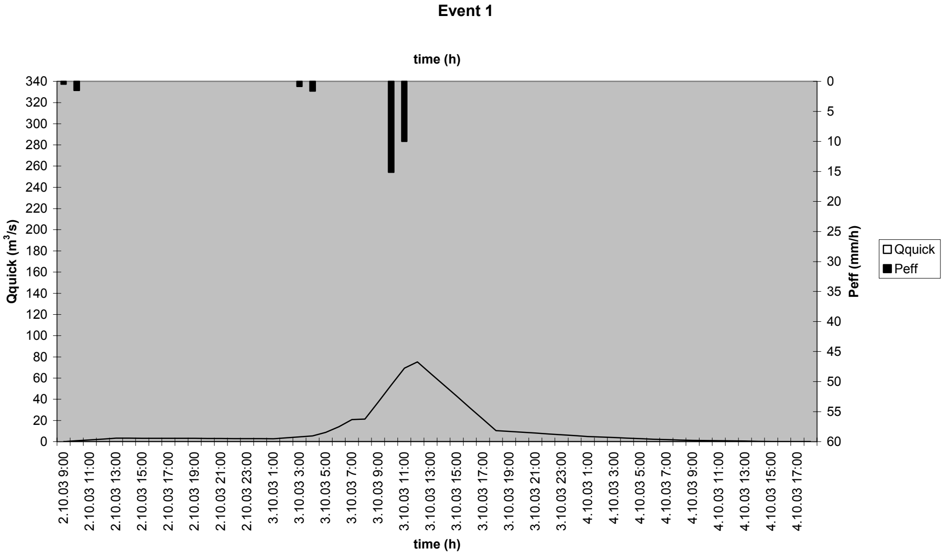


Figure 4.6.1: The effective rainfall and the direct runoff calculated for the first event, for the measurements conducted in Lo Dong river basin 2003.

The second event can be seen in Figure 4.6.2. Here, the rainfalls are spread over a longer period. At 13.00 on the 6th October, the rainfall becomes heavier and the flow increases and reaches the peak at 15.00 on the 6th of October and is then 38 m^3/s. It starts to decrease and reaches the baseflow at 23.00 on the 6th of October.

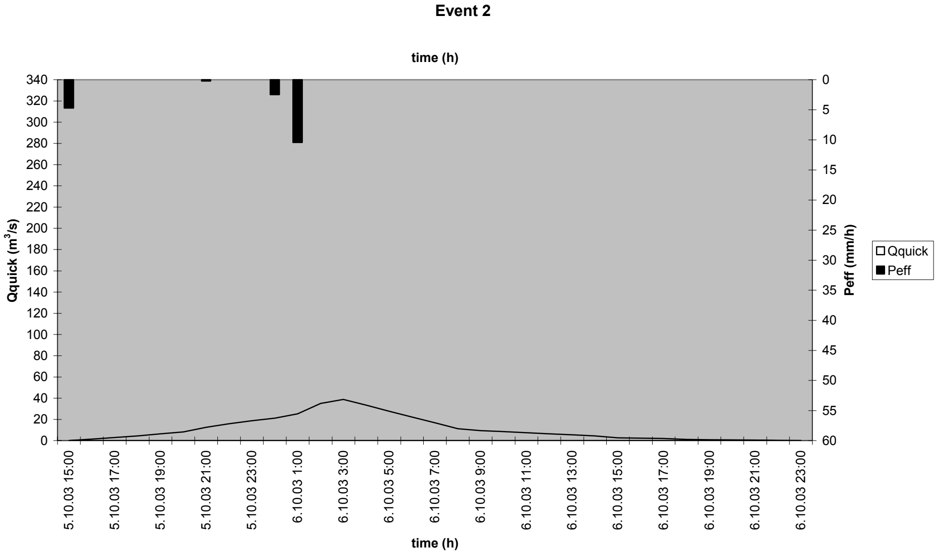


Figure 4.6.2: The effective rainfall and the direct runoff calculated for the second event, for the measurements conducted in Lo Dong river basin 2003.

The graph for event can be seen in Figure 4.6.3. The first rainfall event creates a flow of 84 m3/s. The flow starts to decrease, but in the same time more rain falls and the decline is interrupted. The flow increases again and the peak reaches 113 m3/s at 8.00 on the 16th of October. The flow starts to decrease when a few small rainfalls occur, which gives small peaks to the flow before it reaches the baseflow at 17.00 on the 21st of October.

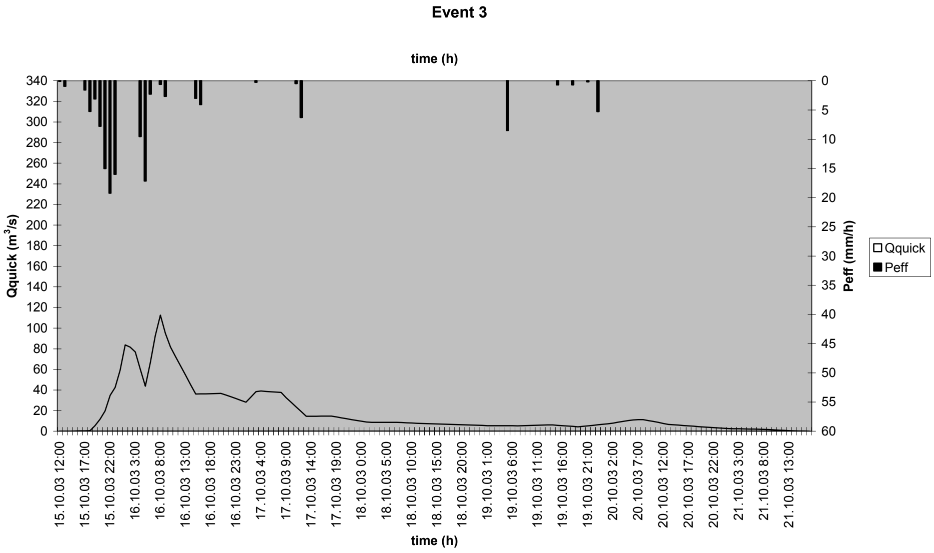


Figure 4.6.3: The effective rainfall and the direct runoff calculated for the third event, for the measurements conducted in Lo Dong river basin 2003.

The fourth event occurs in November see Figure 4.6.4. It starts with a number of rainfalls and the flow increases to 57 m3/s, starts to decline and reaches the baseflow for a few hours. After that, there is a long period, almost 24 hours, with low intensity rainfall, which gives rise to a peak of 43 m3/s at 8.00 on the 13th of November. The flow decreases, but a new rainfall starts before it reaches the baseflow and give rise to a high peak in the flow, 72 m3/s, at 15.00 on the 14th of November. The flow then decreases and reaches the baseflow at 9.00 on the 15th of November.

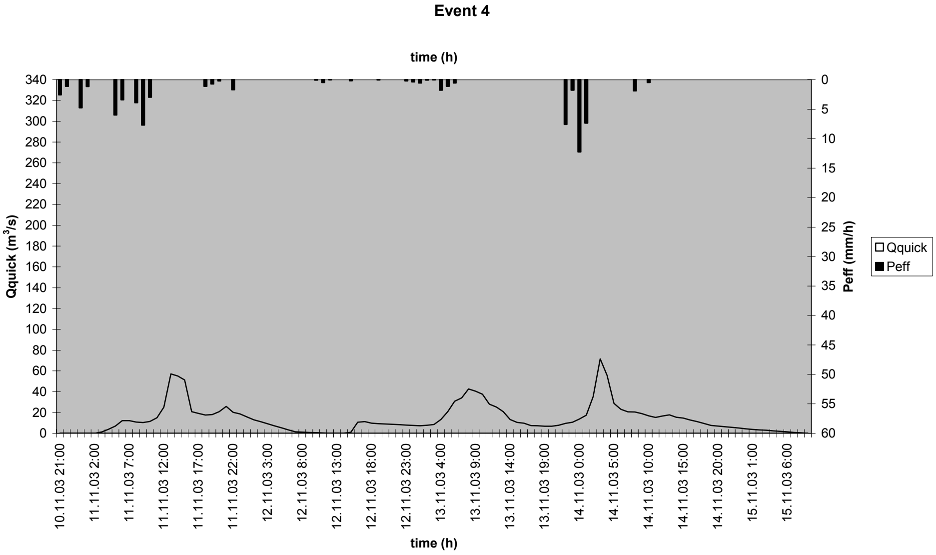


Figure 4.6.4: The effective rainfall and the direct runoff calculated for the fourth event, for the measurements conducted in Lo Dong river basin 2003.

The fifth event, see Figure 4.6.5, is the largest flood during the period of measurements. In the beginning, the flow is just above baseflow, and then it starts to rain, which gives raise to a small peak of the flow. The flow increases rapidly to 67 m^3/s and starts to decline when another large rainfall event occurs. During this event, there is an intensity of over 30 mm/h, which is the largest during these two months. The flow increases to the highest values 256 m^3/s at 17.00 on the 24th of November. The flow decreases and reaches the baseflow at 14.00 on the 25th of November.

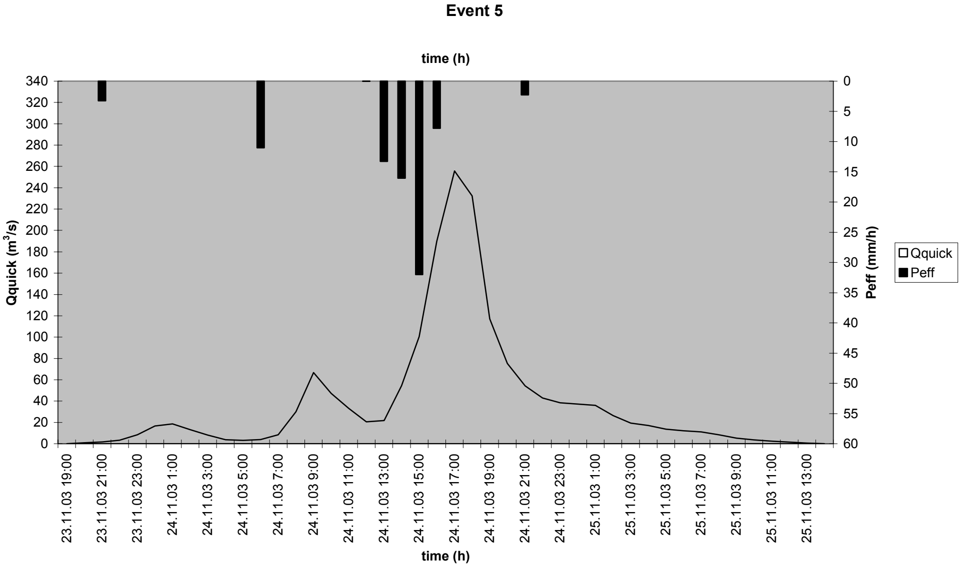


Figure 4.6.5: The effective rainfall and the direct runoff calculated for the fifth event, for the measurements conducted in Lo Dong river basin 2003.

