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Preface

How often have I been asked the question –since my years here in Delft- where I come from! And what surprising remarks have I received after the questioner realizes that I am not from Asia and that Dutch is my first language. Being born and raised in Suriname it never struck me how unique it is to live among people from different continents, who share a common language and who live in harmony with each other. Studying in the Netherlands though has truly made me feel more independent and self-assured and has given me the opportunity to travel all over the world.

A year ago -after having experienced so many wonderful years in Delft- I decided that it was time to spend Christmas once again with my family in Suriname. Searching for a research topic did not take long, and this particular subject got my attention especially because of the location in the hinterlands of Suriname and because of the focus on sustainable energy resources. A large part of my research has been carried out in Suriname, which has been a truly magnificent journey and which has brought back all the –it never feels as good as home- feelings. The main challenge throughout my stay in Suriname was the difficulty of obtaining the required hydrological and meteorological data and literature. Literature is very often not readily available in libraries or at the responsible institutes but is in possession of individuals who have had some sort of business in preparing the reports.

To my supervisors in Suriname and Delft, Ir. S. Naipal and Ir. R. Nurmohamed & Prof. dr. ir. H.H.G. Savenije, Ir. W.M.J. Luxemburg and Ir. R.J. Labeur I want to say thank you for your patience and useful remarks.

As a final note, I want to thank each and everyone who have supported me through these years in Delft both physically and mentally. A special thanks to those who have made much effort in supporting me with seeking data and literature in Suriname. Being back in my home country has been by far the most interesting and intriguing part of my life thus far. Thank you to those who I was privileged to meet during my stay in Suriname and who have made all the difference during my visit. And thank you Suriname for making me realize where my home is.

Delft, September 2005





Summary

Can we imagine a life without turning on the lights in the dark? Or without daily communication with people from all around the world? These daily activities are just a few examples out of so many which we take for granted while there are numerous people around the world which lack electricity in the simplest form: illumination. In the midst of the tropical Amazon, an Amerindian village is not far from achieving a long desired goal: to be able to generate electricity with flowing water. The village, named Palumeu, is located in the South of Suriname and the people here are self-sufficient in every aspect of their way of living, which is mainly composed of fishing, hunting and practicing agriculture. The village, like so many others in the hinterland of Suriname, lacks besides electricity, sanitation and drinking water facilities. The joint initiative to provide the village with a sustainable energy source consists of the Anton de Kom University of Suriname, a tourism organisation, Word and Music ministeries and the local people. The location of the micro hydro-power project has been chosen not far from the village, in a creek called the Panato which is a tributary of the Tapanahony river (see appendix 14).

My research aims at determining whether a rainfall-runoff relationship of the Panato catchment can be established by calibrating a rainfall-runoff model with other catchments in the vicinity of the Panato catchment. With the insights in the runoff fluctuations of the Panato creek an optimum management of the hydro power generation at Panato can be realized. The question that arises during the long dry season is: "How to maximize the hydro-power generation with the available water resources? ". The catchment of the Panato can be defined as an ungauged basin, a basin which lacks adequate records of hydrological observations to enable computations of hydrological variables of interest. The method used in this research to be able to predict the basin responses is the extrapolation of response information from a gauged to an ungauged basin (I.A.H.S., 2003). This approach is found very appropriate for the interior part of Suriname.

The great challenge during the research was the calibration and validation of the Rainru model, a rainfall-runoff model developed by Savenije (1997), with the available hydrometric and meteorological data. The model being used is especially useful for ungauged basins like in Suriname, where there is a minimum of hydrological and meteorological data available. The input of the model is limited to one parameter only, the rainfall. Various catchment areas have been used to calibrate and validate the model. The different model outputs have resulted in regional model coefficients, a threshold value and a net runoff coefficient to a certain area of interest. Hence, the model could be applied to the ungauged basin of Panato, where only rainfall data was available. A visit to Suriname was of importance to collect all relevant data and literature and to make an observational visit to the site of the dam. The search for the hydrometric and meteorological data and the analysis which had to be made to fill in the missing gaps in the data series has led to very satisfactory results. When two rainfall stations are closely together, data from these stations may show a good correlation (through linear regression). The correlation can be witnessed in a graph and with a corresponding equation. The numerous gaps in the rainfall data series have been filled in with this equation.

With the simulated discharges for the Panato catchment, scenarios have been analyzed for the generation of hydro-power. A first step has therefore been made to predict the availability of water for hydro-power generation. Managing the outflow of the dam can result in maximising the benefits of hydro-power generation for the people in the village. In Suriname, the dry season can be very pronounced with less than 20% of the annual rain totals. However, the daily variations in rain can be very large, even in the dry season. Mini hydro-power projects have a good performance in those areas where rain falls frequently, even if it is only for a few hours. Since there are numerous villages like Palumeu in the hinterlands of Suriname, this project can be seen as a pilot project for other future mini hydro-power projects. A prerequisite for these hydro-power projects is a hydrological research to determine the availability of water. The results from this report will hopefully serve as an example for future hydrological modelling in Suriname. Hydrological modelling in Suriname is still not common practice, due to a scarcity of finances and know how.





1 Background information and introduction

1.1 The Palumeu electrification project



The village of Palumeu is located on the left bank of the Tapanahony river, just downstream of the confluence of the Tapanahony and the Palumeu rivers in Suriname. The distance from Palumeu to Paramaribo is approximately 170 km., and the elevation of Palumeu is 170 m above sea level. Up till now this area has not been affected by the small gold miners, as is the case in other tributaries of the same region. Economical activities here consist mainly of hunting, fishing and elementary agriculture, and recently, also tourism introduced by the METS (Movement for Eco-Tourism in Suriname), which is now an important source of income for this village.

The village is home to approximately 200 Amerindians. Two tribes, the Trio and the Wajana live peacefully together in this village despite their difference in language. The village has a school and medical clinic. A Captain, the highest authority, assisted by basja's, controls the village.

