Effects of land use change and climate change on irrigation water availability in the Mea Pheam catchment, Thailand

An aerial view of a section of the Mea Pheam catchment.

Master's Thesis

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Abstract

The Mea Pheam River in the northern part of Thailand is the main supply of irrigation water for the hill tribes that live within its catchment. The catchment lies in the Huay Nam Dang National Park which is a matrix of highly diverse habitat types. However, the natural system within the catchment is under pressure and the availability of irrigation water for the inhabitants and their crops is decreasing, which could be an effect of land use change (LUC) and climate change (CC). The aim of this study is to provide a better understanding of the processes of LUC, CC, and their effect on the irrigation water availability in the Mea Pheam Catchment (MPC), with a focus on the effects of expected LUC and CC in the future. Following the aim, this master's thesis provides a scenario-based quantitative model analysis of the irrigation water availability in the MPC. The main research question is:

What is the current availability of irrigation water in the Mea Pheam catchment and will land use change and climate change affect this in the future?

The possible changes were translated into four scenarios: (1) LUC in 2030 and 2060, (2) CC in 2030, (3) CC in 2060, and (4) a combination of LUC and CC in 2060. Scenario 1, 2 and 3 each have two sub-scenarios to represent LUC in 2030 and 2060, and the Intergovernmental Panel on Climate Change (IPCC) scenarios A2 and B1. The A2 CC scenario is seen as an extreme scenario and B1 as an intermediate. A model was developed to estimate the irrigation water availability of the four scenarios. The model results were assessed in respect to the annual present irrigation water availability. Calibrating the model was not possible due to the lack of long term discharge data. Validation of the model by comparing discharge measurements, which were conducted during field research, with simulated discharges during the same time period (2 months of the dry season) of the present showed that the model might underestimate the discharges. The sensitivity analysis showed that the model is most sensitive for the precipitation input, while the precipitation data that was used had some significant deficiencies. This could explain the underestimation of the irrigation water availability. Nevertheless the model was able to give estimations of the irrigation water availability of the 4 scenarios. The effects of LUC and CC on the future irrigation water availability came forward by assessing the scenarios hydrographs and flow duration curves (FDC) in respect to the present.

In conclusion, the annual irrigation water availability of the present is roughly $2.2*10^7$ m^3. Land use changes are expected to lead to a decrease of irrigation water availability -only- in 2060 of 3.7%. Climate change is expected to lead to a decrease of availability in 2030 and 2060 of 1.2% and 8.3%, respectively. Both changes combined (scenario 4) decrease the availability in 2060 with 14.6% in respect to the present. The FDCs of all 4 scenarios showed that the discharges with a high exceedance probability (90%) decrease relatively the most during the dry season, with percentages varying between 30% and 70%. This further stresses the irrigation water availability during dry periods. Comparing the effects of LUC and CC, the latter negatively affect the irrigation water availability relatively the most. But only if the climate changes according to IPCC scenario A2, which is seen as an extreme CC scenario.

Although the inhabitants of the catchment have applied adaptive forms of agriculture in the past. The simulated decreasing availability of irrigation water shows that the catchment´ ability to provide irrigation water will decline in the future, especially during the dry seasons, which forms a very serious threat for its inhabitants knowing that their livelihoods depend on the availability of irrigation water and agricultural adaptations has its limits.

Contents

List of abbreviations

CAP:	Catchment Action Plan
CN:	Curve Number
CC:	Climate change
ET :	Evaporation
FDC:	Flow-Duration Curve
GLCC:	Global Land Cover Characteristics
IGBP:	International Geosphere and Biosphere Program
IPCC:	Intergovernmental Panel on climate change
LUC:	Land use change
M:	Meters
MB:	Millibar
Mha:	Million hectares
MODIS:	Moderate Resolution Imaging Spectroradiometer
NGO:	Non government organization
NOAA:	National Oceanic and Atmospheric Administration
MPC:	Mea Pheam Catchment
PET:	Potential evaporation
R^2:	Pearson's coefficient of determination

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1 Introduction

1.1 Irrigation water availability in the world

For agricultural production the use of water is a key and essential driver. In the very beginning of the cultivation process, over 10,000 years ago, irrigation water enabled farmers to improve their crop yields by becoming less dependent on precipitation patterns, thus increases the production of crops and meanwhile decreases the inter-annual variability. In the past decades the irrigated area has expanded to over 270 Mha over the world, which is about 18% of total cultivated land. Agriculture is the largest user of water among human activities (Günther Fischer, 2007).

Concerns are growing about agricultural water requirements in the future ***vis-à-vis*** water availability under the combined effects of CC, growing population demands, changes in land use, and competition from other economic sectors under future development. Water resources are being progressively more recognized as fundamental to the sustainability of human societies in coming decades. The fact that an increasing numbers of people live and will live in water-scarce conditions makes it even more important to realize (Millennium Ecosystem Assessment, 2005; Watson, et al., 2000; Stockholm Environment Institute, 1997).

Throughout the world CC and LUC and the associated changing availability of irrigation water resources cause environmental, economic and social impacts. Research shows that while crops would react optimistically to elevated CO2 in the absence of CC (Kimball et al., 2002; Jablonski et al., 2002; Ainsworth & Long, 2005), the associated impacts of high temperatures, altered patterns of rainfall and possibly increased frequency of extreme events, will probably coalesce to influence the availability of irrigation water and depress yields and increase production risks in many world regions (IPCC, 2001a; IPCC, 2001b; Dingman, 2002). A global consensus has emerged that the developing countries in the world are more vulnerable to CC than developed countries. This is because of the (1) predominance of agriculture in their economies, (2) the scarcity of capital for adaptation measures, (3) the warmer climates and, (4) rapidly expanding populations (Jakeman & Letcher, 2003; Parry, 2001).

The rate, range and spatial reach of human alterations of the Earth's land surface are unparalleled. Changes in land use (human purpose or intent applied to these attributes) are among the most important alterations (see Fig 1) (Turner et al., 1990; Lambin et al., 1999). The changes in land use are so pervasive that, when aggregated on a global scale, they considerably affect key aspects of Earth System operation. By altering Earth System operations services, they affect the capability of biological systems to sustain the needs of humans and their irrigation water demand (Vitousek et al., 1997).

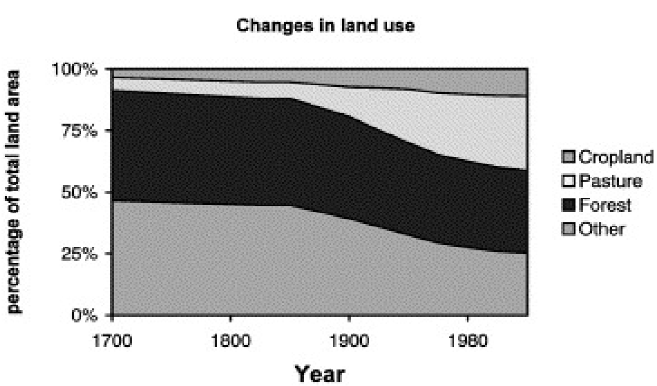

Figure 1: Estimated changes in land use from 1700 to 1995 (Goldewijk & Battjes, 1997).

LUC often causes that rainfall infiltration opportunities are reduced to such an extent that groundwater reserves are insufficiently recharged during the rainy season, which causes strong declines in dry season irrigation water availability (Bruijnzeel, 2004).

A sign of water shortages, caused by LUC and CC, is that many major rivers now run dry during the whole, or parts of the dry season, when irrigation water is most needed. The Ganges in South Asia, the Amu Dar'ya and Syr Dar'ya in Central Asia, the Nile in Africa, and the Colorado in the American Southwest are all affected by this (Postel S. , 1996). Another example is China's Yellow River, which has run dry in its lower reaches every year this decade. The dry section of this river often stretches over 600 km, from Henan Province to the river's mouth. In 1997, the river ran dry for 226 days, up from 133 days in 1996 and 122 days in 1995. China's main river and the cradle of the Chinese civilization, the Yellow supplies water to 140 million people and 7.4 Mha of irrigated cropland (Postel S. , 1999). With many river systems being over-exploited to meet current irrigation water demands, stresses on water systems will worsen considerably as population increases (Postel. , 2000).

1.2 Irrigation water availability in the Mea Pheam watershed, Thailand

In the last three decades, LUC also occurred in the hills of northern Thailand[1]. In these areas this has been driven by an increase of population, immigration, the protection of the state controlled remaining forest areas, and limitation to use old fallows. In the past three decades a shifting cultivation system, characterized by at least 7 year long fallow periods, was replaced by shorter fallow periods (1 – 4 years) or in some cases even permanent agriculture, which currently occupies more than half of the land with an agricultural function. As a result of this the highly populated mountainous areas became dominated by rain fed fields, wetland terraces, secondary fallow vegetation, and patches of (unnatural) forest (Turkelboom et al., 2008). This agricultural caused competition for water at different scales and may result in further problems considering irrigation water availability in the future. The nature of rainfall in this area, which has a monsoonal character, also intensifies demand for irrigation water, especially, in the dry season. (Jakeman & Letcher, 2003). The effects of CC occur as well, which further stresses the availability (Walker, 2010; Dingman, 2002).

In the northern part of Thailand lies the Chiang Dao National Park National Park which covers an area of 1.300 square kilometers and extends from the northwest of Chiang Mai until the Burmese border. Within this park flows the Mea Pheam river (see Fig 2c), which is a tributary of the Mae Taeng River and originates in the hill slopes of the western part of the National Park.

Within the MPC[2] the same processes of LUC and CC and the effects from this are eminent. The original inhabitants, which are the largest “upland” ethnic group of northern Thailand are known as the Karen. The members of this tribe are known as conservationist and cooperative. Genuine Karen livelihood is based on a livelihood production system which fundaments are: a rich body of local environmental wisdom, a robust

[1] Thailand is located in The Southeast part of Asia between latitudes 5° 37’ N and 20° 27’ N and longitudes 97° 22’ E and 105° 37’E It covers an area of approximately 518000 km2. To the west it is bounded by Myanmar, by Laos and Myanmar to the north, to the east by Laos and Kampuchea, and in the south by Malaysia.

[2] The study area, the Mea Pheam catchment (approximately 24 km2), is located northwest of Chiang Mai in Thailand, is a mountainous landscape with elevations ranging from 750 m above sea level in the south-west area to 1,850 in the north-east. The Mea Pheam River originates in the hill slopes of the western part of the Chiang Dao National Park and is a tributary of the Mae Taeng River (Harten, 2014). It is the main supply regarding drinking and irrigation water for several hill tribes that lie adjacent to the river (Zijderhand, 2013). The site has a monsoonal climate, with a rainy season beginning in May and lasting until November. Almost no rain falls during the cold season in December and January, or in the hot season beginning in mid-February and lasting until the rains start in May or June. Average rainfall is approximately 3,000 mm/year. Temperatures vary between 5° C and 34° C, with higher elevations several degrees cooler than lower elevations (Fox et al., 1994).

communal orientation and non-commercial ideas. There is a broadly held view in NGO and academic circles that the Karen represents a fragile ideal of mutually beneficial interaction between culture and nature. (Walker, 2010).

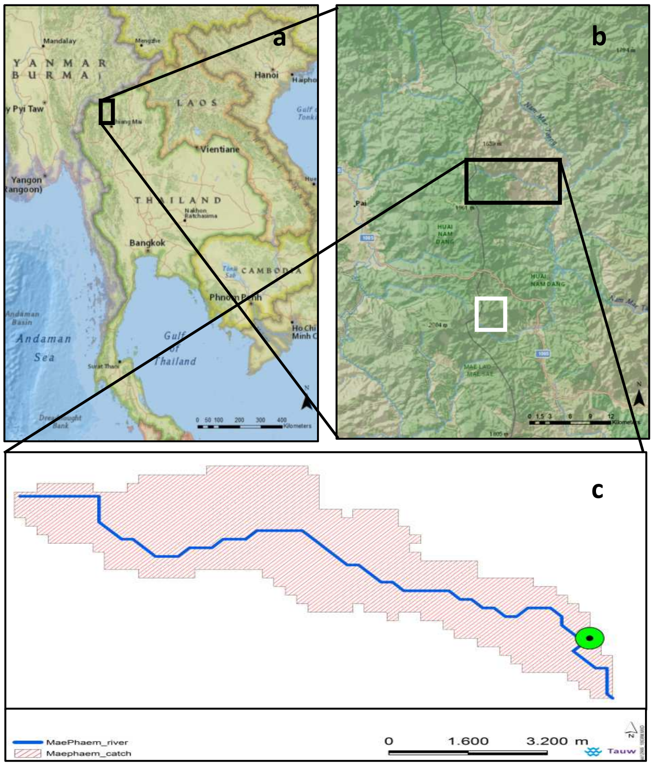

Figure 2a-b: a) Overview of Asia. b) The north-western part of Thailand. c) The Mea Phaem river and its catchment. Green dot represents the village of Ban Mea Pheam. The white box represents in Fig 2b the study area of Fox et al. from 1994. The role of this study in this thesis will be elaborated on in chapter 3.

However, throughout the past decades the population, due to immigration of other ethnic groups, has grown in the MPC, the available space has declined and state regulation increased as well. Therefore many communities are now following a path of adaptive agricultural intensification. This adaptive approach has caused a higher demand for irrigation water compared to the past, which causes shortages (Ekkawatpanita et al., 2009). Besides this, increasing temperatures and changes in precipitation amounts are expected in the future. Both changes can possibly cause changes in the amount and distribution of irrigation water (Dingman, 2002). Kwadijk and Middelkoop in 1994 showed that, in the case of the Rhine River, an increase of 4°C and 20% less precipitation can lead to a runoff discharge decrease of minimal 50%.

Based on these studies it comes forward that LUC and CC could affect the availability of irrigation water. Further research, focused on the MPC, may give insights in this process.

1.3 Problem description

In the mountainous areas of northern Thailand and in the MPC irrigation water availability is decreasing, especially during the dry season (Walker, 2010; Jakeman & Letcher, 2003). The ruling views are that mainly LUC and CC are causing the decrease. It is expected that within a time span of roughly 50 years (2060) these changes will significantly affect the availability in respect to the present (Van Beek, 2013). At this moment it is unknown how these changes, during (near future) and at the end (far future) of this time span, affect the irrigation water availability in respect to the present situation.

1.4 Stichting Buffelen

During the past five years an organization of volunteers called Stichting Buffelen (www.buffelen.org) has travelled towards Thailand to give aid to the inhabitants of the MPC. During these visits the focus lay on improving the living conditions, and help raising (water) buffalos. But this has always been from a short term perspective, such as in handing out clothes and books. Since 2013 the organization decided to address their aid in the MPC in the form of a long term project. This was kick-started by two Dutch engineers; ir. Floris Boogaard and ir. Marius Palsma in January 2013.

The organization describes this long term project in a so called “Catchment Action Plan” (CAP; Appendix 1). One of the goals of the CAP is to gain insight in the effects of LUC and CC on irrigation water availability in the MPC and to estimate the availability in the future. The results from this study will be used as a first insight in the possible effects of LUC and CC in the future.

1.5 Research aim and questions

At this moment knowledge regarding LUC, CC, and how they affect irrigation water availability in the Mea Pheam catchment is lacking (Zijderhand, 2013). The aim of this study is to gain insight in these processes and their development in the future, hence their effect on future irrigation water availability.

The main research question of this thesis is:

What is the current availability of irrigation water in the Mea Pheam catchment and will land use change and climate change affect this in the future?

To answer of this research question two different sub-questions are formulated, which are divided into two categories (present and future):

Present:

1. What is the irrigation water availability of the present?

Future:

2. How will land use change and climate change affect the irrigation water availability in 2030 and 2060, when land use continues to change as it did in the past and climate change according to the IPCC scenarios?

2 Theory

In this chapter the focus lies on identifying the main factors that influence the irrigation water availability in the MPC. This has a direct link with the method (chapter 3) in which is explained how the theory is transcribed into formulas to develop the model.

2.1 Generation of irrigation water

We consider irrigation water, represented in Fig 3a as Q, as water that is generated via surface runoff[3] or sub surface flow (ground water) and is transported into a stream or river, thus generates a certain discharge, and is available for irrigation purposes. In order to gain insight in the irrigation water availability within the catchment, understanding the hydrologic cycle is essential knowledge. Within this cycle , the availability depends mainly on three components of the hydrological cycle: (1) P (precipitation), (2) T (temperature), and (3) the land uses of within a certain area (Dingman, 2002).

A brief visualization of the cycle is given in Figure 3a. The fraction of P (R_n), which generates surface runoff or sub surface flow is determined by the effects of interception, evaporation, and infiltration, see Fig 3b.

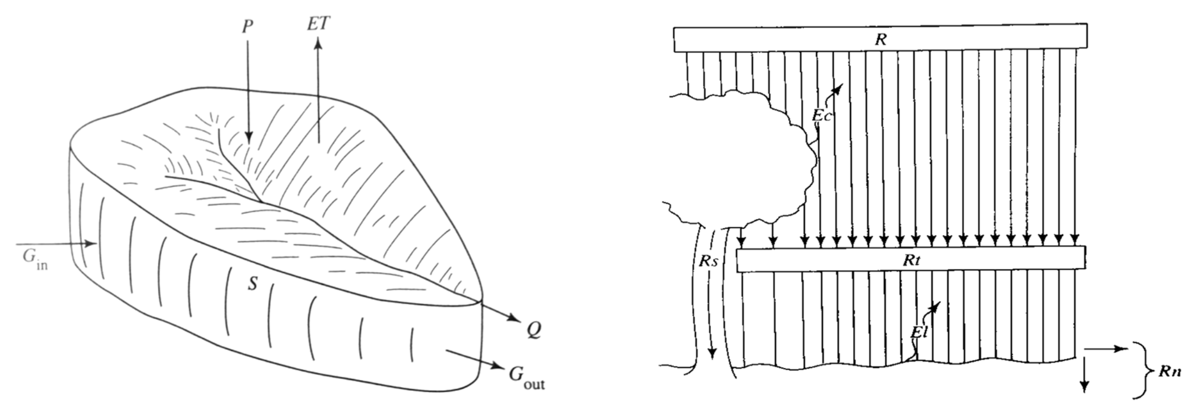

Figure 3a-b: a: Schematic diagram of a watershed, showing the components of the regional water balance: P = precipitation, ET = Evapotranspiration, Q = stream outflow, G_{in} = ground-water inflow, G_{out} = ground-water outflow. b: Definition of terms used in describing the interception process. R = gross rainfall, E_c = canopy interception loss, R_t = net precipitation, R_s = stem flow, E_l = litter interception loss, R_n = net rainfall. E_c and E_l together are considered as the phenomena evapotranspiration (Dingman, 2002).

2.1.1 Influence of land use

In the process of precipitation to surface runoff or subsurface flow (R_n and G), there are stages that precipitation has to go through. The stages cause losses from the initial amount of precipitation, reducing the available amount that shall generate irrigation water. With changing land uses, man can substantially influence certain aspects of these stages. This can cause differences in the amount of generated irrigation water and therefore the availability of it.

[3] Surface runoff can be defined in the following way: the amount of precipitation that is not lost due to interception, infiltration, evapotranspiration or surface storage and flows over land towards a stream channel.

2.1.1.1 Influence of vegetation

On top of the soil, in a natural situation, vegetation serves as a protective layer. Changes in land use causes the removal of vegetation, which causes alteration of interception, infiltration, and evaporation and thus the quantity of surface runoff or sub surface flow, which is responsible for the generation of irrigation water (Morgan, 1995). Interception takes place when, during a rainstorm event precipitation is intercepted by vegetation canopy. If not intercepted by a canopy, it falls onto the soil as net precipitation (White, 1997). On a canopy, rainfall can either evaporate or when canopy storage capacity is exceeded fall to the ground as leaf drainage or stem flow (Morgan, 1995; Rientjes, 2004). The rainfall that eventually evaporates in vegetation canopy is referred to as interception loss (White, 1997). The amount of the loss depends on the characteristics of the vegetation, thus the land use, and on the rainfall event (Dingman, 2002).

2.1.1.2 Influence of soil properties

When a rain drop hits the soil, as net precipitation, and enters the soil at a certain rate during a rainstorm event or after. This is seen as the infiltration rate (Schwab et al., 1997). Changes in land use cause a disruption of the natural composition of a soil. It goes without saying that this plays an important role in determining the irrigation water availability (Morgan, 1995). It is drawn into the soil by a suction gradient of the pores and gravitational forces. In a situation when the soil is dry the suction of the pores is the largest pulling force. When the soil becomes saturated with water the suction force decreases and the gravitational head gradient is the main force pulling the water into the soil. When the amount of precipitation is larger than the infiltration capacity of the soil surface runoff along the gravitational gradient occurs. (Hillel, 1980; White, 1997).

Surface runoff then may cause fine particles, by example fine sand, to clog pore spaces provided by soil aggregates which results in a thin compact (top) layer. This process is known as surface crusting which prevents water from infiltrating into the soil (Hillel, 1980; Schwab et al., 1981; White, 1997). This process has a large effect on the infiltration capacity of the soil and increases the amount of water that is considered as surface runoff. The process is later described in this study as the Hydrologic condition of the soil and land use.

When an increase of surface runoff occurs it increases the amount of soil that is eroded, which causes problems regarding land degradation (Morgan, 1995). As a result of erosion soil compaction occurs which disrupt the natural arrangement of soil particles and their aggregates. Leading to a decline in the hydraulic conductivity which has a direct effect on the infiltration capacity of the soil (Green et al., 2000).

2.1.2 Influence of climate change

In 2007 the IPCC stated in their Special Report on Emissions Scenarios that by 2020 the global average surface temperature will increase by 0.5°C in comparison with the pre-industrial period. Expected is that the average annual temperature in the end of 2100 in most regions of the world is to increase even more compared with that of the 2020s (Junxu Chen, 2014). This possible future situation may lead to an increase in the frequency and intensity of tropical storms, floods and droughts and thus changes in the availability of irrigation water (IPCC, 2001b).

CC Scenarios

The IPCC have developed in their Special Report a set of scenarios: A1, A2, B1, and B2. In this study the scenarios B1 and A2 will be used to assess the effects of CC. The climate in scenario A2 will develop towards an extreme situation and B1 towards an intermediate in respect to the pre-industrial climate (IPCC, 2000). The A2 scenario is chosen to gain insight in the irrigation water availability if a worst case climate change scenario occurs and the B1 scenario to gain insight in the effects of a relatively less extreme climate change scenario.

2.2 Estimating irrigation water availability

To quantify the volume of surface runoff, the sub surface flow and from there the irrigation water availability several approaches are possible. Possible the first thing that would come into mind is to gauge a stream channel and determine its discharges. This will only give insight in the present availability, not in the in the effects of LUC and CC in the future, which is necessary to answer the main research question. Spatial and temporal heterogeneity of the catchment characteristics, demands a model approach which includes these aspects and simulates the availability. (Beven, 2000; Dingman, 2002).

Every model can be seen as a simplification of the actual natural process described by mathematical formulas. At the base of every model lies a mathematical description which simplifies the (natural) aspects that need to be taken into consideration and enables models to make quantitative predictions (Beven, 2000; Rientjes, 2004). Soil characteristics may vary over small distances and are considered as an important factor involved in the process of generating irrigation water but it is impossible to implement every variation in the model. Therefore average values of variables are taken and translated or reclassified into valid model input values. This makes that all models are based on many assumptions (Beven, 2000).

With every model the goal is to represent the natural situation as best as possible. But increasing the complexity of a model by underscoring the physical basis of certain processes does not imply a direct improvement of the model. By making a model more physically based, the more input parameters it needs, which makes it more complicated to acquire them (Deursen, 1995; Pfeffer, 2003). However, this does not directly imply that a simpler empirical model needs to be used. These kinds of models tend to generalize the details of environmental processes which can result in the loss of spatial and temporal information (Beven, 2000; Deursen, 1995). Thus a perfect model that can include all details involved and represent the natural processes does not exist.

The preferred choice of a model should be mainly based on the objective of the study and by additional factors (available time, money, data etc.) (DeRoo et al., 2000). Once a model has been selected irrigation water availability is simulated, taking spatial and climatologically differences through time into account, the predictions can be very helpful. It can possibly identify the sensitivity of irrigation water availability to LUC and CC in the future.

2.3 Time slice

To determine the influences of LUC and CC on the future availability the choice was made to assess this in 2030 and 2060, as stated in the second sub research question. Were 2030 is seen as the near future and 2060 as the far future. This will give insight in the short term effects and long term effects of these changes.

3 Methodology

This chapter explains which method will be applied to answer each (sub) research question, which will lead to answering the main research question. This chapter follows the sequence of the research questions.

The most recent data that is necessary to determine the present availability covers the year 2012. So we consider the “present availability” as the availability over the year 2012. The databases that will be used are presented in paragraph 3.1.2.

3.1 Research question 1: Present irrigation water availability

We consider irrigation water as water that is generated via surface runoff and sub surface flow which is transported into a stream or river and becomes available for irrigation purposes. This leads to Equation 1.

Equation 1

$$Q_a = Q_s + Q_b$$

Were:

Q_a = irrigation water availability

Q_s = surface runoff

Q_b= sub surface flow

Thus to simulate the availability of irrigation water we need to determine the amount of surface runoff and sub surface runoff that occurs in the MPC after a rainfall event.

Taking into account the available amount of time and the aim of this thesis, the use of the Curve Number (CN) model is seen as the best suitable choice to determine the surface runoff. It needs a limited amount of input parameters and its responsiveness to watershed parameters such as LUC and CC has been proven (Ponce & Hawkins, 1996). To determine the sub surface flow, due to the same reasons, the model of Hamon with a linear reservoir model was chosen.

The combination of the three models has led to a conceptual model which is visualized in Fig 4. A short explanation of the processes that the model represents and how these interact is given in the figure as well. The black boxes in Fig 4 represent the processes described by the CN model, the red boxes the model of Hamon, and the blue the linear reservoir model (Lu et al., 2005; USDA, 1986).

In the following paragraphs we will elaborate on the models, their mathematical formulas, and how these lead to the determination of the irrigation water availability. In paragraph 3.1.1 the surface runoff by the CN model is elaborated on. In paragraph 3.1.2 the determination of sub surface flow by the Hamon model with the linear reservoir is elaborated on.

