

University of Twente
Faculty of Engineering Technology
Civil Engineering and Management
Enschede, The Netherlands

Padjadjaran University
Faculty of Agricultural Industries Technology
Institute of Ecology
Bandung, Indonesia

Bachelor thesis

Modeling the impact of climate and land use change on discharges in the Citarum river



Anne Nobel

24th August 2011

Modeling the impact of climate and land use change on discharges in the Citarum river

A report of modeling discharges of the Citarum river in relation to rainfall, climate change and land use change.

Anne Nobel

University of Twente
Faculty of Engineering Technology
Civil Engineering and Management
Enschede, The Netherlands

Padjadjaran University
Faculty of Agricultural Industries Technology
Institute of Ecology
Bandung, Indonesia

24th August 2011

Supervisors:
dr. ir. M. Booij
dr. ir. C. Asdak

SUMMARY

The discharge in the Citarum river in West Java, Indonesia frequently exceeds the discharge capacity, causing floodings on the highly populated river banks. In this report the influence of land use change and climate change on the discharges in the Citarum river is investigated. The outcome is a scenario framework in which four scenarios are formulated based on fictitious model parameter changes in the used hydrological model and based on the A1 climate scenario from IPCC (2007).

The research is done by means of building and applying a hydrological model. The HBV model is a conceptual, semi-distributed model that is regarded as suitable for this modeling problem. The hydrological data that were necessary for the calibration and validation of the model were scarcely available for this study. In total five years of hydrological data have been available for the assignment. The poor quality of the data turned out to be an important restraint on the model performance, as the maximum Nash Sutcliffe coefficient was 0,65. The availability of high quality data would lead to better model results and thus would facilitate the achievement of better model results in future projects.

It has been tried to relate the land use change with the model parameters. As the model does not simulate the discharge very well it is impossible to draw this relationship. The calibration results show a Nash-Sutcliffe efficiency ranging from 0,55 to 0,65 with the Thiessen averaged rainfall, while the results varies from 0,41 to 0,58 for the arithmetically averaged rainfall. According to the scenario framework the continued deforestation and the climate change cause the discharges in the Citarum to be more variable. This means that the occurrence of very low and high flows increases and the peak flow is higher compared to the scenario with no land use change and no climate change.

The land use in the Upper Citarum area has changed dramatically. In 2005 the built-up and industrial area was 76% while this was 60% in 1997. The extreme scenario from IPCC states that the temperature will increase on average by 2 degrees, while the precipitation increases a few millimeters per day in winter and spring and decreases one millimeter per day in autumn.

The resulting framework is a supportive means for policymaking but cannot be used for quantitative predictions. The scenarios show that policymaking should aim at reducing the climate change. Furthermore, at a local level the government should try to stop the conversion of forestial area into industrial and built-up area in order to reduce the inundations.

PREFACE

For the bachelor thesis as part of the bachelor Civil Engineering I worked on a project for two and a half months at the Padjadjaran University at Bandung, Indonesia. During this time I faced several challenges. The most important challenge was adapting to the Indonesian way of working and scheduling while at the same time finishing the bachelor thesis had to be stressed. This two and a half months have enriched my knowledge about Indonesia and its working culture enormously.

I would like to thank dr. Chay Asdak and especially dr. Ir. Martijn Booi for their supervision and useful criticisms before and during the internship period. Furthermore I am thankful for the effort Dody Lihardo Saragih spent for trying to get the required data. Lastly, I want to thank all others who helped me during the internship period.

Hollum, 24th August 2011

Anne Nobel

CONTENTS

List of figures.....	6
List of tables.....	7
1. Introduction.....	8
1.1 Background.....	8
1.2 Research questions and objectives.....	11
1.3 Outline.....	11
2. Methods.....	12
2.1 Precipitation.....	12
2.2 Potential evapotranspiration and temperatures.....	12
2.3 HBV model.....	13
2.4 Sensitivity analysis.....	14
2.5 Calibration and validation process.....	14
2.6 Parameter uncertainty.....	15
2.7 Land use change and climate change in the HBV model.....	16
3. Study area and Data.....	18
3.1 The Citarum watershed.....	18
3.2 Data.....	19
4. Results and discussion.....	23
4.1 Sensitivity analysis.....	23
4.2 Parameter uncertainty.....	24
4.3 Calibration and validation results.....	25
4.4 Climate and land use change.....	27
4.5 Relation land use and model results.....	29
4.6 Land use and climate scenarios.....	30
4.7 Discussion.....	32
5. Conclusion.....	33
5.1 Conclusions.....	23
5.2 Recommendations.....	23
References.....	35

LIST OF FIGURES

Figure 1: Flood in Citarum watershed.....	8
Figure 2: The HBV-96 model	13
Figure 3: A land use change and climate change scenario framework.....	16
Figure 4: The Citarum watershed.....	18
Figure 5: Application of Thiessen method	20
Figure 6: Graphical representation sensitivity analysis.....	23
Figure 7: Upper boundary curves α , β and K_{uz}	24
Figure 8: Upper boundary curves K_{Iz} , $CFLUX$, $PERC$, FC and LP	24
Figure 9: Hydrograph 1997 - 6/1999.....	26
Figure 10: Hydrograph 7/1999 - 2001.....	26
Figure 11: Hydrograph 2005.....	26
Figure 12: Scenarios land use and climate change, 2040-2059.....	30
Figure 13: Results scenarios land use and climate change with HBV model, 2040-2059.....	30
Figure 14: Changes in percentage in scenarios land use and climate change according to HBV model, 2040-2059.....	31

LIST OF TABLES

Table 1: Parameter starting values	15
Table 2: Data partition for calibration and validation	15
Table 3: Streamflow data	19
Table 5: Precipitation data	20
Table 6: Potential evapotranspiration data.....	21
Table 7: Development of land use in upper citarum catchment area	21
Table 8: Projected changes in Southeast Asia 2050	22
Table 9: Calibration and validation results with averaged rainfall	25
Table 10: Calibration and validation results with Thiessen averaged rainfall.....	25
Table 11: Average annual precipitation 1997-2001, 2005 and t-test.....	27
Table 12: Average temperature 1997-2001, 2005 and t-test	27
Table 13: Student's t-test land use	28

1. INTRODUCTION

1.1 BACKGROUND

Since the very beginning all over the earth human societies have had to deal with floodings. Floods are potentially very dangerous: many lives have been taken by the floods in for instance the Yangtze river (China) in 1998. In Bangladesh over 1000 people were killed by floodings, caused by three weeks of rain (O'Connor, 2004). Floodings are a common problem in the world. In Indonesia, one had to deal with floodings for several times also. "Flash floods hits Bandung, killing one", the Jakarta Post headed late March 2009 (Suwarni, 2009). Hundreds of houses were inundated due to excessive high discharges in the Citarum watershed.

Another flooding in the Citarum watershed occurred in April 2010. The damage was estimated up to hundred million dollars (Nus, 2010). The floodings also cause damage to the paddy and crop fields in the area. The question arises: what are the causes of these floodings? This will be the subject of this thesis.



FIGURE 1: FLOOD IN CITARUM WATERSHED (BY DAYAPUTRI, 2008).

The growing demand for wood as fuel has led to continued deforestation in Indonesia (Directorate General of Water Resources Development, 1989). More recently, Machbub et al. (2003) suggested this deforestation together with industrial development are the main causes of the floodings. Thus, the change of land use is suggested as being the perpetrator of the inundations. Land use change causes a decrease in the retention capacity of the soil (Nik, 1988). From a hydrological perspective the floodings brings up several questions. We could wonder how issues like climate change and land use change influence the relation between rainfall and discharges. As illustrated by the above mentioned examples, there is a need for information about future discharges so appropriate measures can be taken. Measures include discouraging incentives for developers who want to build in the watershed area or even legal restrictions. When it comes to future predictions, the relation between land use change, climate change and the discharges has to be clear. These relations can be described with a hydrological model. A hydrological model is a simplified representation of the water balance in a specific area in which rainfall and discharges are related (Booij & Krol, 2010). A hydrological model can also give insights in future discharges based on fictitious land use, climate change and rainfall.

Chen et al. (2009) state that land use change is a force that can change hydrological processes dramatically. Land use change alters hydrological processes like interception, infiltration and evaporation in such a way that it magnifies or diminishes the total runoff and peak discharges from a river. Besides land use change, the change of climate causes an global increase in extreme rainfall events and higher temperatures which can increase the area that is prone to floodings (IPCC, 2007).

Several models have the capability of taking into account directly or indirectly the impact of land use change on discharges (Viney et al., 2008). These models vary from lumped to distributed regarding the spatial resolution. Models can also range from

statistically-based to physically-based. In statistically based models the data are processed with statistical procedures in so-called black box models. Examples are autoregressive models and artificial neural network models (Bruen & Yang, 2006). The physically-based models use physical principles that actually occur to describe relationships.

The usefulness of a model depends on the amount of available data. Statistically based models need less specific data records than physically based models (Viney et al., 2008, Saghafian et al., 2007). The Storm Water Management Model (SWMM) is such a physically based model. This model has many parameters, which for instance represent surface roughness and slope (Rossman, 2011). Nevertheless, physically-based models require more specific data about internal processes. These data are probably not available for the catchment area of this study. This makes the SWMM model not very likely to be appropriate for application in Indonesia.

The Hydrologiska Byråns Vattenbalansavdelning (HBV) model (Lindström et al., 1997) is a conceptual semi-distributed model. This means the model is based on sound scientific knowledge, but is also understandable for users and has a good model performance. The HBV-96 model is an improved version of the HBV model (Bergström, 1976). A major improvement is the ability of dividing the catchment area into subbasins. This leads to more accurate results (Lindström et al., 1997). Because the HBV model is semi-distributed, it is not able to handle much spatial variability of the hydrological processes (Legesse et al., 2003). The conceptual model is in between physically based and statistically based models. The HBV model has few model parameters and requires less data than fully distributed models.