For the five events above, four unit hydrographs were calculated. Event number four was excluded from the calculations because the complexity in this event made it impossible to produce a reasonable unit hydrograph. For the remaining four unit hydrographs, an average unit hydrograph was calculated. The four unit hydrographs and the average unit hydrograph can be seen in Figure 4.6.6.

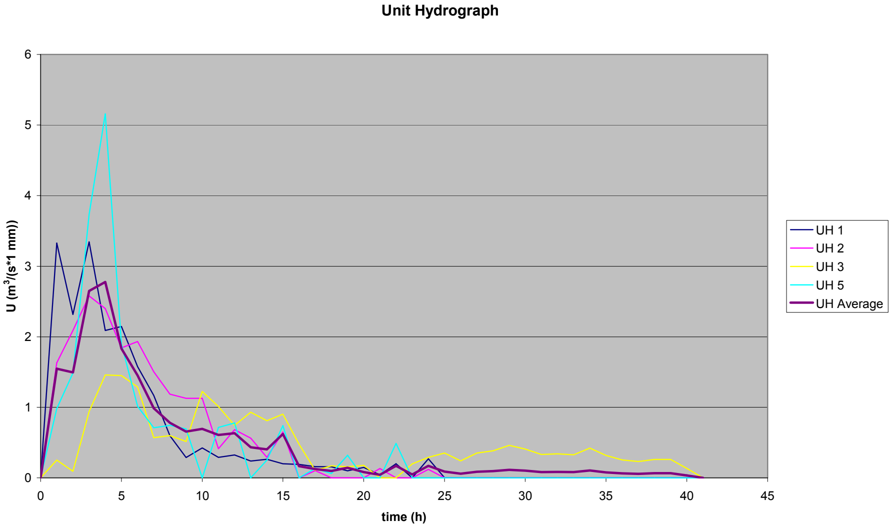


Figure 4.6.6: The four calculated unit hydrographs and the average unit hydrograph for the Lo Dong river basin in October and November 2003.

The average unit hydrograph was then used for simulating the events. This was done with an average Φ index that was calculated from the Φ indexes used for the four unit hydrographs. The average Φ index was calculated to be 7.1 mm/h. The simulations of the four events can be seen in Figure 4.6.7-4.6.10.

The first event can be seen in Figure 4.6.7. Here, it can be seen, that the peak is a bit dislocated in time, but the height of the peak is the same as for the direct measured values.

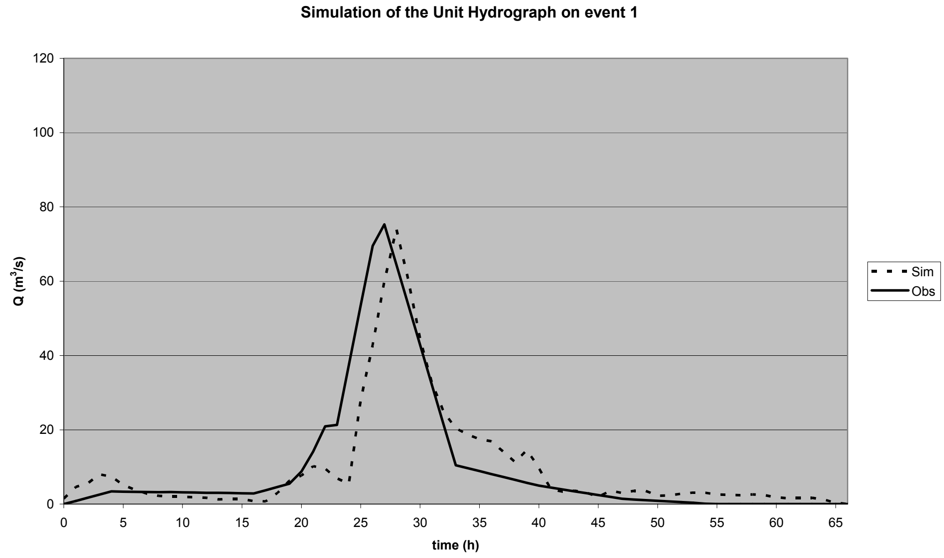


Figure 4.6.7: The first event simulated from the average unit hydrograph calculated for Lo Dong river basin, October and November 2003.

For the second peak, see Figure 4.6.8, it can be seen that the simulated peak does not reach as high as the direct measured. The first small peak that can be seen for the direct measured values is also not visible for the simulated curve.

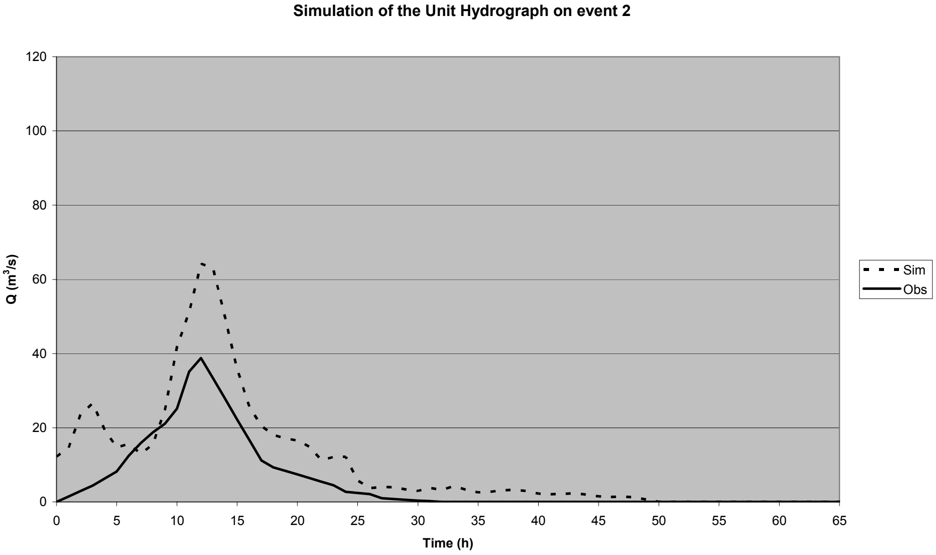


Figure 4.6.8: The second event simulated from the average unit hydrograph calculated for Lo Dong river basin, October and November 2003.

The third event, see Figure 4.6.9, consists of two peaks. For the fist peak, the simulated curve is too high compared to the direct measured and for the second it is too low. The simulated peaks do also seem to be a bit dislocated in time compared to the direct measured. The recession is a bit too fast for the simulated values and the small peaks in the end are dislocated or not visible at all.

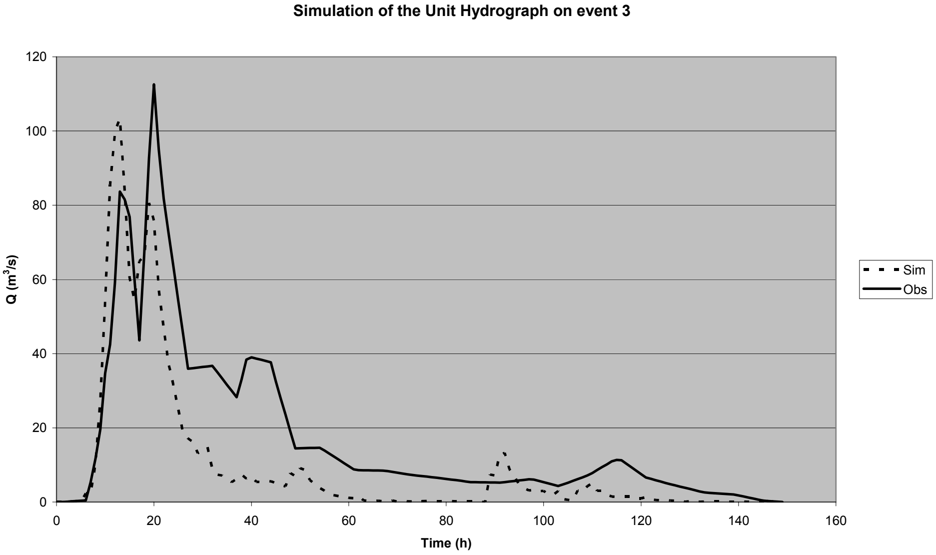


Figure 4.6.9: The third event simulated from the average unit hydrograph calculated for Lo Dong river basin, October and November 2003.

The fifth simulated event, which also was the largest event of the period for the measurements in 2003, can be seen in Figure 4.6.10. This simulation follows the changes in flow quite well but at the large peak it does not reach the same level as the direct measured.