The regular connection with Paramaribo and contact with tourists, mostly from abroad, have stimulated serious developments within the village, as for instance, the establishment of a primary school and an elementary health care service. However, lack of electricity hampers proper functioning of these developments. Electricity is generated on purpose here with diesel generators, when there is an urgent need. For permanent electricity generation a large amount of diesel fuel is required, which is (due to the difficult accessibility) at least three times more expensive as is the case in Paramaribo, and is therefore scarce.

The present need for electricity in the village is estimated to be about 5 kW minimum, mainly for illumination purposes during nocturnal hours, conservation of food and medicine, tourism and other economical activities such as elementary wood processing. The local authority together with a number of stakeholders including the METS and the government have decided, after a preliminary study, that energy from hydropower would be the best sustainable solution for the village.

The project site has been chosen in the Panato euku (euku = creek), at the left watercourse of the Tapanahony river, about 3 km downstream of the village. At 200 m upstream of the creek a rapid is found, which with small effort can be made suitable for micro hydro-power purposes. (Naipal, 2003)

One of the preliminary studies includes a hydrological research of the catchment area of the Panato creek that can give an indication of the potential hydro-power capacities. This will be the subject of my research and will be carried out under supervision of the Anton de Kom University of Suriname.





1.2 The energy sources for Suriname

In those remote areas in the south of Suriname electricity is generated with diesel generators. The advantages of generators are the low investment costs and their mobility. They can be placed at random at any village in the hinterlands of Suriname. On the other hand, they require expensive diesel fuel and maintenance. Both of these which are not readily available in these remote areas and need to be imported from the capitol Paramaribo. As a consequence, there is a need for other more sustainable energy sources.

1.2.1 Alternative energy sources

Due to its geographical location, Suriname is ideally placed to capture energy from the sun. On an average, there are more than 3,000 hours of sunshine a year. Solar energy in Suriname is not yet developed on a large scale mainly because of the high investment costs. If one looks at the possibilities for wind energy in Suriname, there are hardly any strong winds except in the coastal area of the North East and North West. Here, winds reach velocities that might be harnessed to contribute slightly to the energy supply of Suriname. On the other hand, the hydro-power potential of the Surinamese rivers amounts to approximately 2,400 megawatts. In spite of the huge potentials for hydro-power, only one hydroelectric dam at Afobakka in the Brokopondo district exists, with an installed capacity of 189 megawatts (O.A.S., 1988). The numerous rapids and falls in the rivers of Suriname provide an ideal location for the generation of hydro-power. Most of the large rivers also have a perennial character, which ensures the continuation of hydro-power generation throughout a year.

1.2.2 Hydro-power generation

At first sight there is a simple answer to the question at to where potential may exist for developing small hydro resources: obviously in all those countries with a great deal of rain resulting in substantial runoff, and with a suitable topography (hills, mountains). In reality, however, it may prove difficult to identify sites. The main criterion is the river discharge and its fluctuations over a period of time and the net head. For most, if not all small rivers, accurate hydrological data and to some extent topographical maps of insufficient detail place do not exist. Careful investigation must therefore precede all projects. However, in most cases there is no choice but to take a pragmatic approach whereby the risk involved should be understood. It can be shown that even under such circumstances the implementation of projects is feasible.

There are two main factors that determine the generating potential at any specific site:

-  The amount of water flow per unit time and
-  The vertical height that water can be made to fall (head)

The formula for calculating the available power is as follows:

$$P_{Watt} = H_n \cdot Q \cdot g \cdot \rho \cdot \eta_{tot} = H_n \cdot Q \cdot \eta_{tot} \cdot 9.81 \cdot 1000 \quad I$$

Where:

P = Output power in Watts

H_n = Net head = gross head – losses (m)

Q = flow in m³/second

g = specific gravity = 9.81 m / s²

ρ = density (for water = 1000 kg/m³)

η_{tot} = overall efficiency = η₁ * η₂ η_n

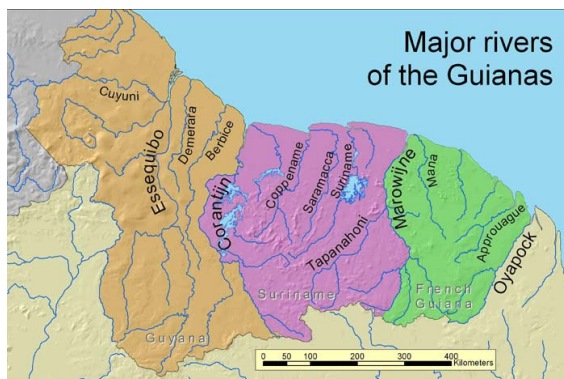




The head may be natural due to the topographical situation or may be created artificially by means of dams. The water flow on the other hand is a direct result of the intensity, distribution and duration of the rainfall, but it is also a function of direct evaporation, transpiration, infiltration into the ground, the area of the particular drainage basin, and the field-moisture capacity of the soil. Runoff in rivers is a part of the hydrological cycle in which - powered by the sun - water evaporates from the sea and moves through the atmosphere to land where it precipitates, and thence returns back to the sea by overland and subterranean routes.

It appears that regions around the equator, Central America and parts of South-East Asia, northern Europe and North America have higher than average runoffs. For areas with average and higher runoff, the short-, medium- and long-term variations of flow are of prime interest. It is this local pattern that determines the availability of water to generate power in relation to time and duration. Such variations are subject to the weather regime, i.e. seasons, and a multitude of other factors such as those already mentioned. Small and very small hydro-power schemes combine the advantages of large hydro on the one hand and decentralized power supply on the other hand. Moreover, the harnessing of small hydro resources, being of a decentralized nature, lends itself to decentralized utilization, local implementation and management, making rural development possible mainly based on self-reliance and the use of natural, local resources (Meier, 1981).

1.3 The characteristics of Suriname



Suriname is the central of three countries located in South America. Its area of 156,000 km² is approximately enclosed between 54° and 58° of W longitude and between 2° and 6° of N latitude. The Marowijne river on the eastern fringe divides Suriname and French Guyana. Similarly, the Corantijn river in the west forms the boundary of Suriname with Guyana. In the south the watershed line passes over a system of mountains and separates Suriname from Brazil.