The HBV model schematizes a catchment area as different linear reservoirs that are connected with each other by flows (Lidén & Harlin, 2000). These flows are described by equations. The parameters in these equations are determined by either past field experience or by calibration, which is comparing observed and predicted discharges (Ferket et al., 2009). By tuning parameters a good fit of the modelled discharges to the observed discharges can be obtained. This fit is more specifically the extent to which the objective function deviates from the ideal value. This fit is measured in the calibration and validation process by means of a performance criterion. The parameters have a physical meaning, but are not measurable. This is because the parameters represent effective values on a catchment scale (Seibert & McDonnell, 2010). The main limitation of the HBV model for predicting the impact of land use change is that land use is not a specific parameter in the model but it is rather represented indirectly by some parameters. With a lack of reliable data, the model cannot be calibrated to the wanted level and thus the application of the model will not be successful. The HBV model is a compromise between the wanted level of describing the hydrological processes on one hand and the availability of the data on the other hand. The HBV model seems suitable for application in Indonesia and will thus be used for modelling the Citarum river.

Being able to predict the impact of land use and climate change on discharges is valuable for developing management policies for catchment areas (Saghafian et al., 2009). Besides, quantifying the impact of land use and climate change on the hydrological response of a river basin is a current challenge in the field of hydrology (Ashagrie et al.,

2006). Developing a HBV model will help to gain insight in the impact of these changes on discharges in the Citarum river.

1.2 RESEARCH QUESTIONS AND OBJECTIVES

Before we can identify research questions, the problem needs to be defined. First, the problem lies in the fact it is not clear what the impact of land use and climate change is on the discharges of the Citarum river. This leads to the need for a hydrological model for relating land use and climate change with the discharges. The main problem lies in the fact there is no quantitative basis on which policy making can be based regarding the relation between land use and floodings in the Citarum river. Policy making can play an important role in preventing the Citarum river from future floodings by influencing land use in the catchment area. This focus on future developments is the starting-point for this report. By means of developing a reliable hydrological model the impact of land use and climate change on discharges in the Citarum river will be shown which will be used for creating future scenarios.

The objective of this thesis is as follows:

“To model the impact of land use change and climate change on the discharges in the Citarum river.”

In order to reach this objective the following main question is answered:

“What is the impact of land use change and climate change on the discharges in the Citarum river?”

The following questions need to be answered:

- What are hydrological properties of the Citarum watershed?
- What is the quality of the available data and how can it be used for the calibration and validation HBV model?
- What are the results of calibration and validation for different periods with different land use?
- What is the change of land use and the (prognosed) climate change?
- What do land use and climate change mean for the discharges in the Citarum river?

1.3 OUTLINE

In this report first the used methods are described in chapter 2. The HBV model is examined and the calibration and validation methods are described. The methods for the sensitivity analysis and parameter uncertainty analysis are given as well. In chapter 3 both the catchment area characteristics and the available data are discussed. Chapter 4 first shows the results of the sensitivity analysis and parameter uncertainty analysis. The chapter continues with the test for climate change and land use change. The calibration and validation results are also discussed in this chapter. The scenario framework will be drawn, based on the found relation between land use change and climate change. Chapter 4 concludes with a discussion of these results. In chapter 5 concluding remarks are made and some recommendations are given for policymaking.

2. METHODS

In the chapter Methods the data processing of precipitation, the potential evapotranspiration and temperatures is illustrated. Subsequently, the HBV model is exemplified. After this, the methods for sensitivity analysis of the model outcome for the parameters is explained. The chapter proceeds with a report of the parameter uncertainty analysis, followed by a description of the calibration and validation process. The chapter concludes with the land use change and climate change in relation to the HBV model.

2.1 PRECIPITATION

As the precipitation measurement stations are unevenly spread over the area a correction has to be executed in order to determine the average precipitation in the area. The Thiessen method will be used (Dirks et al., 1998). In the Thiessen method the sensing stations are connected by lines. Then, perpendicular lines are drawn at the middle of these lines that mark out the areas belonging to each station. The relative area of each station is the weight factor C_k in calculating the average rainfall in the total area. In formula:

$$P = \frac{\sum_{k=1}^m A_k \cdot P_k}{\sum_{k=1}^m A_k} = \sum_{k=1}^m C_k \cdot P_k$$

Where P is average precipitation, A_k is the area, P_k is the precipitation at a station. The average precipitation will also be calculated by normal averaging as this enables the possibility to compare the results of two types of calculating rainfall.

2.2 POTENTIAL EVAPOTRANSPIRATION AND TEMPERATURES

The potential evapotranspiration can be estimated by (Hargreaves & Samani, 1982):

$$PET = 0.0075 \cdot R_a \cdot C_t \cdot \delta^{\frac{1}{2}} \cdot T_{day\ avg}$$

where R_a is the net radiation, C_t is a humidity coefficient, δ is the difference between mean minimum and maximum monthly temperatures and T is the average temperature in the timestep. From this formula it becomes clear the temperatures are very important in calculating the potential evapotranspiration (PET). As the PET data are already given there has only to be attention for a possible climate trend in the temperature data (see paragraph 3.2.4). The formula can be used for calculating the new PET, based on a temperature increase as the PET increases linearly with day temperature. The mean monthly temperatures according to the Directorate General of Water Resources Development (1989) and expected increases according to the Fourth Assessment Report: Climate Change (IPCC, 2007) are used for this calculation. The new PET in a scenario becomes:

$$PET_{new} = PET_{old} \cdot \frac{T_{monthly} + \Delta T}{T_{monthly}}$$

2.3 HBV MODEL

The HBV model consists of three reservoirs (Lidén & Harlin, 2000). These are the soil box, the upper response box and the lower response box. The water content of these reservoirs are respectively the soil moisture (parameter SM), water height h_{uz} and water height h_{lz} . The flow from the soil box to the upper response box is determined by the capillary flux, comprising parameter $CFLUX$ and the actual and maximum soil moisture storage. The recharge is the opposite flow and is determined by the precipitation, maximum soil moisture, actual soil moisture and parameter β . The evapotranspiration depends on the maximum and actual soil moisture, parameter LP and the potential evapotranspiration. The percolation is also determined by a parameter $PERC$, parameter β and the actual and maximum soil moisture. The total outflow comprises a flow from the upper response box and from the lower response box. These flows are determined by a retention time K and in case of the upper response box, also by h_{uz} , soil moisture, maximum soil moisture and parameters α and β . The parameter $MAXBAS$ determines over how much days the calculated discharge of one day is distributed. The discharge is distributed by a triangular distribution function (Lindström et al., 1997). This parameter could be necessary for big catchment areas ($>1000 \text{ km}^2$), because the retention time of the water in the catchment area probably exceeds the timestep. Because the modeled catchment area comprises 1675 km^2 , the $MAXBAS$ parameter might be necessary in the model for this watershed and is therefore taken account for in the model implementation.

The HBV model is summarized in the following flowchart (Lidén & Harlin, 2000):

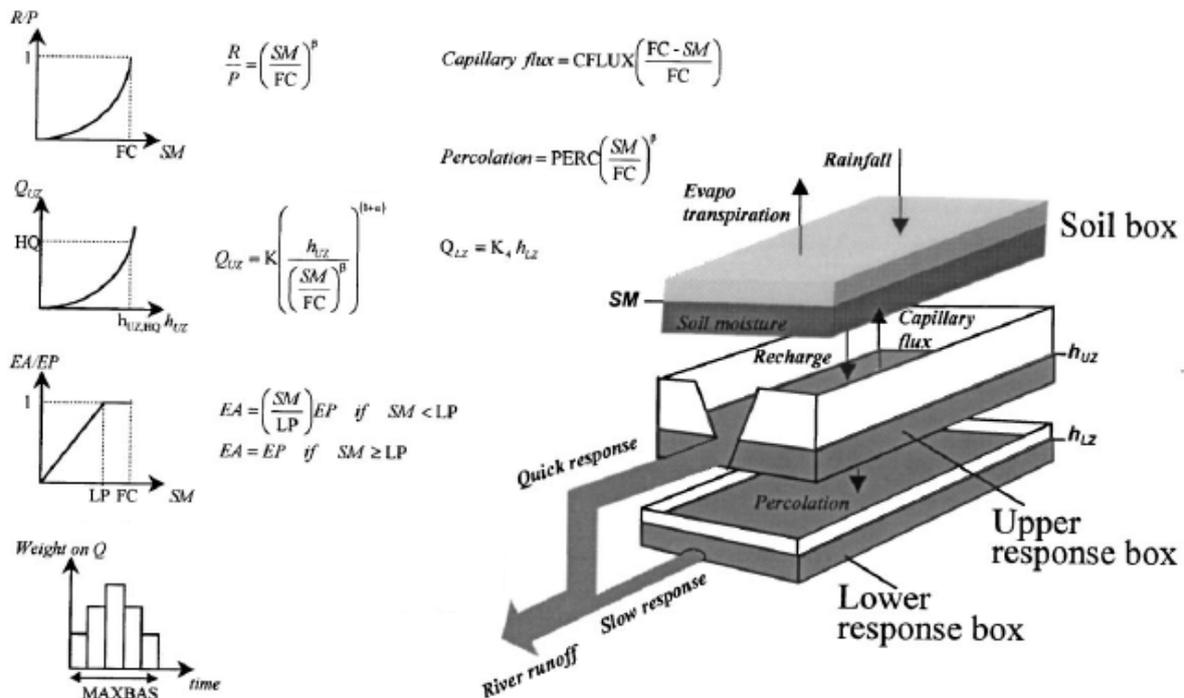


FIGURE 2: THE HBV-96 MODEL (BY LIDÉN & HARLIN, 2000).

2.4 SENSITIVITY ANALYSIS

Before the HBV model is calibrated it is useful to know how the model reacts on changes in parameters. Such a sensitivity analysis shows which parameters have much influence on the model output. The sensitivity analysis in this assignment is conducted by varying each parameter over the range as suggested by Lidén & Harlin (2000), while for a random day in the time period 1997 – 6/1999 the discharge is recorded. The results of the sensitivity analysis is shown in the chapter Results.