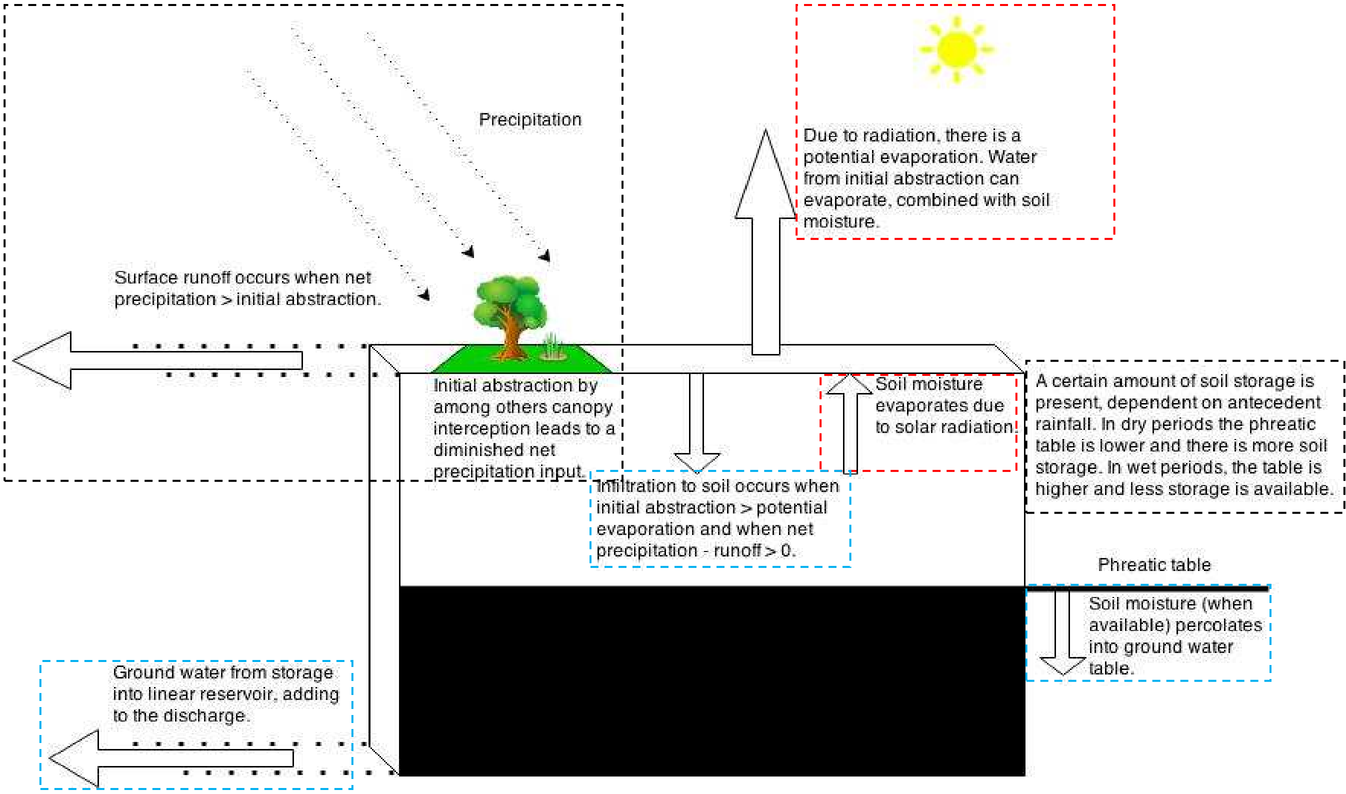

Figure 4: Conceptual model to estimate the irrigation water availability in the MPC. The black dashed boxes represent the processes which are part of the CN model (USDA, 1986). The red boxes represent the processes that are represented by the model of Hamon (Lu et al., 2005). The blue boxes represent the linear reservoir model.

3.1.1 Surface runoff determination

The basis of this is a conceptual model which represents simplified procedures for estimating runoff and peak discharges in small watersheds. Within the model lies the assumption that precipitation is uniformly imposed on the watershed over a specified time distribution, in this case on a daily base. Where the precipitation is converted to surface runoff by using a runoff curve number (CN) (USDA, 1986). The relation between the precipitation and the conversion to surface runoff and how the CN determines this is visualized in Fig 5. The statement that is given in the box in the graph will be elaborated on further in this paragraph.

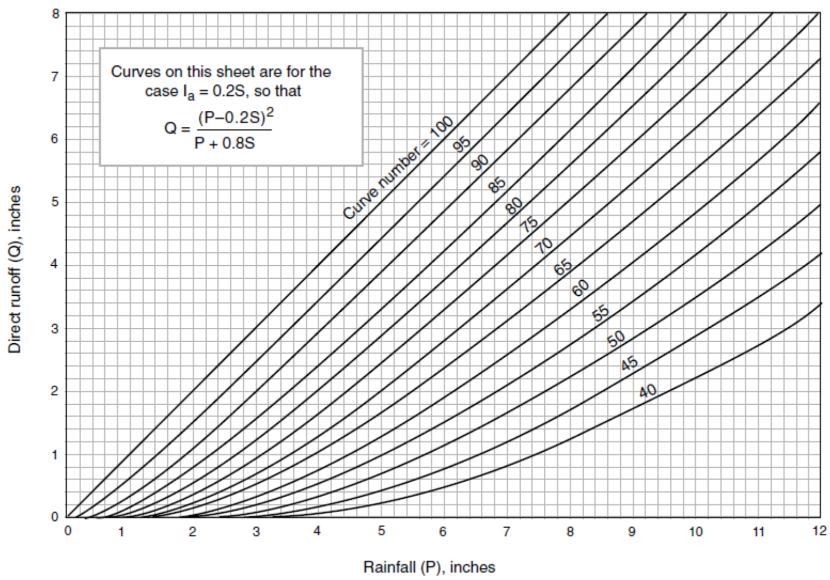

Figure 5: Relationship between precipitation (P) and surface runoff (Q) (USDA, 1986). Note that the unit of the axis are in this case in inches, in the model these are recalculated into mm.

The model is based on two input parameters; (1) the "Curve Number (CN)" and (2) the precipitation. The model does not directly take into account the spatial variability of precipitation. Rather, it aggregates it into a calculation of the total loss (initial abstraction) for a given rainfall event and drainage area by the CN (USDA, 1986).

The input parameter P is relatively self-explanatory but the CN parameter needs clarification. The CN value is a function of (1) land use, (2) hydrologic soil group, (3) land treatment, (4) hydrological condition, and (5) antecedent moisture condition of an area of the catchment. Higher CN value implies higher runoff potential (Harssema, 2005). The method is widely used in the United States of America and other countries (Bosznay, 1989; Hjelmfelt, 1991; Hawkings, 1992; Steenhuis et al., 1995; USDA, 1986). Perceived advantages of the method are (1) its simplicity; (2) its predictability; (3) its stability; (4) its reliance on only one parameter; and (5) its responsiveness to major runoff-producing watershed properties. Perceived disadvantages are (1) its marked sensitivity to CN; (2) the method's varying accuracy for different biomes; (3) the absence of an explicit provision for spatial scale effects; and (4) the fixing of the initial abstraction ratio at 0.2, generalizing a regionally geologic and climatic setting (Ponce & Hawkins, 1996).

The equation of this model is seen in Equation 2 (USDA, 1986). In equation 3, 4, 5, and 6 is shown how this formula arose.

Equation 2

$$Q = \frac{\left(P - 0.2(\frac{1000}{CN} - 10)\right)^2}{\left(P + 0.8(\frac{1000}{CN} - 10)\right)} \quad \frac{[mm/day]^2}{[mm/day]}$$

Where:

Q = Runoff [mm]

CN = Curve Number [-]

The base formula of Equation 2 is shown as Equation 3,

Equation 3

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \frac{[mm/day]^2}{[mm/day]}$$

Where:

Q =	Runoff	[mm]
P =	Precipitation	[mm]
I_a =	Initial abstractions	[mm]
S =	Storage	[mm]

The initial equation is constructed based on trends observed in collected data from field experiments, therefore it is an empirical equation. The initial abstraction represents water that is retained in surface depressions, is intercepted by vegetation, or infiltrates into the soil (USDA, 1986). The initial abstractions can be defined as a percentage of *S* (equation 4). With this assumption, the equation (equation 5) could be written in a more simplified form with only 3 variables. The parameter CN is a transformation of S, and it is used to make interpolating, averaging, and weighting operations more linear (equation 6).

In which P is the precipitation [mm/day].

I_a can further be defined as :

Equation 4

$$I_a = 0.2\,S$$

$P > 0.2\,S$, otherwise infiltration occurs. Substituting equation 2 into 1 gives:

Equation 5

$$Q[in] = \frac{(P - 0.2S)^2}{(P + 0.8S)} \quad \frac{[mm/day]^2}{[mm/day]}$$

In equation 1 and 3 *P* is a measurable quantity and can easily be obtained. On the contrary, *S* is difficult to determine. Therefore the CN is used to determine *S* from the following relationship:

Equation 6

$$S = \frac{1000}{CN} - 10$$

Substituting equation 6 into 5 gives the formulas we mentioned as first, Equation 2. In which CN reflects a curve number. This curve number can be computed using the tabulated CN values for different land-use types within the catchment area, such as agricultural, forest and urban. The final CN is a summation of all the CN values for different land-use multiplied by their fraction of the total area (if multiple land uses occur). In the next paragraph we elaborate on the determination the CN value.

3.1.1.1 Curve Number determination for the Mea Pheam Catchment

To determine the CN values five aspects need to be taken into account:

1. Land use
2. Hydrologic soil group
3. Land treatment
4. Hydrological condition
5. Antecedent moisture condition

Each aspect influences the determination of the CN value. In Fig 6 a part of the table is shown from which the CN values will be retrieved. In the table is seen how the aspects influence the CN. Land use is expressed in the figure as Cover type. According to the description of the aspects, which is elaborated on in the text below, the CN values will be chosen.

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88

Figure 6: The effects of the 5 aspects on the determination of the Runoff Curve Number values.

1. Land use

In order to gain insight in the present land use the MODIS Land Cover Type Yearly L3 Global 500 m SIN Grid database is used. This database provides a collection of land use types by assessing spectral and temporal land cover type information derived from MODIS. It supplies global maps at annual time steps and with a 500-m spatial resolution for 2001 until the 2012. The classification scheme is provided by an IGBP land use classification (Friedl M. , 2014). This recognizes 17 categories (see Table 2) of land uses following the scheme adopted by the IGBP (Belward & Loveland, 1995)

In Fig 7a the MPC is shown, in Fig 7b the outline of the catchment is exported and projected on the World Imagery database from Esri. This step was performed in order to check if the water shed delineation was successful and in order to gain insight in the total area of the catchment. From there the base layer is replaced with a raster from the MODIS database, which is shown in Fig 7c. The final step is to export the land use types within the catchment, the result of this is shown in Fig 7d.

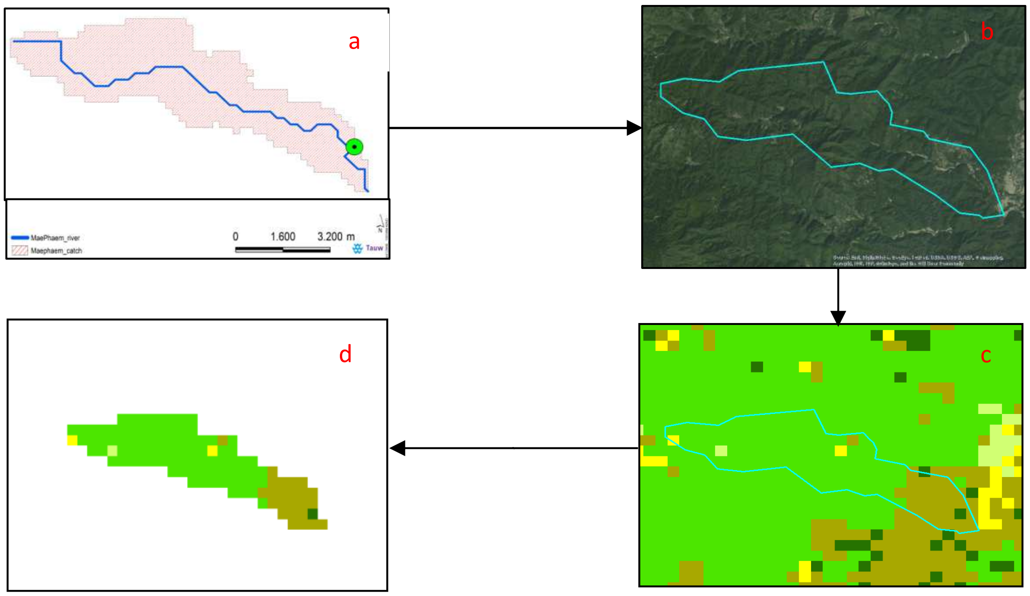

Figure 7: (a) Watershed outline and area delineated with the aid of spatial analyst tool in ArcMap (GIS). (b) Outline of the watershed projected in the World Imagery Database. (c) Outline plotted on the Modis land cover map of 2001. (d) Land cover types exported of the year 2001

In order to calculate the percentual distribution of land use of the present (2012) a reclassification of the Modis classification towards the classifications of the Curve Number method. This reclassification, which is developed during this study, is shown in Table 2 and is based on the description of both classifications of land use types. Both can be found in Appendix 3.

Table 1: overview of the IGBP Land Cover Types (Friedl et al., 2010) and Curve Number Method Classification (USDA, 1986)

IGBP classification used in the Modis Database	Reclassification based on Curve Number Method land cover	Curve number
Type	**Type**	
Water Bodies	Waterbodies	No value
Evergreen Needleleaf Forest	Woods	73
Evergreen Broadleaf Forest		
Deciduous Needleleaf Forest		
Deciduous Broadleaf Forest		
Mixed Forest		
Closed Shrublands	Brush-brush-weed-grass mixture	70
Open Shrublands		
Woody Savannas	Woods-grass combination	76
Savannas	Fallow	90
Grasslands	Pasture	79
Permanent Wetlands	Waterbodies	No value
Croplands	Close-seeded or broadcast legumes or rotation meadow	80
Urban and Built-Up	Farmsteads-buildings, lanes,driveways and surrounding lots	82
Cropland/Natural Vegetation Mosaic	Pasture	79

Permanent Snow and Ice	Waterbodies	No value
Barren or Sparsely Vegetated	Desert shrub	81

2. Hydrologic soil group

The determination of the tabulated CN values depend on hydrologic soil group as well. Higher infiltration capacity leads to a lower CN value, see Fig 6. There are four soil types: A, B, C, and D which are depicted in table 2 based on Dingman from 2002.

Table 2: The four hydrologic soil groups of the CN-method including their description

Hydrologic soil group	Characteristics
A	Low overland flow potential; high minimum infiltration capacity even when thoroughly wetted (>0.76 cm h^{-1}). Deep, well- to excessively drained sands and gravels.
B	Moderate minimum infiltration capacity when thoroughly wetted (0.38 to 0.76 cm h^{-1}). Moderately deep to deep, moderately to well-drained, moderately fine- to moderately coarse grained (e.g. sandy loam).
C	Low minimum infiltration capacity when thoroughly wetted (0.13 to 0.38 cm h^{-1}). Moderately fine- to fine-grained soils or soils with an impeding layer (fragipan).
D	High overland-flow potential; very low minimum infiltration capacity when thoroughly wetted (<0.13 cm h^{-1}). Clay soils with high swelling potential, soils with permanent high water table, soils with a clay layer near the surface, shallow soils over impervious bedrock.

In this study the choice is made that the soil in the MPC can be considered as Soil group C. This was based on the research of the lithology of the soil. The top and sub soil have a composition of mainly clay and loam (FAO, 2009), which have a low infiltration capacity (Dingman, 2002).

3. Land treatment

The treatment is a modifier for the land use type. Only used in the case of cultivated agricultural lands. It takes into account mechanical practices, such as contouring, terracing, and management practices such as crop rotations (USDA, 1986). In the case of the land use Fallow, the Curve Number will be chosen which includes crop residue cover. Regarding Close-seeded or broadcast legumes or rotation meadow the treatment contoured and terraced will be chosen. Both choices are based on the field research and descriptions of this modifier, which are presented in Appendix 3. The influence of this aspect on the CN value can be seen in Fig 6.

4. Hydrologic condition

The Hydrologic condition indicates the effect of a land use on runoff and is estimated from density of vegetation and residue cover on sample areas. Good hydrologic condition indicates a low runoff potential for that specific hydrologic soil group, land use, and treatment. Factors to consider regarding estimating the condition are (a) density of vegetation; (b) amount of year-round cover; (c) amount of vegetation in rotations; (d) percent of residue cover; and (e) surface roughness (USDA, 1986). In the case of cultivated agricultural lands the condition is considered to be poor, this choice was based on field research, and the conditions of other land uses to be fair in order to choose a mediate value. The changes of CN as a result of these choices can be found in Appendix 3 and in Fig 6.

5. Antecedent moisture condition

When taking the antecedent moisture condition (AMC) into account three types of CN, namely CN(I) CN(II) and CN(III), can be calculated. The tabulated values are always CN(II) values, which averages that the soil has an average moisture condition. To assess whether a soil is in the AMC(I) = dry, AMC(II) = average, or AMC(III) = wet stage, a summation of the 5-day antecedent rainfall has to be made and the following numbers from Fig 8 can be used (WUR, sine anno). When the AMC is 1 or 3 a recalculation of the CN(II) will be done according to equation 7 and 8. Due to the high amounts of precipitation that can occur in the MPC the AMC will be determined according to the "Growing season" values (Fox et al., 1994). The AMC is calculated within the model and when necessary adjust the CN.

Antecedent Moisture Condition Class	5-day antecedent rainfall (mm)		
	Dormant season	Growing season	Average
1	2	3	4
I	< 13	< 36	< 23
II	13 – 28	36 – 53	23 – 40
III	> 28	> 53	> 40

Figure 8: Determination of antecedent moisture condition class (Tarboton, 2003).

CN(I) can be calculated by use of equation 20:

Equation 7

$$CN(I) = \frac{4.2CN(II)}{10 - 0.058CN(II)}$$

and CN(III) can be calculated using equation 21 (van Beek R. , 2011):

Equation 8

$$CN(III)\frac{23CN(II)}{10 + 0.13CN(II)}$$

3.1.2 Sub surface flow determination

The main equation that is used is shown in equation 9. The sub surface flow is in the formula expressed as base flow Q_b, which is mostly but not always groundwater flow independent of a storm event. This is seen as the linear reservoir component of the model.

Equation 9

$$Q_b = f * Q_{b-1} + (1 - f) * P_{c-1}$$

Where:

Q_{b-1} =	sub surface flow from the previous day	[L^3 T^{-1}]
f =	reservoir constant	[-]
P_{c-1} =	percolation to groundwater table of the previous day	[mm d^{-1}]

The reservoir constant, is basically an indicator of how fast stored groundwater is released. This constant can be determined by studying the natural logarithm of the river discharge[4] and determine where a descending discharge becomes linear, which can then be calculated using equation 10 and 11. Q2 is at the right lower point of the linear discharge line and Q1 the left upper point of the linear line and the number of days the difference between the days at Q2 and Q1.

Equation 10

$$f = \frac{k - 0.5}{k + 0.5}$$

Equation 11

$$k = \frac{Number\ of\ days}{LN\ (Q2 - Q1)}$$

P_c can be calculated by equation 12.

Equation 12

$$P_c = p * S_{m-1}$$

Where:

S_{m-1} =	Soil moisture content from the previous day	[mm]
p=	percolation rate, assumed to be four days in this case	[d^{-1}]

S_m can be determined with equation 13.

Equation 13

$$S_m = S_{m-1} + I - ET - P_{c}.$$

Where:

S_m =	Soil moisture content	[mm d^{-1}]
P_c=	Percolation to groundwater table	[mm d^{-1}]
ET=	Evaporation	[mm d^{-1}]
I =	Infiltration	[mm d^{-1}]

Infiltration only occurs when initial abstraction is larger than potential evaporation and when net precipitation – surface runoff is larger than 0. If PET is substracted from I_a (initial abstraction), and the calculated difference between net precipitation $(P - I_a)$ and runoff Q is added, the infiltration I [mm d-1] is acquired. Soil moisture can also evaporate as is expressed in Equation 13 as well. ET can be calculated with equation 14.

[4] It was impossible to determine that K of the Mae River because no discharge data was available. Therefore it was determined by analyzing the discharges of the Mae Teang River.

Equation 14

$$ET = (I_a - PET) * \sqrt{(\frac{S_{m-1}}{S_{max}})}$$

Where:

ET =	Evaporation	[mm d^{-1}]
S_{m-1} =	Soil moisture content of the previous day	[mm d^{-1}]
S_{max} =	Maximum assumed storage of the soil, in this case assumed to be 75% of S1	[mm d^{-1}]
PET =	Potential Evaporation	[mm d^{-1}]

It has to be noted that $I_a \geq PET$, because evaporation rates cannot be negative. *PET* can be calculated by equation 15, which represents the model of Hamon (Lu et al., 2005)

Equation 15

$$PET = k * 0.165 * 216.7 * N * \left(\frac{e_s}{T + 273.3}\right)$$

Where:

PET=	Potential Evaporation	[mm d^{-1}]
k =	Proportionality constant 1[1]	[unitless]
N =	Daytime length	[x/12 hours]
e_s=	Saturation vapor pressure	[mb]
T =	Temperature	[°C]

Where:

Equation 16

$$N = \left(\frac{24}{\pi}\right) * \omega$$

Where:

ω =	The sunset hour angle	[radians]

Equation 17

$$E_s = 6.108e^{\frac{17.27T}{T+237.3}}$$

Equation 18

$$\omega = cos^{-1}(-\tan(\delta)\tan(\varphi))$$

Where:

φ =	Latitude	[radians]
δ =	Declination	[radians]

Equation 19

$$\delta = \frac{180}{\pi} * [0.006918 - 0.399912 * \cos(d) + 0.070257 * \sin(d) - 0.006758 * \cos(2d) + 0.000907 * \sin(2d) - 0.002697 * \cos(3d) + 0.00148 * \sin(3d)$$

Equation 20

$$\mathrm{d} = 1 + 0.033 * \cos(\frac{2\pi}{365} * j)$$

Where:

J =	Julian day of the year	[-]

The Hamon model works with monthly temperature input. In order to avoid large differences in evaporations between months. The average temperature of say April is higher than March, so on 01-04 there would be a sudden increase of PET compared to 31-03, which is not realistic. This was done by averages of equation 21, taking into account that daily temperature fluctuations in a year follow a sinus pattern (van de Moortel, 2007):

Equation 21

$$T = T_g + a * \sin(b(t - t_0))$$

Where:

T =	Daily temperature	[°C]
T_g=	Average year temperature, $T_g = \frac{T_{\min} + T_{max}}{2}$	[°C]
a =	Amplitude, given by $a = \frac{T_{\min} - T_{max}}{2}$	[-]
b =	$\frac{2}{\pi}$/365.25	[-]
t_o =	Ascending bending point	[d]
t =	Numerical day of year	[d]

If we then apply the earlier mentioned formula of $Q_a = Q_s + Q_b$ the irrigation water availability in millimeters per day will be modeled. This will be recalculated into meters and multiplied with the surface area of the catchment, which leads to the average daily irrigation water availability in m^3/s. The whole model will be applied in Excel.

3.1.3 Precipitation and temperature determination

The inputs that were used for the models a retrieved from the NOAA database. The database consists weather stations with climate data from the past until 2012. The five core elements of the climate data are (Menne et al., 2012) :

- $PRCP$ = Precipitation [tenths of mm]
- $SNOW$ = Snowfall [mm]
- $SNWD$ = Snow depth [mm]
- T_{max} = Maximum temperature [tenths of °C]
- T_{min}= Minimum temperature [tenths of °C]

The closest weather station with an available dataset from the NOAA database is the Mae Hong Son weather station. This station is located 75 kilometers south-west from the MPC. This dataset was chosen because of its time resolution and quality of the data. It was retrieved from the online database (NOAA, 2014). In this case the core elements that were used are, T_{max} , and T_{min} , which determines T_{mean}[5]. Snow does not occur in the catchment

3.2 Research question 2: Future Irrigation water availability

The Curve Number model will also be used to determine the future irrigation water availability affected by LUC and CC. The first inputs for the model are the expected land uses in 2030 and 2060, which is based on the trend of the past which is extrapolated towards 2030 and 2060. This trend is calculated with the aid of the data from the MODIS database and the database of Fox et al. from 1994. The second input is the climate data from the NOAA database for the future, which will be altered with the IPCC scenarios in order to model the effects of CC in 2030 and 2060.

3.2.1 Land use change

In order to predict the land uses in the future, the trend in LUC from the past will be extrapolated into the future.

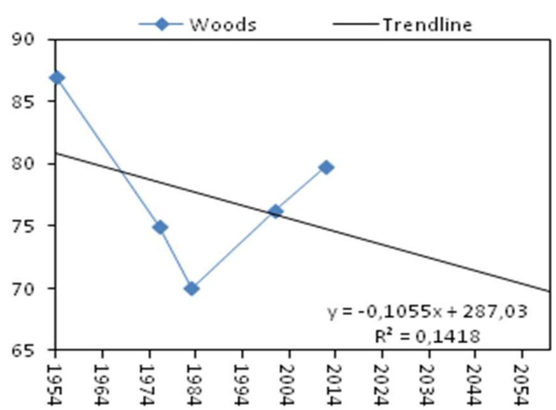

Figure 9: Overview of the average temperature per day and the measured amount of precipitation on the right y-axis

To determine past LUC two databases are consulted; firstly, the database presented in the article of Fox et al (1994) gives insight in the LUCs between the 1954 and 1983. The second database is the MODIS database[6], which gives insight in the land uses in 2001 and 2012. Thus, this will result in an overview of the land uses in the years; 1954, 1976, 1983, 2001, 2012, and in the changes between 1954 and 2012. The trend of the LUCs between 1954 and 2012 will be extrapolated into the future, thus 2030 and 2060. This will be done according to the linear regression method[7] in Excel. In Fig 9 an example of the result is given of this method, the x axis represents the years and the y-axis the percentage of land use in the catchment. This creates a trend line for the near and far future which is a function of time (years).

In the text below each database is shortly elaborated on.

Database created by Fox et al (1994)

The study area of this database (approximately 10,000 ha) is located northwest of the study area, Thailand (see Fig 2b). The database is based on land-cover maps derived from aerial photographs, field surveys, and satellite images. Aerial photographs were used that were taken in 1954 (1:50,000), 1976 (1:15,000), and 1983 (1:15,000).

[5] T_{mean} is used as input for the Hamon formula

[6] The MODIS database is used to answer research question 1 as well.

[7] Linear regression is an approach for (1) modeling the relationship between two variables, (2) determine the regression function, and (3) estimate the conditional expectation (Armstrong, 2012) , which is in this case are the expected land uses in 2030 & 2060.

These photographs produced land-cover maps classified in terms of:

- closed-canopy forests,
- sparse forests,
- swiddens including opium,
- fallow swiddens,
- fruit orchards,
- tea gardens,
- forest plantations,
- villages,
- grasslands,
- paddy fields.

The MPC is located close to the study area of Fox et al. from 1994. The assumption is made that the LUC in the MPC have occurred in the same pace as it did in the study area of Fox et al from 1994. This choice is made because (1) detailed satellite images of the MPC and the land uses within it are not available between 1954 and 1983 and (2) the distance between the two mentioned area’s is limited (approximately 40 km). A benefit of the database is that the percentual land uses are already calculated, which saves time. In order to use this database to determine the CN a reclassification of the types is necessary, which is shown in Table 4. The reclassification method is the same as is used for the MODIS database.

Table 3: Reclassification based on Curve Number Method land cover

Fox et al Land Cover Types Classification	Curve Number Method Land Cover Classification	Curve number
Type	**Type**	
closed-canopy forests,	Woods	73
sparse forests,		
swiddens including opium,	Close-seeded or broadcast legumes or rotation meadow	80
fallow swiddens,	Fallow	90
fruit orchards,	Woods-grass combination	76
tea gardens,		
forest plantations,		
villages,	Farmsteads-buildings, lanes,driveways and surrounding lots	82
grasslands,	Meadow-continuous grass	71
paddy fields.	Close-seeded or broadcast legumes or rotation meadow	80

3.2.2 Climate change

The climate data of 2012 will be altered according to two IPCC scenarios, namely scenario B1 and A2. A2 is seen as an extreme future situation and B1 as an intermediate in respect to the present climate. These alterations will be done with the aid of a dataset provided by the Tyndall Centre for CC Research. The dataset consists expected alteration of precipitation and average temperature data affected by the IPCC CC scenarios for the period between 2001 and 2100. These alterations are based on the assumption that the average climate between 2001 and 2100 remains fixed at 1961-90 levels but will only be altered with the emissions scenarios.