Around 75% of the country is covered with tropical rainforests (see appendix 2), and Suriname has been known for the establishment of one of the largest nature reserve parks. At the same time, the great diversity of flora and fauna is increasingly threatened by new developments such as mining (both on a large and small scale) and lumbering.

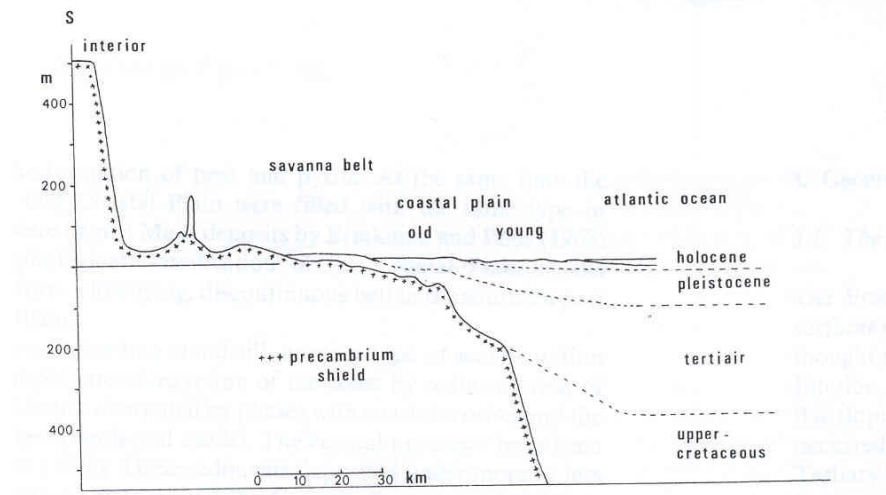
1.3.1 Physiography and geology

Suriname contains three hydrologically distinct provinces: an interior Precambrian shield of crystalline rocks comprising 80% of the country where surface water is the most important, a Savannah Belt and a coastal basin comprising the remaining 20% where ground water resources are of major importance (see figure 1 and 2).





Figure 1 Simplified North-South section of the coastal area near Paramaribo (Ouboter, 1993)



The Precambrian shield is composed mainly of crystalline rocks and extends over an area of approximately 126,500 km² or about 80% of the country. It is at elevations mainly up to 250 m with a few peaks rising above 1000 m. The Juliana top is the highest point at an elevation of 1,230 m. The Precambrian rocks continue northward beyond the shield, where they form the basement of a coastal basin. In various literatures it can be found that the topsoil of the Southern part of Suriname is a very thin layer on top of mostly weathered rocks. The topsoil is quickly saturated and infiltration is minimal. The infiltration in the interior part therefore is comparatively small. As a consequence, the surface runoff is relatively large and the drainage density high.

The Savannah Belt is formed out of predominantly sandy sediments that form a belt of alluvial fans along the northern edge of the basement. See figure 1, where the geographical outline of the Savannah belt is clear, north of the Savannah belt is the coastal plain while south of it lies the Precambrian shield. One may expect that the infiltration and percolation is high and the surface runoff small.

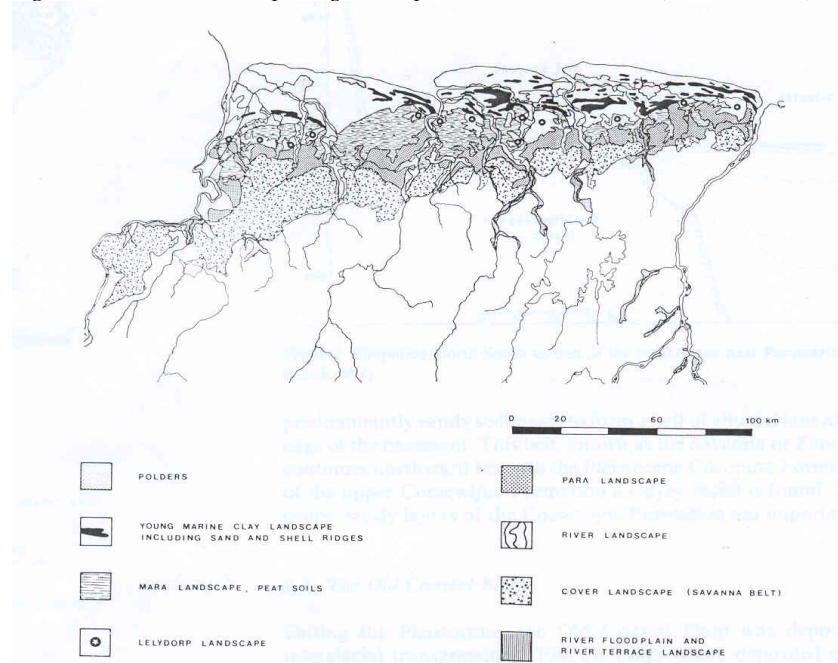
The coastal plain is at elevations below 75 m, and in the coastal fringe elevations are seldom more than 5 m. It extends inland about 40 km in the east and 140 km in the west and is underlain by sedimentary formations from Cretaceous to Recent age, named the Corantijn Groep (Duba, 1971). The surface runoff here is small and the drainage network is not developed well.