2.5 CALIBRATION AND VALIDATION PROCESS

The Nash Sutcliffe coefficient (NS) is often used to measure the overall appropriateness of the shape of the modeled hydrograph (Nash and Sutcliffe, 1970). The Nash Sutcliffe coefficient is defined by:

$$NS = 1 - \frac{\sum_{t=1}^T (Q_o^t - Q_m^t)^2}{\sum_{t=1}^T (Q_o^t - Q_{o,avg}^t)^2}$$

Where Q_o is the observed discharge and Q_m is the modeled discharge. The Nash Sutcliffe coefficient emphasizes higher discharges because the difference between the observed and modeled discharges are squared. The Nash Sutcliffe coefficient will be used as target function. Because the Nash-Sutcliffe coefficient may show good results while the simulation of the overall water balance can be poor, the Relative Volume Error is calculated as well (Booij & Krol, 2010). The relative volume error (RVE) is an indicator that tests the performance of the model regarding the simulation of the overall water balance in the watershed (Deckers et al., 2010). The relative volume error is defined by:

$$RVE = 100 \cdot \frac{\sum_{t=1}^T (Q_m^t - Q_o^t)}{\sum_{t=1}^T Q_o^t}$$

In a study of Lidén et al. (2000) a certain degree of equifinality is demonstrated with the HBV model: a certain degree of model efficiency was reached through different sets of parameters. It is rarely possible to obtain a 'winning' parameter set. The calibration process will be carried out using a Monte Carlo simulation so the calibration results are not arbitrary. In this simulation, randomly chosen parameters will form a predefined amount of parameter sets. The winning parameter set is the set which produces the best scores on the objective function. In a study with the HBV model the testing results got stable after 5000-10000 simulations (Shrestha et al., 2009). Thus, 10000 simulations are carried out for each time period in this thesis.

In table 1 the lower and upper limits and starting values are given as suggested by Lidén et al. (2000).

TABLE 1: PARAMETER STARTING VALUES (LIDÉN ET AL., 2000).

Parameters	Units	Starting values	Lower limit	Upper limit
FC	mm	400	100	800
LP	mm	100	100	800 & < FC
β	-	2	1	6
CFLUX	mm·day ⁻¹	0.1	0	1
PERC	mm·day ⁻¹	1	0.1	5
K_{upper}	·day ⁻¹	0.2	0.05	0.8
K_{lower}	·day ⁻¹	0.05	0.0005	0.1
MAXBAS	day	1	1	4
α	-	0,5	0	3

After calibration, the model is validated with the Nash Sutcliffe coefficient and relative volume error. For the effect of the initial states of respectively the soil box, upper response box and lower response box is taken care of by setting these at the average values of the model after a first calibration which is not recorded in the results.

The following data periods are available (see also paragraph 3.2): 1997-2001 and 2005. The dataset is divided into three subsets for calibration and validation. A split-sample test is used (Klemes, 1986). This leads to the data division of months in the following table.

TABLE 2: DATA PARTITION FOR CALIBRATION AND VALIDATION [MONTHS]

	1/1997 - 6/1999	7/2000 - 12/2001	1/2005 - 12/2005
Calibration (Months)	20	20	8
Validation (Months)	10	10	4

The calibration and validation are carried out by using two methods for calculating the average areal rainfall. In the first method the rainfall data of the eight stations are averaged without weighting. In the second method the rainfall data are weighted using the Thiessen method.

2.6 PARAMETER UNCERTAINTY

The uncertainty in the parameter estimation of the HBV model is assessed using the earlier mentioned Monte Carlo simulation (Seibert, 1997). In this Monte Carlo simulation, the HBV model is run with 100,000 different parameter sets for the period 1997 until 6/1999. For each run the Nash Sutcliffe efficiency is recorded. This range of the parameters is the same as the ranges set by Lidén et al. (2000). After this, a scatter plot can be drawn from the results with the Nash Sutcliffe efficiency on the y-axis and the parameter on the x-axis. The upper boundary curve reveals the extent to which each parameter is defined.

2.7 LAND USE CHANGE AND CLIMATE CHANGE IN THE HBV MODEL

Land use influences the soil surface properties. In a case study of a 3220 km² catchment in tropical South Central Ethiopia the impact of climate and land use change on the water balance was simulated using a distributed rainfall-runoff model (Legesse et al., 2003). This study shows the impact of a fictitious change in land use on the discharges by means of a possible scenario only. This was done by changing the parameters ‘maximum soil water capacity’ and the ‘vegetation cover density’. The model showed a significant higher peak discharge as a result of changing the parameters. In another recent study for a subtropical catchment of 727 km² in China, land use scenarios were modelled using a land use model called CLUE-s. For each land use type the model was calibrated for 14 parameters. By means of the HEC-HMS model the peak discharges were simulated based on the parameter sets belonging to the land use type (Chen et al., 2009). The results showed that the expansion of the built-up area led to increased total runoff and higher peak discharges as well. The study also proved that the sensitivity of the hydrological response for land use change increases when the rainfall events take place less often.

Some lessons can be learnt from these studies. The first one is that the parameters *FC* and *LP* in the HBV model are likely to be subject to change due to land use change, because these parameters are related to the soil. The second point is that more built-up area leads to higher peak discharges. One can imagine that in a built-up area precipitation runs off more quickly because the water retention capacity of the area is low. The lack of vegetation means the lack of a sponge function. Therefore, *K_{uz}* is also likely to be subject to change when the land use changes. The surface properties can have influence on the evapotranspiration. This follows also from the HBV model as the actual evapotranspiration is calculated by means of the maximum soil moisture parameter *LP*. Concluding, based on the conducted parameter uncertainty analysis especially the parameters α , β and *K_{uz}* are suitable for measuring a change caused by land use change. As there is, according to literature, no physical explanation for the change of the parameters α and β , the most likely parameter to change is *K_{uz}*.

The relevant factors in the HBV model regarding the climate change are the precipitation and temperature (IPCC, 2007). A simulation of the future scenarios will be made by adjusting the precipitation and evapotranspiration based on the Fourth Assessment Report on climate change of IPCC, which is further discussed in paragraph 3.2.

A 2-by-2 matrix will be created with the land management on the horizontal axis and climate change on the vertical axis (figure 3). In calculating the scenarios, the data and parameter set for the period 1997-6/1999 will be used as a base scenario in the upper left corner.

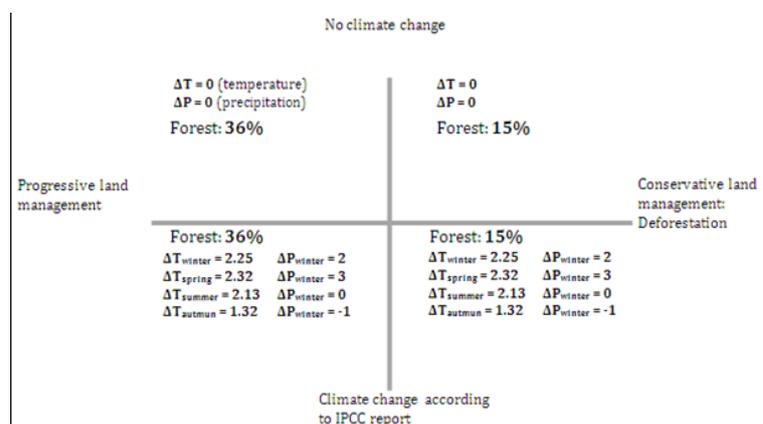


FIGURE 3: A LAND USE CHANGE AND CLIMATE CHANGE SCENARIO FRAMEWORK.

In the base scenario it is assumed no change occurs in land use because of progressive, sustainable land management. The climate stays the same too. In the upper right corner the climate stays equal, but the land use changes dramatically. The deforestation is the result of conservative land management. In the lower left corner the land use does not change, but the climate changes according to the worst case scenario described by IPCC. In the lower right corner both the land use and climate change, leading to an extreme scenario. This figure will also show the amount of days on which the discharge exceeds $200 \text{ m}^3/\text{s}$ or is lower than $5 \text{ m}^3/\text{s}$. These are arbitrarily chosen values which reflect the amount of days with a significant high or low discharge, based on the average discharge of $79 \text{ m}^3/\text{s}$ in the whole data series.

3. STUDY AREA AND DATA

In chapter 3 a description of the study area is given. Furthermore, the streamflow, precipitation and evapotranspiration data that are discussed. Lastly, the change in land use and climate is discussed.

3.1 THE CITARUM WATERSHED

The Citarum watershed is the largest among Indonesia's catchment areas, with a total surface of 12000 km² (Citarum Integrated Water Resource Management Project, 2007). 25 million inhabitants live in this watershed, making the Citarum river a very important factor in people's daily lives. The river rises at an elevation of 2200 m on the Mount Wayang near the southern coast of West Java. It generally flows in northwest direction until it reaches Bekasi, just east of Jakarta. The river is 270 kilometers long.

The study area of this thesis is restricted to a part of the Upper Citarum watershed as the data comes from the discharge measurement station Nanjung, located south of Bandung. The Upper Citarum watershed comprises 4400 km², while the catchment area of the Nanjung discharge station amounts to 1675 km² (Takeuchi, Jayawardena & Takahasi, 1995). See figure 4.

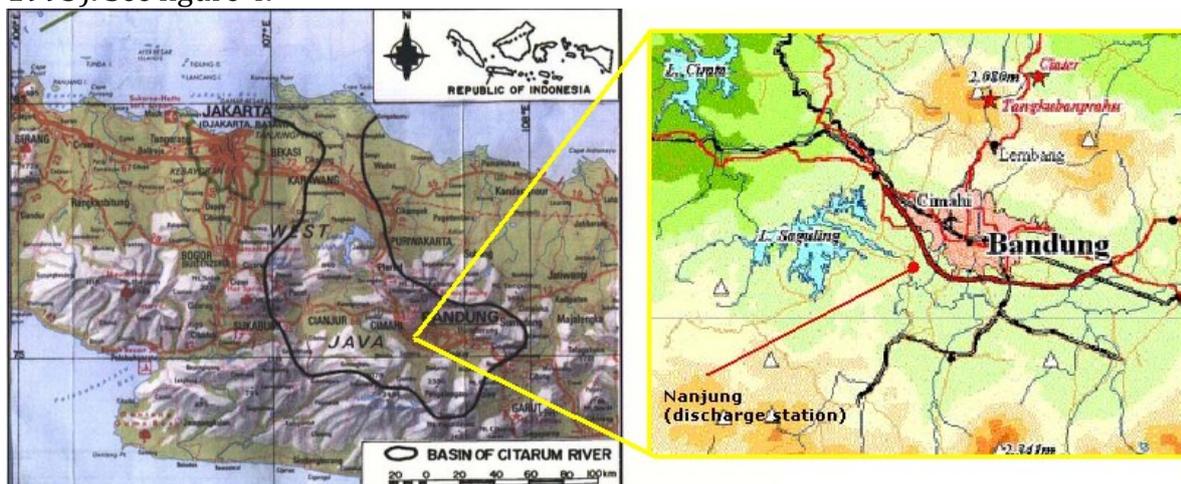


FIGURE 4: THE CITARUM WATERSHED (BY TAKEUCHI ET AL., W. (1995)).