The assumption was made that between the fixed 1961-90 levels and 2012 no permutations have occurred yet. The Tyndal dataset consists of monthly permutation, compared to the 1961-90 levels, for 2030 and 2060 of the average temperature and cumulative precipitation. The temperature input of the CN model is the average value as well, so the expected positive or negative alteration are easily implemented. But the precipitation input of the CN model has a daily interval. Therefore the data from the Tyndall Data Centre is recalculated from a monthly cumulative amount towards a daily alteration, which is done by dividing the cumulative amount by the amount of days of the specific month.

3.2.3 Scenarios

In total 4 main scenarios, the first 3 having 2 sub scenarios (a & b), will be assessed with the model. The overview of the scenarios and the necessary input datasets are presented in Table 5. The scenarios give insight in the present and in the irrigation water availability over the years 2030 and 2060 affected by LUC and CC. Scenario 4 is seen as representation of the worst case scenario in 2060, where expected LUC and CC under the extreme IPCC scenario A2 have taken place.

Table 4: Overview of the scenarios, their description and inputs.

Scenario	Scenario description	**Land use data**		**Climate data**		Amount of scenarios
Present: RQ 1						
	Present irrigation water availability	Present				
Future: RQ 2						
1	Effect of LUC on irrigation water availability	2030 **(a)**	2060 **(b)**	Present		2
2	Effect of CC on irrigation water availability in 2030	Present		IPCC B1 (**a**) and IPCC A2 (**b**) for 2030		2
3	Effect of CC on irrigation water availability in 2060	Present			IPCC B1 (**a**) and IPCC A2 (**b**) for 2060	2
4	Effect of CC and LUC on irrigation water availability in 2060	2060		IPCC A2 for 2060		1
Total amount of scenarios						7

3.3 Verification

In order to verify the simulated discharges, discharge measurements will be done in the Mea Pheam River. This will be done according to two methods, which are elaborated on in paragraph 3.3.1 and 3.3.2. With the verification insight is given in the difference between the measured and simulated discharges. This could benefit the interpretation of both and will be taken into account when assessing the results.

3.3.1 Rehbock weir

To measure the discharges in the Mea Pheam River rehbock weirs will be constructed according to the principle that is shown in Fig 10. To calculate the discharges with this Rehbock weir the following equation is adopted (STOWA, 2009):

Equation 22

$$Q = C_d \times \frac{2}{3} \times (2g)^{1/2} \times b_c \times h_e^{3/2}$$

Where:

Equation 23

$$h_e = (h_1 + 0{,}0012)$$

And,

Equation 24

$$C_d = 0{,}602 + (0{,}083 * \frac{h_1}{p_1})$$

In which

Q =	Discharge	[m^3/s]
C_d =	Discharge coefficient for the weir	[-]
b_c =	Width of the weir	[m]
h_1 =	Piezometric head over the weir	[m]
g =	Acceleration of gravity.	[m/s]
B_1=	Width of the stream or channel	[m]
p_1=	Height difference between bottom and crest Rehbock weir	[m]

The boundary conditions to apply these formulas are;

- $B_1 - b_c \geq 4 * h_1$
- $h_1/p1 \leq 0{,}5$
- $h_1/b_c \leq 0{,}5$
- $0{,}07\,m \leq h_1 < 0{,}60\,m$
- $b_c \geq 0{,}30\,m$

This equation is commonly used and widely accepted for sharp crested weirs and has been extensively applied to determine the discharges (Johnson, 2000; STOWA, 2009). In Fig 10 the parameters of the formulas are visualized.

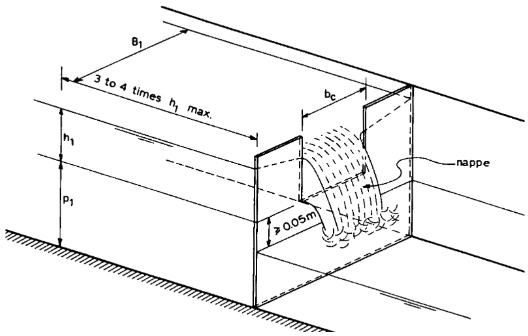

Figure 10: Visualization of the parameters to determine the discharges (STOWA, 2009)

3.3.2 Dilution gauging method

The basis of dilution gauging is the measurement of the degree of dilution of a known quantity of tracer (by example of salt) after its mixing in a stream of water. There are two general approaches that could be used: Firstly, the slug injection of a known amount of tracer into a stream of water, which requires that tracer needs to be fully dissolved in the water. Secondly the methodology of the injection of a tracer solution at a constant-rate into the stream.

The first mentioned method of injecting of a tracer into a flowing stream is the simplest and is therefore applied in the project area. An example of the possible response curves can be seen in Fig 11. The curves represent measurements at three different distances downstream in respect to the injection point, which could result from a single slug injection of tracer in the middle of the stream. These response curves are time concentration curves stream the passage of an entire cloud or response curve is relatively short, it rarely exceeds 1 hour.

The discharge as measured by the slug injection tracer-dilution technique is:

$$M = Q * \int_0^\infty \{\emptyset(t) - \emptyset_1\} dt$$

Where

- M is the mass of tracer injected [g]
- Q rate of flow of the stream; [l/s]
- $\emptyset(t)$ is the concentration of the tracer [g/l]
- A_c is the area under the response curve obtained after adequate mixing of the tracer in the flow. [g/l]

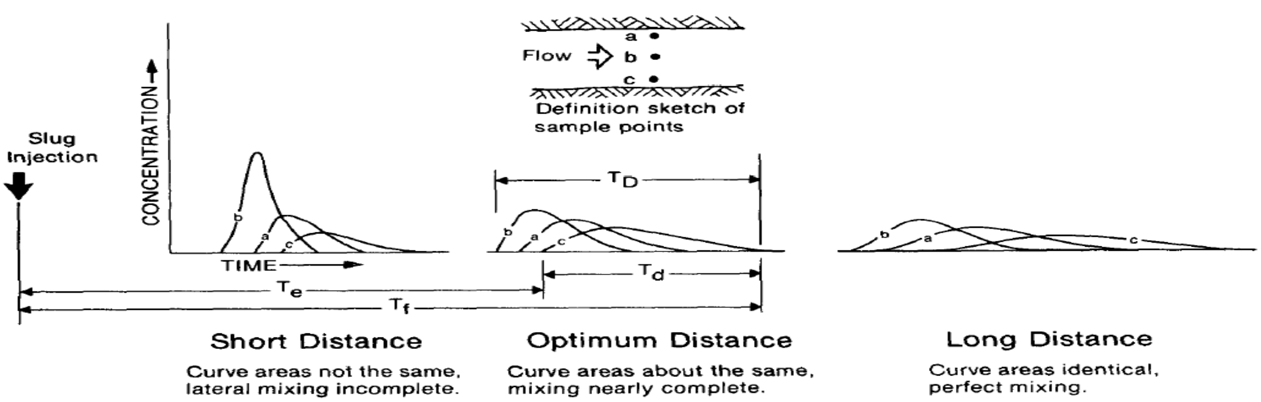

Figure 11: Typical response curves observed laterally and at different distance downstream form a slug inject of a tracer in the centre of a stream.

It is most important that a measurement of the response curve is done far enough downstream ensuring that mixing is almost complete within a cross section. In the case when a sample is taken at short distances downstream from the injection point, the tracer is not fully mixed in the total cross-sectional area and therefore the flow of the stream, being more in the centre of the stream than near the banks, the effect of this is shown in the second curve in Fig 11. Besides this, the response curve measured in the centre may be considerably shorter in duration (T_D) compared to the other. This is caused by the fact that, flow along the banks is usually slower and lengthens the tracer cloud. At a short distance, a measurement of discharge by dilution cannot be realized with ordinary methods.

A good dilution-discharge measurement can be made at what is defined here as an optimum distance. A rough indication for this optimum is 25 times the stream width (Day, 1977). Note that at this distance the peaks of the curves do not have to be the same, regarding their lengths, or durations, and arrival and departure times. But the areas under each curve are comparable, which allows a good discharge measurement (USGS, 1985).

Applicable tracer

For dilution gauging table salt (sodium chloride) is popular for dilution gauging for three reasons. First, table salt is inexpensive and readily available, even in the most unreachable areas. Second, it can be easily and accurately measured in a stream using an electrical conductivity meter. It measures the ease of which an electrical current can travel through water (Moore, 2003).

4 Results

First the present irrigation water availability is presented, which is followed by the irrigation water availability in the future under different circumstances (scenario 1, 2, 3, and 4). In all cases an overview of the inputs for the model are presented. Followed by the availability expressed in a hydrograph and in the all-year flow duration curve (FDC). The latter shows the relation between the simulated discharges, at a point and the probability with those magnitudes are exeeded or equaled over an certain time period. FDCs are mostly constructed for daily average stream flows. The slope of the FDC is proportional to the vaiability of daily discharges. A steep slope indicates a possible deficiency of significant storage, which could imply a decrease of the irrigation water availability. A commonly used expression of the usable water resources in a catchment is the discharge available most of the time -say- the flow exceeded 90% of the time (Q90) (Dingman, 2002). Q10 represent the discharge which is available during 10% of the year.

The present availability forms a baseline with which the scenarios are compared. The availability is expressed in average m^3/s per day.

4.1 Present irrigation water availability

4.1.1 Land use input

In the year 2012 four land uses types, shown in Fig 12, were distinguished according to the Modis Database:

- Evergreen Broadleaf Forest (Light green)
- Deciduous Broadleaf Forest
  (Dark green)
- Woody Savannas (Brown)
- Cropland/Natural Vegetation Mosaic (Yellow).

Fig 13 represents the percentual distribution of land uses within the catchment after reclassification into the CN classification.

The land use types within the catchment were; woods with 79.8 percent, second largest is the woods grass combination land use (19.3%), and pasture (0.9%) is the smallest measured land use within the catchment. The Curve Number of these uses are: 73, 76, and 79. When these numbers are individually multiplied by the fraction of the area that they cover relative to the total area of the catchment and are summed up, the Curve Number of the total area comes forward; 73.63.

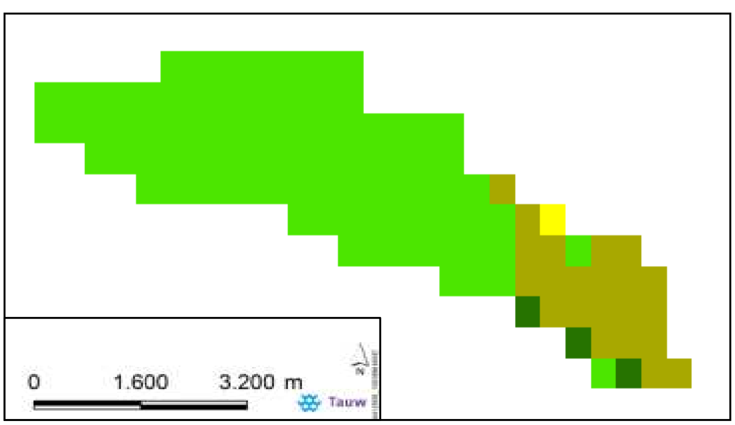

Figure 12: Land uses within the Mea Pheam Catchment classified according to the Modis database classification system. Each cell represent an area of 500m x 500m.

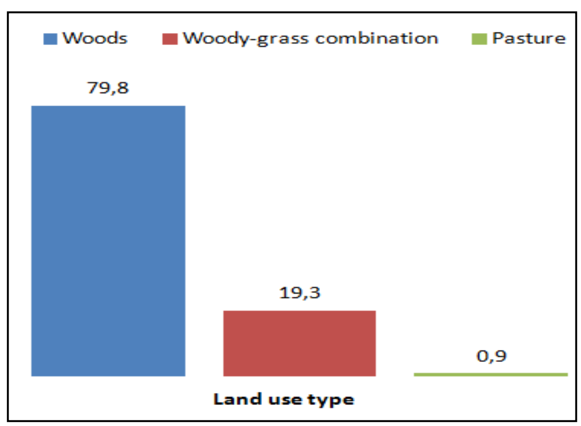

Figure 13: Land use percentages within the Mea Pheam Catchment classified according to the Curve Number Method classification system.

4.1.2 Precipitation and Temperature input

The monthly cumulative amount of precipitation and monthly average temperature in the MPC are shown in Table 6. Average monthly temperatures and daily cumulative precipitation amounts are used in the model. The daily cumulative precipitation amount can be found in Appendix 5. The monthly cumulative amount is precipitation is presented to gain insight in the amount of precipitation that are measured in 2012.

Table 5: Overview of the average monthly temperature and monthly cumulative precipitation of the present.

Season	Dry season				Rainy season							Dry season
Months	J	F	M	A	M	J	J	A	S	O	N	D
Precipitation [mm]	8.70	0.00	6.60	136.80	245.80	286.80	325.20	216.00	5.41	99.50	56.20	7.40
Average Temperature [°C]	22.27	24.47	27.31	30.04	29.28	28.16	27.45	27.90	28.47	27.93	26.77	26.85

4.1.3 Simulated irrigation water availability

Above mentioned inputs have been used to calculate the irrigation water availability of the present by using the model. The availability is elaborated on in the text below and in the graphs of Fig 14 and Fig 15.

The 8 largest daily amounts of precipitation are measured on 24-05, 29-05, 04-06, 06-07, 19-08, 14-09, 14-10, and 20-11. The 8 largest simulated discharges were found on 29-05, 05-06, 06-06, 07-06, 10-07, 27-07, 20-08, 24-08, and on 14-09. Only on 29-05 and 14-09 the precipitation affects the simulated discharges on the same day. The precipitation on 04-06, 06-07, and 19-08 had a delayed effect, peak discharges are seen 1 day after. The other rainfall events had different effects on the simulation of the discharges, which is caused by the configuration of the model. The AMC configuration determines which fraction of precipitation that infiltrates into the soil or forms surface run off, both dependent on the 5-days antecedent precipitation amount. If the latter is relatively high, relatively less infiltration and more surface runoff occurs. Surface runoff generates directly discharges while infiltration forms a base flow according to the linear reservoir. The configuration of the latter is responsible for delay. During the relatively dry months of January, February, March, April, Oktober, November, and December, simulated discharges were relatively low and decreased through time in respect the last rainy day.

To gain insight in the temporal variability of the availability, the exeedence probability of the simulated discharges are analyzed. This is done by the FDCs, which are shown in Fig 15. The average, cumulative availability over the whole year, the Q10, and Q90, during the rainy season, and the dry season are presented in table 6. The average discharges in Table 6 corresponds with the all year Q50 value of the FDCs.

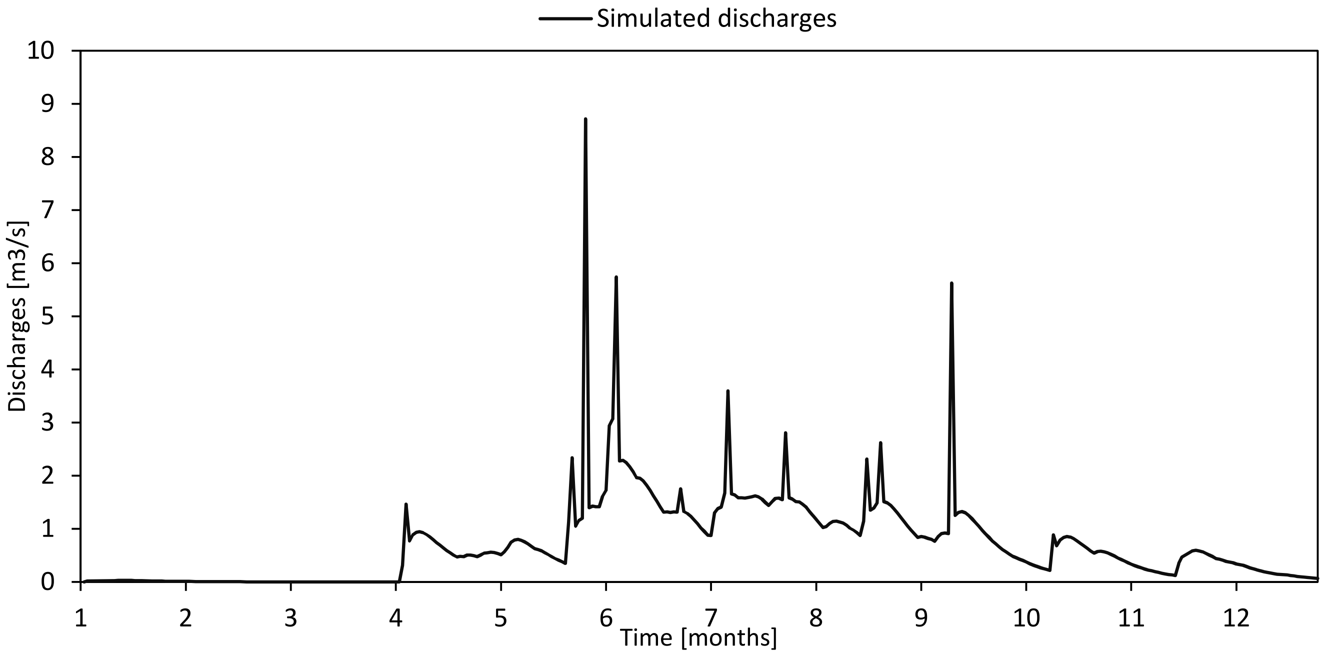

Figure 14: Hydrograph showing the simulated average daily discharges of the present in the Mea Pheam River.

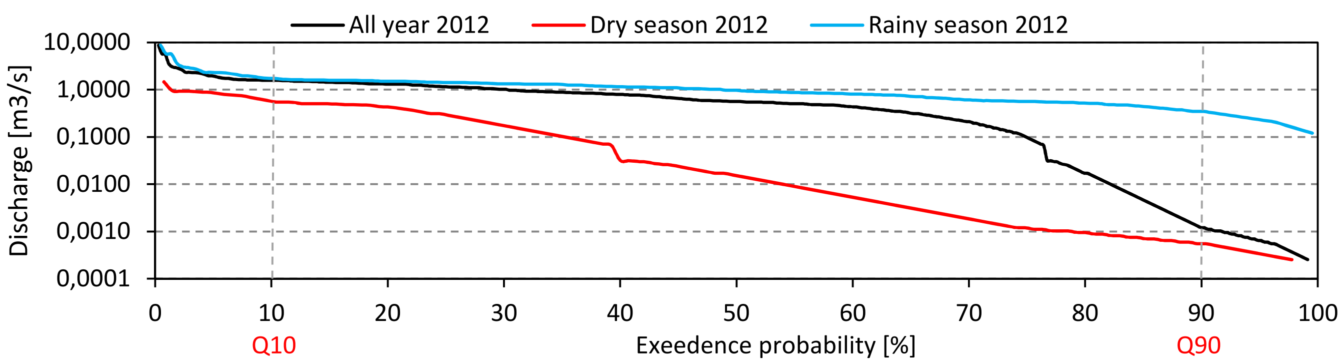

Figure 15: Flow duration curves showing the average daily discharges in 2012 and during the dry and rainy season. Note that the y-axis is given on a log-scale to better illustrate the large differences discharges between the seasons.

Table 6: An overview of the present average daily, cumulative annual availability, and the discharges which corresponds with the Q10 and Q90 per season in m^3/s.

	Average $[m^3/s]$	Cumulative $[m^3]$	Q10 $[m^3/s]$	Q90 $[m^3/s]$
2012	0.75	$2.251*10^7$	1.58	0.0012
Rainy season	1.10	$2.046*10^7$	1.72	0.35
Dry season	0.20	$2.051*10^6$	0.55	0.00055

4.2 Future irrigation water availability

We first elaborate on the LUC and CC inputs for 2030 and 2060, and as second the simulated discharges are presented and compared with the present availability.

4.2.1 Land use input

Statistics of observed changing land uses in this catchment appear in Fig 16. The trend lines that were extrapolated to predict the land uses in 2030 and 2060 appear in Fig 17. These inputs are used for scenario 1a and 1b, where the precipitation and temperature inputs were left unchanged in respect to the present values.

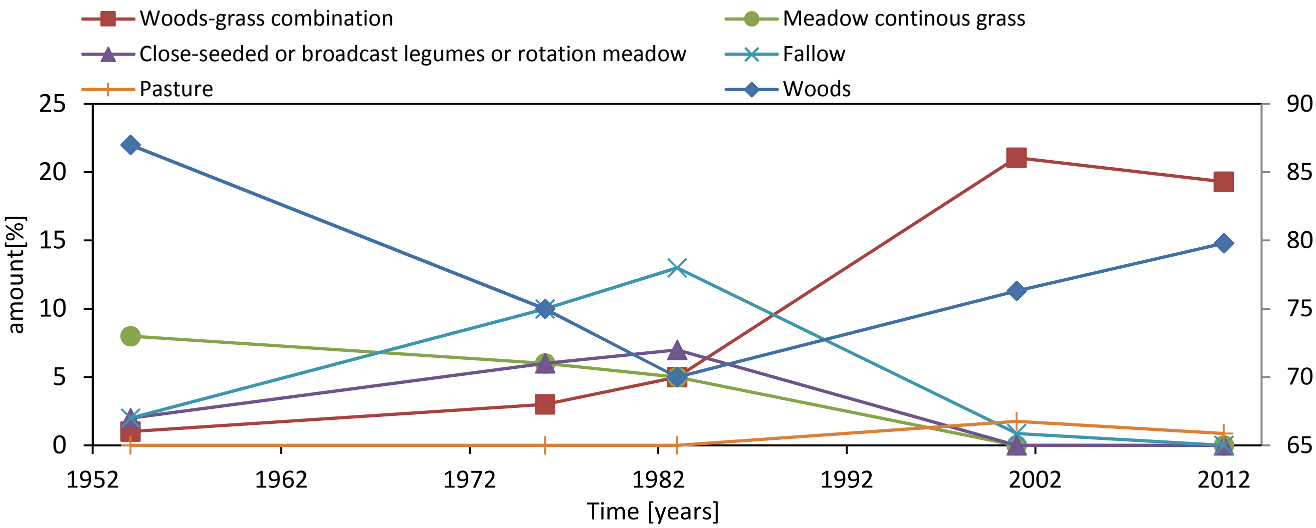

Figure 16: Observed Land use changes between 1953 and 2012 in percentages. The right y-axis represents the percentages of the classification woods. The left y-axis the other classifications.

The land use type Woods covered the greatest part of the catchment between 1954 and 2012 where it covered an area between roughly 70% and 87%. It is expected that the type Woods will remain the dominant land use type in 2030 and 2060, with respectively cover percentages of roughly 73% and & 70%, see Fig 17. The second largest is the type Woods-grass combination, which covered 1% of the area in 1954 and is expected to cover roughly 24% and 30% in 2030 and 2060, respectively. The trend line of this type and of the other types, which are based on changes between 1954 and 2012, are visualized in Fig 17. The mentioned two land use types are expected to influence the irrigation water availability the most due to the large area that they cover within the catchment.

Meadow continuous grass declined from 8% towards in 1954 5% in 1983, after that year it has not been detected in the catchment. Close-seeded or broadcast legumes rose from 2% in 1954 towards 7% in 1983, after that this land use type was no longer abundant. Fallow declined from 2% to 0% in 2012, but peaked in 1983 with 13%, which caused the extrapolated trend line to show a coverage of 1.4% in 2030. Pasture rose from 0 percent to 0.9 in 2012 and is expected to cover 1.6% in 2030 and 0% in 2060. The effect of these LUCs on the CN is shown in Table 7.

Table 7: Overview in the changes of the CN respect to the CN of 2012

	2030	2060
Change CN [%]	0.5	11.5

The R^2 of the extrapolated trend lines varies between minimum of 0.1 and a maximum of 0.93 respectively for the land uses Fallow and Meadow continuous grass. The variation of the R^2 needs to be taken in to account when assessing the results.

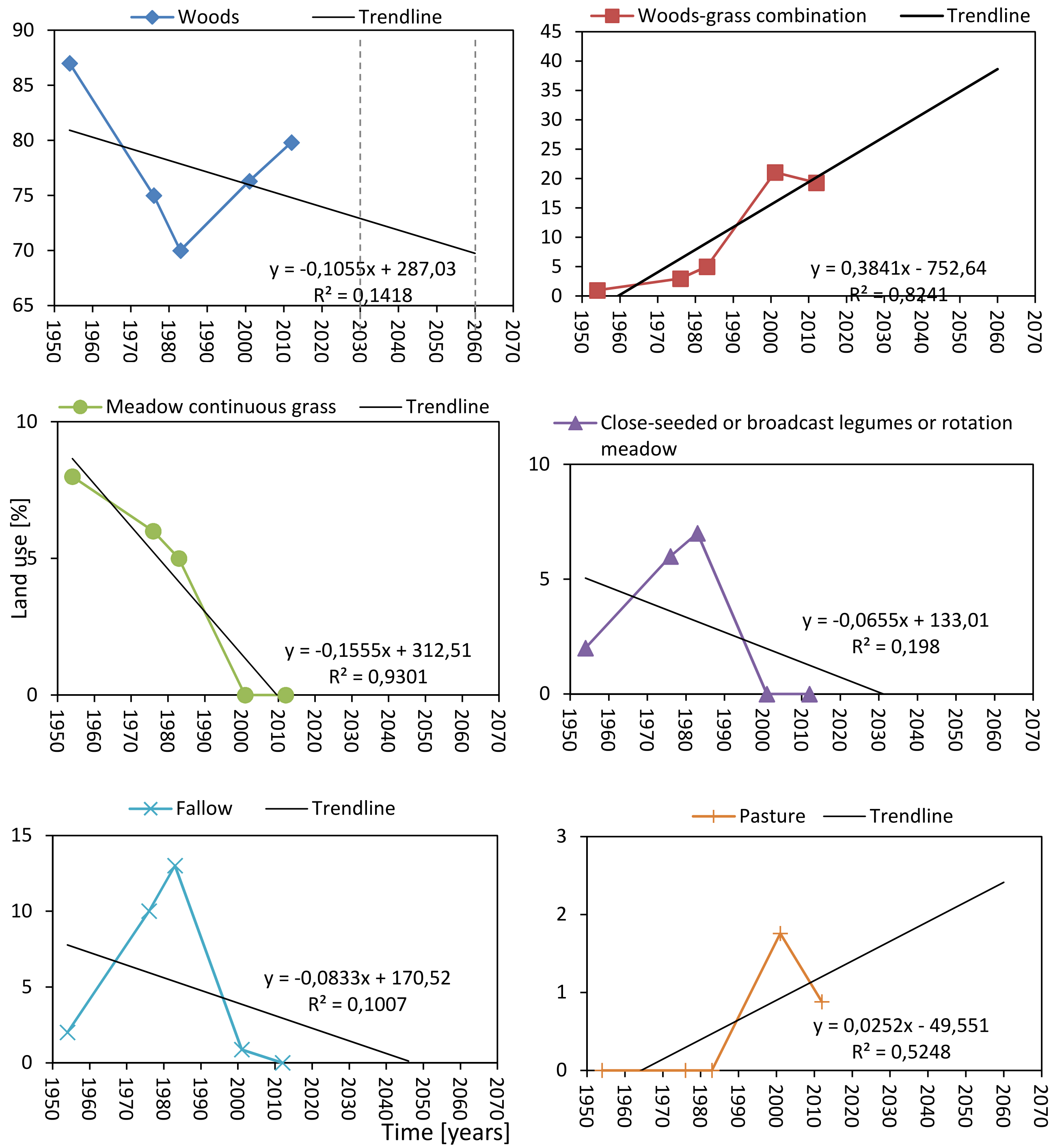

Figure 17: Extrapolation of the land uses towards 2030 and 2060, woods-grass combination, meadow continuous grass, and etc. based on the trend of the land uses between 1954 and 2012. In the first graph the vertical lines are shown of x-axis values 2030 and 2060. Were these lines cross the trend line determines the percentage in 2030 and 2060. The same principle is applied in the other graphs.