The North West – South East highlands of the Bakhuis, Wilhelmina and Eilerts de Haan ranges form a prominent drainage divide separating the Corantijn (the Western boundary river with Guyana) river from the remaining rivers (see appendix I)





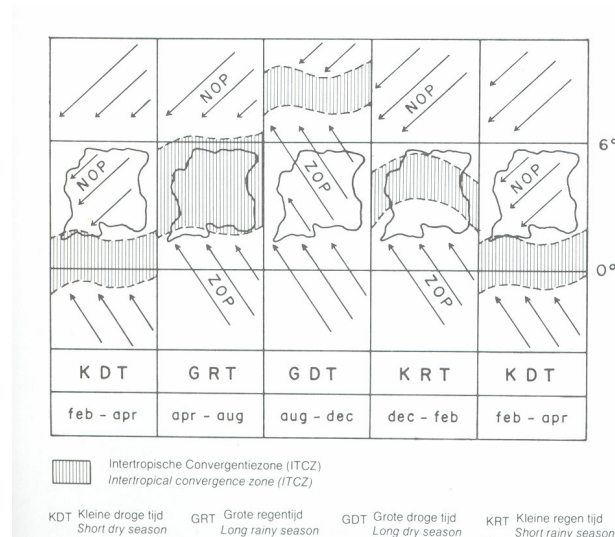
Figure 2 Geomorphological map of Northern Suriname (Ouboter, 1993)



1.3.2 Climate

The climate of Suriname is according to Köppen humid-tropical (Af) (P.E. Ouboter, 1993). “A” stands for a tropical climate, warm during the entire year and “f” means always moist with average rainfall of more than 60 mm. in the driest months. The tropical climate reflects in high temperatures and humidity. The mean annual temperature for Paramaribo is 27.1 °C (1901 – 1980). The long term annual mean rainfall in Suriname (1971 – 1980) varied between approximately 1,450 mm at Coronie (the west coast) to 3,000 mm at the Tafelberg (central Suriname). For Paramaribo, the average is about 2,200 mm. The relative humidity averages about 80 to 82% and is only slightly lower in the interior.

Two wet seasons and two dry seasons are evident (see figure 3), with 50% of the annual rainfall occurring in the four-month long wet season (April to the end of July) and only about 20% occurring during the long dry season (August to the end of November).



KDT stands for short dry period and KRT stands for short rainy period.

Trade winds are very steady winds that blow more or less from the same direction and with the same force every day. When they converge in the “equatorial trough”, they cause an uplifting of air, which causes clouds to condense and rain to fall if sufficient moisture is available. The equatorial trough, which is influenced by variations in the general circulation of air, is the most decisive factor in creating the climate of Suriname.





It is a belt of low surface pressure lying between the subtropical highs of the hemispheres.

More particularly, it is the area of tropical atmosphere approximately 1,000 to 2,000 km wide where the trade winds (which dominate the lowest 2 to 3 km. of the atmosphere in the outer portions of the trough) decrease in speed as they converge in the intertropical convergence zone (ITCZ). The mean annual position of the trough centre or “meteorological equator” is about 5°N. The zone migrates meridionally (from South to North and back), following the zenithal position of the sun. The annual range of trough migration is about 15 to 20 degrees of latitude, from about 5° to 10° S to about 10° to 15°N. The centre of the equatorial trough passes over the country twice a year. The activity of the equatorial trough is determined by the character and temperature of the surface of the earth. On average, the equatorial trough reaches its southernmost position over southern Suriname or northern Brazil in February and March. Suriname then finds itself almost entirely under influence of the northeast trade winds and relatively little rain falls producing the short dry season (In Paramaribo the short dry season lasts from early February through April). The equatorial trough follows the sun with some delay as it moves northward and passes over Suriname in May/June July, bringing the long rainy season (the end of April through Mid-August in Paramaribo). The equatorial trough then remains over the Atlantic Ocean until around November. During this period, Suriname is under the influence of the southeast trade winds and moves into its long dry season (mid-August through early December in Paramaribo). Due to the reduction of its activities over the ocean, the equatorial trough will be accompanied by less rain when it migrates over Suriname on its passage from north to south bringing the short rainy season (early December through early February in Paramaribo (O.A.S., 1988).

1.3.3 Rainfall and evapotranspiration

The mean annual rainfall for Paramaribo the period 1931 – 1960 was 2,208 mm. In the interior the seasonal distribution is the same as in the coastal area, but the depth is commonly between 2,500 and 3,000 mm in places and locally exceeds 3,000 mm. As can be seen in appendix 3 it is evident that heavier rainfall occurs in the centre of the country. This pattern suggests the influence of highland areas.

Observations of evaporation are made from pans. In use are American Class A pans (120.65 cm in diameter and 25.4 cm deep) and “Boiten” pans, also of cylindrical design (100 cm in diameter and 35 cm deep). The waterlevel is measured by a hook-gauge. Pans were in use at the following stations: Nickerie, Cultuurtuin, Moengo, Paranam, Marienburg, Jarikaba, Wageningen-Noord and in the Brokopondo lake near Afobaka dam (W.L.A., 1969). The above mentioned evaporation stations are all located in the coastal area, except for the one in the Brokopondo lake. It is not sure which of these stations are still under operation, but it is suspected that the Nickerie and Cultuurtuin are the ones most likely to be so, since they are located in the two largest cities in Suriname. One may estimate the potential evaporation by multiplying the pan evaporation with the pan-coefficient, which is on average about 0.7 for the class A pan (Ouboter, 1993). Direct pan evaporation has been measured since 1961 at Cultuurtuin in Paramaribo. The average annual evaporation for the period 1961 – 1968 is 1,655 mm, with a maximum of 1,825 mm and a minimum of 1,407 mm. The monthly evaporation is higher during the dry season and exceeds the average rainfall for the months of September, October and November. The following figures show the trends in rainfall and evaporation and indicate that the main outflow component in the water balance is the evaporation, see figure 3 (Dubá, 1971). Evaporation measurements in the interior of Suriname could not be obtained. The other element of importance in the hydrologic cycle is the infiltration (groundwater recharge), but of the outflow components, evaporation is the largest (see figure 3 and 4).