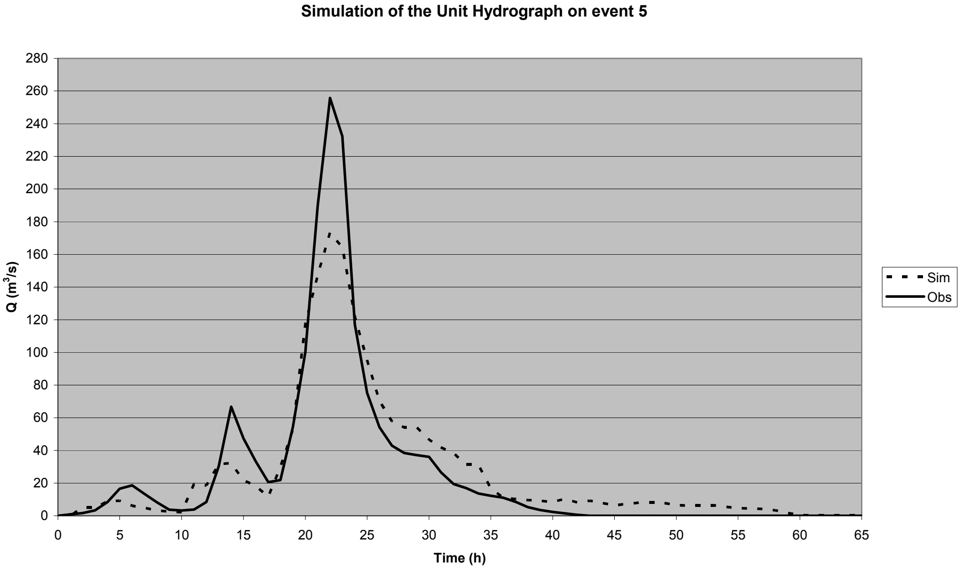


Figure 4.6.10: The fifth event simulated from the average unit hydrograph calculated for Lo Dong river basin, October and November 2003.

4.7 Lag-time

The lag time was first calculated using the same periods as used for the unit hydrograph. The result can be seen in Table 4.7.1.

Table 4.7.1: The response time using the same periods as for the unit hydrographs.

Peak nr	Start	Stop	Duration (h)	Lag-time (h)
1	02-10 09:00	04-10 18:00	44	3.51
2	05-10 15:00	06-10 23:00	33	8.16
3	15-10 12:00	21-10 17:00	152	17.84
4	10-11 21:00	15-11 09:00	133	19.80
5	23-11 19:00	25-11 14:00	58	6.59

The result showed an average response time of 11.2 hours. This response time is not likely for a catchment of this size, as discussed in chapter 1.4.2. In the hydrograph, Figure 4.3.1, it is possible to observe that each event consists of more than one peak due to the complexity of the rainfall. The events were therefore divided into smaller periods that only contained one peak of the discharge with the corresponding rainfall.

To find smaller events the data file for the precipitation and discharge was examined. When this was done, eight different events were found. These events are much narrower in time than the ones used for the unit hydrographs. The response time was then calculated using the method described in chapter 3.9.1 and the result can be seen in Table 4.7.2.

Table 4.7.2: The response time for the different rain peaks using periods especially designed for calculating the lag time.

Peak nr	**Start**	**Stop**	**Duration (h)**	**Lag-time (h)**
1	03-10 09:00	03-10 22:00	14	2.53
2	06-10 00:00	06-10 09:00	10	2.58
3	15-10 16:00	16-10 03:00	12	3.37
4	16-10 03:00	16-10 10:00	8	1.44
5	11-11 07:00	11-11 15:00	9	2.93
6	12-11 19:00	13-11 09:00	15	2.91
7	13-11 21:00	14-11 13:00	17	2.78
8	24-11 10:00	25-11 00:00	15	1.79

The mean value for the basin was calculated to 2.5 hours. Three of the peaks occur at daytime and the others at night.

4.8 Correlation

In Figure 4.8.1, below, the precipitation from Doc Kien, inside Tuy Loan, with no shifting, and Da Nang, outside Tuy Loan, with one hour shifting is displayed. The figure is not for the whole period, because it would then have been impossible to discern anything. The period is from the 1st of October to the 6th of October. From the Figure 4.8.1, it can be seen that the rainfalls appear to be from the same origin. To see if this is true a correlation test was carried out.

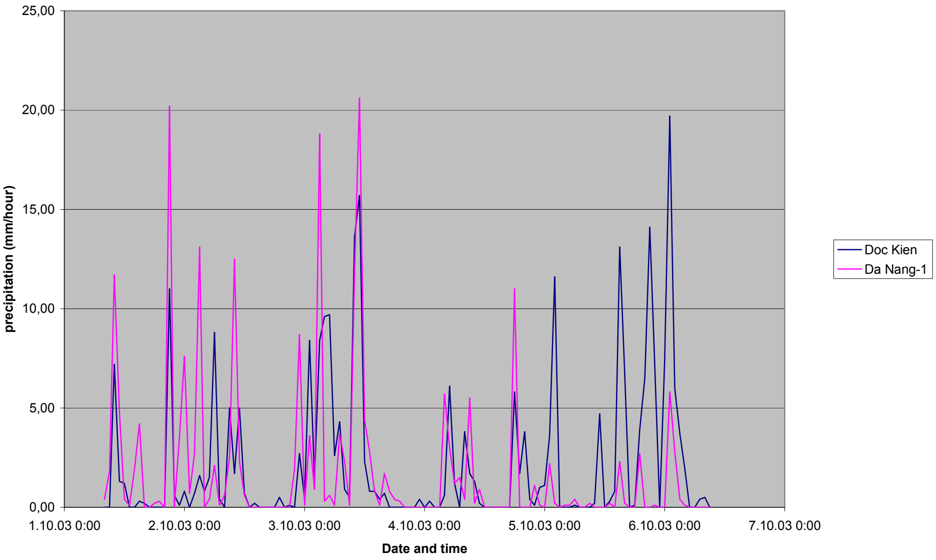


Figure 4.8.1: The precipitation from Doc Kien and Da Nang with one hour delay for five days in October 2003.The distance between the two stations is 29 km

The result of the correlation of the stations within the basin and Da Nang is showed below in Table 4.8.1 and in Figure 4.8.2. The hourly values inside the basin correlate between 71-64%, where Doc Kien correlates best with the shifted value from Hoa Phu. The other correlations are done with values that are not shifted. For Da Nang station the correlation rate is best when the rain gauge is shifted one hour to the stations inside Lo Dong basin. This means that the rain reaches Lo Dong approximately one hour after it hits Da Nang. They then correlate between 59-56%.

Table 4.8.1: Correlation for precipitation in Lo Dong basin and Da Nang station based on hourly values.

Station	**Hoa Phu**	**Ba Na**	**Doc Kien**	**Da Nang**
Hoa Phu	100			
Ba Na	71	100		
Doc Kien	58	64	100	
Da Nang	59	53	34	100
Hoa Phu-1	48	49	64	28
Ba Na-1	42	50	63	27
Doc Kien-1	37	34	55	24
Da Nang-1	59	56	59	47
Hoa Phu-2	32	27	37	20
Ba Na-2	26	28	33	19
Doc Kien-2	20	25	33	16
Da Nang-2	43	40	47	32

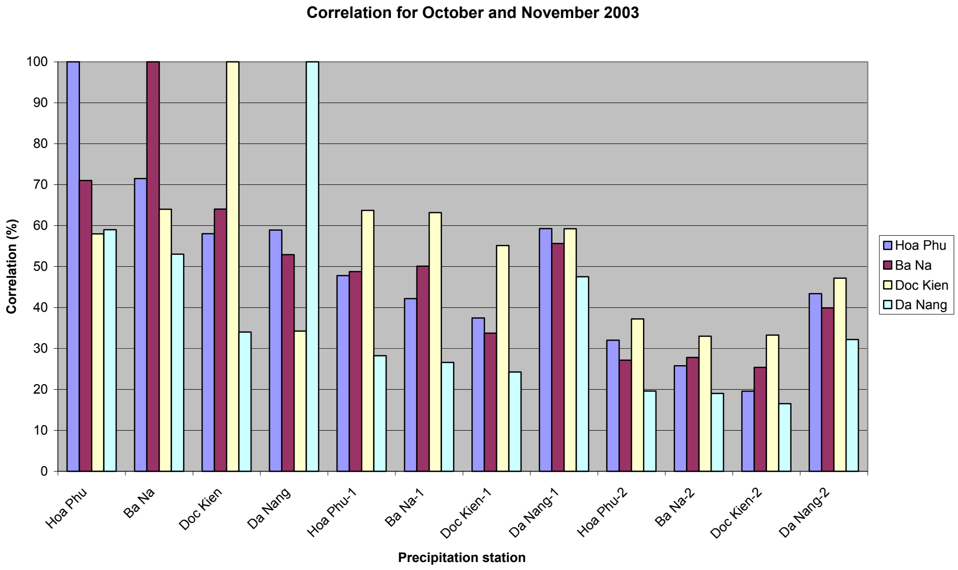


Figure 4.8.2: The correlation between the precipitation stations in Tuy Loan and Da Nang for hourly values during October and November 2003.

When using daily values the correlation increases to over 90% for the stations inside Tuy Loan, see Figure 4.8.3. For the stations outside Tuy Loan, the best correlation was with Da Nang and Hoa Phu, were the value become 88% . The second best correlation was with Hoa Phu and two stations in Thu Bon, Clau and

Que Son, with a value of 86%. The worst correlation was for the stations inside Tuy Loan and Nong Son, with correlation values from 52% to 56%.The correlation between the stations in Thu Bon can be seen in Appendix D.

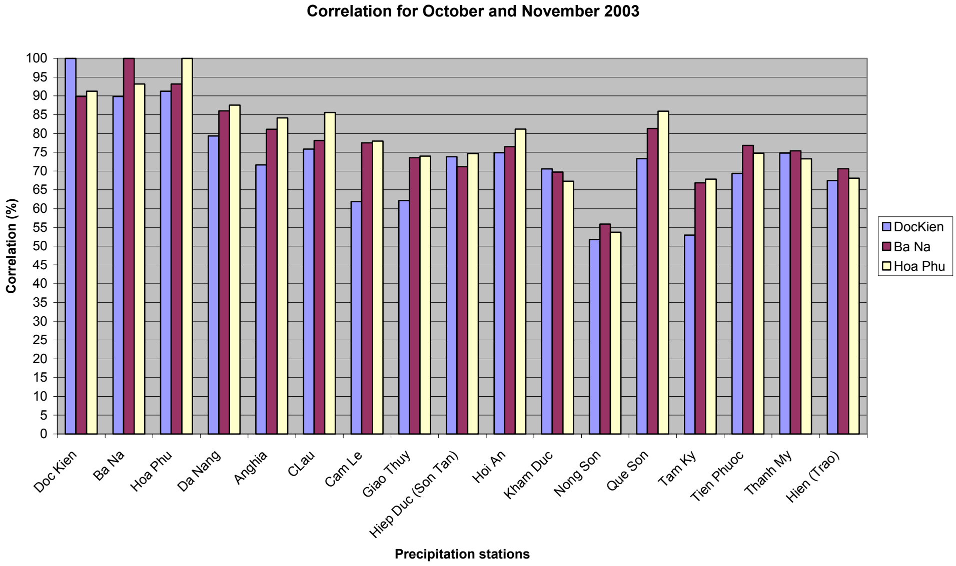


Figure 4.8.3: The correlation between the precipitation stations in Thu Bon for daily values during October and November 2003.