4.2.2 Climate change inputs

In Table 8 the percentual changes of precipitation and temperature according to the IPCC CC scenarios, are shown for scenario 2a, 2b, 3a, and 3b. These percentages are shown to give insight in the effects of the IPCC CC scenarios on the inputs. Average monthly temperature is used as input for the model but the precipitation has a daily time scale. The effect of the IPCC CC scenarios on the daily values can be seen in Appendix 5. In these scenarios the land use input were left unchanged in respect to the present values.

Table 8: An overview of the changes of scenario 2 and 3 regarding precipitation and temperature. Note that the changes are assessed in respect to present values (table 6).

Precipitation	J	F	M	A	M	J	J	A	S	O	N	D
Scenario 2a [%]	1.72	0.00	-1.67	1.25	-0.39	-4.62	-3.95	2.15	0.00	1.72	-5.07	-0.81
Scenario 2b [%]	-0.46	0.00	-3.18	0.37	-1.07	-9.80	-4.62	0.58	-2.40	1.63	-2.72	7.30
Scenario 3a [%]	58.73	0.00	0.00	0.07	-0.63	-7.19	-6.30	3.45	0.10	2.77	-7.94	-1.20
Scenario 3b [%]	-1.05	0.00	0.00	0.75	-2.20	-18.96	-9.28	1.19	-4.67	3.34	-5.60	15.07
Temperature	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Scenario 2a [%]	4.09	4.13	4.25	3.70	3.79	3.23	2.77	2.54	2.49	1.25	0.75	2.83
Scenario 2b [%]	5.34	4.58	4.58	4.26	4.27	3.98	3.06	2.90	3.06	2.47	1.64	3.61
Scenario 3a [%]	6.56	6.63	6.83	5.94	6.09	5.18	4.43	4.07	3.99	3.30	1.21	4.53
Scenario 3b [%]	10.92	9.42	9.37	8.74	8.74	8.18	6.30	5.96	6.29	5.04	3.35	7.39

4.2.3 Simulated irrigation water availability

The analysis of irrigation water availability in the scenarios is presented in three graphs. The (1) all year FDCs, (2) the rainy season FDCs, and (3) the dry season FDCs. In the all year the analysis is done with a hydrograph and the FDCs. The rainy and dry season are analyzed with the latter. The hydrographs gives insight in the discharges throughout the period and the FDCs insight in the exceedance probability during the seasons.

4.2.3.1 All year

In Fig 18 the hydrograph of the simulated discharges of all scenarios are shown. It can be seen that the overall behavior of all lines are comparable. All peak discharges of the scenarios occur at roughly the same moments as in the present situation. But more peak discharges are noticed in all scenarios. Higher peak discharges in respect to the present peak discharges are seen in scenario 1a, 1b, and 4. The simulated overall minimum discharges of all scenarios appear to decrease relative to the present. These three observations could be explained by the decreasing land use type Woods (scenario 1a and b) and increasing amounts of precipitation (scenario 2, 3, and 4). With the exception of scenario 1a were during the months April, June, Oktober, and November slightly higher minimum discharges are seen. The hydrographs and all year FDCs of each individual scenario plotted in respect to the present can be found in Appendix 6.

From figure 19 it can be observed that in all scenarios, discharges with an exceedance probability larger than 10% decrease in respect to present discharges. Except for scenario 1a were an increase in discharges is seen by a exceedance probability greater than 75%. Discharges with an exceedance probability smaller than 10% are likely to increase. The overall slope of the FDCs steepens slightly in all scenarios but in scenario 1b and 4 relatively stronger in respect to the present FDC.

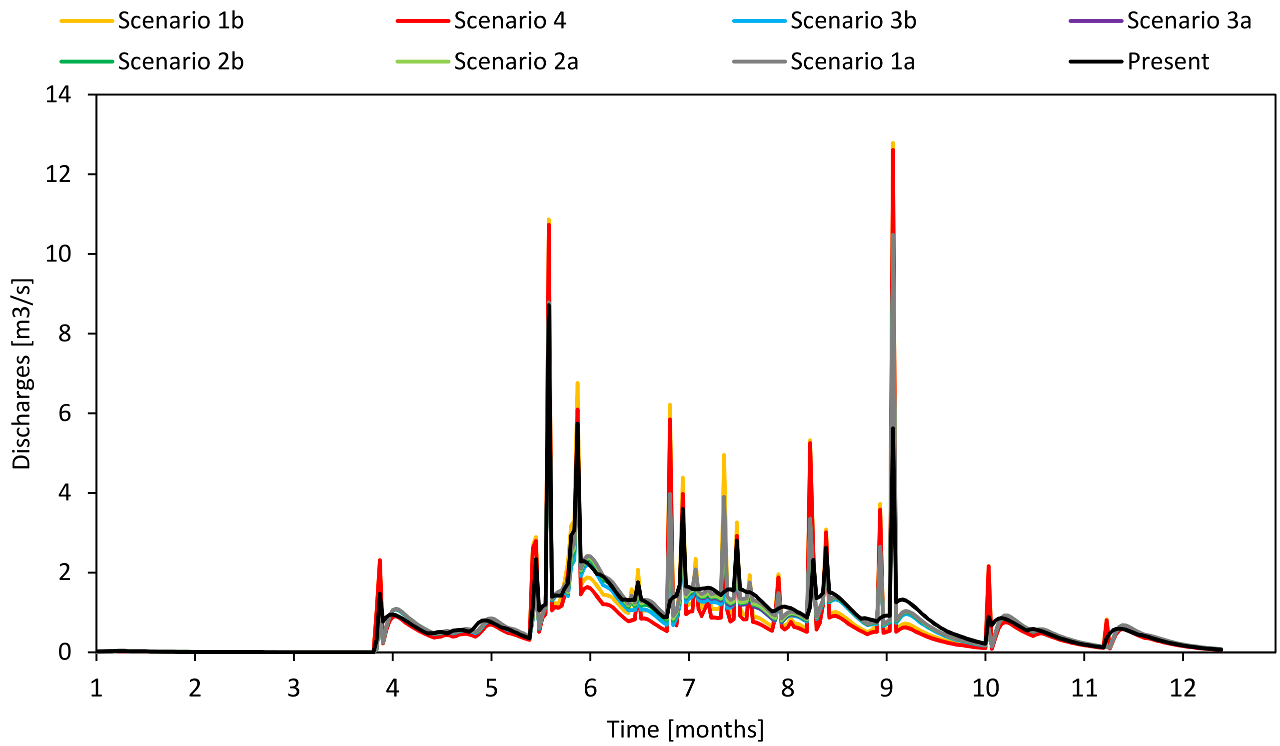

Figure 18: Hydrograph showing the simulated average daily discharges of the present and all scenarios in the Mea Pheam River. Order of appearance in the graph has been optimized to show the deviations in respect to the present.

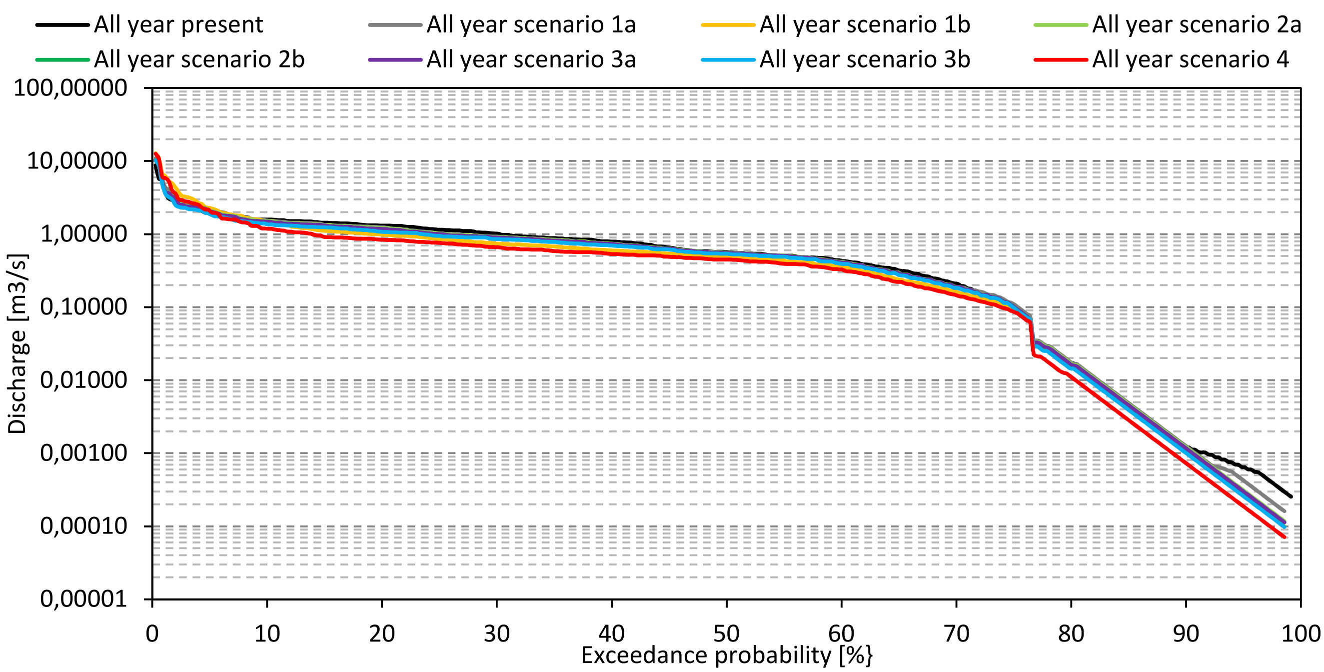

Figure 19: FDCs showing the exceedance probability of the simulated average daily discharges of the present and all scenarios during the whole year in the Mea Pheam River. Note that the y-axis is given on a log-scale to better illustrate the large differences in discharges within a scenario.

4.2.3.2 Rainy Season

Roughly the same shape of the all-year FDCs of all scenarios is also visible in the rainy season FDCs, which is shown in Fig 20. All the discharges decreases in respect to the present rainy season discharges, except with exceedance probabilities smaller then roughly 15%, these increases. Scenario 1b and 4 show the largest deviations in discharges in respect to discharges of the present. Overall, it leads to increasing discharges with small exceedance probability, albeit with decreasing discharges with high exceedance probabilities. The slope of the FDCs deepens in each scenario in respect to the present slope. The rainy season FDCs of each individual scenario plotted in respect to the present can be found in Appendix 6.

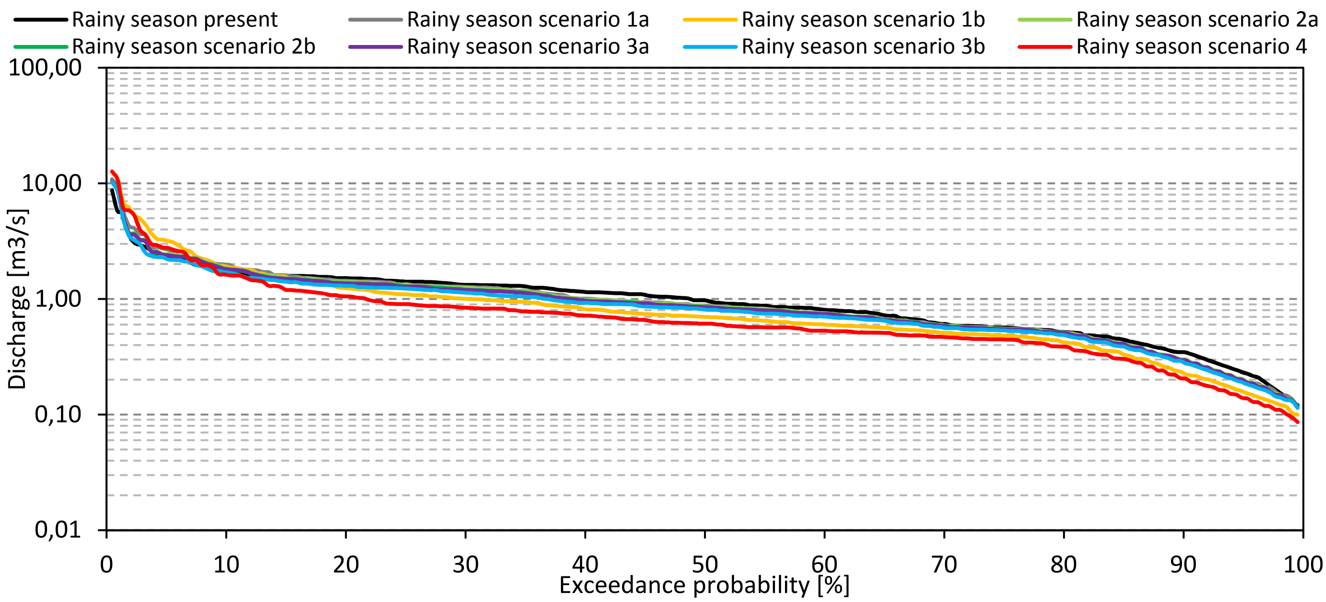

Figure 20: FDCs showing the exceedance probability of the simulated average daily discharges of the present and all scenarios during the rainy season in the Mea Pheam River. Note that the y-axis is given on a log-scale to better illustrate the large differences in discharges within a scenario.

4.2.3.3 Dry season

In all scenarios the discharges with an exceedance probability smaller than roughly 40% vary slightly or remain equal in respect to the present, as can be seen in Fig 21. Discharges with an exceedance probability greater than 40% decrease in respect to the present. Which stresses the irrigation water availability in the dry season. The dry season FDCs of each individual scenario plotted in respect to the present can be found in Appendix 6.

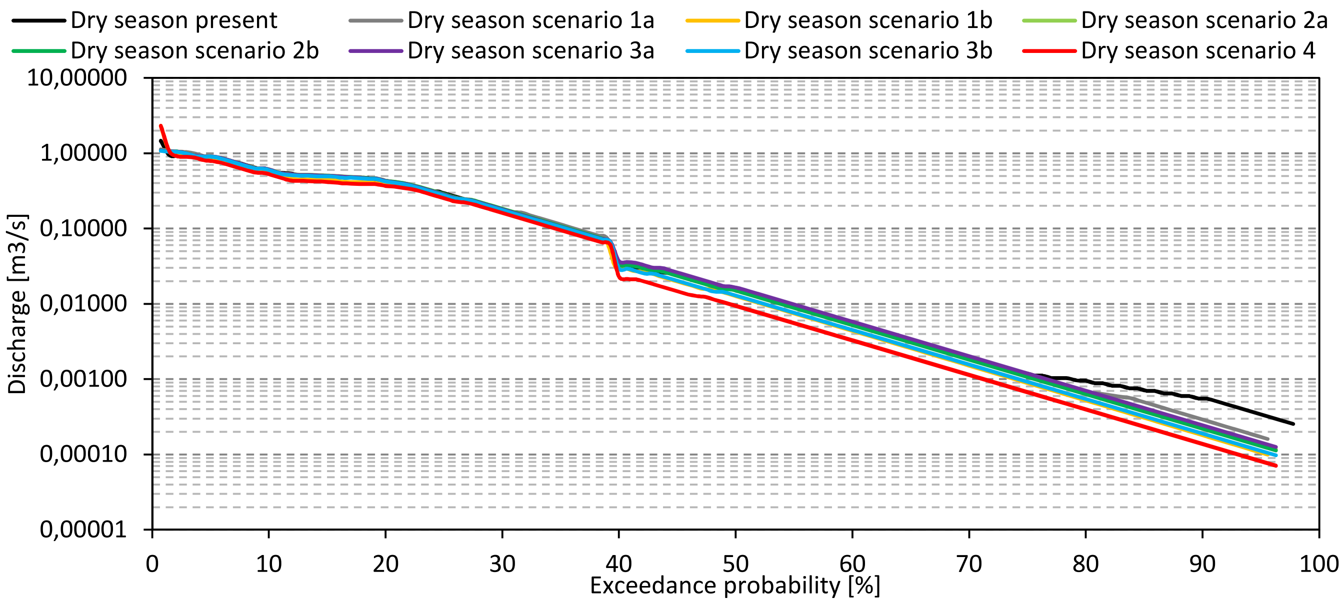

Figure 21: FDCs showing the exceedance probability of the simulated average daily discharges of the present and all scenarios during the dry season in the Mea Pheam River. Note that the y-axis is given on a log-scale to better illustrate the large differences in discharges of a scenario.

4.2.4 Statistics of the FDCs

The statistics shown in table 9 give an overview of the percentual changes in respect to the present. In all scenarios the cumulative amount of available irrigation water declines, except for scenario 1a. The largest (negative) deviations are seen regarding the Q90 during the dry season of all scenarios. Albeit in some scenarios positive deviations are seen regarding the Q10, it implies an increase in uncertainty of irrigation water availability during dry periods, caused by the increase of duration of low discharges.

Looking at the all year deviations, which gives a overall view of the changes in availability. It is seen that climate change negatively affect the availability of irrigation water relatively more than LUC. However only in the case of when the IPCC CC scenario A2 is applied. If we compare the effects of CC scenario B1 with the effect of LUC on the irrigation water availability in 2060, the effects of land use change are relatively stronger. Thus CC affects the availability relatively the most, but only if the climate changes according to IPCC scenario A2.

The combination (worst case scenario) of CC scenario A2 and the expected land uses in 2060 affects relatively, in respect to the present, irrigation water availability the most with a decrease of 14.59%.

Table 9: An overview of the changes in al the scenario of the average, cumulative, Q10 and Q90 in respect to the simulated present discharges per year and season (table 7). A green colored value indicates a increase and a red a decrease of the average, cumulative, Q10, or Q90.

Scenario	Average	Cum.	Q10	Q90
All year scenario 1a [%]	1.3	1.53	3.6	0
All year scenario 1b [%]	-2.67	-3.7	-9.49	-16.67
All year scenario 2a [%]	-1.33	-1.21	-4.43	-8.33
All year scenario 2b [%]	-2.67	-3	-6.33	-8.33
All year scenario 3a [%]	-2.67	-3.29	-7.59	0
All year scenario 3b [%]	-8	-8.26	-13.92	-21.67
All year scenario 4 [%]	-13.33	-14.59	-25.32	-50
Rainy season scenario 1a [%]	1.82	1.04	14.53	-17.14
Rainy season scenario 1b [%]	2.73	-3.89	9.3	-37.14
Rainy season scenario 2a [%]	-2.73	-3.89	9.3	-20
Rainy season scenario 2b [%]	-2.73	-3.45	3.49	-17.14
Rainy season scenario 3a [%]	-2.73	-3.75	4.65	-17.14
Rainy season scenario 3b [%]	-8.18	-9.02	-1.74	-18.84
Rainy season scenario 4 [%]	-14.55	-15.44	-6.98	-42.86
Dry season scenario 1a [%]	-10	2.41	3.64	-49.09
Dry season scenario 1b [%]	-10	-1.81	-3.64	-69.09
Dry season scenario 2a [%]	-10	-1.81	7.27	-60
Dry season scenario 2b [%]	-17.14	-17.14	-17.14	-61.82
Dry season scenario 3a [%]	-10	1.35	5.45	-56.36
Dry season scenario 3b [%]	-10	-0.63	3.64	-67.27
Dry season scenario 4 [%]	-15	-6.08	-7.27	-27.27

4.3 Verification

During the field trip the Rehbock weirs were set up at two locations in the Mea Pheam River, in Fig 22 these locations are shown. The slug tracer discharge measurements were done at the same location.

The discharges measurements were done between 16-02-2014 and 01-04-2014, which has resulted in discharges in l/s during that period.

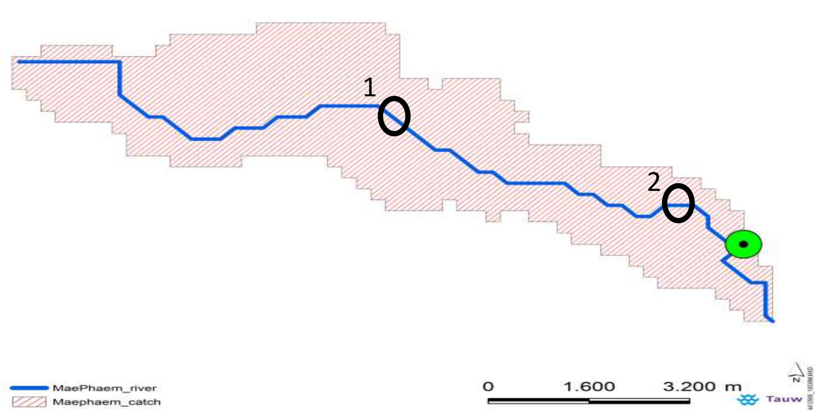

Figure 22: Overview of the Mea Pheam catchment. Green dot represents the village of Ban Mea Pheam, circles represents the measurement location.

The locations were chosen because these offered the most ideal condition to construct a Rehbock weir, see Appendix 4 for photographs. Although it is impossible to calibrate the model with these measurements, verification will be made between the simulated discharges of the present and the field measurements. Limitation of this is that the present irrigation water availability is simulated on a daily base during a whole year (2012) and the measurements have taken place during 1.5 month in 2014, which was during the dry season. Thus, a verification of the whole period is not possible.

4.3.1 Rehbock weirs

Statistics of the measured discharges at the two locations appear in Fig 23 and 24. On the date of 21-02-201 Rehbock weir 1 was replaced by a better fitting one. Initially it did not fully close off the bottom and sides of the channel. This could explain the relatively large differences in measured discharges between the 15th and 21th. The characteristics of both weirs which are necessary to determine the discharge are shown in Appendix 4.

The average measured discharge between the 21th of February and 11th of March at location 1 was 0.075 m^3/s. The drops in discharges on 20-02, 22-02, and 08-03 are caused by the reading out of the monitoring equipment. The initial weir that was placed at location 2 is replaced on 21th of February as well, due to the same reasons that occurred at location 1. The average measured discharge at location 2 between 21th of February and 30th of March was 0.038 m^3/s. These measurements have taken place in the dry season and during the whole measuring period no rainfall occurred.

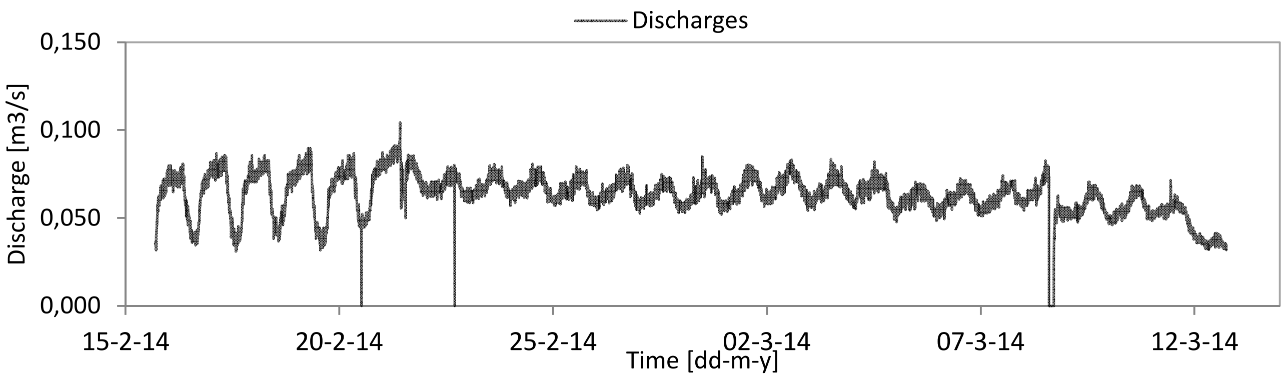

Figure 23: Hydrograph showing the measured discharges in the Mea Pheam River at location 1

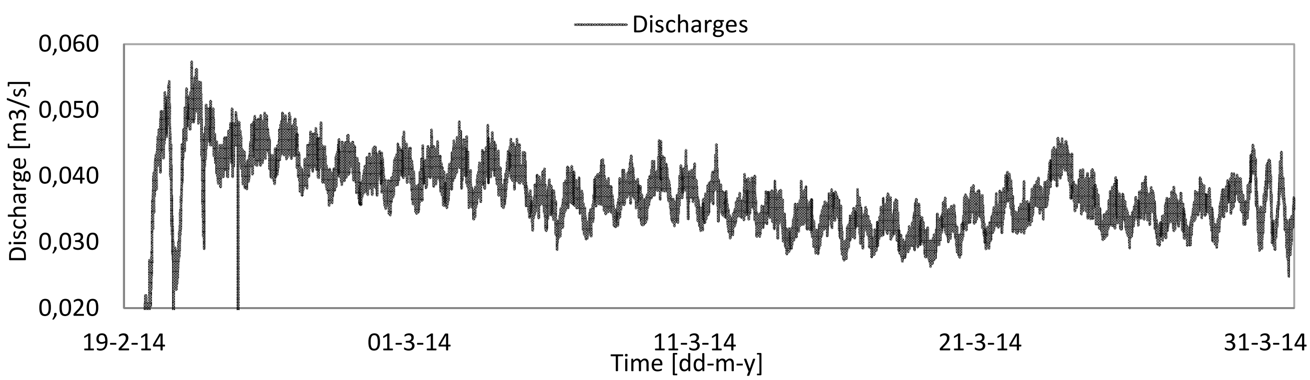

Figure 24: Hydrograph showing the measured discharges in the Mea Pheam River at location 2

4.3.2 Dilution gauging

Statistics of the measured discharges at the two locations appear in Table 10.

Table 10: Overview of the measured discharges with the dilution gauging method.

Location 1		**Location 2**	
Date [dd-mm-jjjj]	Discharge[m^3/s]	Date [dd-mm-jjjj]	Discharge[m^3/s]
04-02-2014	0.040	22-02-2014	0.030
04-02-2014	0.041	22-02-2014	0.034
20-2-2014	0.041	22-02-2014	0.037
20-2-2014	0.040	22-02-2014	0.038
20-2-2014	0.046	22-02-2014	0.035
Average	0.0416	Average	0.0348

The results from field measurements conducted with the Rehbock weir at location 1 and 2 were compared with the average simulated discharges of the same periods. The results from the dilution gauging method were compared with the same period. The results of the comparison are shown in Table 11.

Table 11: Comparison between the discharges from the field measurements and the model. Deviation is expressed by a unit less factor.

	Rehbock weir		**Slug tracer test**	
	Location 1	Location 2	Location 1	Location 2
Factor [-]	30	16	18	15

On average the measurements differ with a factor of 20 in respect to the discharges calculated with the model, which could imply an significant under estimation of the simulated discharges by the model during that time period .

5 Sensitivity analysis

The three most important inputs of the Curve Number Method are (USDA, 1986):

1. The CN number, which is based on the land uses
2. The amount of precipitation
3. The temperature, which determines the amount of evaporation.

Which all directly influence the simulation of the availability of irrigation water. In order to gain insight in the sensitivity of the model to changes of these inputs a sensitivity analysis is done. Firstly the CN number is adjusted by increasing and decreasing the land use type woods with 10% , which respectively implies an decrease or increase of the land use type woods grass combination, secondly the amount of precipitation, and as third the temperature both with a increase and decrease of 10% as well. The deviation factor with respect to the present simulated discharges are shown in Fig 25. When a particular input was manipulated the others were put to present values. The value on the y-axis of 1 represents the present discharges.