The several volcanoes make the altitudes in the catchment area considerably variable. The annual average precipitation and estimated potential evapotranspiration are respectively 2118 mm and 2040 mm, while the temperature amounts to 24 degrees Celsius averagely in the period 1982-1993 (Takeuchi et al., 1995).

In the Upper Citarum catchment the exploitation of the hilly area for farming purposes is popular (Directorate General of Water Resources Development, 2001). Vegetables are planted on the expense of forest. The deforested ground does not give enough protection to the soil and has a decreased power to capture the rain, leading to increased peak flows during heavy raining and low flows during droughts. Until twenty years ago, the land was mostly covered by paddy field and forest (Watung, Tala'ohu & Dariah, 2005). After this, the land turned into developed area and agriculture. In paragraph 3.2.4 the changes in land use will be described more extensively.

3.2 DATA

The discharge data at station Nanjung, the precipitation at eight stations spread over the catchment area and the potential evapotranspiration originate from the University of Twente. The temperature data come from the website of the National Oceanic and Atmospheric Administration (2011). Furthermore, there is data about the land use in the Upper Citarum area coming from Watung et al. (2005). Data about climate change is coming from IPCC (2007). In this paragraph the data are further described.

3.2.1 STREAMFLOW DATA

In a study from Perrin et al. (2007) streamflow data of at least one hydrological cycle (one year) have been found as the minimum requirement for building a sound model. The calibration results of rainfall-runoff models were used to determine how much data are necessary. The study shows that the Nash-Sutcliffe coefficient in general stabilizes after 350 timesteps. Using a split sample test, in which two third of the timesteps is used for calibration and one third is used for validation, a minimum of 525 timesteps per land use period would be required. The acquired streamflow data for the Citarum river consists of data from 1997-2001 and 2005. The first data period is sufficient for dividing it into two datasets, but the last period (2005) is too short.

TABLE 3: STREAMFLOW DATA

	Streamflow data
N	2194
Missing values	0
Range	4.4 – 469.3

The minimum and maximum values show consistency with the ranges described in literature for the Citarum (Takeuchi et al., 1995). From this perspective, the data seem reliable.

3.2.2 PRECIPITATION DATA

As described in chapter 2, the Thiessen method is used for weighting the data from the rainfall measurement stations. In total eight stations are spread over and near the upper Citarum catchment area. In figure 5 the thick red lines separate the polygons.

TABLE 4: RELATIVE SURFACE ACCORDING TO THIESEN METHOD

#	Name	Relative surface (C_k)
1	Dangdeur	0.20
2	Bandung	0.04
3	Pangalengan	0.23
4	Malabar	0.04
5	Lembang	0.11
6	Saguling	0.20
7	Cililin	0.11
8	Ciparay	0.07
	$\sum C_k =$	1.00



FIGURE 5: APPLICATION OF THIESEN METHOD (IMAGE BY CITARUM INTEGRATED WATER RESOURCE MANAGEMENT PROJECT, 2007).

TABLE 5: PRECIPITATION DATA

Precipitation stations	#	1	2	3	4	5	6	7	8
N		2194	2194	2117	2194	1804	2163	2194	2194
Missing values		0	0	77	0	390	31	0	0
Range		0-192	1-88	0-89	0-91	0-133	0-152	0-91	0-128

A total of 498 values are missing. Prékopa and Szántai (1978) state that streamflows often follow the Gamma parameter distribution. Furthermore, the 2-parameter Gamma distribution function is the most preferred function for precipitation (Hanson & Vogel, 2008). Therefore, in the data analysis a 2-parameter Gamma probability function is used for identifying the occurrence unrealistic values. Because the catchment area is tropical it has to be considered there is a rain season and a dry season. Therefore, there is much variability in precipitation data throughout the year. The ranges of the measurements from each precipitation station show this variability. This means it does not make sense to use a global gamma distribution for filling in missing values. Therefore, for each day on which one or more values are missing the remaining values are used for calculating the average rainfall, taking into account the relative weight of each station according to the Thiessen method.

3.2.3 POTENTIAL EVAPOTRANSPIRATION DATA

As in literature the distribution of evapotranspiration is often considered normal, this distribution is used for assessing the evapotranspiration (Luke, 1987, Woodhead 1970). The potential evapotranspiration data for the Citarum watershed seem to follow a normal distribution with a mean of 4 mm and a standard deviation of 0.59 mm. Values that differ more than three times of the standard deviation are considered as outliers. Thus, values should be $D_T \cap \mu \pm 3 \cdot \sigma$.

TABLE 6: POTENTIAL EVAPOTRANSPIRATION DATA

	PET data
N	2194
Missing values	0
Range	1.8 – 6.3

The PET data set is complete and have no outliers according to the described criterion.

3.2.4 LAND USE DATA

The change in land use in the upper Citarum watershed is outlined by Watung et al. (2005). In distinguishing the types of land use it is important to look at the hydrological properties of each type. Paddy fields are fields in which rice is grown. The so-called mixed gardens are places for growing vegetables. In this thesis the most important property is the water retention capacity. As Watung et al. point out, forest, paddy field and mixed gardens have the ability to absorb water and thus reducing runoff. This implies that a decline in the percentage of these land use types and an increase in built-up area will cause a decline in soil moisture capacity. The following table is acquired from Watung et al. (2005).

TABLE 7: DEVELOPMENT OF LAND USE IN UPPER CITARUM CATCHMENT AREA (ACCORDING TO WATUNG ET AL. (2005)). * ESTIMATED VALUES

[km ²]	1997	1998	1999	2000	2001	2005
Forest	555	545	535	525	425	225*
Paddy field	700	675	650	625	625	625*
Mixed gardens	490	435	380	325	300	200*
Other	2655	2745	2835	2925	3050	3350*
Total	4400	4400	4400	4400	4400	4400
Percentage Forest, Paddy field, Mixed gardens / total	40%	38%	36%	34%	31%	24%*

For the land use the values for 2005 are calculated by extrapolation the linear trend. The category *Other* consists of industry and built-up area. A student's t-test is conducted on the derived percentages in the Results chapter.

3.2.5 CLIMATE CHANGE

The climate is likely to be subject to change in the coming decades. The IPCC conducted research on the change of the climate (IPCC, 2007). In the IPCC reports, six scenarios are distinguished. The main drivers are the population growth, economic growth and the development of energy technology. The trends used for the Citarum are based on the most extreme scenario in which a high future CO₂ emission is expected (leading to an increase of CO₂ emission of 1.58% per year). Furthermore the economy does not shift towards renewable energy and the population increases significantly. The global prediction following from this scenario is an increase in temperature of 4.0 degrees until 2050. The climate model of IPCC uses physical principles for relating key processes on earth with the climate. As the models are spatially distributed the climate change for certain areas can be simulated. An increase in surface air temperature of 2 degrees towards 2050 for the area of Southeast Asia is reported in the extreme scenario. This so-called A1 scenario assumes further globalization and a strong focus on economic development (IPCC, 2007). The precipitation is likely to increase 3 mm in spring and decrease 1 mm in autumn. See table 8.

TABLE 8: PROJECTED CHANGES IN SOUTHEAST ASIA 2050 IN A1 SCENARIO (IPCC, 2007).

	Increase temperature [degrees]	Increase precipitation [mm]
Winter	2.25	2
Spring	2.32	3
Summer	2.13	0
Autumn	1.32	-1

These changes will have an impact on the hydrology of the Citarum river catchment. The increased temperatures lead to an increased evapotranspiration and an increase of the precipitation in the winter leads to higher peak flows, while the reduction of the precipitation in the autumn can extend the periods of low flows. The increases in temperature and precipitation in the described scenario are adopted for the climate change scenarios in this thesis. This is done by adding up the precipitation and precipitation increase per season in the data series. In paragraph 2.2 it is explained how the increase in temperature will be implemented in the data.

4. RESULTS AND DISCUSSION

In this chapter the results of the sensitivity analysis and the parameter uncertainty analysis are discussed. The chapter proceeds with respectively the calibration and validation of the model and the t-tests for land use change and climate change in the data. Subsequently, the relation between land use change and the model results is examined. Furthermore, a scenario framework is created. The chapter concludes with a discussion of the obtained results.

4.1 SENSITIVITY ANALYSIS

In figure 6 the change of a discharge Q is given for changes in parameter values.