4.9 Loop-Rating Curve

The loop-rating curve from the direct measurements for the period can be seen in Figure 4.9.1. In the figure, the direct measured flow measurements have been connected in time order, which creates a loop. The arrows in the figure show the direction in which the measurement points were connected.

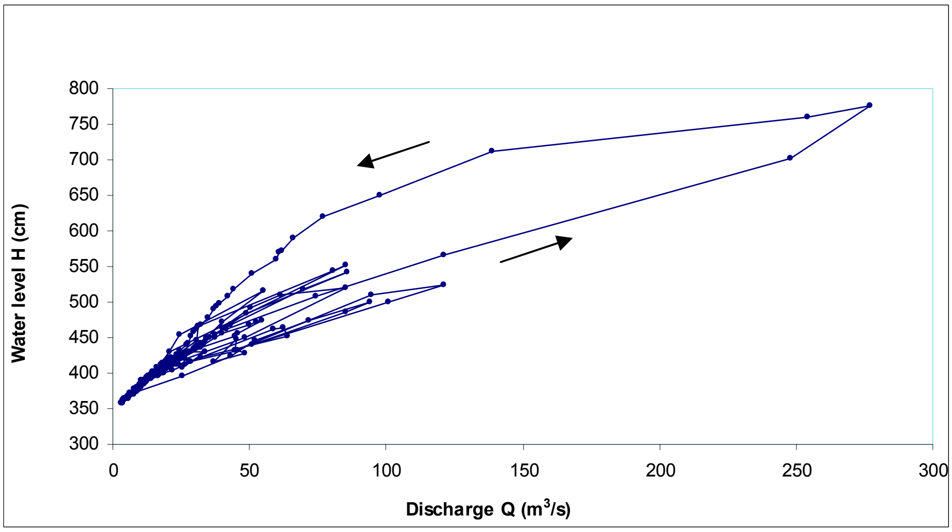


Figure 4.9.1: The loop-rating curve from the directly measured values at Hoa Phu for October and November 2003. One loop is particularly pronounced and here the stages of the wave propagation are marked. The arrows show the time order of the event.

The calculations were carried out for seven measurement points from 15.00 to 21.00 on the 24th of November, which is the pronounced loop in Figure 4.9.1. The area was calculated by hand from the cross section of the river, which can be seen in appendix E. For the calculations of the theoretical loop, the following values were used:

- The Manning number (n) was set to 0.032 (French, 1994).
- The ratio r was set to 170 (Henderson, 1966).

To calculate the theoretical loop the area, velocity, Froude number and wave velocity was also needed. The values used can be seen in Table 4.9.1

Table 4.9.1: The values of the different parameters used for calculating the theoretical loop.

Time for maesurement	**v** (m/s)	**A** (m^2)	**Fr**	**c=2/3*v** (m/s)
15:00	1.5	81.2	0.129	2.2
16:25	1.8	135.3	0.110	2.7
17:00	1.7	164.6	0.074	2.5
18:05	1.6	157.6	0.071	2.4
19:00	1.0	138.5	0.035	1.5
20:00	0.85	114.1	0.029	1.3
21:00	0.75	102.1	0.025	1.1

The result from the calculations can be seen in Table 4.9.2.

Table 4.9.2: The result of calculations for constructing a theoretical loop.

Time for measurement	**Q** (m^3/s)	**Water level** (m)	**Q/Q_0** eq. 3.11.14	**Q** eq. 3.11.14 (m^3/s)
15:00	74.6	1.16	1.065	116
16:25	121	2.52	1.076	199
17:00	248	3.26	1.091	246
18:05	277	3.1	1.0	217
19:00	254	2.62	0.997	190
20:00	139	2.0	0.996	155
21:00	97.5	1.7	0.998	139

Because the calculated loop did not have as pronounced loop as the measured one, a new calculation was done where r was set to 1.7. The calculated loop from the two calculations together with the directly measured discharge can be seen in Figure 4.9.2.

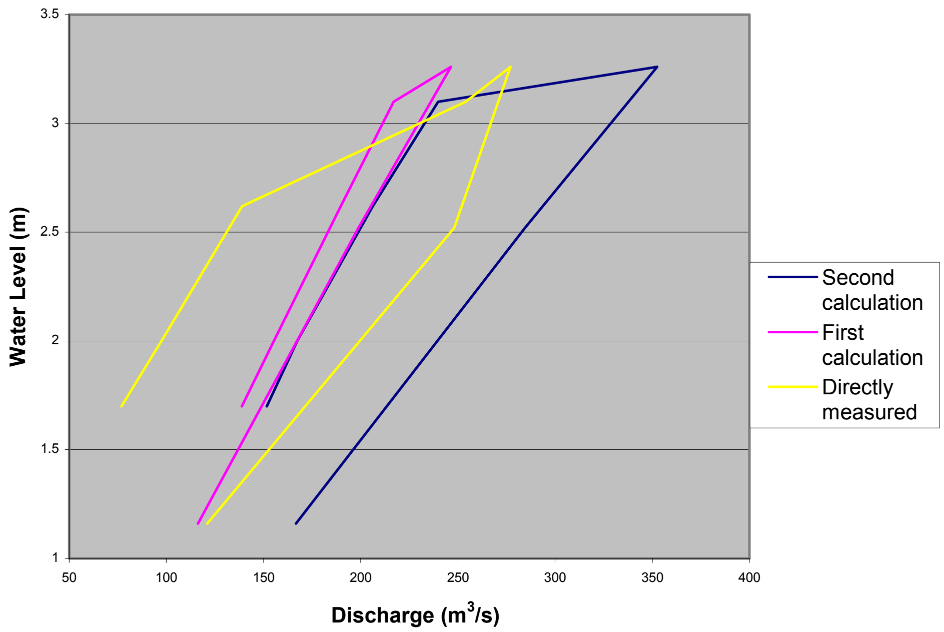


Figure 4.9.2: The largest loop from the measured discharge, together with the discharge for the two calculated loops for the same time with different subsidise terms, plotted against the water level.

It can be seen in Figure 4.9.2, that the first calculated loop is very narrow compared with the directly measured one. For the second calculation the loop is wider but the discharge value is too high.

4.10 HRC-model

The rainfall runoff model was calibrated using data of October 2003 and then validated for the values of November 2003. The best weighting of the precipitation stations were when the weighting was similar to the influence areas calculated with Thiessens method.

When calibrating the model for October the highest value of the Nash coefficient was 84.5%, and for the validation in November it was 77.9%. The values of different parameters that were used when calibrating the model can be seen in Table 4.10.1. The highest value of the Nash coefficient was reached in the sixth try. These values were then used for validation with the data for November.

Table 4.10.1: The different parameters (see section 3.12) used when calibrating the model for October 2003. The order in the column for the weighting of the precipitation stations is Hoa Phu-Doc Kien-Ba Na.

	Weight of the stations	**C_1**	**C_2**	**C_3**	**C_4**	**K_1**	**P_1**	**K_2**	**P_2**	**Nash** (%)
1	1-1-1	0.9	7.4	0.3	90	7.2	0.6	312	0.6	80.9
2	0.8-1.4-0.8	0.9	7.4	0.3	90	7.2	0.6	312	0.6	82.8
3	1.4-1.0-0.6	0.9	7.4	0.3	90	7.2	0.6	312	0.6	83.0
4	1-1.4-0.6	0.9	7.4	0.3	90	7.2	0.6	312	0.6	83.9
5	1-1.4-0.6	0.9449	0.5458	0.4653	6.758	11.14	0.4448	561.2	0.7963	84.4
6	1-1.4-0.6	0.9233	0.2974	0.5368	4.357	11.48	0.3796	583.6	0.8068	84.54
7	1-1.4-0.6	0.9214	0.3541	0.5347	3.638	11.53	0.4028	640.1	0.8190	84.53

In Figure 4.10.1 and Figure 4.10.2 the measured and simulated flow was plotted to obtain a visual idea of how well the model works.

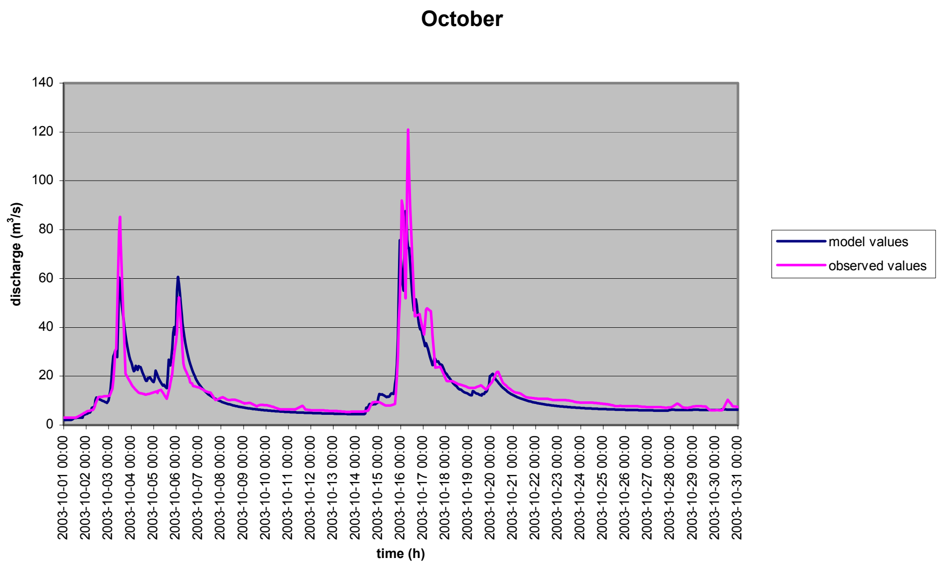


Figure 4.10.1: Simulated and direct measured discharge when calibrating the HRC-model for Lo Dong, October 2003.