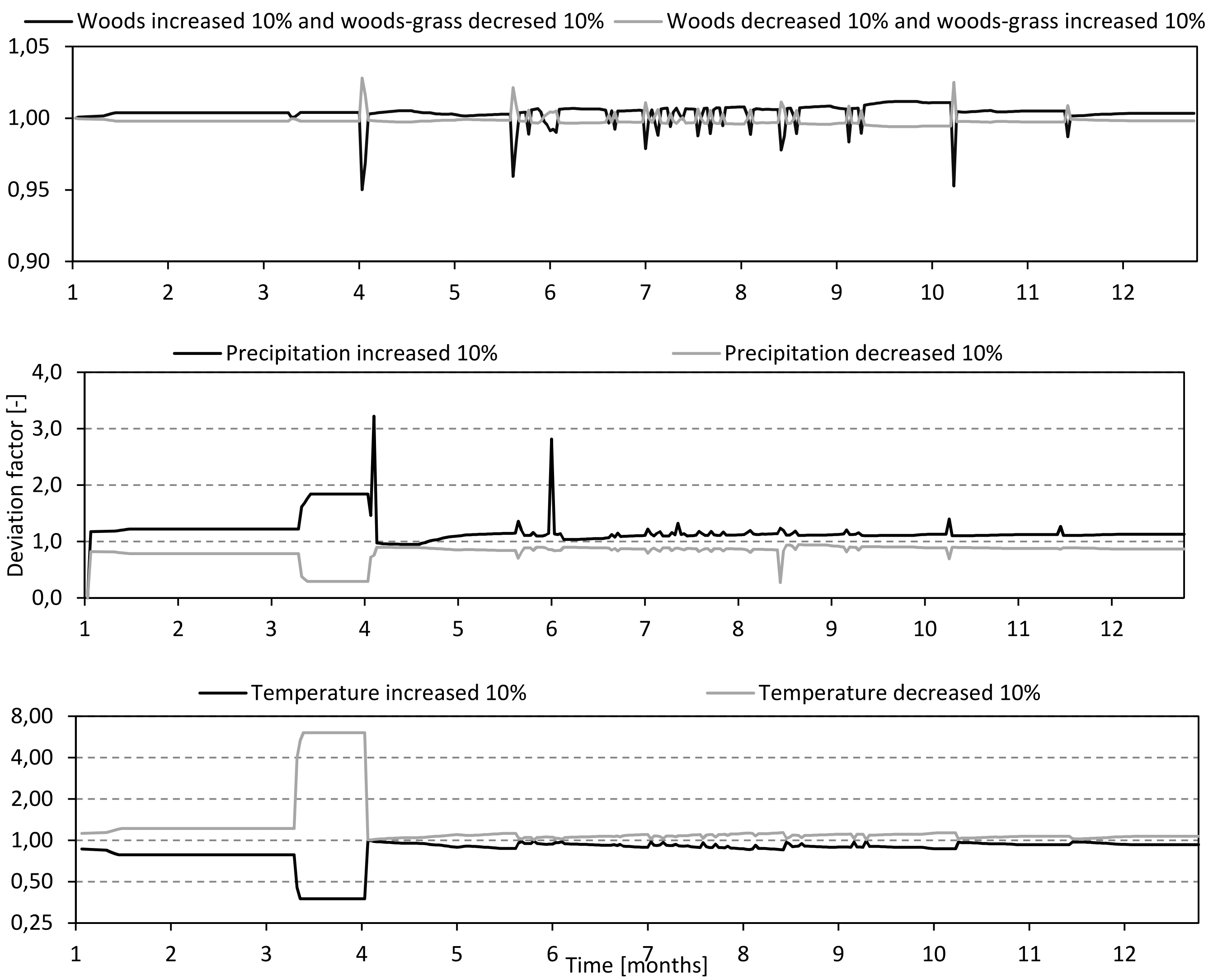

Figure 25: Sensitivity analysis of the model to the land use, precipitation, and temperature inputs.

The increase and decrease of land use type woods and woods-grass caused the CN to change from 73.63 to respectively 73.23 (-0.54%) and 73.83(0.27%), which explain the relative small deviations. But it does show the effect of the land use type woods on the availability of irrigation water. In the case of an increase the deviation is generally positive and negative when decreased. Besides this the peak discharges are influenced in the opposite way. The increase of the land use type woods contribute to an increase of the irrigation water availability. The alterations of the other two inputs have expected effects. An increase and decrease of precipitation amount results in an increase and decrease of discharges. An increase and decrease of temperature results in respectively a higher and lower amount of evaporation and therefore decreases and increases the discharges.

If we deviations factors are compared it is seen that the model is most sensitive to the precipitation input and the least by changing the CN as an effect of altering the percentage of woods and woods-grass.

6 Discussion

6.1 Model performance and assumptions

It was found that for this study, the model was able to estimate the changes in availability of irrigation water in the present and affected by LUC and CC in the future. But the comparison between the model outputs and the measured discharges did show the model might underestimate the discharges by a factor of roughly 20, which could imply a underestimation of the availability as well. Calibrating the model with the discharge measurement was not possible due to relatively small time period that these measurements covered and due to the used methodology on which is elaborated later. The measurements gave an estimation of the discharges, just as the model did. Hence, this makes it hard to state whether the model gives overestimations of the discharges.

If the assumptions is made that the model overestimated the discharge, this could be caused by the fact that the model (1) does not take into account that during dry periods, percolation could take longer due to higher soil storage (lower ground water table) and therefore a deficit in percolating moisture, which leads to a lower base flow. (2) Crop factors, which influence the evaporation, were used from other studies. It was not taken into account that these agricultural crop factors vary strongly throughout the year and even during the growing season. Therefore the crop factor could be higher (Siebert & Döll, 2010). This could have lead to higher evaporation rates and lower discharges (Dingman, 2002). The sum of the 5 days antecedent rainfall led to AMC conditions varying between 1, 2, and 3 throughout the year. (3) Due to the climate of the study area the AMC condition could vary within a day. This average $P>0.2S_{1,2,3}$, and thus peak discharges are rapidly simulated. The CN-method was not very powerful in this case. Changing to 15-day antecedent rainfall conditions –as suggested sometimes (WUR, sine anno) – would only increase this effect. A better fitting solution for this could be that the AMC calculations are modified for the geographic location of the study area, thus the local climate and soil characteristics. Besides this the AMC threshold values for the growing seasons were used throughout the whole year. These threshold values are the highest relative to the other seasons so adjusting the model to correspond would further increase the simulated of discharges. The calculation of the PET, which is done with the Hamon model, is mainly influenced through the temperature input. This model works with the monthly temperature input. But in order to avoid large differences between outcomes (which did occur in the case of simulating discharges) this input was modified by averages to equation 12.(4) It takes into account that the temperature fluctuation fallows a sinus pattern, which decreases the average temperature of a month and therefore the amount of simulated PET, which increases the discharges. As last, (5) the assumption was made that the 25% of the soil moisture percolates into the ground water table and forms the base flow. It was not researched if this percentage represented actual percolation rates.

Slope of FDC, steepness correlation with each other and compare with other.

6.2 Input uncertainties

As stated before the main inputs for the model in all scenarios are the CN, the temperature and precipitation. On which we will elaborate in the same sequence, respectively.

6.2.1 Curve Number

Firstly, each land use type has a tabulated CN which is obtained through measurements or observation from filed experiments and are mostly not free of error. Therefore error will be introduced into the model which affects the overall accuracy of a model (Deursen, 1995). Secondly, the determination of the future CNs is based on land use of the past and present. Two databases were consulted and a reclassification into the CN classification system was necessary. This had the effect that land use types of both databases were converted into a comparable CN land use type. This reclassification was based on the description of both classifications which did not always fully match. Besides this in some cases two or more land use types were reclassified into one CN land use type. This led to a loss of spatial heterogeneity of the area. Allthough this reclassification was necessary to use the model, this shows indirectly the constraints of the use of the CN.

After the reclassification the trend lines of the land uses between 1954 and 2012 were extrapolated until 2060. The R^2 of these trend lines, which evaluate the “goodness-of-fit” of the lines, varied between 0.1 and 0.93. The “goodness-of-fit” can otherwise be explained as the degree of collinearity between the observed land uses and the trend line (Legates & McCabe, 1999). This showed that the trend line, in some cases, has a bad degree of collinearity. This can be caused by (1) the usage of two different databases, with different methods to retrieve and asses the data. (2) Another reason lies in the method of generating the trend line itself. The trend line is generated by the regression equation which represents the regression analysis between the variables; percentage of land use during the analyzed period and the time in years. The extrapolation of land uses towards 2030 and 2060 is done according to this regression equation and can otherwise be described as the conditional expectation of those years. Thus greater differences in land use between the analyzed years decreases the R^2 and makes the conditional expectation more unreliable (Armstrong, 2012).

Thirdly, the CN for each scenario is calculated by multiplying each CN number of the abundant land uses by the fraction of the area that they cover, relative to the total area of the catchment. When these values are summed the Curve Number of the area comes forward. So eventually the characteristics of each land use type are aggregated into a single Curve Number. This implies a second aggregation, since the first aggregation was the reclassification into the CN classes. These aggregations cause a loss of spatial variability within the model but does occur in reality.

The CN is also determined by the hydrologic soil group, the land treatment, and the hydrological condition. In all scenarios hydrologic soil group C was chosen. This choice was based on the description of the groups (Table 2) and observation during the field research. It was assumed that every land use type had the same hydrologic soil group conditions. In reality this could vary between the types within a study area. Due to time constraints and the size of the study area it was not possible to determine the group of each land use type. The land treatment variation was only applicable for the land use types fallow and close-seeded or broadcast legumes or rotation meadow. The assumption was made that the treatment does not vary within or between the scenarios. The same assumption was made regarding the hydrologic condition. These assumption influence the CN values that were used as inputs and thus the availability of the scenarios.

6.2.2 Temperature and precipitation

In the model performance discussion we elaborated on the use of the temperature input in the Hamon model. The temperature was retrieved from the NOOA database. The database consisted daily maximum and minimum temperature from which the average was calculated. The database consisted 262 days of which the average temperature could be determined. On average in each month the daily average temperature could be determined of 22 days. In December only the average daily temperature of 1 day could be determined, so the assumption was made that this values was the average monthly temperature. Obviously these missing values affected the calculation of the average monthly temperatures and thus the simulation of discharges. This lack of data was known in the early stage of this study but other datasets of better quality were not available and taking into account the location and purpose of this study (area) this database was more than suitable.

Regarding the precipitation, of the 365 days the database consisted 174 days on which the precipitation was measured. The cumulative amount of precipitation of the present was roughly 1500 millimeters. But could, in theory, be the double if the dataset covered the full year, which is the average amount of precipitation that is measured in comparable areas. This would, in simplified terms, double the discharges.

The weather station that collected the data was located 75 kilometers south west of the study area, with a height difference of minimal -400 meters in respect to the study area. Because climate parameters bear strong relationships with geographic location and especially elevation, increasing elevation could imply increasing precipitation and thus discharges, a calibration of this data could improve the validity of it. (Daly et al., sine anno; Lee & Peck, 2010). It goes without saying that the differences in elevation could influence the temperature significantly and thus the simulation of discharges. Because temperature drops relative to increasing elevation, thus less evaporation and a increase of discharges. Summarizing, the missing data of the precipitation database and the location of the weather station could explain the underestimation of the simulated discharges.

The uncertainties regarding input data were expected. Therefore a weather station is installed in the Ban Mea Pheam village, which measures the daily average temperature and precipitation. This data could improve the performance of the model in the future.

6.3 Sensitivity analysis

It shows that altering the main inputs of the model has the expected effect on the model outputs. The largest effect is seen when the precipitation input is altered. The relatively small deviation as a result from increasing the land use type woods can be declared by the way CN is calculated. An increase or decrease of 10% of a certain land use implies respectively a decrease or increase of one or multiple other abundant land use types. This balance of the land uses and the relatively small differences between the CNs of each land use type explain the relatively small deviation. Altering the precipitation and temperature input causes relatively large deviations. The precipitation alteration can cause that the threshold value for changing the AMC are reached or not relatively to values of the present which causes a relatively large increase or decrease of the simulated discharges. Increasing the temperatures with 10% leads to plausible decreasing discharges. Decreasing this parameter leads to the expected increase as well, but the average scale of this raises some doubts. The high average deviation is caused by the deviations in May and beginning of April. When these are not taking into account the average deviation would be 10%. In all three situation relatively large deviations are noticeable in begin April. An analogy between the inputs of the model and the deviations is the relatively large scale of both at the same moment. Begin April a precipitation amount of 50.5 millimeters was measured in 2012 after a relatively long period of drought. As stated before the AMC threshold values have a strong effect on the model, which can lead to sudden peak discharges. The alterations of could have increased this effect and thus the deviations.

6.4 Discharge measurements

6.4.1 Rehbock weir

The discharge measurements were done with the aid of self constructed Rehbock weirs at two locations. Because the study area was located in a remote area the Rehbock weirs were constructed with local materials. The weir itself was placed between two concrete walls and was made out of wood. Because of imperfections of both the concrete wall and the wooden weir, full disclosure between both was not possible. This caused leakage of which the quantity could not be determined. The measured discharges could increase if leakage did not occur. In paragraph 3.3.1 we elaborated on the boundary conditions that are necessary to apply a Rehbock weir and the associated formulas. After processing the first results of both weirs the conclusion was drawn that the boundary condition of $h_1/p1 \leq 0.5$ was exceeded with 0.13 during peak water heights. This results in increasing errors in the measurements. Besides this the measuring point to determine h_1 was located to close to the weir. Which may have resulted in an underestimation of the h_1 , because the draw down increases in proportion to the decreasing distance between the measuring point and the weir. Thus resulting in an underestimation of the discharges. The used formula is commonly used for sharp-crested weir, these are typically 1/4" (6.35 mm) thick and made of thin metal plates. The applied weirs were roughly 3.5 centimeters wide. The effects of the relatively large width and the material of the weir were not taken into account nor their possible effects on the calculated discharges. The possible error of the measurement equipment is left out of this discussion as well.

6.4.2 Dilution gauging method

This method was applied in the best possible way and no boundary conditions were exceeded. The distance between the injection point of the tracer and the measuring point at location 1 and 2 were roughly 55 meter and 80 meter, respectively. A visualization of this is found in Appendix 4. To determine the discharges each measurement was repeated three times and the amount of injected salt was precisely measured.

Although this method is the best suited for the conditions in which it was applied they were not ideal. As seen in in Appendix 4 vegetation and stones covered the banks of the stream. The stream meandered relatively strong at location 1 but less at location 2. These characteristics at both locations could affect the measurements and the correlated discharges in a negative way by partially intercepting the tracer solution (STOWA, 2009; Dingman, 2002). This could imply an underestimation of the discharges, which could imply that the factor of underestimation of the simulated discharges by the model increases.

6.4.3 Research scope

Besides the effects of LUC and CC the effects of anthropogenic changes within the catchment have not been taken into account. This scope of this study is to determine the availability of irrigation water and how this could change in the future. Were the availability is seen as the river discharge that is generated by surface run off and the base flow (ground water). The actual irrigation water demand is not taken into consideration in this study. The changes in availability are not placed in a relationship with the present and expected future demands. Hence, a decrease in availability does not need to be a negative development; this depends on the needs of the inhabitants and the water demand of their crops. What it possible could imply is a disturbance of the natural ecosystem.

7 Conclusion

The main research question for this study is:

What is the current availability of irrigation water in the Mea Pheam catchment and will land use change and climate change affect this in the future?

From the model analysis came forward that the average availability of the present is 0.75 m^3/s, with a total availability of $2.2*10^7$ m^3. The scenarios showed that LUC will lead to a decrease of availability in 2060 by 3.7%, while CC leads to a decrease of 1.2% and 8.3% in 2030 and 2060, respectively. The combinations of both leads to a decrease of irrigation water availability of 14.6%. Where all percentages of change are expressed in respect to the values of the present. Comparing the effects of LUC and CC, the latter negatively affect the availability of irrigation water in the future relatively the most. But only if the climate changes according to IPCC scenario A2, which is seen as an extreme CC scenario.

The FDCs gave insight in the exceedance probability of the simulated discharges during the two seasons of the year, the dry and rainy. This showed that the discharges of all scenarios during the dry season with an exceedance probability of 90% (Q90) decrease relatively the most. These discharges decrease with percentages varying between roughly 30% and 70% in respect to the dry season Q90 discharges of the present. This showed that the irrigation water availability during dry period's stresses even further compared with the decrease of irrigation water availability of the whole year. Although the inhabitants of the catchment are familiar with adaptive forms of agriculture, which proved to be necessary in the past. The decreasing irrigation water availability shows that the catchment´ ability to provide irrigation water will decline in the future, especially during the dry seasons, which form a very serious threat for its inhabitants, because their livelihoods depend on the availability of irrigation water.

8 Recommendations

8.1 General recommendations

1) In this study, it has been found that the model simulates relatively large sudden peak discharges and relatively small minimum discharges compared with the measurements during the field research. Since simulating the discharges, especially during the dry season where low discharges determine the availability, is its most important feature, it is recommended to use other models or other configuration to assess whether these are realistic or that it is a result of the model configuration.

2) In order to gain insight in the effect of LUC, it is key to fully map these changes. The reclassification into CN land use types caused loss of spatial deviations. Measuring and monitoring the land changes is important to make better prediction on the effects of it. Stichting Buffelen could take a leading role in this by setting up a monitoring plan in cooperation with consultancy companies or universities.

3) An increase in (locally) observed data could improve the model results. It is therefore recommended to realize the constant monitoring of precipitation, precipitation, and discharges in the Mea Phaem watershed, which can help to improve the present and possible future model results. During the field research the methods to realize this were applied. So in the future long term discharge and climate data will become available. But it is of utter importance that these measurements remain to continue in the future, which is in the hands of Stichting Buffelen.

4) The effects of LUC and CC on irrigation water availability are assessed. How this affects the functioning of the ecosystem and its services to provide in the livelihoods (the exact demand) of the local inhabitants and their crops are not included. This needs further research to gain better insight the effects.

8.2 Model recommendations

5) The AMC threshold values should be adjusted to local climate and soil condition to improve the simulation of discharges. Values of local characteristics could be obtained by a field research. Which could be performed by a student as part of a master´s thesis research.

6) The percolation rate and amount needs to be more dependent on the AMCs instead of static values throughout the simulation period.

7) Changes in crop factors as an effect of the seasons and agricultural activity needs to be included in the model. This needs to be done according to local patterns. Thus a long term research regarding this is essential.

8) The Hydrologic soil group, the land treatment, the hydrological condition influence the CN. In the model it is assumed that these aspects do not vary during the simulation period, thus during the year. It need to be researched to what extend these aspects could vary and what the possible effects could be on the simulation of irrigation water.

9) The configuration of the Hamon model needs to be assessed. The leveling off of the temperature inputs , to prevent sudden jumps in temperature, needs to be compared with a model run without this.

10) The construction of the Rehbock weirs could be improved. This can lead to more reliable results. Besides this a monitoring plan needs to be set up to continue the discharge measurements in the future. The results of this could be used for the calibration of the (future) model.

11) The sensitivity analysis showed that the model is most sensitive for the precipitation input. Thus, the priority of improvement of the model should be focused on this aspect.

8.3 Recommendations for the Stichting

12) This study shows the effects of LUC and CC by a model analysis. In order to improve the model and thus to gain better insight in the effects, the model needs to be improved. This can only be done by people with knowledge of catchment modeling and who are willing to conduct a research pro bono. Therefore the involvement of students, perhaps of the University Utrecht, and guidance from water related consultancy companies in the future is of great importance. Besides this the results of this study need to be used as inputs for the CAP.

13) The Stichting needs to make sure that the monitoring of the local climate and discharges will keep on going in the future because the Stichting is the only reliable actor in the catchment area. It is recommended to improve both Rehbock weirs and to assess if both are necessary.

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Figure 26: Lee in the middle with his mother (right) and wife (Zijderhand, 2013).

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Appendix 1: Catchment Action Plan description (Dutch)

<table>
<tr><td colspan="2">Buffelen Voor Een Betere Toekomst (Thailand)
Projectomschrijving Stroomgebied Actie Plan (SAP)</td></tr>
<tr><td>Project algemeen</td><td>De stichting Buffelen leert de mensen in Het Huay Nam Dang National Park in het noorden van Thailand met het verbeteren van hun leefomstandigheden en omgeving met instandhouding en gebruikmaking van de aanwezige natuurlijke hulpbronnen en kwaliteiten van de bevolking.
De stichting richt haar focus op:

– Bescherming en cultivering van natuurlijke hulpbronnen
– Versterken samenwerking stammen en overheid
– Ontwikkelen lokaal ondernemerschap
– Werkgelegenheid
– Educatie in alle lagen</td></tr>
<tr><td>Situatie</td><td>Landgebruik voor landbouw is niet efficiënt en de mensen maken gebruik van Slash&Burn technieken om grond geschikt te maken voor landbouw. Het bos dunt uit wat leidt tot vermindering van de biodiversiteit, erosie en watertekort met alle gevolgen van dien. Daarnaast neemt de bevolking in aantal toe net als de druk op het gebruik van natuurlijke hulpbronnen. Voor de landbouw worden bestrijdingsmiddelen gebruikt die een bedreiging vormen voor de kwaliteit van het drinkwater. Rijst en aardappelen zijn de meest voorkomende gewassen. Voor 2014 heeft de stichting drie projecten gedefinieerd:

Nieuwe waterbron
Vinden en transportsysteem naar dorp aanleggen ten behoeve van drinkwater en landbouw.

Pilotplot landbouw ontwikkelen en aanleggen ten behoeve van efficiënte en duurzame landbouw

Stroomgebied Actieplan (SAP) opstellen voor het beschermen van de natuurlijke hulpbronnen en het in evenwicht brengen van mens en natuur.
– Link leggen tussen land gebruik & klimaat verandering in relatie tot de beschikbaarheid van irrigatiewater.
– Samenhang tussen de drie projecten
– De nieuwe waterbron voedt de pilotplot voor de landbouw. De implementatie van efficiënte en duurzame landbouw is een wezenlijk onderdeel van het SAP.</td></tr>
</table>

<table>
<tr><td>Actie</td><td>Voor het opstellen van het SAP gebruik maken van de methode in ontwikkeling Assesment of Water Management and Governance (Inhoud, Institutie, Relatie)

Inhoud
– Stroomgebied definiëren;
– Vraag naar en aanbod van natuurlijke hulpbronnen in beeld brengen (in ieder geval water en gewasopbrengsten)
– Waterbalans stroomgebied opstellen
– Toekomst perspectief schetsen betreft beschikbaarheid van water
– Meetprogramma voor monitoring

Wat is nodig voor onderhoud en monitoring?

Relatie
– Welke groepen leven in het stroomgebied en hoe verhouden die zich tot elkaar
– Wat is de rol van de overheid, parkbeheerder en overige organisaties in het gebied
– Welke (bestaande) overlegstructuren in het gebied zijn er en zijn deze geschikt voor bijvoorbeeld een stroomgebiedscomite

Institutie
– Hoe is de wet- en regelgeving op dit moment en wat is nodig?

Het SAP bestaat uit in ieder geval vier delen:
– Huidige situatie;
– Gewenste situatie;
– Strategie om van huidige naar gewenste situatie te komen.
– Implementatie (geen aanbevelingen)

Dit geldt voor alle hierboven genoemde items (Inhoud, Institutie en Relatie).

Het is belangrijk om bij het opstellen van het plan zoveel mogelijk uit te gaan van lokale materialen en technieken en de aanwezige kwaliteiten van de bewoners!</td></tr>
<tr><td>Project resultaat</td><td>SAP met 5 jaren plan klaar voor implementatie 2014-2018</td></tr>
<tr><td>Partners</td><td>Karen en Lisu (lokale stammen), CMU, WUR, TUD, HvA, Rijkszwaan, Lokale overheid, Stichting Buffelen, Tauw BV, WaterWegen</td></tr>
<tr><td>Duur</td><td>3-6 maanden</td></tr>
<tr><td>Start</td><td>Januari 2014</td></tr>
</table>

Appendix 2: Description NOAA-GHCN database

GHCN (Global Historical Climatology Network) – Daily Documentation

I. Description

GHCN (Global Historical Climatology Network)-Daily is a database that addresses the critical need for historical daily temperature, precipitation, and snow records over global land areas. GHCN-Daily is a composite of climate records from numerous sources that were merged and then subjected to a suite of quality assurance reviews. The archive includes over 40 meteorological elements (see Table 4 below for complete list) including temperature daily maximum/minimum, temperature at observation time, precipitation, snowfall, snow depth, evaporation, wind movement, wind maximums, soil temperature, cloudiness, and more.

GHCN-Daily will serve as a replacement product for older NCDC-maintained data sets that are designated for daily temporal resolution (i.e. DSI 3200, DSI 3201, DSI 3202, DSI 3205, DSI 3206, DSI 3208, DSI 3210, etc.). It will function as the official archive for daily data from the Global Climate Observing System (GCOS) Surface Network (GSN) and is particularly well suited for monitoring and assessment activities related to the frequency and magnitude of extremes. Containing observations of one or more of the above elements at more than 40,000 stations that are distributed across all continents, the dataset is the world's largest collection of daily climatological data. The total of 1.4 billion data values includes 250 million values each for maximum and minimum temperatures, 500 million precipitation totals, and 200 million observations each for snowfall and snow depth. Station records, some of which extend back to the 19th century, are updated daily where possible and are usually available one to two days after the date and time of the observation.

Some of the data provided here are based on data exchanged under the World Meteorological Organization (WMO) World Weather Watch Program according to WMO Resolution 40 (Cg-XII). This allows WMO member countries to place restrictions on the use or re-export of their data for commercial purposes outside of the receiving country. Those countries' data summaries and products which are available here are intended for free and unrestricted use in research, education, and other non-commercial activities. For non-U.S. locations data, the data or any derived product shall not be provided to other users or be used for the re-export of commercial services.

II. Format/Observation Definitions

(note: the term 'element 'or 'value' is used throughout this documentation and refers to an individual meteorological/climatological measurement or statistical value such as temperature, precipitation (amount), etc.)

Users are given the choice between the following two delivery formats:

1) GHCN-Daily Form- Portable Document Format (PDF) output giving 5 core values (see Table 1) and, if available, the following additional values: TOBS (temperature at the time of observation), EVAP (evaporation of water from evaporation pan), WDMV (24-hour wind movement), SN*# (minimum soil temperature) and SX*# (maximum soil temperature). More details about these values are in Table 4 (below). There are no flags (attributes) given with the GHCN- Daily Form pdf file other than

measurement flag “T” (trace value for precipitation, snowfall or snow depth, as per table 3 below). Temperature/soil temperature data on GHCN- Daily Form pdf file is to tenths of degrees Fahrenheit and precipitation/evaporation/snowfall/snow depth values are in inches, tenths of inches, and hundredths of inches. Wind movement values are in miles. Because these values are converted from SI units, rounding can cause minor deviations from what is shown in ASCII output form described next or original forms. Empty, or blank, cells indicate that a data observation was not reported.

2) Custom GHCN-Daily CSV- Output files contain .csv extension and optimized for spreadsheet usage (i.e. delimited file). The user is given the choice whether to include flags, station name or geographic location in data request. The user can define which of the elements listed in Table 4 (below) to include in the data request.

3) Custom GHCN-Daily ASCII Form-Output is ASCII text file and the user is given the choice whether to include flags, station name or geographic location in data request. The user can define which of the elements listed in Table 4 (below) to include in the data request.

Table 1 (observation/value)

Note: 9’s in a field (e.g.9999) indicate missing data or data that has not been received.