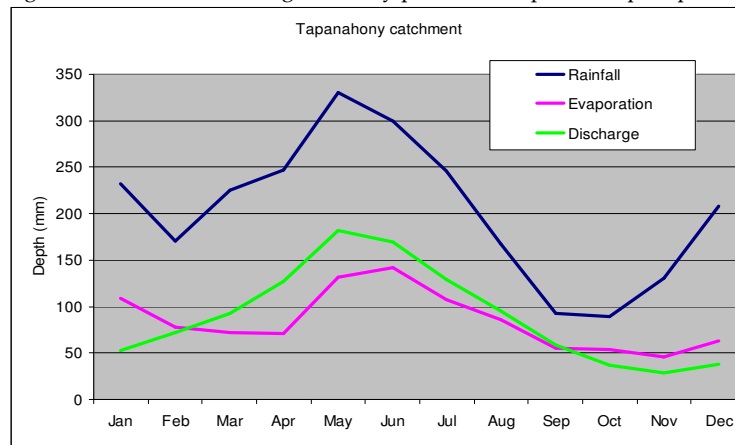
Water discharged by the rivers is only a small portion of the precipitation. Precipitation is temporarily stored in and on the soil and most returns to the atmosphere through evaporation (O.A.S., 1988). The





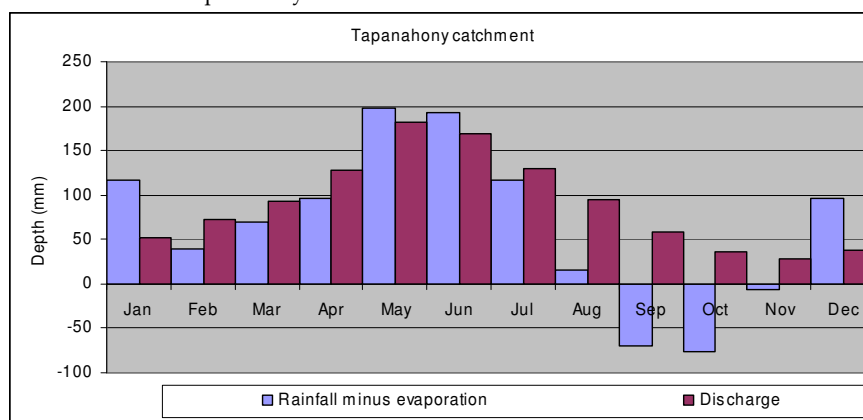
precipitation surplus (precipitation minus potential evaporation) of the Tapanahony catchment shows clear similarity with the runoff, see figure 4. The distinct differences are the result of storage of precipitation in the soil. This soil moisture is extracted by plant roots and eventually evaporates through leaves or seeps down to become groundwater and slowly flows underground to the creeks and rivers. Thus, soil and vegetation regulate precipitation surplus. Figure 4 shows that the peak precipitation surplus during the wet season is higher than the runoff peak. However, runoff in the dry season never falls to zero in the larger rivers of Suriname, even though there is a precipitation deficit.

Figure 3 The average monthly potential evaporation, precipitation and runoff



The discharge of Tapanahony in figure 3 is the average for the period 1960 – 1985. The pan evaporation data is from Cultuurtuinlaan (Paramaribo) as measured (pan coefficient = 1,0) and is the average for the period 1961 – 1968. Precipitation data is from the meteorological station Stoelmanseiland (805).

Figure 4 The rainfall for Stoelmanseiland station minus evaporation Cultuurtuin, Par'bo vs. discharge Tapanahony



For the geographical location of the meteorological station Stoelmanseiland (805) and the Tapanahony catchment (at Alamandidon sula) see appendix 5 and 6.

1.3.4 River basins

Seven main rivers drain the area of Suriname towards the Atlantic Ocean. Three main groups are distinguishable when comparing the extent and shape of the drainage areas: (see also appendix 4)





-  The first group is represented by the larger Marowijne and Corantijn rivers, with drainage areas of 68,700 and 67,600 km² respectively, which form the eastern and western boundaries of Suriname. Together they drain almost 58% of the country.
-  A second group is represented by the Coppename river (21,700 km²) and the Suriname river (16,000 km²), which drain approximately 24% of the country. The basins are elongated in a NE-SW direction located in the north-central area. They are separated by the Saramacca basin except in the extreme headwater area, where they have a common divide.
-  A third group is represented by the Nickerie river (10,100 km²), the Saramacca river (9,000 km²), and the Commewijne river (6,600 km²). Together they drain about 16% of the country. The centrally located Saramacca basin is elongated in a NE-SW direction. The Nickerie basin in the west is less elongated, and the Commewijne basin in the east is sub-triangular. (W.H.O., Public water supplies and sewerage project)

Table 1 The catchment areas of major streams (Duba, 1971 and Ouboter, 1993)

River name	Total catchment area (km ²)	Mean discharge (m ³ /s)	Interior Precambrian Shield (%)	Savannah Belt (%)	Coastal Plain (%)
Marowijne	68,700	1,791	99.5	0.05	0.5
Corantijn	67,600	67,600	90.0	4.6	5.4
Coppename	21,700	565	65.5	9.2	26.3
Suriname	16,500	422	84.4	4.5	10.7
Nickerie	10,100	174	42.3	23.6	34.1
Saramacca	9,000	257	74.1	3.1	22.8
Commewijne	6,600	169	36.4	11.5	52.1

In table 1 the different characteristics of the seven largest rivers of Suriname have been presented. The Nickerie river flows for a great deal in the Savannah belt and coastal plain. This reflects in a low annual unit discharge value if compared with the other rivers. The same explanation can be given to a similar low annual unit discharge value of the Kabalebo river, which will be dealt with in the following chapters.

According to the information in this chapter, the physical characteristics such as the geology, topography, hydrology and the meteorological features are overall similar for the interior of Suriname. This part of Suriname is almost uninhabited and consists of pristine regions with a minimum of human influences. The south of Suriname finds itself entirely in the district of Sipaliwini, and the population density here is less than 1 inhabitant/km². Along the Suriname and Tapanahony rivers however, the population density increases sharply with the presence of respectively Maroon and Amerindian villages (O.A.S., 1988).





2 The research objectives

2.1 Objectives

This research will focus primarily on the hydrological analysis that enables the simulation of the rainfall-runoff relationship in the small catchment area of the Panatocreek. Consequently this research is only targeted on the hydrological research of the Palumeu electrification project as mentioned in the first chapter and not at all on the construction of the dam. A visit to Suriname was very useful for collecting the necessary data and literature and for intensive communication with the counterparts in Suriname.