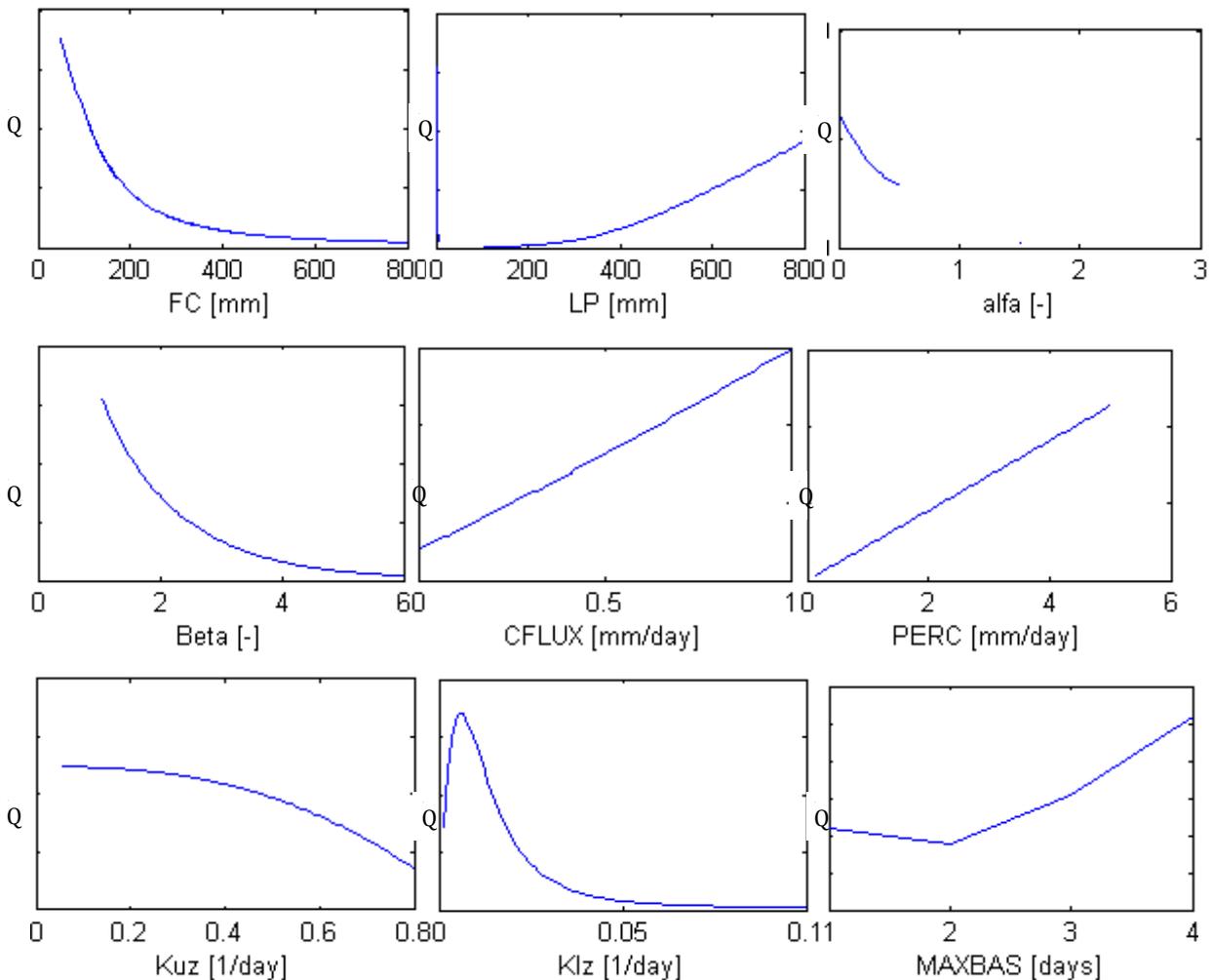


FIGURE 6: GRAPHICAL REPRESENTATION SENSITIVITY ANALYSIS

The parameters CFLUX and PERC have a linear relationship with the modeled discharge. K_{lz} and K_{uz} are very influential for the discharge. The sensitivity decreases when K_{lz} becomes bigger and when K_{uz} gets smaller. Parameter LP and FC show sensitivity for specific ranges. Parameter alfa is only working for a very small range, making this parameter very important. The greatest sensitivity for beta is shown near 1. As MAXBAS can transform the discharge to a distribution over more days only, it does not make sense to interpret the continuous sensitivity of the modeled discharge for this parameter. The sensitivity of the model result for the other parameters will be different

for different timesteps. It is therefore useful to draw the above graphs with a performance indicator like the Nash Sutcliffe coefficient. Due to time restrictions this is not done in this thesis. In paragraph 2.5 there will be attention for the uncertainty of the parameter estimation.

4.2 PARAMETER UNCERTAINTY

The results of the parameter uncertainty analysis divide the parameters in two groups. The first group consists of the well-defined parameters α , β and K_{uz} . Figure 7 illustrates the upper boundary curves that show only for a specific range the model result is optimal, while for parameter values deviating much from the optimum the model result gets worse.

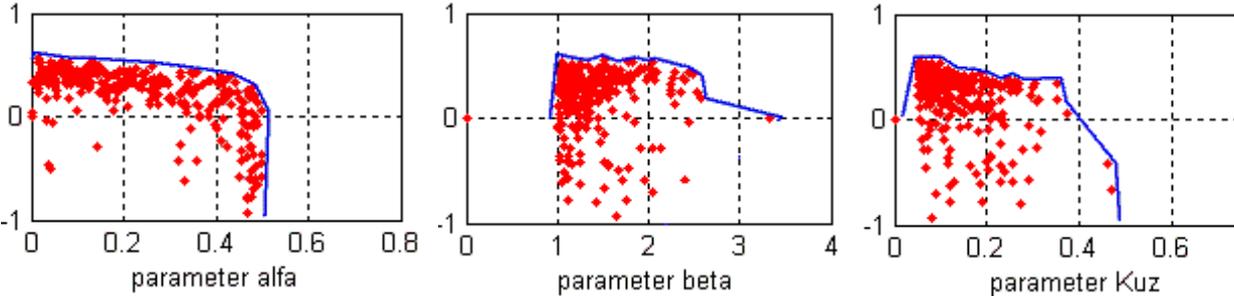


FIGURE 7: UPPER BOUNDARY CURVES ALFA [-], BETA [-] AND K_{uz} [1/DAY]

The second group of parameters consists of the poor defined parameters, which show a more or less equal model efficiency over a broad range of parameter values. These parameter are K_{Lz} , CFLUX, PERC, FC and LP. See figure 8.

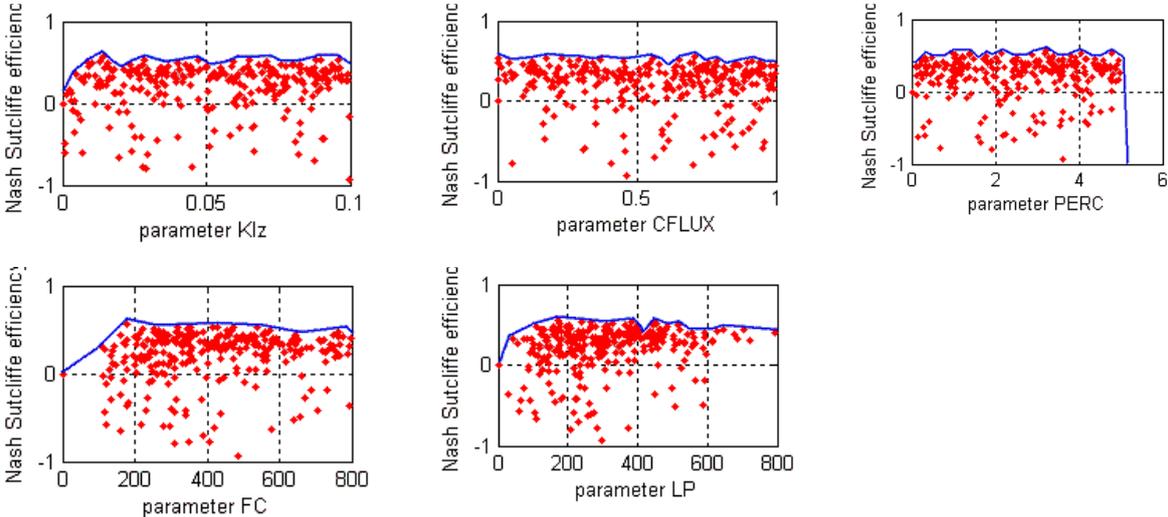


FIGURE 8: UPPER BOUNDARY CURVES K_{Lz} [1/DAY], CFLUX [MM/DAY], PERC [MM/DAY], FC [MM] AND LP [MM].

From this parameter uncertainty analysis it can be concluded that it is uncertain if the parameters of the second group will be estimated correctly by the HBV model. The same results can be obtained with values over a broad range. It will therefore be hard to relate

the change of these parameters with a changing land use.

4.3 CALIBRATION AND VALIDATION RESULTS

The best results are obtained with the calculation of the rainfall according to the Thiessen method. The results for the normally averaged rainfall and the rainfall with the Thiessen method are shown in tables 9 and 10 respectively.

TABLE 9: CALIBRATION AND VALIDATION RESULTS WITH NORMALLY AVERAGED RAINFALL.

<i>Parameters</i>	<i>Units</i>	1/1997-6/1999	7/1999-2001	1/2005-12/2005
FC	mm	201	177	166
LP	mm	180	171	163
β	-	1.59	1.52	1.23
CFLUX	mm·day ⁻¹	0.050	0.709	0.123
PERC	mm·day ⁻¹	4.56	3.23	1.34
K_{upper}	·day ⁻¹	0.091	0.056	0.070
K_{lower}	·day ⁻¹	0.0287	0.0142	0.0436
MAXBAS	day	2	2	2
α	-	0.029	0.016	0.10

	NS [-]	RVE [%]	NS [-]	RVE [%]	NS [-]	RVE [%]
Calibration	0.562	12.10	0.407	-27.4	0.576	-17.0
Validation	0.458	-16.2	0.002	-37.0	0.110	7.47

An almost reasonable Nash Sutcliffe coefficient is reached for the first and last calibration period with the normally averaged rainfall. Though, the overall model performance is poor. Especially the validation results are disappointing.

TABLE 10: CALIBRATION AND VALIDATION RESULTS WITH THIESSEN WEIGHTED AVERAGE RAINFALL.

<i>Parameters</i>	<i>Units</i>	1/1997-6/1999	7/1999-2001	1/2005-12/2005
FC	mm	450	230	266
LP	mm	440	133	263
β	-	1.004	1.113	1.002
CFLUX	mm·day ⁻¹	0.029	0.044	0.085
PERC	mm·day ⁻¹	0.15	1.63	0.61
K_{upper}	·day ⁻¹	0.026	0.028	0.061
K_{lower}	·day ⁻¹	0.08	0.061	0.0534
MAXBAS	day	1	2	2
α	-	0.09	0.007	0.096

	NS [-]	RVE [%]	NS [-]	RVE [%]	NS [-]	RVE [%]
Calibration	0.645	-1.00	0.553	2.84	0.554	-12.72
Validation	0.564	-3.28	-0.07	-37.4	0.134	7.55

The results for weighted rainfall, are best for the period 1/1997-6/1999 with a Nash Sutcliffe efficiency of 0.645 and 0.564 for the calibration and validation respectively. The resulting hydrographs are shown in figure 9, 10 and 11.

In the first hydrograph, 1997 – 6/1999, the modeled curve follows the observed curve

quite well, except for the peak flows in some periods. The model does not seem responsive enough to the sudden increases and decreases in rainfall.