The five core values are:

PRCP = Precipitation (tenths of mm, inches to hundredths on Daily Form pdf file)
SNOW = Snowfall (mm, inches to tenths on Daily Form pdf file)
SNWD = Snow depth (mm, inches on Daily Form pdf file)
TMAX = Maximum temperature
TMIN = Minimum temperature

Appendix 3: Curve Number & IGBP Land use classes

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]	77	86	91	94	
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1] Average runoff condition, and $I_a = 0.2S$.

[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition, and I_a=0.2s

[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

[3] Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. 2/	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. 3/	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 4/	48	65	73
Woods—grass combination (orchard or tree farm). 5/	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. 6/	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 4/	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.

2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.

3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

4 Actual curve number is less than 30; use CN = 30 for runoff computations.

5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition [2]	A [3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

1 Average runoff condition, and I_a, = 0.2S. For range in humid regions, use table 2-2c.
2 Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: > 70% ground cover.
3 Curve numbers for group A have been developed only for desert shrub.

Figure 27: Overview of the Curve Number land use classen and their description

Table 12: IGBP land cover legend and description

IGBP Land Cover Legend		
Value	**Type**	**Description**
0	Water Bodies	Oceans, seas, lakes, reservoirs, and rivers. Can be either fresh or salt water bodies.
1	Evergreen Needleleaf Forest	Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Almost all trees remain green all year. Canopy is never without green foliage.
2	Evergreen Broadleaf Forest	Lands dominated by trees with percent canopy cover >60% and height exceeding 2 meters. Almost all trees remain green year all year. Canopy is never without green foliage.
3	Deciduous Needleleaf Forest	Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Consists of seasonal needleleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
4	Deciduous Broadleaf Forest	Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Consists of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
5	Mixed Forest	Lands dominated by trees with a percent canopy cover >60% and height exceeding 2 meters. Consists of tree communities with interspersed mixtures or mosaics of the other four forest cover types. None of the forest types exceeds 60% of landscape.
6	Closed Shrublands	Lands with woody vegetation less than 2 meters tall and with shrub canopy cover is >60%. The shrub foliage can be either evergreen or deciduous.
7	Open Shrublands	Lands with woody vegetation less than 2 meters tall and with shrub canopy cover is between 10-60%. The shrub foliage can be either evergreen or deciduous.
8	Woody Savannas	Lands with herbaceous and other understory systems and forest canopy cover of 30-60%. The forest cover height exceeds 2 meters.
9	Savannas	Lands with herbaceous and other understory systems and forest canopy cover of 10-30%. The forest cover height exceeds 2 meters.
10	Grasslands	Lands with herbaceous types of cover. Tree and shrub cover is less than 10%.
11	Permanent Wetlands	Lands with a permanent mixture of surface water and herbaceous or woody vegetation. The vegetation can be present in either salt, brackish, or fresh water.
12	Croplands	Lands covered with temporary crops followed by harvest and a bare soil period (e.g., single and multiple cropping systems). Note that perennial woody crops will be classified as the appropriate forest or shrub land cover type.
13	Urban and Built-Up	Land primarily covered by buildings and other man-made structures.

14	Cropland/Natural Vegetation Mosaic	Lands with a mosaic of croplands, forests, shrublands, and grasslands in which no one component comprises more than 60% of the landscape.
15	Permanent Snow and Ice	Lands under snow and/or ice cover throughout the year.
16	Barren or Sparsely Vegetated	Lands with exposed soil, sand, rocks, or snow that never has more than 10% vegetated cover during any time of the year.

Appendix 4: Photographs and characteristics of the Rehbock weirs

Figure 28: Rehbock weir 1, overview and zoom in after the installation of the weir. The weir can be seen as the dark brown color between the two black lines. The lower line is the bottom of the river and upper the weir crest. The weir was tightened between the concrete construction.

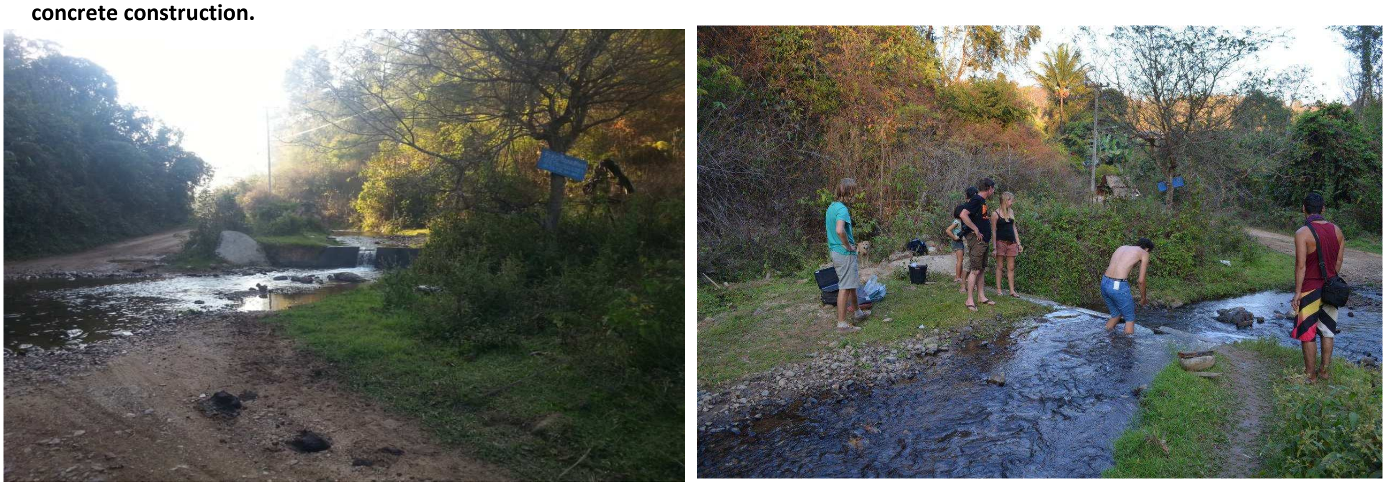


Figure 29: Rehbock weir 2, first image is taken downstream in upstream direction. Second image is taken in opposite direction during the installation of the weir. The same principle of construction the weir was applied as in Rehbock weir 1.

Table 13: Overview of the characteristics of both weirs and the check of the boundary conditions.

Rehbockstuw	B_1 [m]	b_c [m]	h_1 [m]	p_1 [m]	$B_1 - b_c$ [m]	h_1/p_1	h_1/b_c
Location 1	2	1,035	0,07 – 0,15	0,24	0,965	0,29 – 0,63	0,07 – 0,15
Location 2	3	0,59	0,09 – 0,15	0,24	2,41	0,38 – 0,63	0,15 – 0,25

Figure 30: Injection point and measuring point of the slug tracer method. The circles represent the injection points and the arrows the measuring points.

Appendix 5: Overview of daily cumulative precipitation

Table 14; Daily cumulative amount of precipitation in millimeters

Date	2012	2030 B1	2030 A2	2060 B1	2060 A2
2-1-2012	0	0.0072	0	0.2433	0
3-1-2012	6.4	6.4072	6.385143	6.6433	6.369524
11-1-2012	0	0.0072	0	0.2433	0
12-1-2012	0	0.0072	0	0.2433	0
13-1-2012	2	2.0072	1.985143	2.2433	1.969524
14-1-2012	0.3	0.3072	0.285143	0.5433	0.269524
15-1-2012	0	0.0072	0	0.2433	0
16-1-2012	0	0.0072	0	0.2433	0
17-1-2012	0	0.0072	0	0.2433	0
18-1-2012	0	0.0072	0	0.2433	0
19-1-2012	0	0.0072	0	0.2433	0
22-1-2012	0	0.0072	0	0.2433	0
23-1-2012	0	0.0072	0	0.2433	0
24-1-2012	0	0.0072	0	0.2433	0
25-1-2012	0	0.0072	0	0.2433	0
26-1-2012	0	0.0072	0	0.2433	0
27-1-2012	0	0.0072	0	0.2433	0
28-1-2012	0	0.0072	0	0.2433	0
29-1-2012	0	0.0072	0	0.2433	0
30-1-2012	0	0.0072	0	0.2433	0
31-1-2012	0	0.0072	0	0.2433	0
2-2-2012	0	0	0	0	0
4-2-2012	0	0	0	0	0
5-2-2012	0	0	0	0	0
6-2-2012	0	0	0	0	0
7-2-2012	0	0	0	0	0
8-2-2012	0	0	0	0	0
9-2-2012	0	0	0	0	0
10-2-2012	0	0	0	0	0
11-2-2012	0	0	0	0	0
12-2-2012	0	0	0	0	0
13-2-2012	0	0	0	0	0
14-2-2012	0	0	0	0	0
15-2-2012	0	0	0	0	0
16-2-2012	0	0	0	0	0
17-2-2012	0	0	0	0	0
19-2-2012	0	0	0	0	0
20-2-2012	0	0	0	0	0
21-2-2012	0	0	0	0	0
22-2-2012	0	0	0	0	0
23-2-2012	0	0	0	0	0
24-2-2012	0	0	0	0	0
25-2-2012	0	0	0	0	0
26-2-2012	0	0	0	0	0
27-2-2012	0	0	0	0	0
28-2-2012	0	0	0	0	0
29-2-2012	0	0	0	0	0
1-3-2012	0	0	0	0	0
2-3-2012	0	0	0	0	0
3-3-2012	0	0	0	0	0
4-3-2012	0	0	0	0	0
5-3-2012	0	0	0	0	0
6-3-2012	0	0	0	0	0

7-3-2012	0	0	0	0	0
8-3-2012	0	0	0	0	0
9-3-2012	0	0	0	0	0
11-3-2012	0	0	0	0	0
12-3-2012	0	0	0	0	0
13-3-2012	3.8	3.74288	3.69704	3.8	3.8
14-3-2012	2.8	2.74288	2.69704	2.8	2.8
15-3-2012	0	0	0	0	0
16-3-2012	0	0	0	0	0
17-3-2012	0	0	0	0	0
18-3-2012	0	0	0	0	0
19-3-2012	0	0	0	0	0
20-3-2012	0	0	0	0	0
21-3-2012	0	0	0	0	0
22-3-2012	0	0	0	0	0
23-3-2012	0	0	0	0	0
24-3-2012	0	0	0	0	0
25-3-2012	0	0	0	0	0
26-3-2012	0	0	0	0	0
27-3-2012	0	0	0	0	0
28-3-2012	0	0	0	0	0
29-3-2012	0	0	0	0	0
30-3-2012	0	0	0	0	0
31-3-2012	0	0	0	0	0
1-4-2012	0	0.05712	0.01664	0.091913	0.034133
2-4-2012	0	0.05712	0.01664	0	0.034133
3-4-2012	0	0.05712	0.01664	0	0.034133
4-4-2012	0	0.05712	0.01664	0	0.034133
5-4-2012	50.5	50.55712	50.51664	50.5	50.53413
6-4-2012	36.8	36.85712	36.81664	36.8	36.83413
7-4-2012	0	0.05712	0.01664	0	0.034133
8-4-2012	0	0.05712	0.01664	0	0.034133
9-4-2012	0	0.05712	0.01664	0	0.034133
10-4-2012	0	0.05712	0.01664	0	0.034133
11-4-2012	0	0.05712	0.01664	0	0.034133
12-4-2012	0	0.05712	0.01664	0	0.034133
13-4-2012	0	0.05712	0.01664	0	0.034133
14-4-2012	0	0.05712	0.01664	0	0.034133
15-4-2012	0	0.05712	0.01664	0	0.034133
16-4-2012	0	0.05712	0.01664	0	0.034133
17-4-2012	0	0.05712	0.01664	0	0.034133
18-4-2012	0	0.05712	0.01664	0	0.034133
19-4-2012	0	0.05712	0.01664	0	0.034133
20-4-2012	0	0.05712	0.01664	0	0.034133
21-4-2012	0	0.05712	0.01664	0	0.034133
22-4-2012	13.7	13.75712	13.71664	13.7	13.73413
23-4-2012	0	0.05712	0.01664	0	0.034133
24-4-2012	11.7	11.75712	11.71664	11.7	11.73413
25-4-2012	0	0.05712	0.01664	0	0.034133
26-4-2012	0	0.05712	0.01664	0	0.034133
27-4-2012	0.5	0.55712	0.51664	0.5	0.534133
28-4-2012	14.7	14.75712	14.71664	14.7	14.73413
29-4-2012	8.9	8.95712	8.91664	8.9	8.934133
30-4-2012	0	0.05712	0.01664	0	0.034133
1-5-2012	8.1	8.0496	7.96111	8.0189	7.815097
2-5-2012	0	0	0	0	0
3-5-2012	0	0	0	0	0
4-5-2012	3.6	3.5496	3.46111	3.5189	3.315097
5-5-2012	20.1	20.0496	19.96111	20.0189	19.8151
6-5-2012	15.2	15.1496	15.06111	15.1189	14.9151

7-5-2012	13.2	13.1496	13.06111	13.1189	12.9151
8-5-2012	2.5	2.4496	2.36111	2.4189	2.215097
9-5-2012	0.8	0.7496	0.66111	0.7189	0.515097
10-5-2012	0	0	0	0	0
11-5-2012	0	0	0	0	0
12-5-2012	0	0	0	0	0
13-5-2012	0	0	0	0	0
14-5-2012	0	0	0	0	0
15-5-2012	9.9	9.8496	9.76111	9.8189	9.615097
16-5-2012	1	0.9496	0.86111	0.9189	0.715097
17-5-2012	0.8	0.7496	0.66111	0.7189	0.515097
18-5-2012	0	0	0	0	0
19-5-2012	0	0	0	0	0
20-5-2012	0	0	0	0	0
21-5-2012	0.3	0.2496	0.16111	0.2189	0.015097
22-5-2012	0	0	0	0	0
23-5-2012	4.1	4.0496	3.96111	4.0189	3.815097
24-5-2012	63.8	63.7496	63.66111	63.7189	63.5151
25-5-2012	24.9	24.8496	24.76111	24.8189	24.6151
26-5-2012	3.3	3.2496	3.16111	3.2189	3.015097
27-5-2012	7.9	7.8496	7.76111	7.8189	7.615097
28-5-2012	0	0	0	0	0
29-5-2012	55.6	55.5496	55.46111	55.5189	55.3151
30-5-2012	3.6	3.5496	3.46111	3.5189	3.315097
31-5-2012	7.1	7.0496	6.96111	7.0189	6.815097
1-6-2012	0.5	0.038	0	0	0
2-6-2012	9.4	8.938	8.36936	8.656583	7.285867
3-6-2012	13.5	13.038	12.46936	12.75658	11.38587
4-6-2012	51.6	51.138	50.56936	50.85658	49.48587
5-6-2012	22.4	21.938	21.36936	21.65658	20.28587
6-6-2012	22.1	21.638	21.06936	21.35658	19.98587
7-6-2012	37.3	36.838	36.26936	36.55658	35.18587
8-6-2012	4.1	3.638	3.06936	3.356583	1.985867
9-6-2012	2.5	2.038	1.46936	1.756583	0.385867
10-6-2012	1.8	1.338	0.76936	1.056583	0
11-6-2012	3.6	3.138	2.56936	2.856583	1.485867
12-6-2012	3.8	3.338	2.76936	3.056583	1.685867
13-6-2012	2	1.538	0.96936	1.256583	0
14-6-2012	24.1	23.638	23.06936	23.35658	21.98587
15-6-2012	1.3	0.838	0.26936	0.556583	0
16-6-2012	0.3	0	0	0	0
17-6-2012	0	0	0	0	0
18-6-2012	3.3	2.838	2.26936	2.556583	1.185867
19-6-2012	1.8	1.338	0.76936	1.056583	0
20-6-2012	2	1.538	0.96936	1.256583	0
21-6-2012	3	2.538	1.96936	2.256583	0.885867
22-6-2012	23.9	23.438	22.86936	23.15658	21.78587
23-6-2012	6.6	6.138	5.56936	5.856583	4.485867
24-6-2012	13.2	12.738	12.16936	12.45658	11.08587
25-6-2012	7.6	7.138	6.56936	6.856583	5.485867
26-6-2012	16.3	15.838	15.26936	15.55658	14.18587
27-6-2012	2	1.538	0.96936	1.256583	0
28-6-2012	4.3	3.838	3.26936	3.556583	2.185867
29-6-2012	2	1.538	0.96936	1.256583	0
30-6-2012	0.5	0.038	0	0	0
1-7-2012	0.3	0	0	0	0
2-7-2012	0.8	0.335019	0.254503	0.051787	0
3-7-2012	2.8	2.335019	2.254503	2.051787	1.681032
4-7-2012	2.3	1.835019	1.754503	1.551787	1.181032
5-7-2012	16.3	15.83502	15.7545	15.55179	15.18103

6-7-2012	55.4	54.93502	54.8545	54.65179	54.28103
7-7-2012	11.4	10.93502	10.8545	10.65179	10.28103
8-7-2012	6.4	5.935019	5.854503	5.651787	5.281032
9-7-2012	13.2	12.73502	12.6545	12.45179	12.08103
10-7-2012	28.4	27.93502	27.8545	27.65179	27.28103
11-7-2012	0	0	0	0	0
12-7-2012	0	0	0	0	0
13-7-2012	0	0	0	0	0
14-7-2012	17	16.53502	16.4545	16.25179	15.88103
15-7-2012	9.9	9.435019	9.354503	9.151787	8.781032
16-7-2012	14.2	13.73502	13.6545	13.45179	13.08103
17-7-2012	10.7	10.23502	10.1545	9.951787	9.581032
18-7-2012	12.7	12.23502	12.1545	11.95179	11.58103
19-7-2012	5.8	5.335019	5.254503	5.051787	4.681032
20-7-2012	1.8	1.335019	1.254503	1.051787	0.681032
21-7-2012	4.1	3.635019	3.554503	3.351787	2.981032
22-7-2012	8.1	7.635019	7.554503	7.351787	6.981032
23-7-2012	31.5	31.03502	30.9545	30.75179	30.38103
24-7-2012	11.9	11.43502	11.3545	11.15179	10.78103
25-7-2012	2.5	2.035019	1.954503	1.751787	1.381032
26-7-2012	1.8	1.335019	1.254503	1.051787	0.681032
27-7-2012	23.4	22.93502	22.8545	22.65179	22.28103
28-7-2012	8.9	8.435019	8.354503	8.151787	7.781032
29-7-2012	6.1	5.635019	5.554503	5.351787	4.981032
30-7-2012	1.5	1.035019	0.954503	0.751787	0.381032
31-7-2012	16	15.53502	15.4545	15.25179	14.88103
1-8-2012	1	1.149574	1.040258	1.240684	1.082581
2-8-2012	2	2.149574	2.040258	2.240684	2.082581
3-8-2012	0	0.149574	0.040258	0.240684	0.082581
4-8-2012	3.3	3.449574	3.340258	3.540684	3.382581
5-8-2012	1.8	1.949574	1.840258	2.040684	1.882581
6-8-2012	5.6	5.749574	5.640258	5.840684	5.682581
7-8-2012	2.5	2.649574	2.540258	2.740684	2.582581
8-8-2012	20.6	20.74957	20.64026	20.84068	20.68258
9-8-2012	18.5	18.64957	18.54026	18.74068	18.58258
10-8-2012	8.4	8.549574	8.440258	8.640684	8.482581
11-8-2012	3.8	3.949574	3.840258	4.040684	3.882581
12-8-2012	3.3	3.449574	3.340258	3.540684	3.382581
13-8-2012	8.1	8.249574	8.140258	8.340684	8.182581
14-8-2012	0	0.149574	0.040258	0.240684	0.082581
15-8-2012	1.3	1.449574	1.340258	1.540684	1.382581
16-8-2012	8.6	8.749574	8.640258	8.840684	8.682581
17-8-2012	0.5	0.649574	0.540258	0.740684	0.582581
18-8-2012	3.8	3.949574	3.840258	4.040684	3.882581
19-8-2012	51.1	51.24957	51.14026	51.34068	51.18258
20-8-2012	22.1	22.24957	22.14026	22.34068	22.18258
21-8-2012	2.3	2.449574	2.340258	2.540684	2.382581
22-8-2012	4.1	4.249574	4.140258	4.340684	4.182581
23-8-2012	10.9	11.04957	10.94026	11.14068	10.98258
24-8-2012	22.6	22.74957	22.64026	22.84068	22.68258
25-8-2012	2.5	2.649574	2.540258	2.740684	2.582581
26-8-2012	1	1.149574	1.040258	1.240684	1.082581
27-8-2012	3	3.149574	3.040258	3.240684	3.082581
28-8-2012	1.5	1.649574	1.540258	1.740684	1.582581
29-8-2012	1.8	1.949574	1.840258	2.040684	1.882581
30-8-2012	0	0.149574	0.040258	0.240684	0.082581
31-8-2012	0	0.149574	0.040258	0.240684	0.082581
1-9-2012	0	0.00336	0	0.005407	0
2-9-2012	2	2.00336	1.82112	2.005407	1.633067
3-9-2012	0.3	0.30336	0.12112	0.305407	0

4-9-2012	4.8	4.80336	4.62112	4.805407	4.433067
5-9-2012	19.3	19.30336	19.12112	19.30541	18.93307
6-9-2012	1.8	1.80336	1.62112	1.805407	1.433067
7-9-2012	2.8	2.80336	2.62112	2.805407	2.433067
8-9-2012	6.9	6.90336	6.72112	6.905407	6.533067
9-9-2012	1.5	1.50336	1.32112	1.505407	1.133067
10-9-2012	27.7	27.70336	27.52112	27.70541	27.33307
11-9-2012	6.1	6.10336	5.92112	6.105407	5.733067
12-9-2012	3	3.00336	2.82112	3.005407	2.633067
13-9-2012	0	0.00336	0	0.005407	0
14-9-2012	65	65.00336	64.82112	65.00541	64.63307
15-9-2012	5.6	5.60336	5.42112	5.605407	5.233067
16-9-2012	0.3	0.30336	0.12112	0.305407	0
17-9-2012	3.8	3.80336	3.62112	3.805407	3.433067
18-9-2012	0	0.00336	0	0.005407	0
19-9-2012	0	0.00336	0	0.005407	0
20-9-2012	0	0.00336	0	0.005407	0
21-9-2012	0	0.00336	0	0.005407	0
22-9-2012	0	0.00336	0	0.005407	0
23-9-2012	0	0.00336	0	0.005407	0
24-9-2012	0.5	0.50336	0.32112	0.505407	0.133067
25-9-2012	0	0.00336	0	0.005407	0
26-9-2012	0.5	0.50336	0.32112	0.505407	0.133067
27-9-2012	3.3	3.30336	3.12112	3.305407	2.933067
28-9-2012	3.3	3.30336	3.12112	3.305407	2.933067
29-9-2012	2	2.00336	1.82112	2.005407	1.633067
30-9-2012	1.8	1.80336	1.62112	1.805407	1.433067
1-10-2012	0	0.055277	0.052335	0.088948	0.107355
2-10-2012	0.8	0.855277	0.852335	0.888948	0.907355
3-10-2012	6.1	6.155277	6.152335	6.188948	6.207355
4-10-2012	1.5	1.555277	1.552335	1.588948	1.607355
5-10-2012	3.3	3.355277	3.352335	3.388948	3.407355
6-10-2012	0	0.055277	0.052335	0.088948	0.107355
7-10-2012	0	0.055277	0.052335	0.088948	0.107355
8-10-2012	0	0.055277	0.052335	0.088948	0.107355
9-10-2012	0	0.055277	0.052335	0.088948	0.107355
10-10-2012	0	0.055277	0.052335	0.088948	0.107355
11-10-2012	2	2.055277	2.052335	2.088948	2.107355
12-10-2012	0	0.055277	0.052335	0.088948	0.107355
13-10-2012	0	0.055277	0.052335	0.088948	0.107355
14-10-2012	61.2	61.25528	61.25234	61.28895	61.30735
15-10-2012	3.8	3.855277	3.852335	3.888948	3.907355
16-10-2012	0	0.055277	0.052335	0.088948	0.107355
17-10-2012	1.5	1.555277	1.552335	1.588948	1.607355
18-10-2012	0	0.055277	0.052335	0.088948	0.107355
19-10-2012	0	0.055277	0.052335	0.088948	0.107355
20-10-2012	0	0.055277	0.052335	0.088948	0.107355
21-10-2012	0	0.055277	0.052335	0.088948	0.107355
22-10-2012	0	0.055277	0.052335	0.088948	0.107355
23-10-2012	0	0.055277	0.052335	0.088948	0.107355
24-10-2012	0	0.055277	0.052335	0.088948	0.107355
25-10-2012	0	0.055277	0.052335	0.088948	0.107355
26-10-2012	1.8	1.855277	1.852335	1.888948	1.907355
27-10-2012	17.5	17.55528	17.55234	17.58895	17.60735
28-10-2012	0	0.055277	0.052335	0.088948	0.107355
29-10-2012	0	0.055277	0.052335	0.088948	0.107355
30-10-2012	0	0.055277	0.052335	0.088948	0.107355
31-10-2012	0	0.055277	0.052335	0.088948	0.107355
1-11-2012	0	0	0	0	0
2-11-2012	0.8	0.54128	0.66064	0.383687	0.514133

3-11-2012	0.3	0.04128	0.16064	0	0.014133
4-11-2012	0.8	0.54128	0.66064	0.383687	0.514133
5-11-2012	0	0	0	0	0
6-11-2012	0	0	0	0	0
7-11-2012	0	0	0	0	0
8-11-2012	0	0	0	0	0
9-11-2012	0	0	0	0	0
10-11-2012	0	0	0	0	0
11-11-2012	0	0	0	0	0
12-11-2012	0	0	0	0	0
13-11-2012	0	0	0	0	0
14-11-2012	1	0.74128	0.86064	0.583687	0.714133
15-11-2012	0.5	0.24128	0.36064	0.083687	0.214133
16-11-2012	1	0.74128	0.86064	0.583687	0.714133
17-11-2012	0	0	0	0	0
18-11-2012	1.8	1.54128	1.66064	1.383687	1.514133
19-11-2012	1.5	1.24128	1.36064	1.083687	1.214133
20-11-2012	46	45.74128	45.86064	45.58369	45.71413
21-11-2012	0	0	0	0	0
23-11-2012	0	0	0	0	0
24-11-2012	0	0	0	0	0
25-11-2012	0	0	0	0	0
26-11-2012	0	0	0	0	0
27-11-2012	1	0.74128	0.86064	0.583687	0.714133
28-11-2012	0	0	0	0	0
29-11-2012	0	0	0	0	0
30-11-2012	1.5	1.24128	1.36064	1.083687	1.214133
1-12-2012	0	0	0.020129	0	0.04129
2-12-2012	6.9	6.872361	6.920129	6.855526	6.94129
3-12-2012	0.5	0.472361	0.520129	0.455526	0.54129
4-12-2012	0	0	0.020129	0	0.04129
6-12-2012	0	0	0.020129	0	0.04129
7-12-2012	0	0	0.020129	0	0.04129
9-12-2012	0	0	0.020129	0	0.04129
10-12-2012	0	0	0.020129	0	0.04129
11-12-2012	0	0	0.020129	0	0.04129
12-12-2012	0	0	0.020129	0	0.04129
13-12-2012	0	0	0.020129	0	0.04129
14-12-2012	0	0	0.020129	0	0.04129
15-12-2012	0	0	0.020129	0	0.04129
16-12-2012	0	0	0.020129	0	0.04129
17-12-2012	0	0	0.020129	0	0.04129
18-12-2012	0	0	0.020129	0	0.04129
19-12-2012	0	0	0.020129	0	0.04129
22-12-2012	0	0	0.020129	0	0.04129
23-12-2012	0	0	0.020129	0	0.04129
24-12-2012	0	0	0.020129	0	0.04129
25-12-2012	0	0	0.020129	0	0.04129
26-12-2012	0	0	0.020129	0	0.04129
27-12-2012	0	0	0.020129	0	0.04129
28-12-2012	0	0	0.020129	0	0.04129
29-12-2012	0	0	0.020129	0	0.04129
30-12-2012	0	0	0.020129	0	0.04129
31-12-2012	0	0	0.020129	0	0.04129