The objective of my research is as follows:

-  Insights in the discharge of the Panato creek are of importance for the generation of hydro-power. The fluctuations in runoff will be simulated with a rainfall-runoff model after it has been calibrated properly. The question which arises is: 'At what intervals and for how long will the generation of hydropower be ceased if the water head and the outflow discharge reach critical values?'
-  Hydrological data collection in the interior parts of Suriname is very scarce, and this research will hopefully serve as an example that will trigger future hydrological research. Another side-effect which is hoped for is the continuation of hydrometric and meteorological data collection. The cost effectiveness of data collection is an important consideration in Suriname. Lack of financial resources and also the difficulties to assess the benefits from data for planning and research purposes impede the collection of hydrological and meteorological data in the interior of Suriname.
-  The results of this research are of no influence of the design of the dam and the turbine. The research subject was proposed after the design of the dam and turbine was already in a very advanced stage. Construction of the dam and the outlet of the dam have already begun, since mid 2004.

2.1.1 The problem definition

The main problem that will have to be faced is the following:

Predictions in ungauged basins must involve extrapolation of some kind from what is observed or inferred at one basin to a time in the future at the same location, or to another basin at a different location (ungauged basin) (I.A.H.S.,2003). In the case of predicting the discharge fluctuations of the Panato creek, hydrological, meteorological and hydrometric information from other nearby catchments will be analyzed and used for calibration and validation of the model and the model results. Afterwards, the discharge of the Panato creek can be simulated and a prediction can be made for the availability of water for hydro-power purposes.

This definition can be made more concrete by the following questions:

-  Which rainfall-runoff model can be applied for simulating the discharges while
-  Which catchments will be used for calibrating and validating the rainfall-runoff model and where can the meteorological and hydrometric data be obtained?
-  What methods can be used to fill in the gaps in the meteorological and hydrometric data series?
-  Is there any logical consistency between the output of the model of the rainfall-runoff model for the different catchments in the interior of Suriname (calibration of the model)?
-  Is it therefore possible to address fixed "regional" values to the above mentioned model variables for a certain area of interest?





- Is it possible to somehow validate the simulated discharges of the Panato creek without the availability of any discharge data?

2.2 Criteria

The choice of a model has fallen upon the Rainru model developed by Prof. Savenije from Delft University of Technology (Savenije, 1997). The model uses a simple linear regression relation and depends on a limited number of input parameters: the rainfall and the runoff. Furthermore, the model incorporates a threshold value for the rainfall, a value below which no runoff takes place. The results with this model have been promising thus far (Savenije, 1997) despite the simplicity of the model and the minimum of input variables. The main criterion for choosing this model is the minimum requirement is has on the number of input variables since hydrological and meteorological data in Suriname is very scarce.

The first step towards applying the model was to determine a number of catchments with sufficient discharge and precipitation data. Given that it is assumed that rainfall measurements are more easily obtainable, the prerequisite for selecting the catchments for calibrating and validating the model was the discharge data at a specific hydrometric station. Five catchments were chosen since the monthly discharge data was readily available from Mr. Naipal (from the Anton de Kom University in Suriname). Discharge data of the Tapanahony river at Alamandidon sula (sula= rapid in Sranang tongo) were obtained from Mr. Boksteen (currently employed at the Surinaamsche Waterleiding Maatschappij). See appendix 16 for an overview of persons who have been contacted in Suriname. In table 2 an overview of the selected catchments has been given, which all find their origin in the interior of Suriname.

For the best comparison of the model results of the different catchments, equivalent time-intervals of the model input (monthly discharge and monthly rainfall data) are desirable. Seeking for a period of overlap for all the catchments concerning the discharge and rainfall data was very difficult since the rainfall data series obtained showed huge gaps. In appendix 5 the number of rainfall stations per catchment (those mentioned in table 2) is presented. Appendix 4 gives an idea of the sizes of the different catchments, especially when compared with one another.

Table 2 The six catchments

Hydrometric station	River	Catchment size (km ²) ¹
Stondansie	Nickerie	5,160
Avanavero boven	Kabalebo	9,020
Maksita	Coppename	12,300
Pokigron	Suriname	7,750
Dramhosso	Saramacca	3,520
Alamandidon sula	Tapanahony	10,210

¹Source: W.H.O., Public Water Supplies and Sewerage

In appendix 5 the geographical locations of the first five hydrometric stations have been given, and in appendix 6 the geographical location of the Tapanahony river at Alamandidon sula can be witnessed. If compared with the catchment of the Panato creek (approximately 80 - 100 km²), the above catchments are much larger. The question which arises is whether the calibrated model can be applied to the Panato creek.





2.3 Assumptions

- For assessing the availability of hydro-power generation throughout a year, insights in the monthly variation of the discharge are assumed to be satisfactory. Therefore it is not necessary to simulate the daily fluctuations, as these can be levelled out by the storage in the creek itself. Daily data series of rainfall and runoff are also not available for most of the meteorological stations as mentioned earlier, and therefore it is not even possible to model on a daily time basis.
- The evaporation values given in figure 3 are performed in the coastal area, but since other evaporation data from the interior of Suriname could not be found, it has been assumed that the evaporation data in figure 3 is representative for the whole country.

2.4 Time schedule

The first months in the Netherlands (May - October 2004) were occupied with intensive correspondence with the counterparts in Suriname and also with seeking relevant literature and writing a first work plan.

From November 2004 – July 2005 a visit was paid to Suriname, where a number of activities have been performed, as can be seen in the following time schedule. It should be noted that alongside these study related activities time has been spent on family related and leisure activities in Suriname. The latter consisted of regular excursions to various locations in the hinterlands of Suriname. These experiences led to a better understanding of the hydrological regime of the country as well as the life-style of the people living in the hinterlands of Suriname.