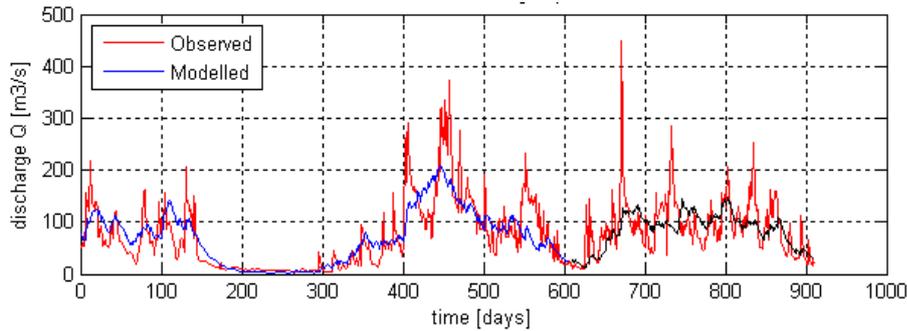


FIGURE 9: OBSERVED AND MODELLED DISCHARGES 1997 - 6/1999

In the hydrograph from 7/1999 – 2001, the model seems not reactive enough to the rainfall variability. Furthermore, especially in the validation period, the overall water balance is not simulated properly as the simulated flows are much lower. This also follows from the relative volume error of 37.4% for this period.

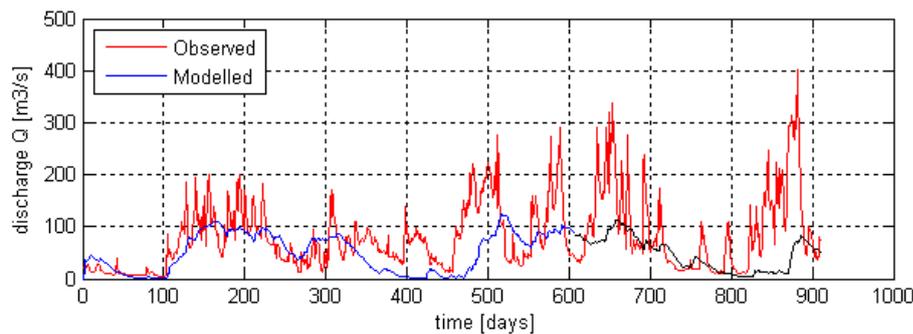


FIGURE 10: OBSERVED AND MODELLED DISCHARGES 7/1999 - 2001

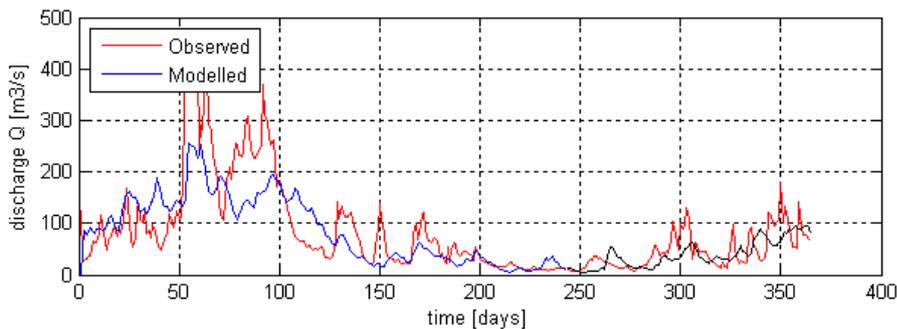


FIGURE 11: OBSERVED AND MODELLED DISCHARGES 2005

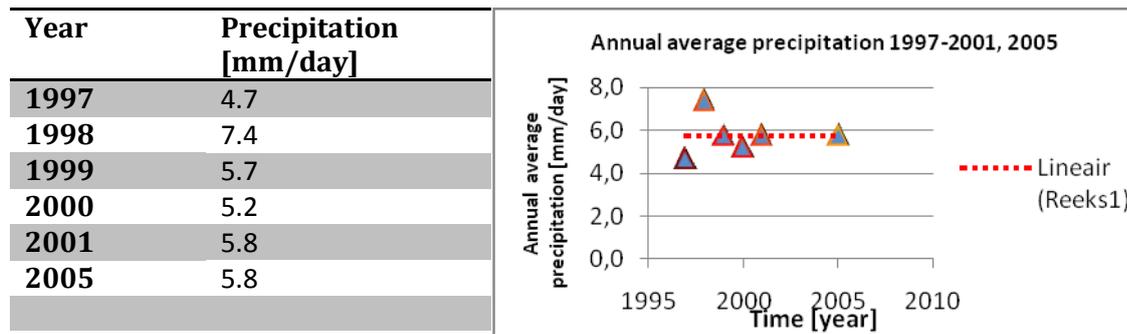
In the hydrograph of 2005 the reason for the poor model performance is visible. At approximately day 75, the modeled curve goes down while the observed curve is going up. Incorrect rainfall data is likely to be the perpetrator of this discrepancy. Together with the period 7/1999-2001 the performance of the model on the period 2005 is disappointing.

4.4 CLIMATE AND LAND USE CHANGE

4.4.1 CLIMATE CHANGE

In this paragraph results of the check for the influence of climate change and land use change on the recorded data are given. A two-tailed student's T-test is conducted on precipitation and temperature data. A 99% confidence interval is used for rejecting the zero hypothesis. If for climate change the zero hypothesis is not rejected, the climate as possible factor that alters the hydrological parameters is excluded.

TABLE 11: AVERAGE ANNUAL PRECIPITATION 1997-2001, 2005 AND T-TEST



T-test (Two-tailed)

$$Y = \beta x + C + \varepsilon$$

$$n = 6$$

$$CI = 99\%$$

$$H_0: \beta = 0$$

(H_0 rejected if T-score > T-limit)

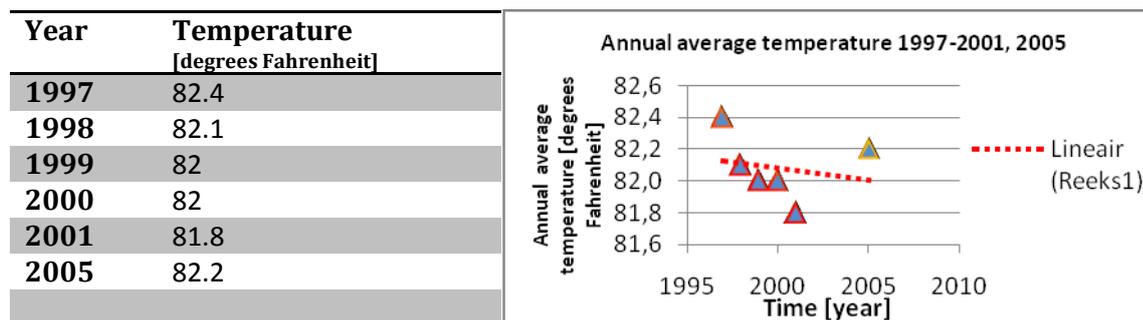
$$H_1: \beta \neq 0$$

$$T\text{-limit: } 4.03$$

$$T\text{-score: } \mathbf{0.008} < \mathbf{4.03}$$

As the T-score is not exceeding the T-limit, H_0 cannot be rejected. Thus, it cannot be assumed there is a trend in the precipitation data. For the temperature data H_0 is also not rejected. This means we cannot assume there is a trend in the temperatures data in the period 1997-2005. See the following table.

TABLE 12: AVERAGE TEMPERATURE 1997-2001, 2005 AND T-TEST



T-test (Two-tailed)

$$Y = \beta x + C + \varepsilon$$

$$n = 6$$

$$CI = 99\%$$

$$H_0: \beta = 0$$

(H_0 rejected if T-score > T-limit)

$$H_1: \beta \neq 0$$

$$T\text{-limit: } 4.03$$

$$T\text{-score: } \mathbf{0.043} < \mathbf{4.03}$$

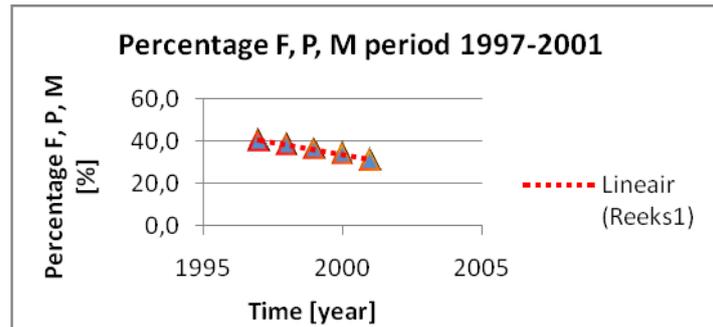
As the climate is usually defined as the average weather conditions over a period of 30 years, it is not surprising no visible trend is found (Slingo, 2010).

4.4.2 LAND USE CHANGE

If a student t-test is conducted at a confidence level of 99%, H_0 is rejected. This means there is a significant decline in forestial area, paddy fields and mixed gardens. The negative trend will be used for the scenarios in the further report. See table 13 for the summary of the results.

TABLE 13: STUDENT'S T-TEST LAND USE.

T-test (Two-tailed)	
$Y = \beta x + C + \varepsilon$	$n = 5$
	CI = 99%
$H_0:$	$\beta = 0$
$H_1:$	$\beta \neq 0$
(H ₀ rejected if - T-limit > T-score > T-limit)	
T-limit:	5.84
T-score:	-19.0



4.5 RELATION LAND USE AND MODEL RESULTS

The results for the normally averaged rainfall are poor. Even for the Thiessen averaged rainfall the model performance does not meet the expectations. The Nash Sutcliffe coefficient should at least be 0.80 (Seibert, 1997). Therefore, reliable suggestions about the relationship between the extent of forestial area and parameters are hard to make. The short period of data is a factor that inhibits the possibility to draw this relationship too. In the further report, the found parameters of the Thiessen averaged rainfall for the period 1997 – 6/1999 will be used as the Nash Sutcliffe efficiency for this time period appeared to be the highest.

A decrease in the parameters FC and LP is seen over the three periods, but this decrease can also be caused by the parameter estimation uncertainty as described in paragraph 3.2.7. Taken this together with the model performance, a relationship can not be drawn. In the calibration, the parameter K_{uz} seems to increase over time. This response parameter is likely to be altered by land use change because of the change in water retention capacity. In case of heavy rainfall, the water runs off more quickly and in case of drought there is less water that was earlier retained and can be released now. Furthermore, K_{uz} is a well-defined parameter as is demonstrated in paragraph 2.5, so a change of this parameter could be plausible. Nevertheless, the evidence based on the model results is too weak for drawing the relationship.