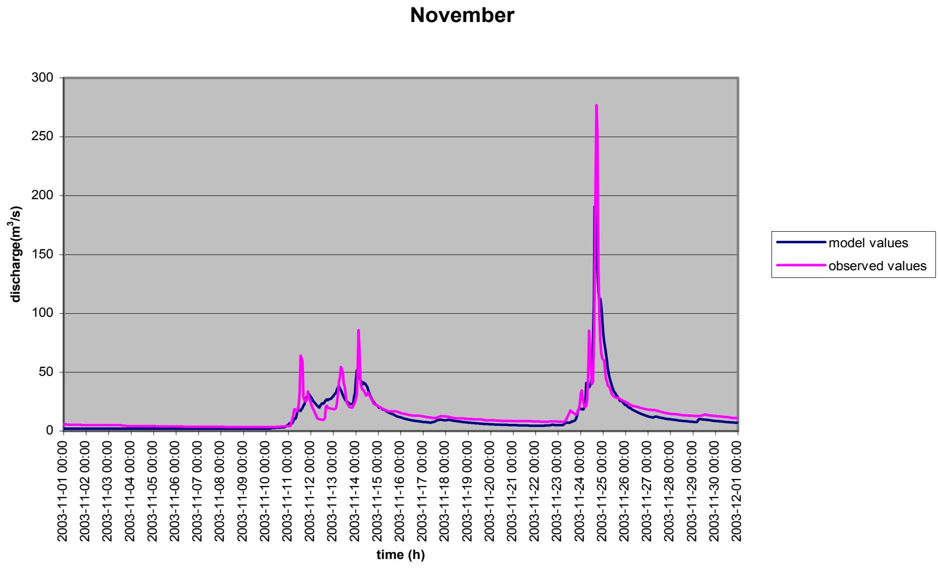


Figure 4.10.2: Simulated and direct measured discharge for validation of the HRC-model for Lo Dong, November 2003.

5. Discussion

5.1 Areal precipitation

To use the Thiessens method when calculating the areal precipitation was the best option with the available data. The method does not take in to consideration the altitude difference in the area, which can cause errors. It is only a simple way of dividing the area in to smaller parts depending on the placement of the rain gauges. This means that it reduces the error due to the heterogeneous placement of the rain gauges but errors can occur in mountainous areas when the rain hits one side of the slope while the other side ends up in rain shadow. The actual amount of rain that enters the different areas is therefore not always the same amount that is calculated with Thiessens method.

Because of the mountains in the area, it would have been better to use the Isohyetal method for calculating the areal precipitation. It would give a more accurate result, but it is also a much more demanding method. If measurements would have been performed for this method, it would have required a much denser network of rain gauges. The gauges would also have to be placed in more exposed places, which might cause errors in the measurements. The cost of the measurements would increase and the question is how large improvement the method would have on the result. The catchment investigated in this report has a very small area, and therefore the difference between the two methods might be small. The benefit of this method could be eaten up by the increased cost.

Because of the low location of the rain gauges, the amount of rain that fell in the area has to be corrected. When this was done a value of 100-200 mm/(year*100 m) was used. This number was gained by personal communication at the Middle of Central Region Hydrological Station but we do not known how the investigation to obtain the value was done because the report was written in Vietnamese. In the calculations in this report the average value of 150 mm/(year*100 m) was used. This number was chosen since the year of 2003 was not an extreme year. From statistics, it was found that, of the total rainfall over the year, 25% fell in October and 25% in November. Because of the lack of more precise values, there might be some errors in the calculations. It was not known if the year of 2003 was a standard year or not so the value of 25% in October and November might not be true. However, the errors caused by this might not be large enough to have any effect on the result.

The effect of the altitude is relatively large. For the rain gauge in Ba Na that was situated at the level of 200 m above MSL the difference in altitude to the peak is 1000 m. This would mean that at the top of the mountain it would rain 1000-2000 mm/year more than at the gauge site. If 25% of the annual precipitation fell in October and 25% in November, it would mean that, the rain would be 250-500 mm/month higher at the top of the mountain.

The correction for the altitude difference was done for the whole area, and the value from MCRHS was only for the mountain Ba Na. In the south part of the catchment area there is another mountain. The increase due to altitude could be different here but that value is not known. Because there was no investigation done in that area the same value was used as for Ba Na, when it was clear that some correction had to be done.

Another point of uncertainty was the size of the area. During the progress of this study, a number of different values have been discussed. The area has an impact on the amount of water that goes into the area. If the area had been larger than the size used in this report, the change in storage would be larger in reality then the calculated value. The area used was however, calculated twice by two different persons with almost the exact same value as result. That is the reason why this value was used.

5.2 Evaporation

The processes of evaporation are well known and the data, which are required for calculating the evaporation, are rather easy to measure. Even so, to measure or calculate the actual evaporation is very difficult. This is due to the interaction between the meteorological factors and the amount of available water.

The data used for calculations of the evaporation in this report were daily values measured at the Middle of Central Region Hydrometeorological Station (MCRHS) in Da Nang. The station is situated in the city of Da Nang that lies close to the sea while the project river basin is situated further inland. The data used might therefore not give the correct value but evaporation measurements are always insecure (as mentioned above) and the distance between the station and the project basin is only about 20 km. For the calculations in this report, the evaporation value does not have such an important part because of the high precipitation intensity and short duration of the events.

5.3 Discharge

The values of the discharge were interpolated from the performed measurements. These were done with sufficiently short intervals and therefore the interpolated values follow the direct measured ones very well. This can also be a weak point because if there were any measurement that was incorrect our values would also be wrong. To avoid this, the values from the interpolation could be plotted, then it could be seen if any value was out of order. They could also be plotted together with values calculated by the level and stage-discharge relationship method described in chapter 3.3. The problem with this method is that the calculated peak values do not reach as high as the directly measured ones. This depends on the flow being unsteady after a rainfall event, see loop-rating in section 4.9.

It would be desirable to obtain a method for calculating the flow from the water level because it is very easy to measure water level compared to flow. This could be used in a warning system. As it is at the moment the discharge can only be obtained by direct measuring of the flow which could be very dangerous for the staff during a flash flood. The bridge where the direct measurements in October and November 2003 were made, were flushed away during the flood in 1999. If the water level and stage-discharge method is used, it might underestimate the discharge. Then the flooding might not be noticed in time and a warning system is useless.

The problems described above could be corrected by finding the function for the loop-rating curve in the river, described in chapter 3.11 and 4.9. The problem when this was used, was that the loop did not get exactly the same as for the direct measured, and therefore has to be further calibrated and adjusted for this area. In this report the loop-rating was only used in order to show that this phenomenon exists in this area and has to be considered. Further analysis of the loop can make the discharge predictions more accurate and should be performed if a warning system should be constructed.

5.4 Water balance

The water balance consists of the terms evaporation, areal precipitation, discharge, groundwater flow, inflow and storage. Advantages and disadvantages of methods used for calculating evaporation, areal precipitation and discharge are discussed in chapters 5.1-5.3. It is important to emphasize that when using areal precipitation the values should be corrected for elevation dependency. If the calculated amount of water coming into the area is too small then the change in storage will be too small.

In Figure 4.4.1, it can be seen that there is a relationship between the amount of water coming into the area from precipitation and the ratio of how much water of the precipitation that is transformed into discharge. It shows that the ratio precipitation/discharge increases with the amount of rain.

Calculations of the evaporation for each event have been based on daily values and evaporation is considered to have an even distribution over the day. This is a simplified assumption since the evaporation is based on the energy from sunlight. When the rain occurred at night, it might be in place to correct the values of evaporation due to the lack of sunshine. The necessity of calculating the evaporation for the events can also be questioned because of the short time of the events and since the discharge and precipitation are 10 times larger than the evaporation.

For all events, there was a positive storage, which means that water was stored in the area during the events. The change in storage for the whole period was rather low and for November, it was even negative. The reason why November has a negative storage could be that the outflow also contains water from the positive storage in October. The storage in the area does not seem to be very large, even so the area does not suffer from water shortage. The farmer, who lived at the rain gauge site Doc Kien (situated at 200 m above MSL), had water in his four meters deep well all year around (Vo Van Minh, 2004).

5.5 Hydrograph

The rain period of 2003 was relatively timid. There was only one large peak and it occurred in the end of November. It would have been desired to have more high peaks during the measurements so that the phenomena of flash floods could be studied more in detail.

5.6 Unit hydrograph

When the unit hydrographs were constructed it was noticed that the Φ-index was too low. The losses were greater than calculated, and had therefore to be adjusted. The new values for the Φ-index were obtained by calibration when the unit hydrographs were constructed. It can be seen when comparing Table 4.5.1 and Table 4.6.1, that the values of the Φ-index after the correction is about twice as large as for the calculated values.

The Φ index for the third and fourth peak was very small. This might be because of the long periods of low intense rain. The last step in calculating the Φ index is to divide the rainfall loss with the length of the rain. This means that shorter and more intense rainfall gets higher value of the Φ index than longer periods of rain. This is because most of the losses occur in the beginning of the rain so if it continues for longer time it will be fewer losses for a longer period. When using the Φ index the losses are considered constant over the period. It can be seen when using the Φ index method that, in the beginning of the rain, the real losses are larger then the losses calculated with the Φ index method. It is possible to avoid these kinds of errors if the method of initial and continues loss is used. In this method the losses in the beginning is much larger, i.e. the entire rain is considered a loss. After the initial stage, the losses are considered constant and equal to the Φ index.

The large range of the values of the Φ-index can cause problems when using the unit hydrograph because it has to be possible to predict the Φ-index. Therefore, when the simulations of the events where done, an average Φ-index was used. It might also be possible to use a value for the Φ-index that is twice the calculated one. This would be closer to the truth and might therefore be better to use in the future.

When deciding the ending point for the direct runoff more than one straight line could sometimes be derived. In these cases, it was hard to know which one to chose. The length of the event also made the number of observations that created the line different in number, which made some lines appear straighter than others. The point where the recession stops does not have a very large impact on the calculations of the unit hydrographs. For the more sensitive calculations like lag-time the periods had to be adjusted.