Table 3 Time schedule in Suriname

Time schedule	nov-04	dec-04	jan-05	feb-05	mrt-05	apr-05	may-05	jun-05	jul-05
Search for rainfall data from the different catchments									
Search for other relevant information concerning topography, geology, etc.									
Christmas and family holiday									
Process the monthly rainfall data in Excel and supplement missing data									
Perform model calculations with monthly input and constant T									
Comparing the output of above mentioned model runs									
Improve the model: variable threshold and improve correlations									
Analyze the differences and abnormalities of the model outputs									
Improve the robustness (validate) of the model: search for other catchment data (Tapanahony)									
Validate the model with another catchment (Tapanahony)									
Look up rainfall data from Palumeu or other station nearby									
Prepare final presentation in Suriname and write article									
Perform model calculations for Panato creek									
Analyze the feasibility of hydropower generation at Panato									
Initiate the writing of final thesis report									

After the visit to Suriname, all the time in Delft has been occupied with finishing the final thesis report and communicating with all the supervisors.





3 The description of the model

The Rainru model which will be used was developed by prof. dr. ir. H.H.G. Savenije from Delft University of Technology (Savenije, 1997). The model is especially helpful for those catchments which are characterized by a scarcity of hydrometric data, the so called ungauged basins. Currently, the most widely used predictive tools for water resources, water quality and natural hazards assessments are essentially data-driven, estimated from hydrometric (gauged) data. In ungauged basins however, major difficulties are encountered when applying traditional prediction tools or models to these river basins (I.A.H.S., 2003).

The “Rainru model” is a moving average model using threshold losses and it requires only one input, the precipitation. The output of the model is the direct result of rainfall: the discharge. The model is a statistical model on the basis of the water balance equation.

As the amount of storage available during a particular time-step t (e.g. a month) depends on the amount of rainfall in the previous time-steps, a relation is sought that relates the runoff in a particular month to the rainfall in the month itself and the previous months. A simple linear backward relation is used:

$$R_t = b_0(P_t - T) + b_1(P_{t-1} - T) + \dots \quad \text{II}$$

Under the condition that if $(P_{t-i} - T) < 0$ then $(P_{t-i} - T) = 0$. This can be referred to as is done in ‘spreadsheet language’ as $\max(P_{t-i} - T, 0)$

Where:

P = the precipitation (mm/month or mm/day)

R = the runoff (mm/month or mm/day)

T = the threshold loss on the time interval basis (mm/month or mm/day)

b_i = the coefficient that determines the contribution of the effective rainfall in time interval $t-i$ to the runoff in month t (the combined effect of surface runoff and groundwater seepage).

The number of time-steps will be determined by performing a number of calculations with variable time-steps t . The threshold accounts for losses, the backward regression accounts for delayed runoff as a result of storage. More about the threshold value is discussed in the next paragraph.

The coefficients b_i are determined through multiple linear regression. The best correlation is sought through calibration with the threshold T . In multiple regressions, a relationship exists between a dependent variable (in this example the discharge) and two or more independent variables (the rainfall). The simplest regression model is the linear regression equation of two variables. This model considers the problem that the observed variable R should be estimated by means of a linear function of the variable $(P_{t-i} - T, 0)$ (Savenije, 2000).

There appears to be a clear threshold rainfall below which no runoff takes place. At the start of the rainy season the contribution of seepage to runoff is minimal, the groundwater storage (S) is virtually empty and the amount to be replenished is considerable. The value of dS/dt is thus positive, reducing the runoff R . At the end of the rainy season the reverse occurs.

The mass balance equation of a catchment yields:

$$Q = P - E - dS/dt \quad \text{III}$$





The presence of the evaporation and the storage terms make it difficult to establish a straightforward relation between Q and P . The problem is further complicated in those regions of the world that have distinctive rainy and dry seasons. The water balance can be elaborated, distinguishing between groundwater storage and storage in the unsaturated zone, and by separating the evaporation E into interception I and transpiration T .

The net rainfall $N = \sum(\max(P_{t-i} - T, 0))$ is defined as the part of the rainfall that enters the rainfall-runoff process after the immediate processes of moisture recycling to the atmosphere within the time-step dt has been subtracted. The net rainfall is the rainfall which exceeds a threshold value T , which consists of interception and other immediate feedback to the atmosphere during the time step considered. T is the separation between the immediate and long-term processes for the time scale considered. The immediate processes consist of the interception, evaporation from temporary surface storage (pools), bare soil evaporation and immediate transpiration (within the time scale considered) from the surface layer (Savenije, 1997).

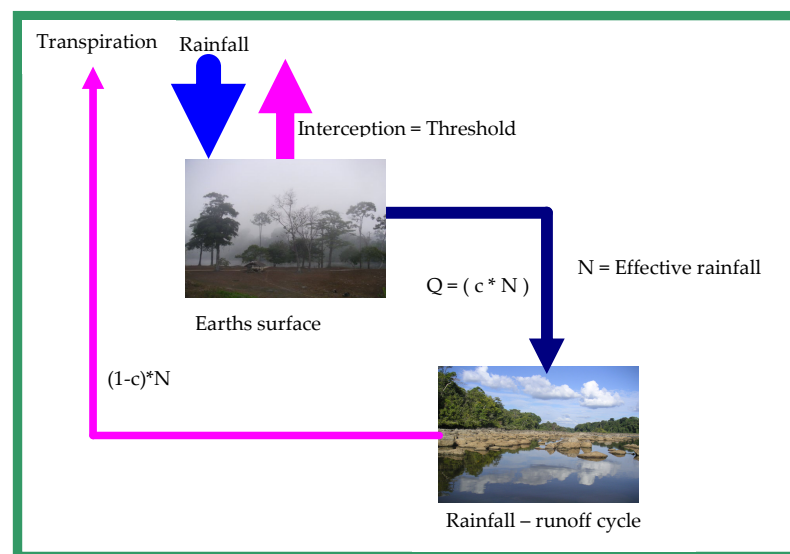
The effective runoff coefficient c on a water year basis is defined as:

$$c = \frac{\sum Q}{\sum \max(P_{t-i} - T, 0)} = \sum b \quad \text{IV}$$

Where P and Q are the annual rainfall and runoff on a water year basis. The total amount of runoff that a certain net rainfall generates is the sum of all the components ($b_i(P_{t-i} - T)$) over n months. Obviously c should not be larger than unity. The net runoff coefficient differs from 'traditional' runoff coefficients in that is purely based on the net rainfall, the rainfall which remains after the immediate moisture feedback processes (threshold T) have been subtracted (Savenije, 1997).