Appendix 6: Hydrographs and Flow Duration Curves

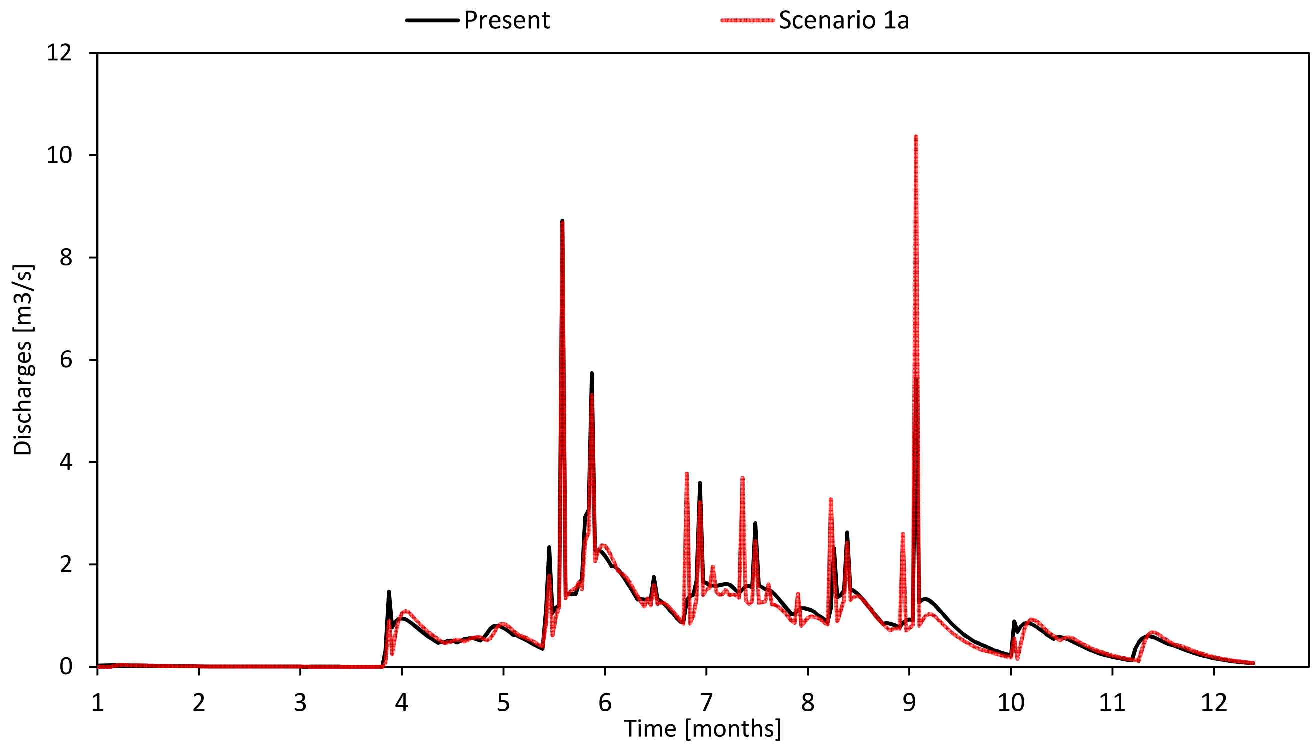
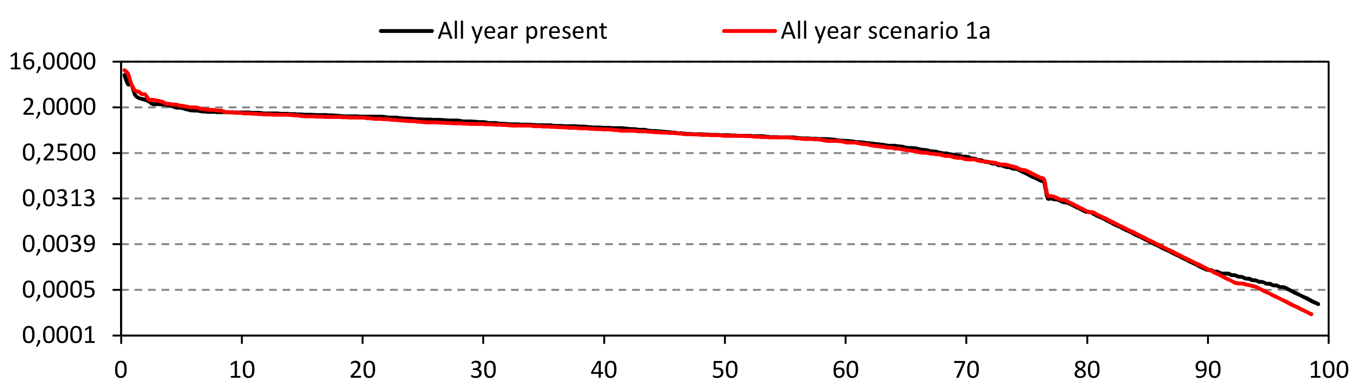
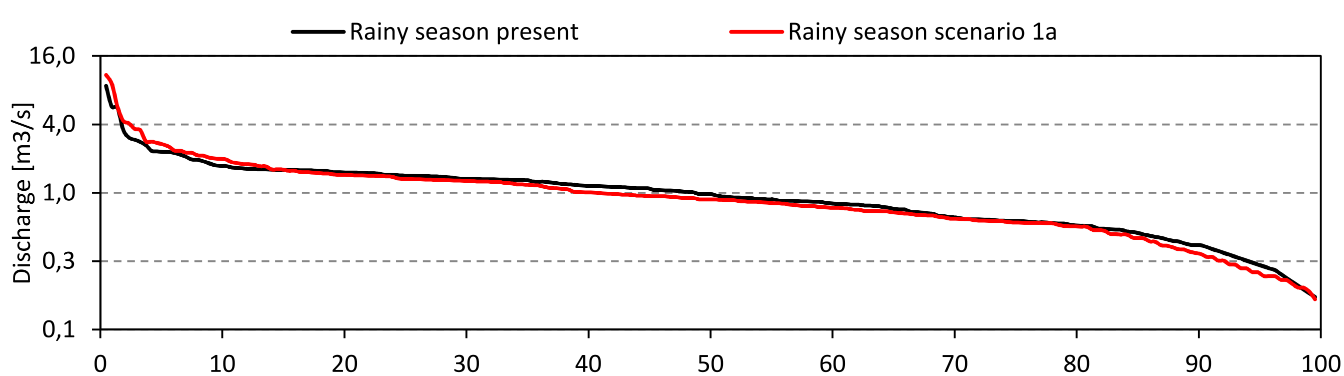


Figure 31: Hydrograph showing the simulated average daily discharges of the present and of scenario 1a in the Mea Pheam River.





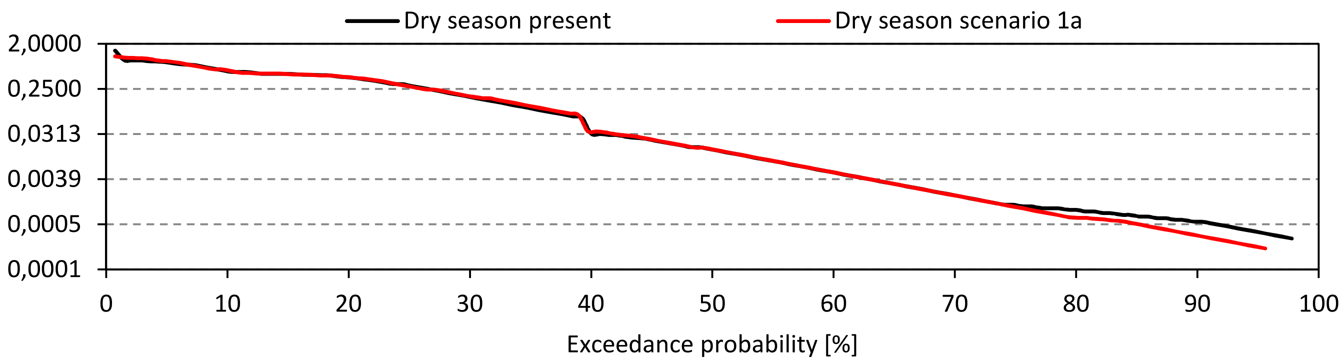


Figure 32: The FDCs of scenario 1a for the entire year and both seasons. The simulated discharges of the present are shown for comparison (black line). Note that the y-axis is given on a log-scale to better illustrate the difference between the scenario and the present.

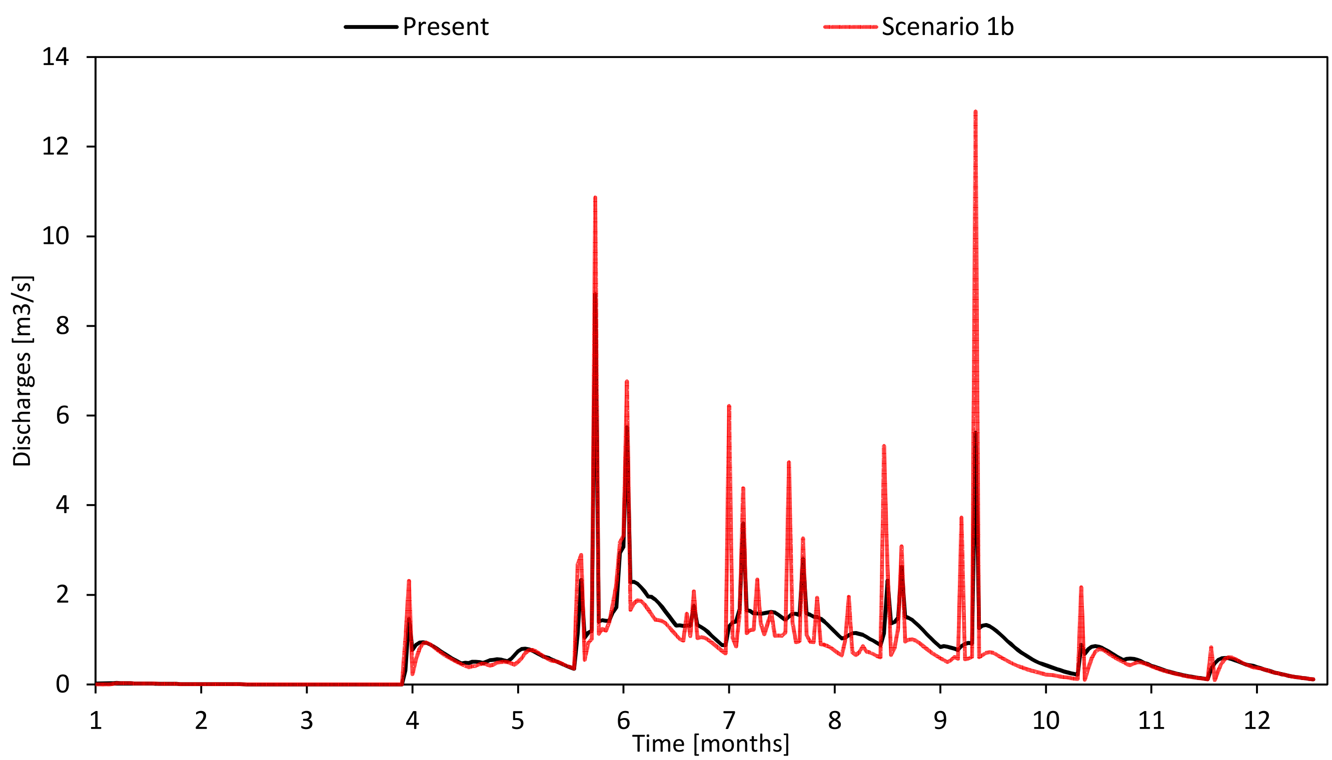
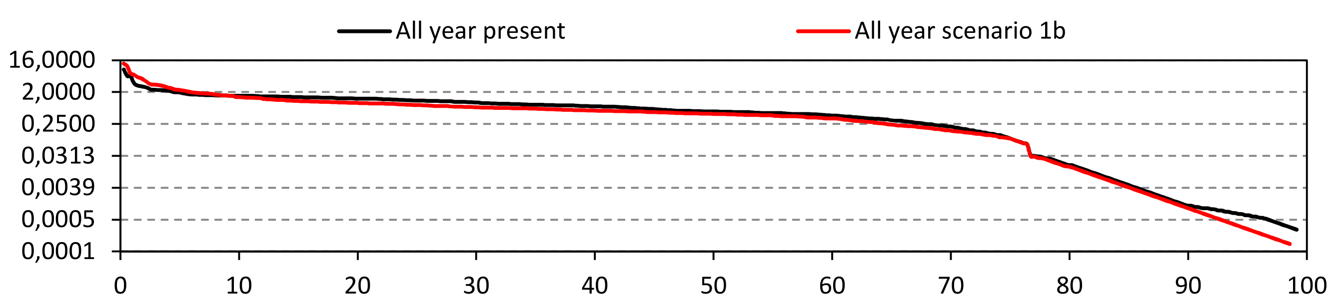


Figure 33: Hydrograph showing the simulated average daily discharges in the Mea Pheam River of the present and of scenario 1b.



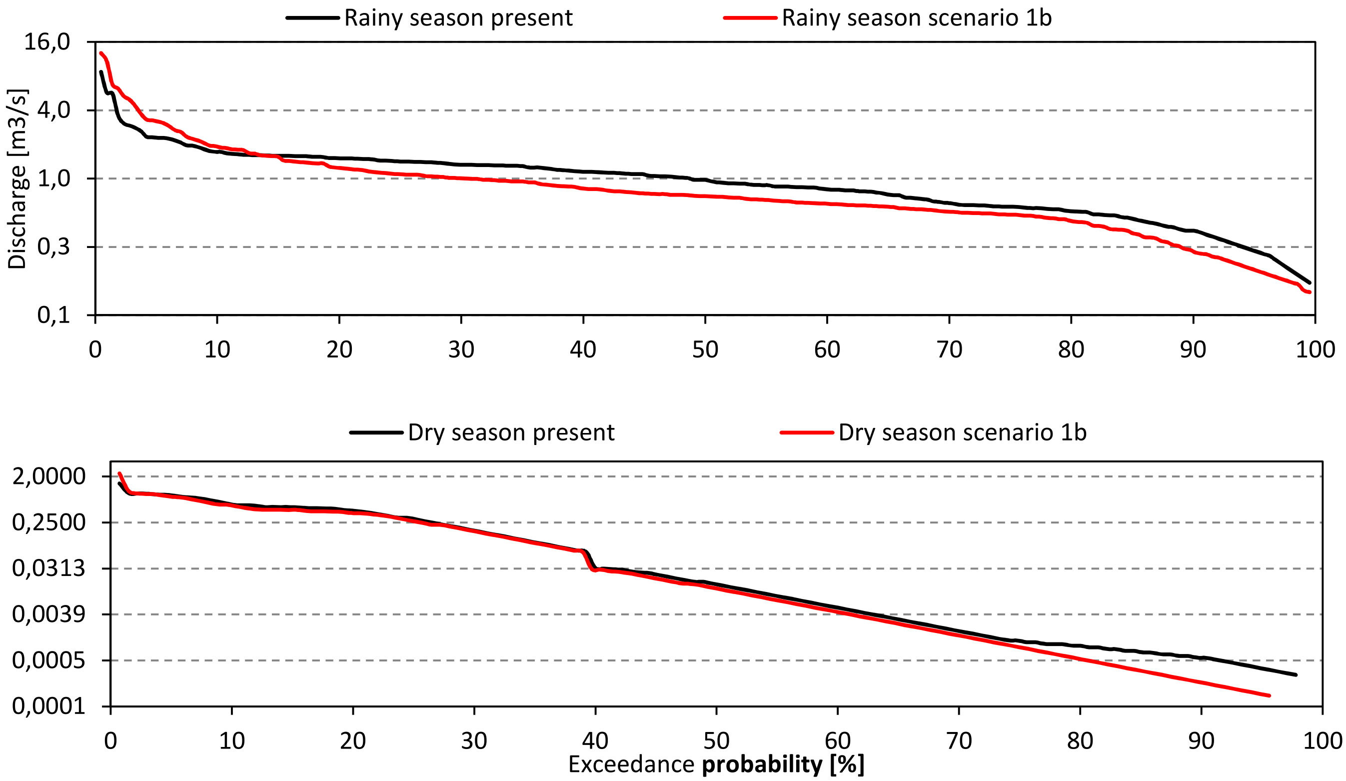


Figure 34: The FDCs of scenario 1b for the entire year and both seasons. The simulated discharges of the present are shown for comparison (black line). Note that the y-axis is given on a log-scale to better illustrate the difference between the scenario and the present.

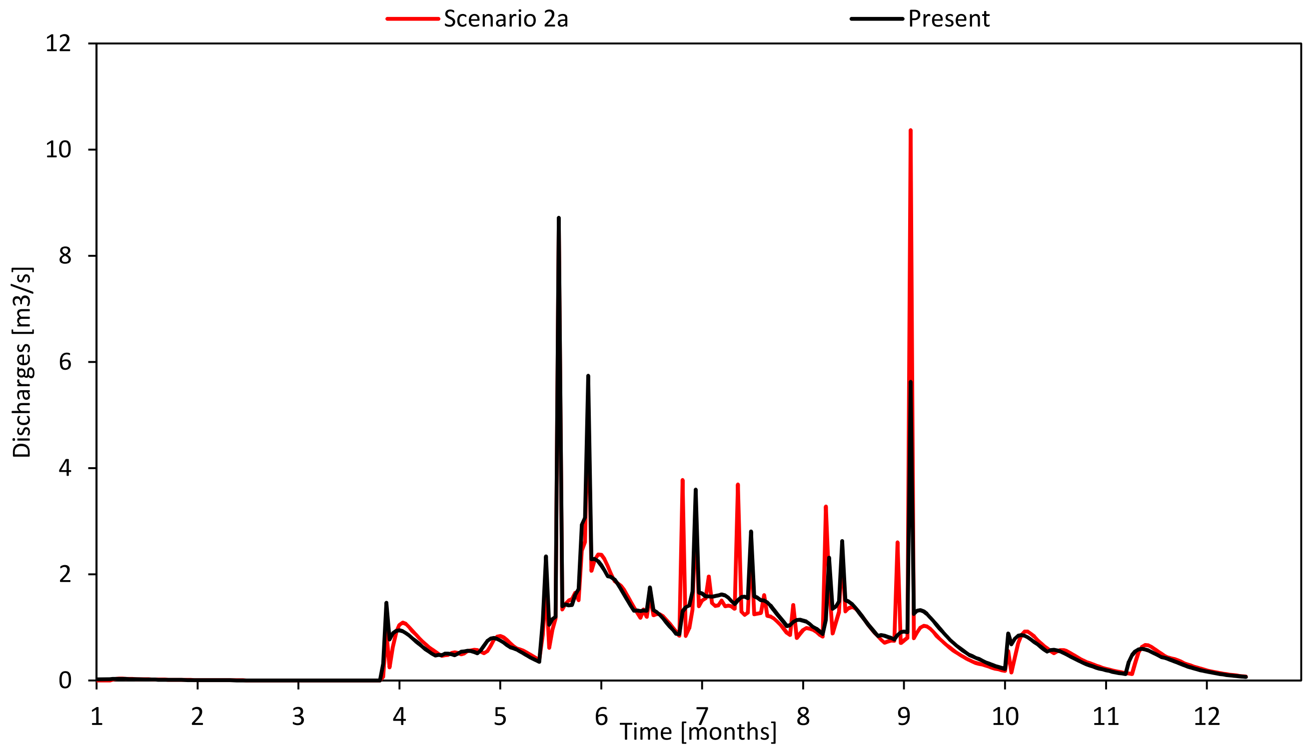
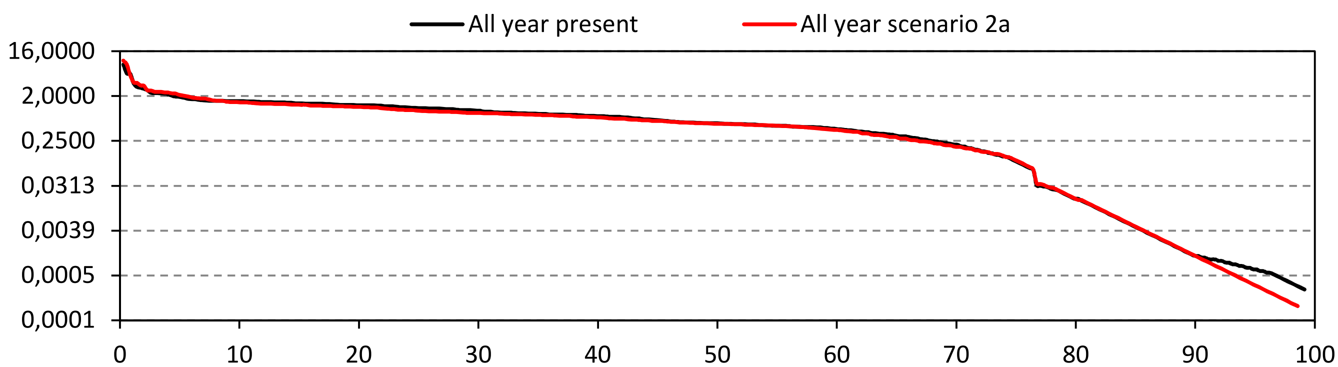


Figure 35: Hydrograph showing the simulated average daily discharges in the Mea Pheam River of the present and of scenario 2a.



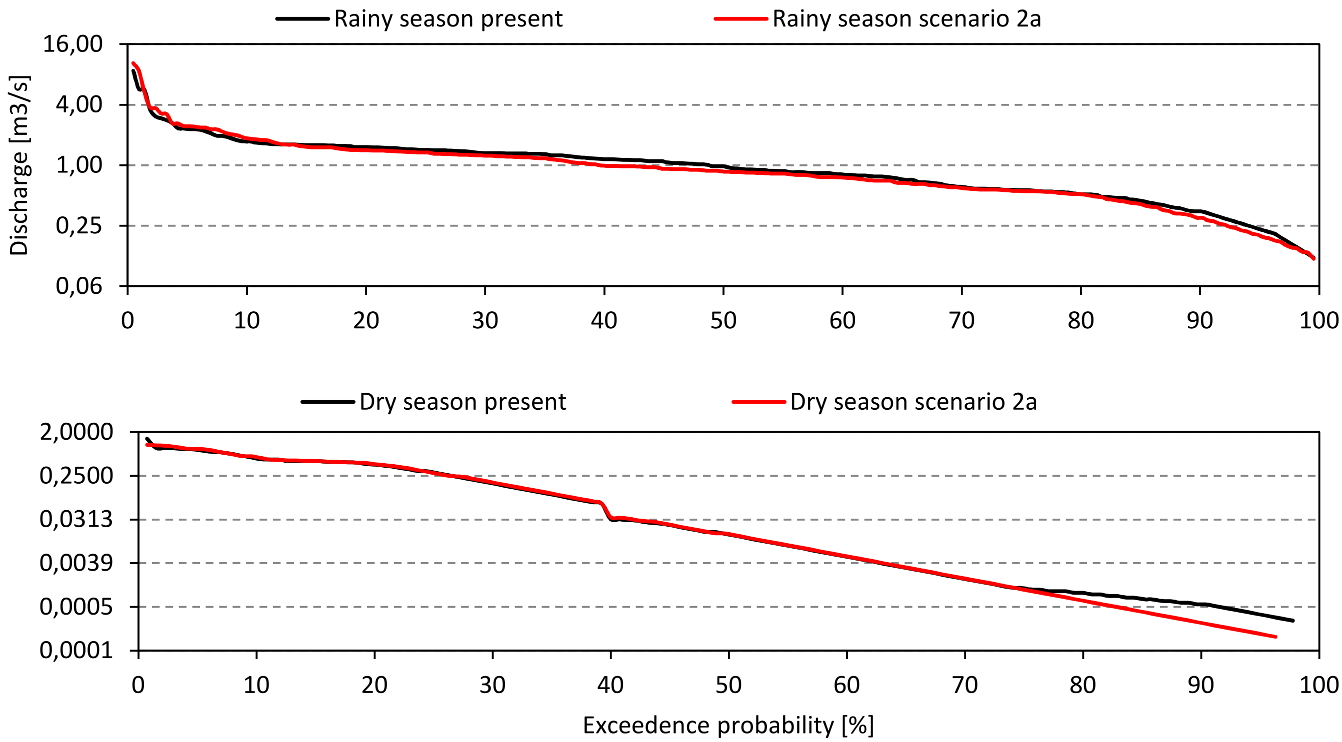


Figure 36: The FDCs of scenario 2a for the entire year and both seasons. The simulated discharges of the present are shown for comparison (black line). Note that the y-axis is given on a log-scale to better illustrate the difference between the scenario and the present.

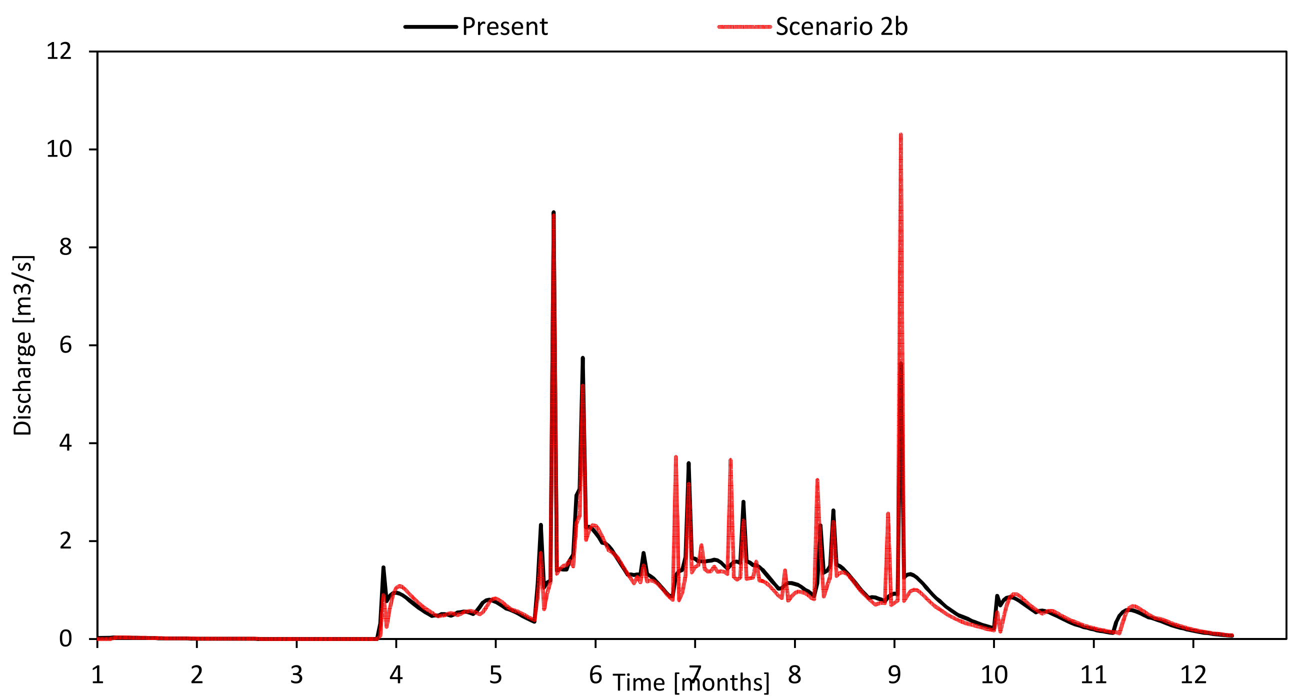


Figure 37: Hydrograph showing the simulated average daily discharges in the Mea Pheam River of the present and of scenario 2b.