In developing the scenarios some limitations show up. The main limitation is that only climate change and land use change are considered as drivers for the development of the hydrology in the Citarum watershed. There are other factors like human activity and economical development which directly have their impact on the hydrology on their own. These factors are beyond the scope of this thesis and are only considered indirectly as the land use is driven by several factors and climate change is a function of several factors too. The second limitation is the poor relationship between model results and land use change. Therefore, the scenario should only be interpreted as a supportive means.

4.6 LAND USE AND CLIMATE SCENARIOS

The 2-by-2 matrix with the land management on the horizontal axis and climate change on the vertical axis is based on the period 1997-6/1999. See figure 12 for an overview.

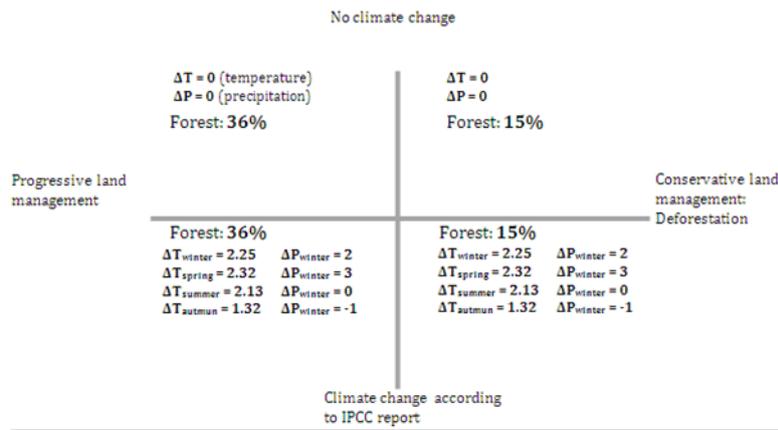


FIGURE 12: SCENARIOS LAND USE AND CLIMATE CHANGE, 2040-2059

K_{uz} is 0.026 for 36% of forestial area (upper left scenario), according to the calibration value. As followed from the parameter uncertainty analysis and literature research, K_{uz} is the parameter that logically alters by land use change. Because no clear relationship is found, a fictitious value for parameter K_{uz} is assumed. K_{uz} is assumed 0.08 for 15% forestial area (upper right scenario) because the retention time decrease with more built-up area.

The data are adjusted for climate change in the lower box scenarios. Put together, four scenarios are simulated with the HBV model for 2040-2059. The results of each scenario are given in figure 13 and figure 14.

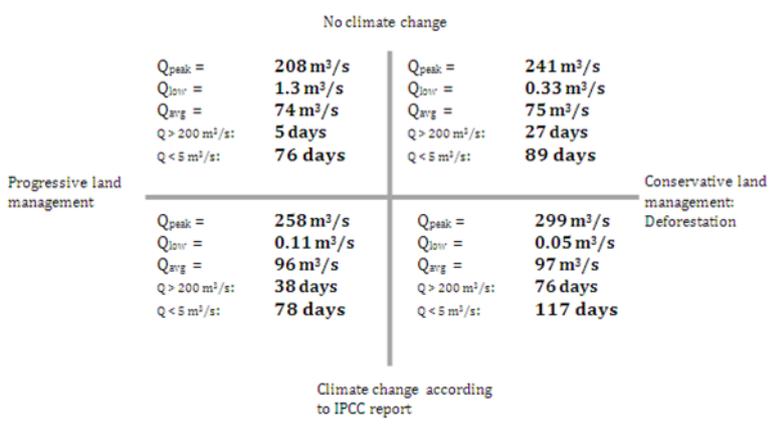


FIGURE 13: RESULTS SCENARIOS LAND USE AND CLIMATE CHANGE ACCORDING TO HBV MODEL, 2040-2059.

In figure 14, the changes in percentage compared to the upper left scenario are shown.

		No climate change			
Progressive land management	$Q_{peak} =$	-		$Q_{peak} =$	16 %
	$Q_{low} =$	-		$Q_{low} =$	-75 %
	$Q_{avg} =$	-		$Q_{avg} =$	1 %
	$Q > 200 \text{ m}^3/\text{s}:$	-		$Q > 200 \text{ m}^3/\text{s}:$	400 %
	$Q < 5 \text{ m}^3/\text{s}:$	-		$Q < 5 \text{ m}^3/\text{s}:$	17 %
Conservative land management: Deforestation	$Q_{peak} =$	24 %		$Q_{peak} =$	44 %
	$Q_{low} =$	-92 %		$Q_{low} =$	-96 %
	$Q_{avg} =$	30 %		$Q_{avg} =$	31 %
	$Q > 200 \text{ m}^3/\text{s}:$	660 %		$Q > 200 \text{ m}^3/\text{s}:$	1420 %
	$Q < 5 \text{ m}^3/\text{s}:$	3 %		$Q < 5 \text{ m}^3/\text{s}:$	54 %
		Climate change according to IPCC report			

FIGURE 14: CHANGES IN PERCENTAGE IN SCENARIOS LAND USE AND CLIMATE CHANGE ACCORDING TO HBV MODEL, 2040-2059.

An increase in high flows and decrease in low flows occurs both when shifting from the base-scenario to the upper right scenario and to lower left scenario. The increase of the peak flows when shifting from a left to a right scenario can be explained by the reduced water retention capacity as there is less forestial area, which causes the water the run off more abruptly. As less water is retented, there is less runoff in case of the absence of rainfall. The increase when shifting from an upper to a lower scenario is caused by the altered water balance. There is a general increase in precipitation and evapotranspiration, but the precipitation has the upper hand as the average streamflow is higher. According to the scenario framework, the highest peak flow and lowest flow occur when there is conservative land management and considerable climate change. In this extreme scenario, the amount of days on which the streamflow drops below $5 \text{ m}^3/\text{s}$ and exceeds $200 \text{ m}^3/\text{s}$ is the highest among the four scenarios. It seems that climate change has more influence on the indicators than the fictitious land use change in this case as the lower left scenario shows more extreme values than the upper right scenario. As the value of K_{uz} is arbitrary, no conclusions can be drawn from this last point.

4.7 DISCUSSION

In this thesis it is aimed to gain insight in the effects of land use change and climate change on the hydrology of the Citarum river. Unfortunately, the model could not provide a simulation of high quality. There are a few possible explanations for this.

The rainfall data or discharge data are possibly not totally synchronized with each other. Although the discharge seems to be low for periods of little rainfall, it is hard to check if exactly the same days are recorded for both types of data. For some rainfall stations the data were lacking but the average rainfall for these timesteps was calculated by the remaining stations. The available data entries can be of too poor quality as well.

Another explanation of the model results is the delineation of the watershed compared to positions of the rainfall stations. Some of the rainfall stations might be too far from the core of the watershed and therefore might give false information about the rainfall. In figure 5 the application of the Thiessen method is shown. In this figure it is visible that stations 1, 5 and 6 are quite far away from station 3, which lies in the center of the watershed. Stations 1, 5 and 6 are the stations which have a relatively high weight in averaging the rainfall. Although, if this explanation is valid, a worse result from the Thiessen method is expected compared to the normally averaged rainfall, but this is not the case.

The hydrographs in paragraph 4.3 show that the model is not able to simulate sudden peak discharges well. This could be caused by a too low value for K_{uz} although this response parameter is acquired by the Monte Carlo simulation and leads to the best model results for this dataset. There are no near dams or other artificial disturbances upstream of the discharge station, but a few kilometers downstream there is a lake on which the water of the Upper Citarum watershed is discharging. As a downstream disturbance can have influence on the water level more upstream and thus on the calculated discharge, the lake might be a factor that inhibits the extent to which the discharge can be properly modeled for this station.

In a study from Mohseni & Stefan (1998) the low validation results are explained as measurement errors. Seibert (1999) points out that many studies lack the testing of the model because there is too little data available but especially when the model is used for more than just simulating the discharge it should be tested and validated thoroughly. Otherwise the model is likely to give misleading results. It is therefore important to gain at least satisfactory calibration and validation results.

Deckers et al. (2010) state that the model structure of HBV can also be the perpetrator of poor model results. Deckers et al. also state that even a model criterion of $NS > 0.75$ is very strict. This implies the stakes are made too high in this thesis, especially because the study area is in a developing country. Concluding, taken into account the good performance of the HBV model in other studies, the HBV model could be appropriate for application for the Upper Citarum watershed but it is likely that at this time the data are qualitatively too poor for using it as input for the HBV model.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The Citarum river seemed not to be very suitable for modeling with the HBV model. The catchment area is rather large and is very hilly, which of course are properties that have effect on the modeling of a watershed. The main restraining factor is the available of hydrological data with sufficient quality. The available data consisted of five years of hydrological data. Some data entries were missing.

The calibration results show a Nash Sutcliffe efficiency ranging from 0,55 to 0,65 with the Thiessen averaged rainfall, while the results varies from 0,41 to 0,58 for the normally averaged rainfall. It can be concluded that the Thiessen average leads to a better performance than the normally averaged rainfall. Although the Thiessen method leads to better results as some rainfall stations are very near but get a very unequal weight because one station is on the outside, it might be questioned if this is the best weighting method.

The land use in the Upper Citarum area changes dramatically. In 2005 the built-up and industrial area was 76% according to extrapolation, while this was 60% in 1997. According to the A1 scenario from IPCC, the climate change causes the temperature to increase on average 2 degrees, while the precipitation increases a few millimeters in winter and spring and decreases one millimeter in autumn.

The continued deforestation and the climate change cause the discharges in the Citarum to be more variable. This means that the occurrence of very low and high flows increases and the peak flow is higher compared to the scenario with no land use change and no climate change.

5.2 RECOMMENDATIONS

The scenarios show that policymaking on a global level should be aimed at diminishing climate change. As the climate change is caused by an increased amount of greenhouse gases in the atmosphere, the emission of these gases should be reduced (IPCC, 2007). Especially, the increase of CO₂ in the atmosphere, caused by the burning of fossil fuels, is a result of human activity.

On a more local level the government in West Java, comprising the Citarum catchment area, should protect the remaining forest in the area so the frequency of floodings in the watershed will not be further increased and the number of periods of very low flows is limited. Recent actions with this aim have already been taken. For instance, the West Java council proposed to establish a better cooperation in preventing the forest conversion in the West Java area by means of legislation (Suwarni, 2011). The council also tries to get budget from the province which can be used for creating a more forest friendly community. Despite the efforts, the forest management seems not to be sufficient. A recent estimation states that the West Java area covered with forest is only 18 percent, while the provincial government set its target at 45 percent (Abdullah & Sulistyawati, 2008). This target seems to be unrealistic for the coming decades when the land use trend according to Watung et al. does not make a huge turn. Therefore, improvements have to be achieved in the effectivity of the forest management if the local government wants to decrease the frequency of floodings.