Four events were simulated from the average unit hydrograph. The first event is a bit dislocated in time but the peak is the same height for both the simulated and the direct measured. The second event is too high. The reason for this can be found in the Table 4.6.1 . If the values for the Φ-index are compared to the average Φ-index it can be seen that the first event has a Φ-index that is very close to the average while the second event has a much higher value. This shows the importance of using a correct Φ-index and it also shows that the average Φ-index can not be used.

In the second event it can also be seen that there is a small peak in the beginning of the simulated values that does not exist for the direct measured values. For the third event it can be seen that the first peak is too large and the second too low. This indicates that it might be better to use the initial and continuing loss method, described in chapter 3.8.1, instead. If this method would be used, the losses would be larger in the beginning and the first peaks would be lower.

The fifth event has a very good rise and recession but the observed peak is much larger than the simulated. For this event the average Φ-index and the calculated is the same so the Φ-index can not be the reason for the low peak. This shows that the unit hydrograph might be hard to use for flash flood events. To predict the impact of a flash flood it should be known how high the peak flow is. This is not obtained in this unit hydrograph.

It is often said about flash floods that they mostly occur at night. By inspection of the hydrographs it can be seen that the events number two, three and four have rainfalls during the night that gives rise to a peak flow. For peak number two there is some rainfall during the whole afternoon but the most intense rainfall occurs at 13.00. For peak number three there is heavy rain between 20.00 and 24.00 and also at about 06.00. The fourth peak consists of a number of rainfalls but most of them occur during evening or at night. All of these events occur as expected at night. It can be worth noticing however, that the largest peak (hydrograph number five) occurs during the day. For this event, there are some showers during the night but the heavy rain occurs during the day. Although this rain was not very large, it is the largest in the period of measurements and shows that flash floods may also occur during the day.

The unit hydrograph is based on three assumptions. These assumptions imply that the catchment area should respond in exactly the same way independent of the rainfall as long as it has the same duration. Since the character of the runoff also depends on antecedent precipitation, this is not always true. In this area the climate consist of a rainy season and a dry season. The runoff does not have the same characteristics during the two periods.

5.7 Lag-time

In the report by Ali-Maher et al, 2004 it is stated that the Tuy Loan river basin has a response time of about 1-2 hours. If the same periods as in the hydrograph were used the response-time was calculated to 11 hours. If the start and stop points were set as narrow as possible and only had one episode of rain in it, the response time became about 2.5 hours. This raises a question about how the response times that are mentioned in different reports and books are calculated. In the book (Shaw, 1994; Chadwick et al, 1998) used for this report, there were no instructions of how the event was supposed to be cut off. The amount of different definitions is also impressive. Early in the progress of this report, a discussion between two hydrologist colleagues arose about how the lag-time was being defined. They had two different ideas about the definition and from books, there can be found even more. The one chosen in this report was the one we felt was most natural and there is nothing that implies that any of the other would be better.

The minimum response time was 1.44 hours and it occurred in the middle of October. The event had only eight hours duration but it can also be seen that the duration of the rain does not seem to affect the response time. The maximum response time was found for the event with duration of only 12 hours, which is not the longest duration. The fifth peak has only duration of nine hours but the lag time is as high as 2.93 hours.

The length of the response time sets one condition for the warning system. The warning system must be able to find the information about the approaching flood and have the time to warn the people in the affected areas. With only two hours response-time it might be difficult but when the area is sparsely populated the evacuation time might not be so long for the people living in the villages. To be able to predict the rain before it reaches the area is necessary in order to warn the people living outside the villages. Rain occurrence could be foreseen with weather radar but it is difficult to accurately forecast the intensity and duration of the precipitation. The duration and intensity is crucial to know when analysing the probability of an approaching flash flood. This means that even if the rain can be predicted it is not enough for telling if there will be a flash flood or not. It would therefore be desirable to be able to use the measurements from Da Nang or another station near the coast for measuring the intensity and duration of the rain. The problem with this is that the correlation between the stations is not 100% and that there will be times when the prediction is incorrect. If this happens too often, people will stop listening to the warnings and the system will be out of order

5.8 Correlation between the precipitation stations

The correlation was calculated in order to see if one precipitation station could represent the Tuy Loan catchment. It was done for the stations in Tuy Loan and Da Nang on hourly values. For the precipitation stations outside Tuy Loan, except for Da Nang, only daily values were known. For the hourly values it was possible to shift the values one and two hours to see if the correlation increased. This would have been desirable to be able to do for the stations outside Tuy Loan also. When the daily values were used it only showed that it rained on the same day and the number of observations is also very limited because the rain is only measured during two months. If the daily measurements are considered, there are 31 days in October and 30 days in November, totally 61 days. Out of these days there are, inside Tuy Loan, 19 days with less precipitation than 0.1 mm/day. It is not very many numbers in order to make a statistical calculation. The correlation ought to be rather high when looking at how many days that there was almost no rain at all.

The result of the daily correlation inside Tuy Loan became over 90%, which was expected when they are situated close and there are not many daily precipitation values. For the stations outside Tuy Loan the best correlation was between Da Nang station and Hoa Phu station. These stations are the two stations in Thu Bon with the shortest distance, 16 km, between each other. The lowest correlation between the stations in Thu Bon and the stations inside Tuy Loan occurs for Nong Son, 52%. This station is situated in the middle of Thu Bon and not furthest away from Tuy Loan which could have been expected. The station which is situated furthest away from Tuy Loan is Tien Phuoc station with a correlation of 69-77%. The reason that Tien Phuoc has a better correlation can be because the numbers of daily values are too few.

When examine the hourly values the correlation value decreases. There are 1464 hours of measurements, which makes the correlation calculation more reliable. These values can be trusted more than the daily ones.

When examining the values from Tuy Loan it can be seen that Ba Na and Hoa Phu has the highest correlation value of unshifted values. These two stations lies north-south in relation to each other. The high correlation between these station implies that the rain comes from the sea, because then they would be hit by the rain at approximately the same time.

If Da Nang station, which is outside Tuy Loan, is examined it can be seen that the values for Hoa Phu and Ba Na is about the same both for no shifting and for one hour shifting. For Doc Kien, that lies furthest to the west, the value for the one hour shifting is almost twice as high as the one with no shifting. This is another indication that most of the rain seems to be moving from the coast towards the mountains.

The correlation calculation is a tool to see if one station with measured rainfall could represent all stations in the whole area. It would also be interesting to see how the rainfall stations in Tuy Loan correlate with the rainfall station in Thu Bon on hourly values. The hourly measurements are more numerous and also more useful because flash floods happens within hour and not days.

The climate in Lo Dong consists of a dry season and a rainy season and the flash floods occur during the rainy season. Knowing this there is no use of measuring the precipitation all year around but more data would be preferred when making correlation.

5.9 Loop-rating curve

When plotting the result together with the measured values it can be seen that the subsidence is totally neglected when using the Jones Formula as mentioned in chapter 3.11. It also shows that even if subsidence is considered in the calculations the real subsidence is much larger. While some of the values used for calculating were only assumed there might be some adjustments that could be done. In order to try to get more subsidence the value of r was changed by changing the slope of the river basin and the ratio between the bottom width and the water level at steady state conditions, S_w. This resulted, as can be seen in Figure 4.9.3, in a larger subsidence but it also resulted in higher discharge values. The calculated loop does not have the same shape as the measured so it might be hard to make them agree.

5.10 HRC-Model

When using the HRC-model, corrected values for the precipitation with correction for elevation was used together with the interpolated discharge from directly measured flow.

The Nash-coefficient describes how well the direct measured flow agrees with the simulated flow. In this case, the result showed for the calibration in October 85% and for the validation in November 78%. It was possible to see that the simulated flow does not reach the peaks in the observed flow. During low flow, the simulated values agree fairly well with the observed values.

As mentioned in chapter 5.6 the low peaks might lead to an underestimation of the flow. This shows again, how difficult it is to predict flash floods even when using a rainfall runoff model, which has been made specifically to simulate flash floods. To be able to use the model for flash flood prediction it has to agree more at the high peaks so that the area will not be flooded without any warning.

6. Conclusions and Recommendations

This is why Tuy Loan river basin is vulnerable to flash floods:

- The basin contains high mountains with steep hillsides.
- The high mountains have a large impact on the amount of precipitation.
- The vegetation consists mostly of forest, some of which is cultivated by slash and burn.
- When the rain comes, it usually moves from the sea towards the basin (which is the longest way over the basin and therefore creates the longest duration of the rainfall) and the floods occur mostly in the night.
- There is not much water stored in the area. After a rainfall almost all water becomes runoff.
- It takes only about two and a half hours after a rainfall until the flow reaches its peak.
- The water level rises faster than the flow, which make the response time even shorter.

Flash floods are very hard to predict. This is because the conditions that create a flash flood can vary from time to time and from place to place. It is also hard to collect hydrological information because of the violent course of event. In many flash flood events, the rain gauges are swept away so that no measurements are recorded. The measurements from 2003 do not include any flash flood, which makes it difficult to predict the behaviour of the catchment area if a flash flood hits. It can be seen that the largest peak do not reach the maximum level when the different models are used. Maybe if there were more high events the unit hydrograph could have been adjusted to these peaks and then also more useful for predicting flash floods.

Because of the difficulties to predict a flash flood, it is hard to warn the people living in the area. If a warning system is created that sends out warnings too often the warnings will eventually be left unheard. If the warning system fail to warn for a flash flood the people will not trust the system and feel like they need to evacuate even if the warning do not come. The conclusion that can be drawn from this is that the warning system has to be very accurate despite of the difficulties.

To be able to do a more thoroughly analyse of the models a larger geological investigation of the basin has to be conducted. By learning more about the soil layer in the area more conclusions can be drawn from the errors in the rainfall-runoff models and thereby improve them. The investigation could also be useful in predicting which areas that is more vulnerable to landslides.