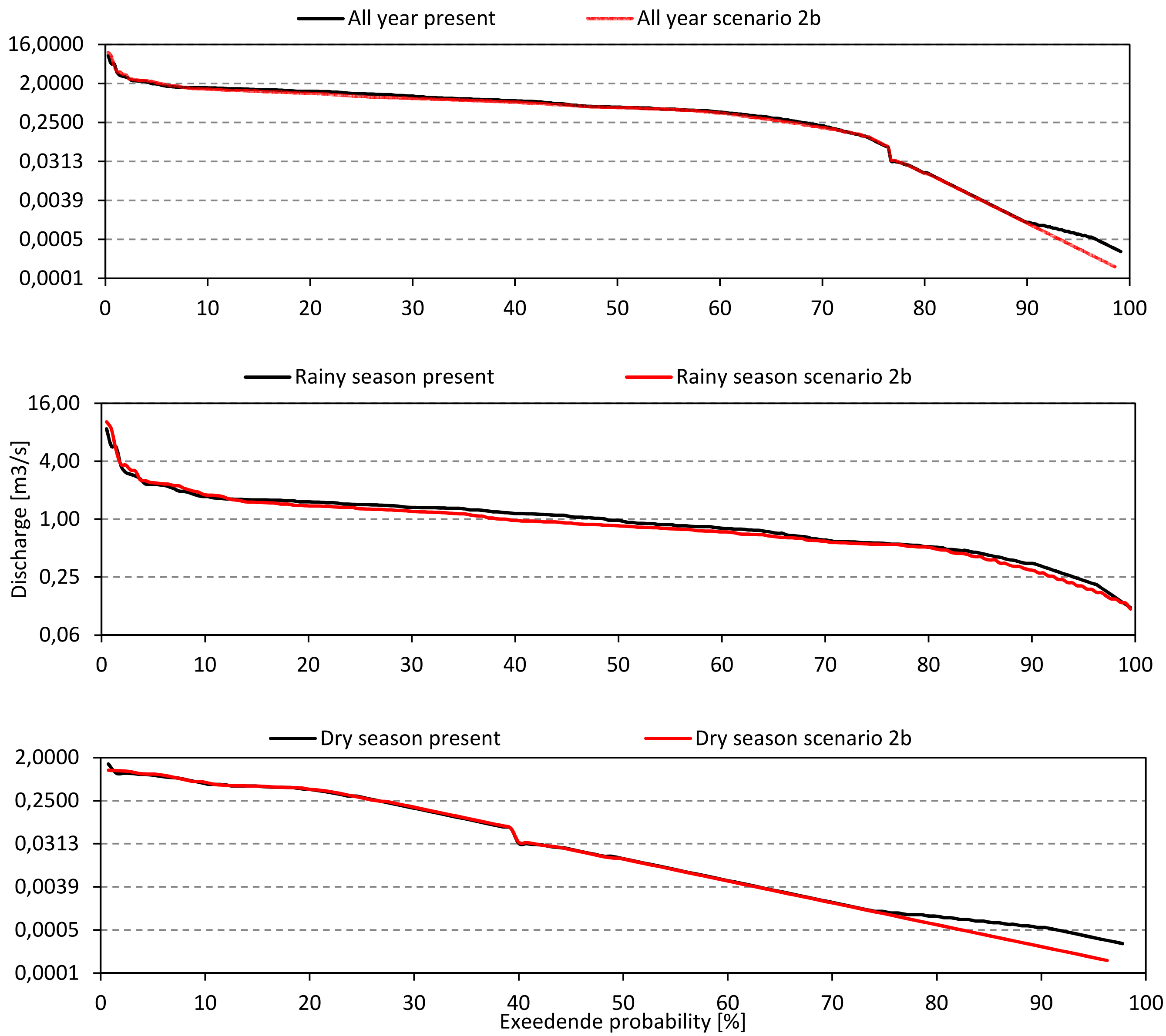


Figure 38: The FDCs of scenario 2b for the entire year and both seasons. The simulated discharges of the present are shown for comparison (black line). Note that the y-axis is given on a log-scale to better illustrate the difference between the scenario and the present.

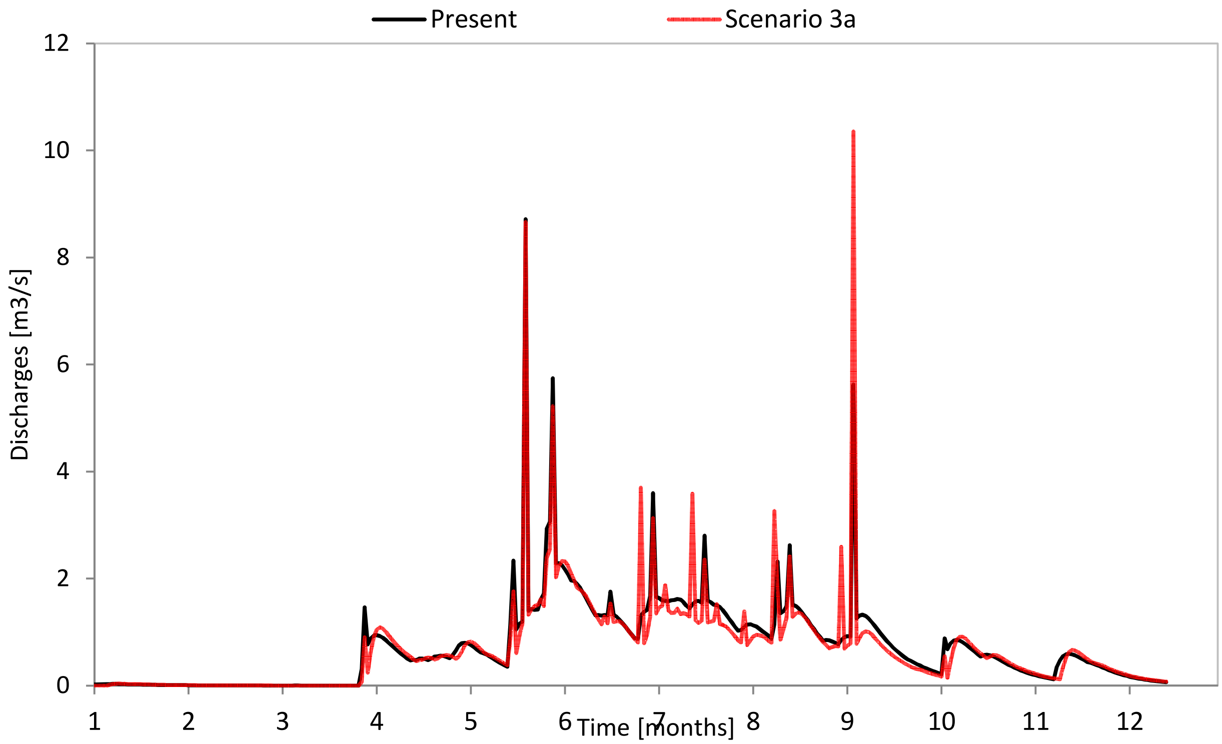
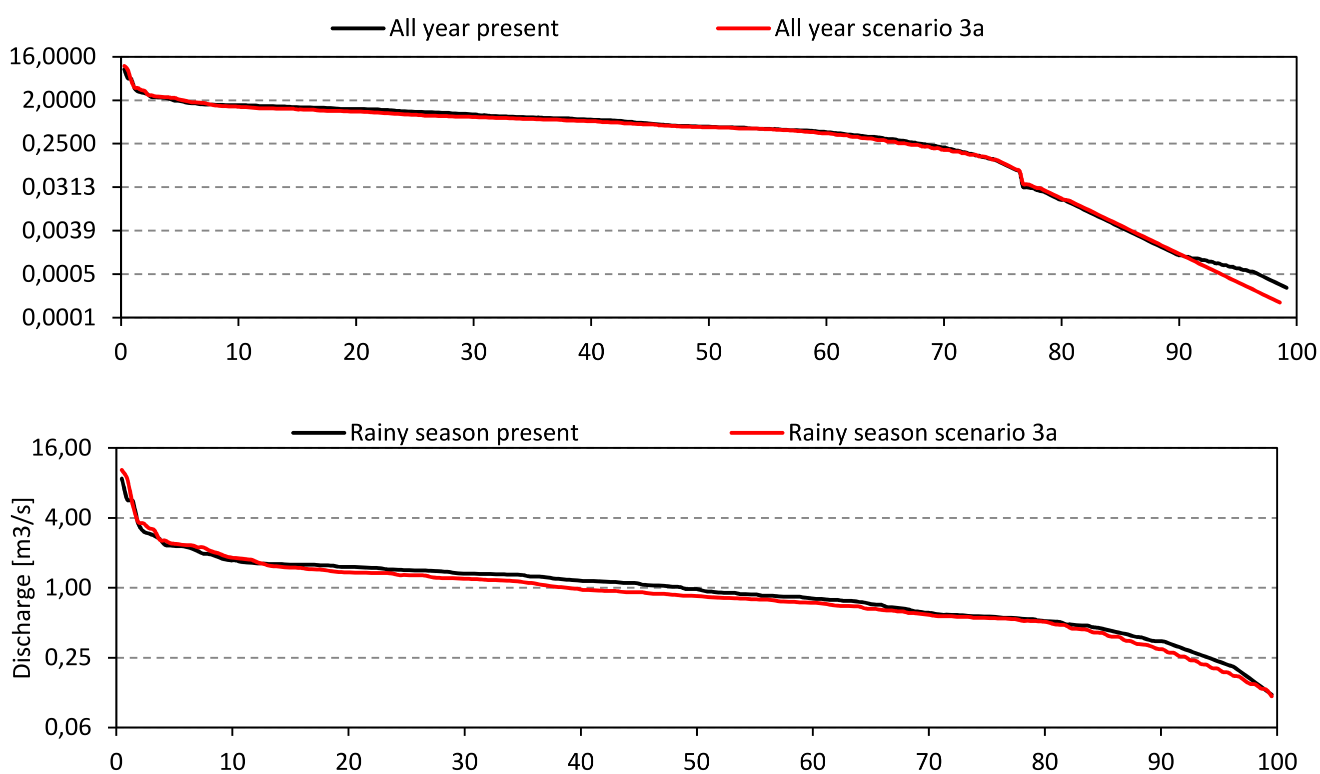


Figure 39: Hydrograph showing the simulated average daily discharges in the Mea Pheam River of the present and of scenario 3a



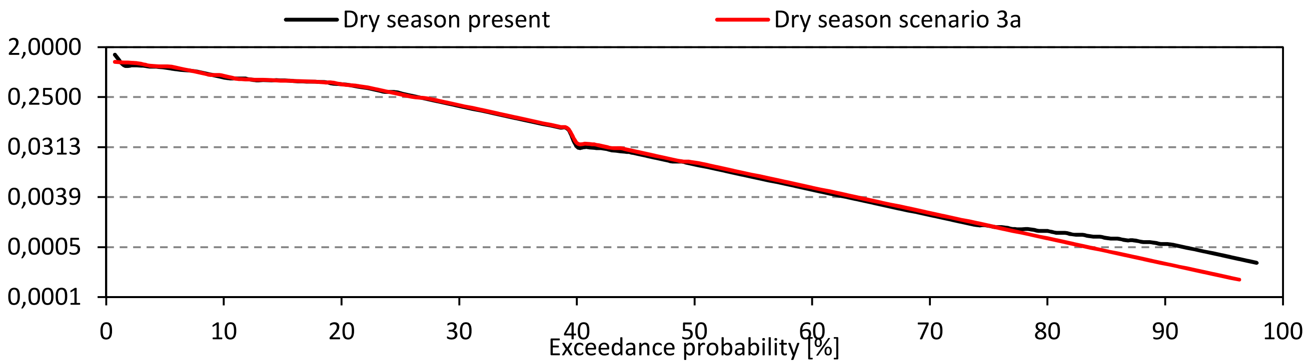


Figure 40: The FDCs of scenario 3a for the entire year and both seasons. The simulated discharges of the present are shown for comparison (black line). Note that the y-axis is given on a log-scale to better illustrate the difference between the scenario and the present.

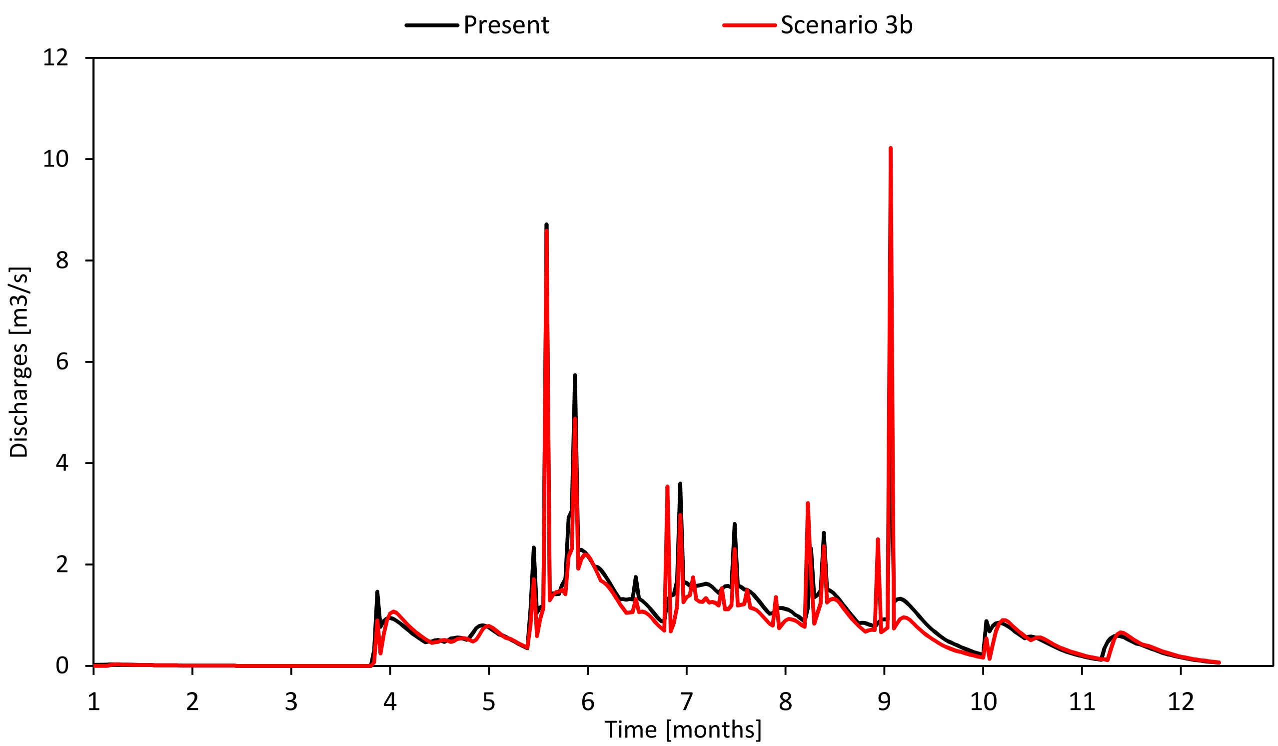


Figure 41: Hydrograph showing the simulated average daily discharges in the Mea Pheam River of the present and of scenario 3b

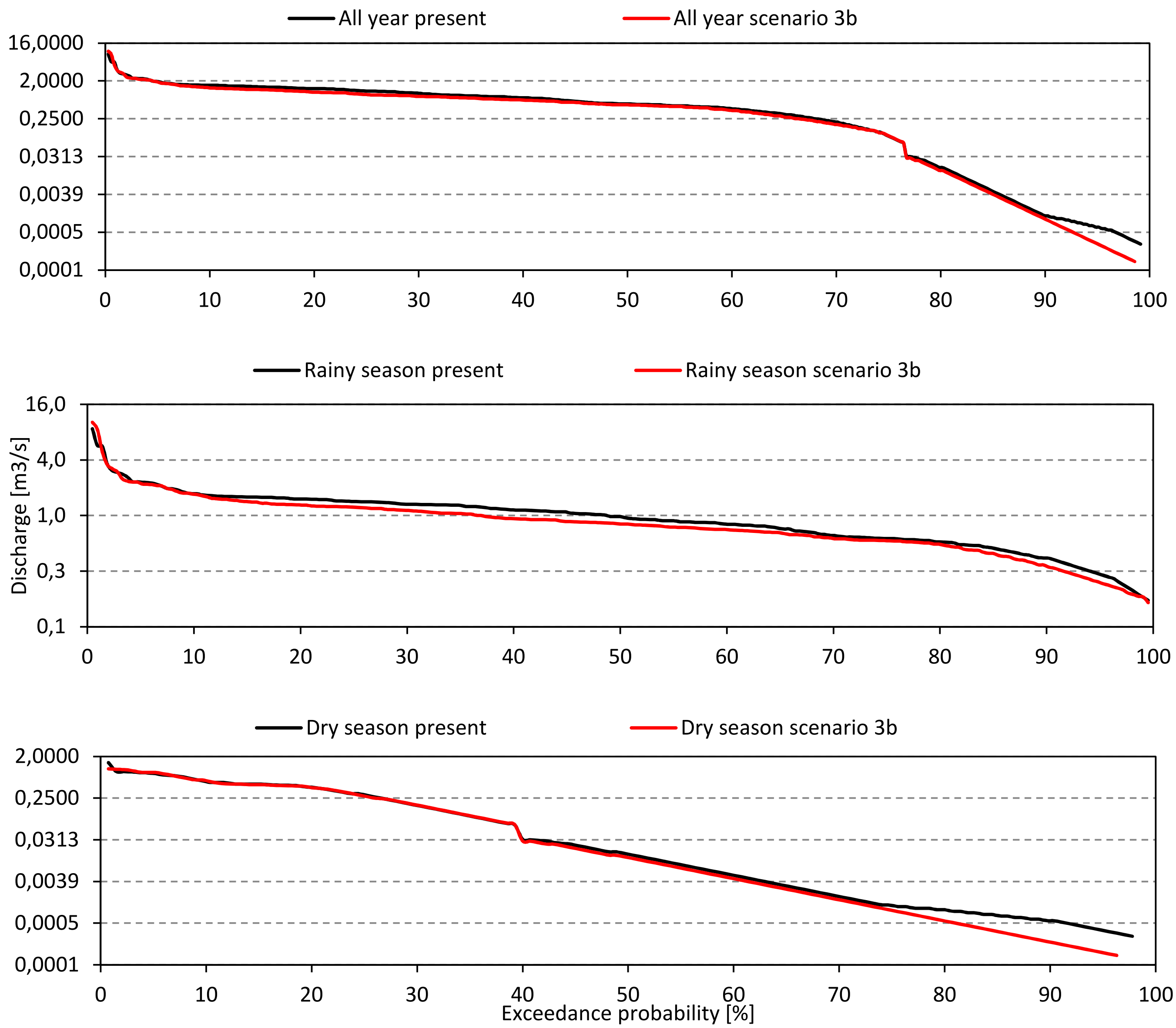


Figure 42: The FDCs of scenario 3b for the entire year and both seasons. The simulated discharges of the present are shown for comparison (black line). Note that the y-axis is given on a log-scale to better illustrate the difference between the scenario and the present.

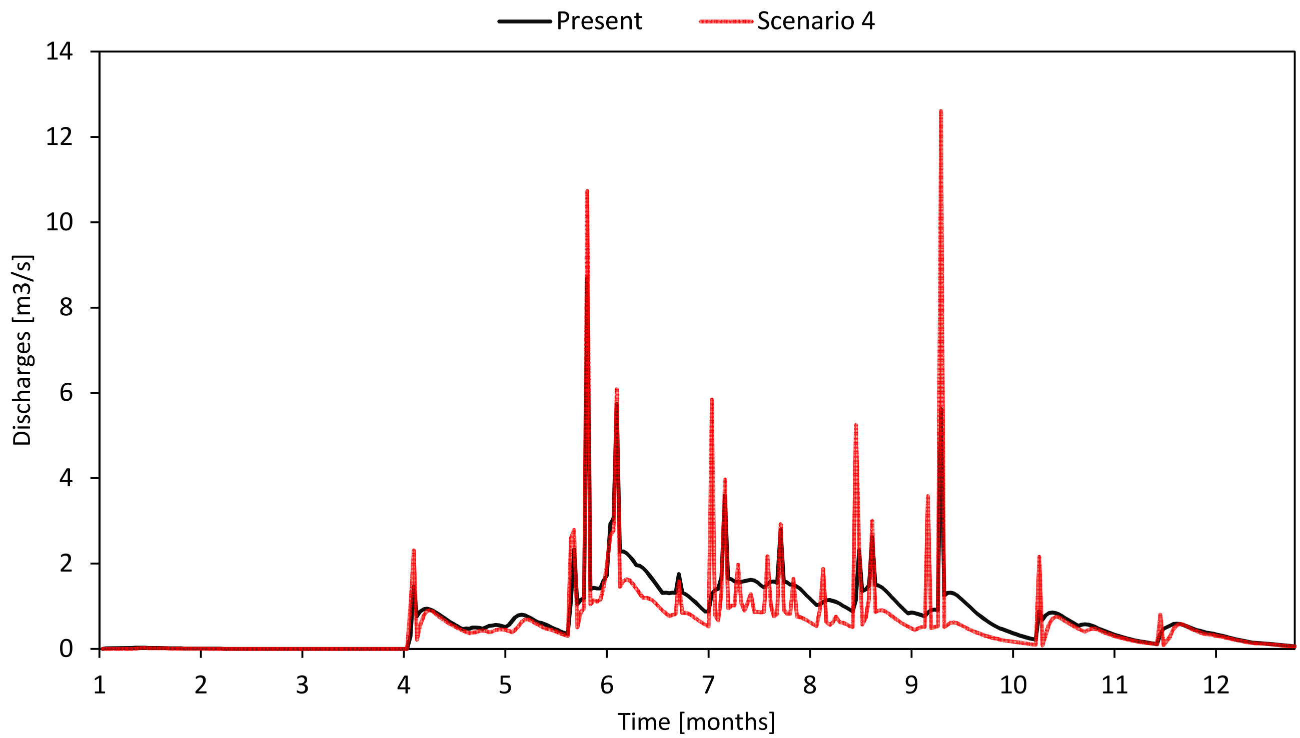
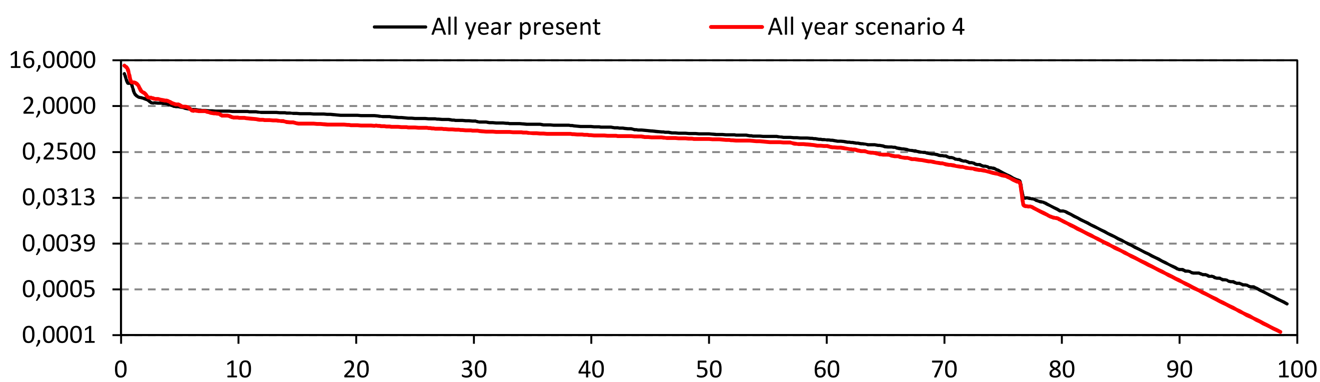
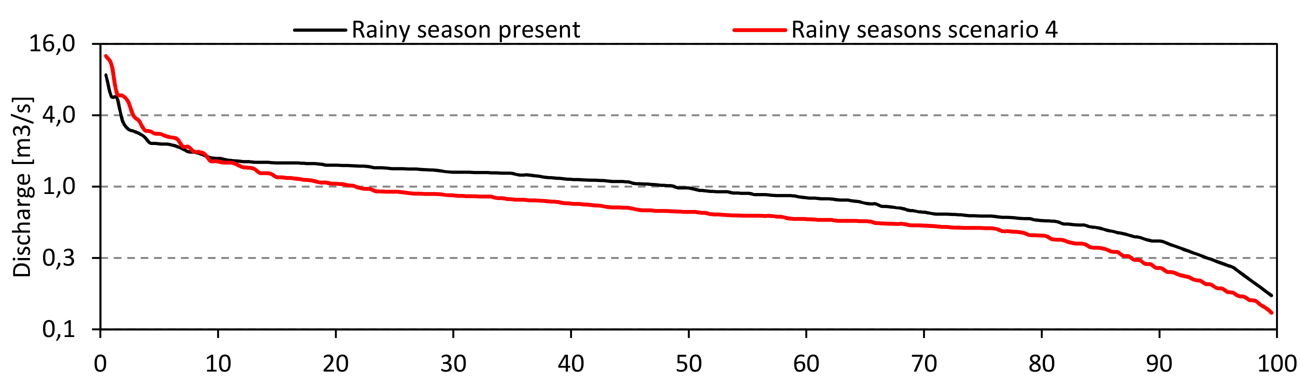


Figure 43: Hydrograph showing the simulated average daily discharges in the Mea Pheam River of the present and of scenario 4





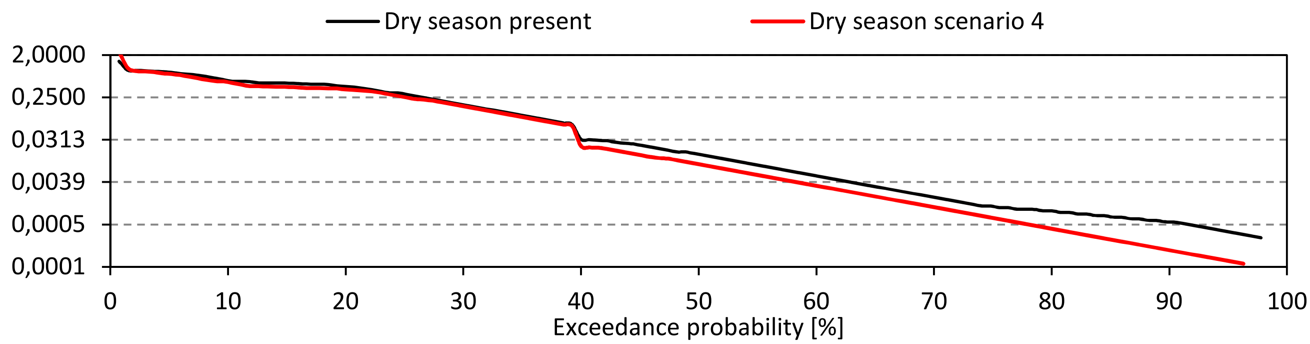


Figure 44: The FDCs of scenario 4 for the entire year and both seasons. The simulated discharges of the present are shown for comparison (black line). Note that the y-axis is given on a log-scale to better illustrate the difference between the scenario and the present.