A last recommendation is in place regarding the data. If the West Java government wants to get more insight in the causes of the discharges in the Citarum river, the quality and quantity of data collection and registration in the area should be improved. Besides, the data should be widely available for academical purposes. Only in this way the area will be more often the subject of study. Each academic exercise will lead to more information about the hydrological consequences of land use change and climate change, which is of high importance for the lives of the millions of people who live at the river banks of the Citarum.

REFERENCES

- Abdullah, A.P., Sulistyawati, E. (2008). Analysis of forest patches in three regencies in West Java based on satellite data. Acquired via <http://www.sith.itb.ac.id/profile/databuendah/Publications/Analysis%20of%20Forest%20Patches%20in%20Three%20Regencies%20in%20West%20Java%20Based%20on%20Satellite%20Data.pdf> on June, 18 2011;
- Aksoy, H. (1999). Use of gamma distribution in hydrological analysis. *Turk J Engin Environ Sci*, 24, 419-428;
- Ashagrie, A., de Laat, P., de Wit, M., Tu, M., Uhlenbrook, S. (2006). Detecting the influence of land use changes on discharges and floods in the Meuse River Basin – the predictive power of a ninety-year rainfall-runoff relation? *Hydrol. Earth Syst. Sci.*, 10, 691–701;
- Booij, M. J., Krol, M.S. (2010). Balance between calibration objectives in a conceptual hydrological model. *Hydrology Sciences Journal*, 55, 1017-1032;
- Bruen, M., Yang, J. (2006). Combined Hydraulic and Black Box models for flood forecasting in urban drainage systems. *Journal of Hydrologic Engineering*, 12-2006, 500-508;
- Chen, Y., Xu, Y., Yin, Y. (2009). Impacts of land use change scenarios on storm-runoff generation in Xitiaoqi basin, China. *Quaternary International* 208, 121-128;
- Cempaka (2011). Cover image, acquired via http://2.bp.blogspot.com/_rku6deQBORg/S6tqYafvoI/AAAAAAAAANBc/v31T5zkWsdI/s400/citarum+river+karawang.jpg on May, 15 2011;
- Citarum Integrated Water Resource Management Project (2007). Citarum Fact based on phase 3 final report. Acquired via <http://citarum.org/upload/upload/Citarum%20Fact%20based%20on%20Phase%203%20Final%20Report.pdf> on May, 16 2011;
- Dayaputri, A.T. (2008). Citarum River Floods (figure 2). Acquired via <http://www.arumaum.com/citarum-river-floods/> on May, 17 2011;
- Deckers, D.L.E.H., Booij, M.J., Rientjes, T.H.M., Krol, M.S. (2010). Catchment variability and parameter estimation in multi-objective regionalisation of a rainfall-runoff model. *Water Resour Manage*, 24, 3961-3985;
- Directorate General of Water Resources Development (1989). Report Cisdana – Cimanuk. Cisdane – Cimanuk integrated water resources development (BTA-155);
- Directorate General of Water Resources Development (2001). Resettlement plans. Acquired via http://www.adb.org/Documents/Resettlement_Plans/INO/37049/37049-06-INO-RP.pdf on May, 16 2011;
- Fares, Y.R. (2003). Water resources management in tropical river catchments. *Journal of Environmental Hydrology*, 2, 1-11;
- Ferket, B.V.A., Samain, B., Pauwels, V.R.N. (2010). Internal validation of conceptual rainfall-runoff models using baseflow separation. *Journal of Hydrology*, 381, 158-173;
- Hanson, L.S., Vogel, R. (2008). The probability distribution of daily rainfall in the United States. Acquired via <http://engineering.tufts.edu/cee/people/vogel/.../DailyRainfall.pdf> on May, 15 2011;
- Hargreaves & Samani (1982). Hargreaves equation. Acquired via http://www.civil.uwaterloo.ca/watflood/Manual/02_03_2.htm on April, 12 2011;
- Hlavcová, K., Szolgay, J., Kohnová, S., Horvát, O. (2009). The limitations of assessing impacts of land use change on runoff with a distributed hydrological model: case study of the Hron river. *Biologia*, 64/3, 589-593;
- Hundecha, Y., Bárdossy, A., (2004). Modeling of the effect of land use changes on the runoff generation of a river basin through parameter regionalization of a watershed model. *Journal of Hydrology*, 292, 281–295;
- IPCC (2007). IPCC Fourth Assessment Report: Climate change 2007. Acquired via http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch10s10-3.html#10-3-1 on May, 24 2011;
- Klemeš, V. (1986). Operational testing of hydrological simulation models. *Hydrological Sciences Journal*, 31, 1;
- Legesse, D., Vallet-Coulomb, C., Gasse, F. (2003). Hydrological response of a catchment to climate and land use changes in Tropical Africa: case study South Central Ethiopia. Amsterdam: Elsevier;
- Lidén, R., Harlin, J. (2000). Analysis of conceptual rainfall-runoff modelling performance in different climates. *Journal of Hydrology*, 238, 231-247;

- Lindström, G., Johanson, B., Persson, M., Gardelin, M., Bergström, S. (1997). Development and test of the distributed HBV-96 hydrological model. *Journal of Hydrology*, 201, 272-288;
- Machbub, B. et al. (2003). Indonesia: Indonesia 7: Cimanuk. Acquired via <http://www.bom.gov.au/water/about/waterResearch/document/cimanuk.pdf> on April 25, 2011;
- Maeda, E., Wiberg, D., Pellikka, P. (2011). Estimating reference evapotranspiration using remote sensing and empirical models in a region with limited ground data availability in Kenya. *Applied Geography*, 31, 251-258. Amsterdam: Elsevier;
- Marula, A. (2010). Floods inundate three subdistricts in Gresik, E Java. *Antara News*. Acquired via <http://www.antaraneews.com/en/news/1289042634/floods-inundate-three-sub-districts-in-gresik-e-java> on May, 9 2011;
- Merz, R., Blöschl, G. (2004). Regionalisation of catchment model parameters. *Journal of Hydrology*, 287, 95-123;
- Mohseni, O., Stefan, H.G. (1998). A monthly streamflow model. *Water resources research*, 34, 1287-1298;
- National Oceanic and Atmospheric Administration (2009). NNDC: Climate data online. Acquired via <http://www7.ncdc.noaa.gov/CDO/> on May, 11 2011;
- Nik, A.R. (1988). Water yield changes after forest conversion to agricultural land use in Peninsular Malaysia. *Journal of Tropical Forest Science*, 1, 67-84;
- Pus, W. (2010). Antara News: waiting for speedy realization of Citarum river normalization project. Acquired via <http://www.antaraneews.com/en/news/1266708966/waiting-for-speedy-realization-of-citarum-river-normalization-project> on May, 15 2011;
- O'Connor, Jim, E., Costa, J. (2004). The world's largest floods, past and present: their causes and magnitudes. United States Geological Survey. Virginia: Department of the Interior;
- Perrin, C., Oudin, L., Andreassian, V., Rojas-Serna, C., Michel, C., Mathevet, T. (2007). Impact of limited streamflow data on the efficiency and the parameters of rainfall-runoff models. *Hydrological Sciences Journal*, 52, 131-151;
- Prékopa, A., Szántai, T. (1978). A new multivariate gamma distribution and its fitting to empirical streamflow data. *Water Resource Research*, 14(1), 19-24;
- Rossmann, L. (2011). Storm Water Management Model (SWMM). Acquired via <http://www.epa.gov/ednrmr/models/swmm/> on March 26, 2011;
- Saghafian, B., Hassan F., Bozorgy, B., Yazdandoost, F. (2008). Flood intensification due to changes in land use. *Water Resource Management*, 22, 1051-1067;
- Seibert, J., McDonnell, J.J., (2010). Land-cover impacts on streamflow: a change-detection modelling approach that incorporates parameter uncertainty. *Hydrological Sciences Journal*, 55/3, 316-332;
- Seibert, J. (1997). Estimation of parameter uncertainty in the HBV model. *Nordic Hydrology*, 28, 247-262;
- Seibert, J. (1999). Conceptual runoff models – fiction or representation of reality. *Comprehensive summaries of Uppsala dissertations from the faculty of science and technology*, 436, 52;
- Setiawan, H. (2009). The need to reforest Citarum. Acquired via <http://sundanese.com/2009/11/10/the-need-to-reforest-citarum/> on May, 16 2011;
- Slingo, J. (2010). Climate Averages (Met Office). Acquired via <http://www.metoffice.gov.uk/climate/uk/averages/> on June, 1 2011;
- Suwarni, Y. (2009). Flash flood hits Bandung, killing one. *The Jakarta Post*. Acquired via <http://www.thejakartapost.com/news/2009/03/27/flash-flood-hits-bandung-killing-one.html> on March 6, 2011;
- Suwarni, Y. (2011). W. Java legislature proposes bylaw on forest management. Acquired via <http://www.thejakartapost.com/news/2011/06/03/w-java-legislature-proposes-bylaw-forest-management.html> on June, 18 2011;
- Takeuchi, K., Jayawardena, A.W., Takahashi, W. (1995). Catalogue for rivers in South East Asia and the Pacific – Volume 1. Acquired via http://flood.dpri.kyoto-u.ac.jp/ihp_rsc/riverCatalogue/Vol_01/ on May, 17 2011;
- Viney, R. N. et al. (2009). Assessing the impact of land use change on hydrology by ensemble modelling. *Advances in Water Resources*, 32, 147-158;
- Wutung, R.L., Tala'ohu, S.H., Dariah, A. (2005). Land use change and flood mitigation in Citarum and Kaligarang watersheds. Acquired via <http://balittanah.litbang.deptan.go.id/dokumentasi/prosiding/mflp2005/wutung.pdf> on May, 18 2011;
- Xinhua, 2010. Indonesian floods inundated parts of Jakarta, East, West-Java. Acquired via <http://world.globaltimes.cn/asia-pacific/2010-02/506156.html> on April, 26 2011;