For buying some time when warning for a flash flood it would be desirable to be able to predict the intensity of the rain in a rain gauge outside of the area. The problem is that the correlation between the stations is not high enough and might therefore cause errors in the warning system. A more thorough investigation of the movement of the weather system before it hits the stations should be desired. This could be used for dividing the rainfall that comes into the area into different groups and it might in that way make the correlation between the stations better. It is also desirable to correlate the basins within the Tuy Loan with the station in Thu Bon on hourly basis. The values calculated on daily basis do not tell us enough about the relationship between the two basins.

The data and information used in this project is not enough when constructing a warning system. For further investigations here are some recommendations.

- Make a larger geological investigation.
- Make a correlation for all the stations in Thu Bon with hourly measured precipitation in order to gain more information of the rain pattern.
- Investigate the origin and the movement of the rain before it hits the area in order to find the most dangerous rainfall.
- Inform the inhabitants how to reduce the risk of flooding by better cultivation method and by placing new houses on safer places.

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Appendix A: Geographic positions of the stations in Thu Bon

Table A.1: The geographic positions of the stations in Thu Bon and the distance to the rain gauges in Tuy Loan.

Station	Longitude	Latitude	Hoa Phu (km)	Ba Na (km)	Doc Kien (km)
Ba Na	108°02’57’’ E	16°00’41’’ N	4.5	-	11.5
Doc Kien	107°56’44’’ E	15°57’31’’ N	13	11.5	-
Lo Dong	108°08’31’’ E	15°57’54’’ N	6	6	7.5
Hoa Phu	108°04’42’’ E	15°58’58’’ N	-	4.5	13
Da Nang	108°12’ E	16°02’ N	16	18	29
Ai Nghia	108°11’67’’ E	15°88’33’’ N	14	18	19.5
Cam Le	108°12’00’’ E	16°00’00’’ N	16	18.5	29
Cau Lau	107°28’33’’ E	15°85’00’’ N	26	30.5	36.5
Giao Thuy	108°01’67’’ E	15°85’00’’ N	23	26	22
Hiep Duc/ Son Tan	108°11’67’’ E	15°58’33’’ N	45	48.5	43
Nong Son	108°03’33’’ E	15°70’00’’ N	31	34.5	29
Tam Ky	108°50’00’’ E	15°53’33’’ N	62.5	67	70
Thanh My	107°83’33’’ E	15°76’67’’ N	35	35.5	24.5
Hoi An	108°20’ E	15°52’ N	30	34	41
Kham Duc	107°78’ E	15°43’ N	69	71	61.5
Que Son	108°1’ E	15°7’ N	31.5	35.5	32.5
Tien Phuoc	108°3’ E	15°48’ N	74.5	78.5	75.5
Hien Trao	107°65’ E	15°58’ N	63.5	64	53

Appendix B: Thiessens method

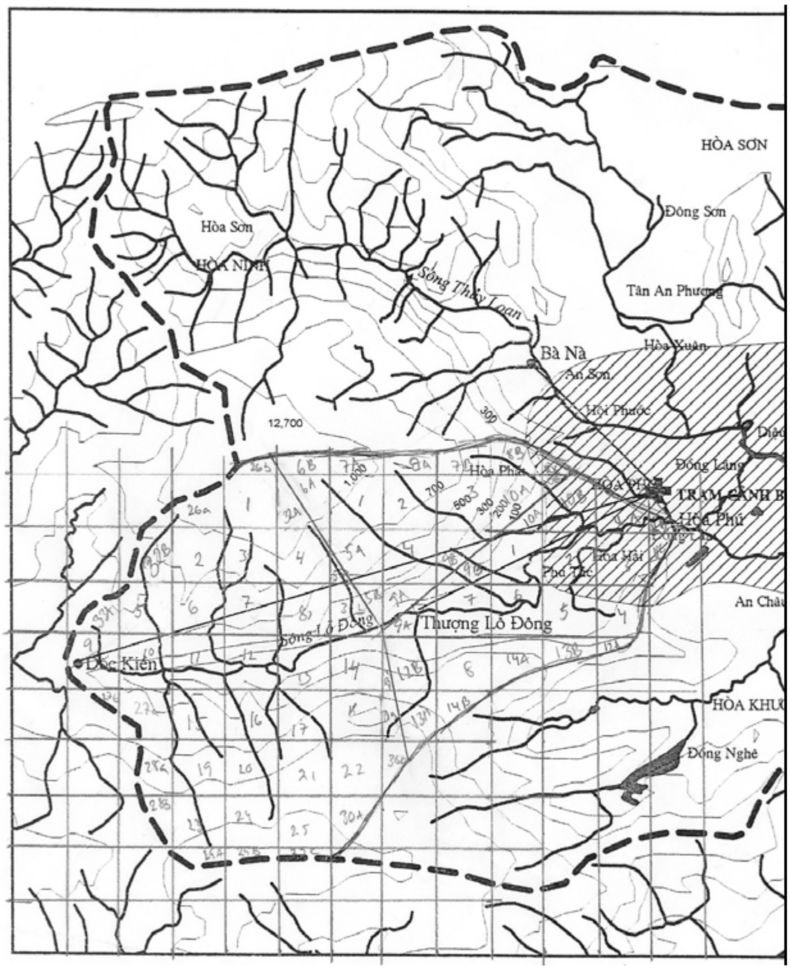

Figure B.1: Thiessens method constructed on the river basin map of Tuy Loan.

Appendix C: The graph used for finding where the recession reaches the baseflow

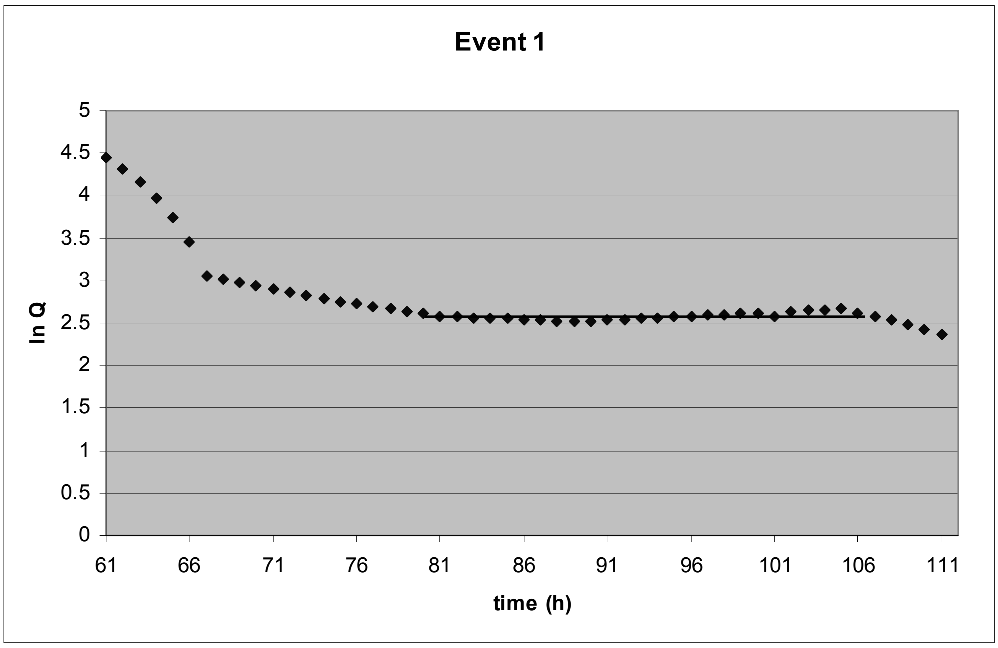

Figure C.1: The graph used for deciding the end of the hydrograph for event 1.

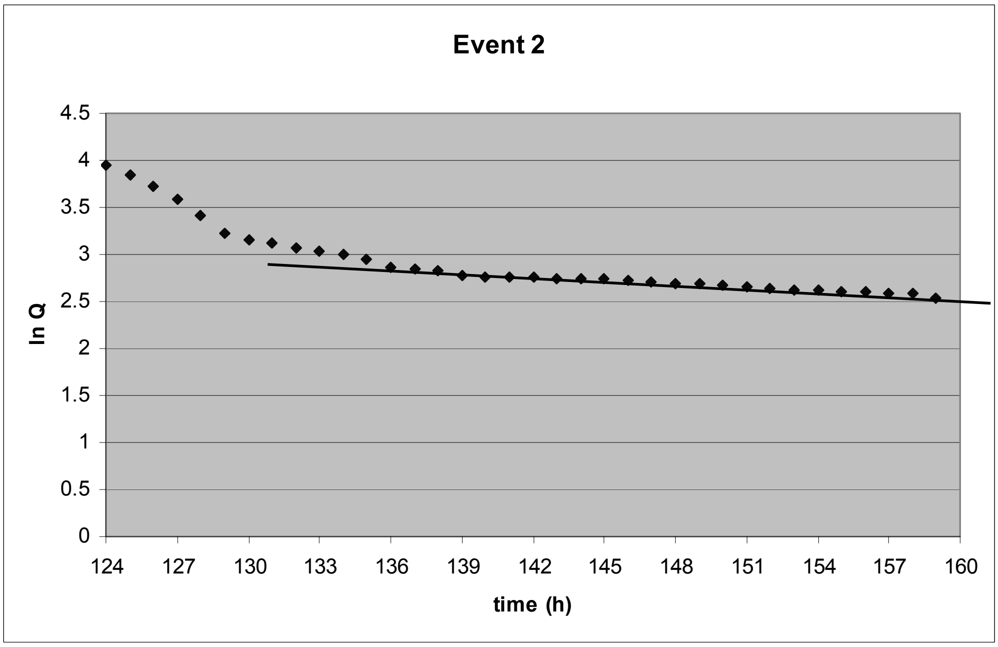

Figure C.2: The graph used for deciding the end of the hydrograph for event 2.

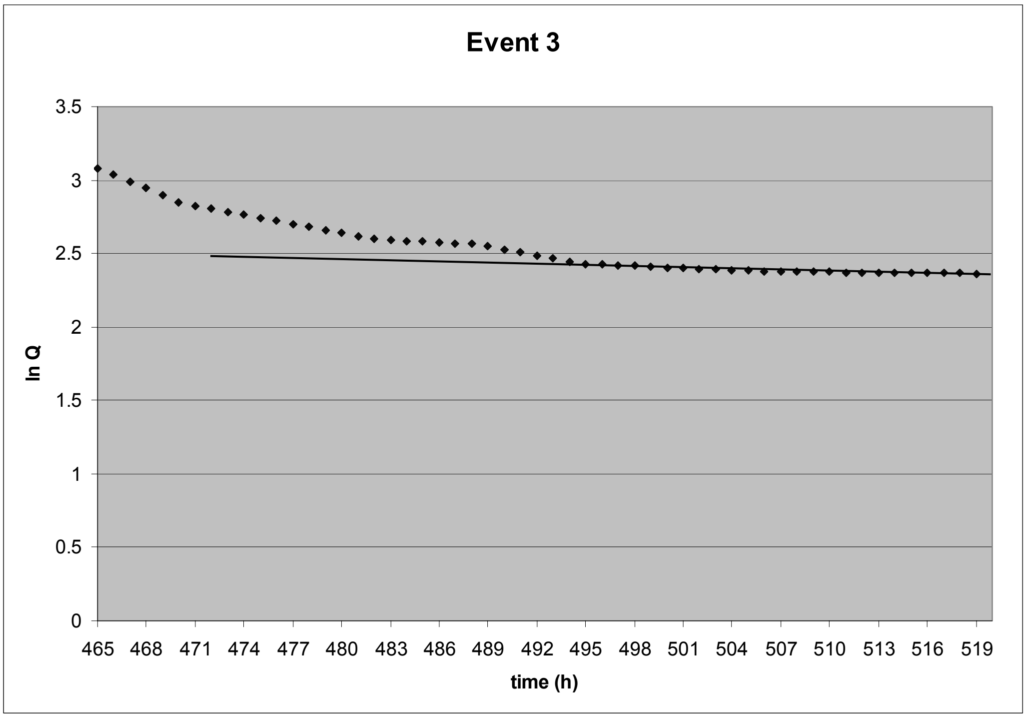

Figure C.3: The graph used for deciding the end of the hydrograph for event 3.

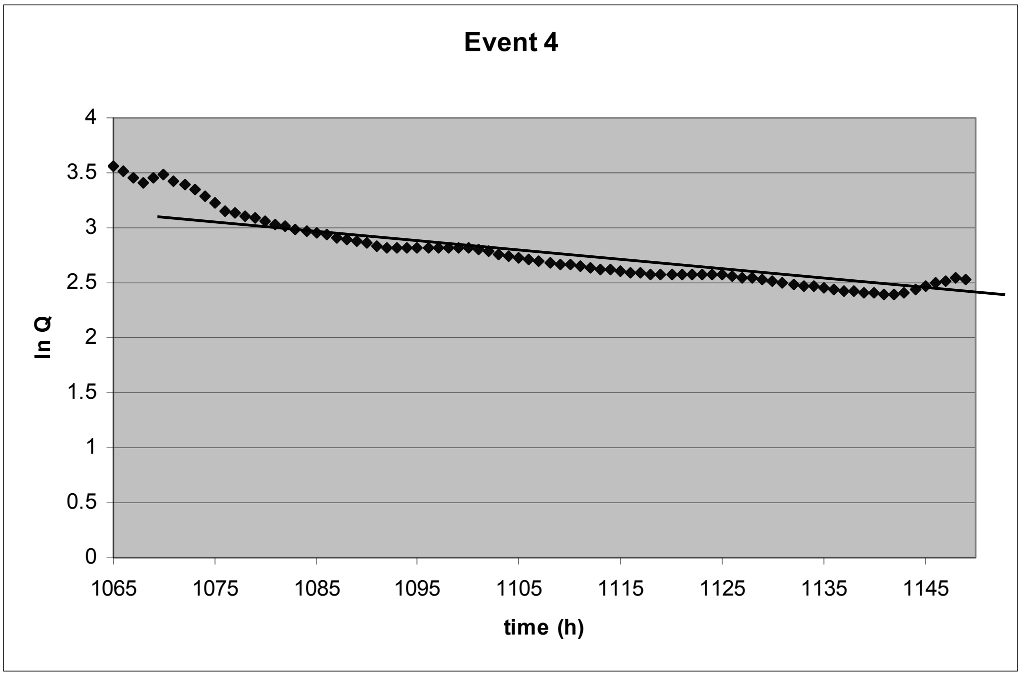

Figure C.4: The graph used for deciding the end of the hydrograph for event 4.

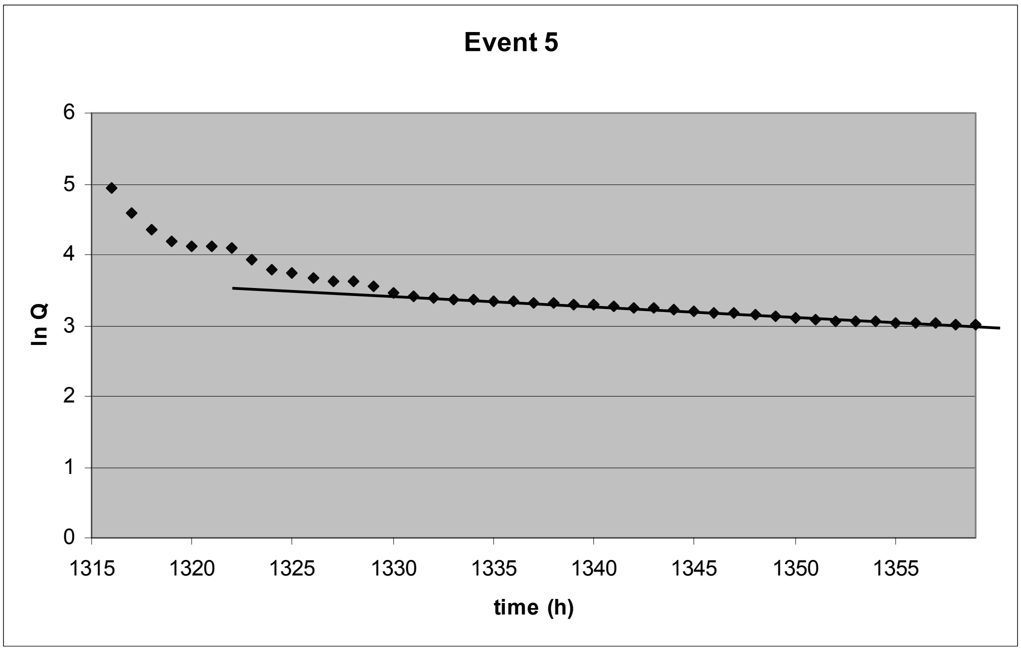

Figure C.5: The graph used for deciding the end of the hydrograph for event 5.

Appendix D: The correlation for all stations inside Thu Bon

Table D.1: The correlation in Thu Bon.

	Doc Kien	*Ba Na*	*Hoa Phu*	*Da Nang*	*Anghia*	*CLau*	*Cam Le*	*Giao Thuy*	*Hiep Duc (Son Tan)*	*Hoi An*	*Kham Duc*
DocKien	100										
Ba Na	90	100									
Hoa Phu	91	93	100								
Da Nang	79	86	88	100							
Anghia	72	81	84	66	100						
CLau	76	78	86	80	91	100					
Cam Le	62	78	78	81	87	89	100				
Giao Thuy	62	74	74	60	96	88	86	100			
Hiep Duc (Son Tan)	74	71	75	62	80	83	72	78	100		
Hoi An	75	76	81	78	87	93	86	84	82	100	
Kham Duc	71	70	67	56	64	68	52	66	86	68	100
Nong Son	52	56	54	38	77	72	64	84	73	71	70
Que Son	73	81	86	67	91	86	77	86	89	80	77
Tam Ky	53	67	68	56	86	77	78	85	71	72	50
Tien Phuoc	69	77	75	60	83	75	70	81	84	74	70
Thanh My	75	75	73	54	83	79	66	83	79	74	78
Hien (Trao)	67	71	68	51	84	72	67	83	73	74	59

Table D.2: The correlation in Thu Bon.

	Nong Son	*Que Son*	*Tam Ky*	*Tien Phuoc*	*Thanh My*	*Hien (Trao)*
Nong Son	100					
Que Son	70	100				
Tam Ky	73	86	100			
Tien Phuoc	73	90	90	100		
Thanh My	70	79	60	71	100	
Hien (Trao)	76	80	80	84	78	100

Appendix E: The crossection of Lo Dong river at Hoa Phu

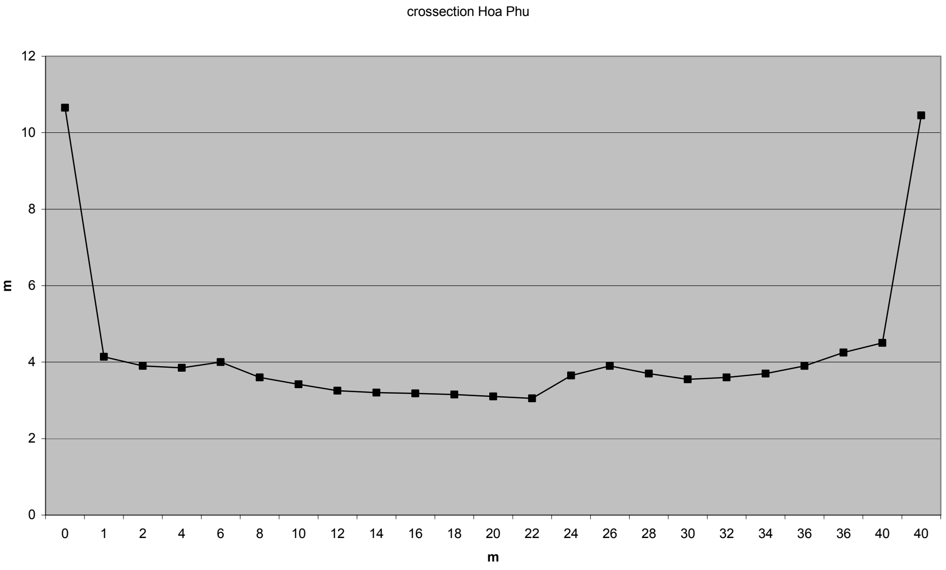

Figure E.1: The bottom contour at the station Hoa Phu, measured above MSL.