Once a value can be assigned to the coefficients b and the threshold value the discharge in the Panato creek can be modelled with the rainfall data from the village Palumeu. The following figure gives the schematization of the Rainru model being used. As mentioned, the threshold values indicates the separation between the immediate (e.g. interception) and long-term processes (transpiration) for the time-scale considered.

Model schematization





3.1 Criteria

To determine the coefficients b the model needs to be calibrated and validated with a series of rainfall data and the corresponding discharge data. However, discharge data for the Panato creek is not available and it is therefore impossible to calibrate and validate the model with the Panato catchment. Together with Mr. Naipal it has been discussed that the model should be calibrated and validated with other catchments in the vicinity of the Panato catchment where data is readily available. This approach of extrapolating knowledge from one basin to another is one of the alternatives currently available for predictions in ungauged basins (I.A.H.S., 2003). The expectations are that some similarity will be reached between these catchments concerning the model output of the variables b, the net runoff coefficient and the threshold value, since the physical characteristics can be assumed to be homogenous for the South of Suriname.

3.1.1 Input requirements

-  The model requires only a series of rainfall and runoff data for calibration and validation.
-  The rainfall data series were very inconsistent and needed further research for supplementing the missing gaps. This has been realized by using the correlation relationship between the station under investigation (X) and other neighbouring meteorological station(s) (Y) on a monthly time basis. The rainfall data series for the stations X and Y are plotted against each other where after a linear regression equation and coefficient can be determined. A correlation coefficient of above 60% is considered to be satisfactory to be used for filling in the gaps in the data series for the rainfall station under investigation.
-  It has been decided that for accurate results at least 5 years of monthly data series are necessary. Naturally, the longer the series, the more accurately the model can be calibrated.

3.1.2 Output requirements

The output of the model is the discharge. To compare the simulated output with the measured results the correlation factor is used. The following formula is being used to define the correlation coefficient r:

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2} \sqrt{\sum (y_i - \bar{y})^2}} \quad \text{V}$$

The correlation coefficient is used to express the degree of association of data points from a regression line. In a graph both the calculated and measured discharge will be plotted for comparison.

The output of the model is represented with the correlation coefficient, which gives the correlation between the measured and simulated discharge. Only correlation coefficients of 70% and up are defined as satisfactory model outputs.

3.1.3 Assumptions

-  Since more recent data does not exist for the area it has been decided that the model will be calibrated and validated with data which is more than 20 – 40 years old. It is therefore assumed, that in the past decades no significant changes have taken place in the climate,





topography or the land use for the area under specific interest which can influence the outcome of the model calculations.

-  For all the meteorological stations under investigation it was very difficult to find more than one rainfall station per catchment with a simultaneous record of time interval where the data availability was above 60%. Hence, it has been assumed that the rainfall data from one or two stations is representative for the whole catchment area under investigation. If rainfall data is available from more than one meteorological station, the arithmetic average has been used as model input.
-  In the equation used in the model the threshold value is constant throughout the year. In reality however, the magnitude of the threshold value depends upon the seasonal varieties of the rainy and dry season. The first model calculations will be performed with a constant threshold value, but calculations with a seasonal fluctuation of the threshold value will also be performed to see if there is any improvement in the model output.
-  The model will be calculated on a monthly time basis.

3.2 The pros and cons of the model

The rainru model has been selected for its simplicity regarding the input data. The model is a so called “black box” model, which requires only rainfall and discharge data for calibration and validation. The South of Suriname (the interior) consists of dense rainforests which makes it extremely difficult to travel and perform hydrometric and/or meteorological measurements. Therefore, using a rainfall-runoff model with a minimum requisite on input data was the most logical choice.

The disadvantage of a so called “black box” model or empirical model is that the model is not universally applicable (catchment dependent) as each area has its own regression model with specific input variables and specific regression coefficients. Accordingly, the model is very sensitive to changes in the system such as land use change or climate change and in such cases might need to be (re) calibrated and validated.





4 Runoff data analysis

Any model, especially deterministic models, should be calibrated properly since they are not universally applicable such as physically based models. In the case of the Rainru model, the six catchments were chosen randomly, but the main motivation was the direct availability of the mean monthly discharge data. The monthly discharge data were obtained from Mr. Naipal and Mr. Boksteen. Daily data could be retrieved from hydrological annuals that were published annually by the Hydraulic Research Division of the Ministry of public works, telecommunication and housing. These annuals are available at the library from the Anton de Kom University for a limited number of years, namely from 1969 – 1978. But as has been explained earlier, the model will be calibrated and validated on a monthly time basis. The daily discharge data have been used only to validate the correctness of the monthly discharge data.

4.1.1 The measurement technique

All discharge measurements were made by the current meter method from a boat attached to a cable across the river or anchored in the stream at fixed positions. The velocity of flow at selected points was measured counting the number of revolutions of a current meter propeller during a short time period measured with a stopwatch (W.L.A., 1969).

4.1.2 The data availability

Of all catchments there are at least 20 years of successive mean monthly data available. The responsible agency is the Hydraulic Research Division of the Ministry of Public Works which is in charge of the national hydrometric observation system, as well as the collection of basic hydraulic and water quality data (Water resources assessment of Suriname). However, the operation and maintenance of the hydrometric net stations of Suriname stopped in the middle of the 80's (due to the civil war) and has not been rehabilitated anymore. Only the station Pokigron is of extreme interest for continued monitoring, since the inflow of Pokigron determines the water-tables in the van Blommenstein reservoir. Hence, insights in the discharge fluctuations at Pokigron are of importance for the Afobakka hydro-power plant.

Table 4 The period of available discharge data for hydrometric stations

Catchment / Hydrometric station	Period of available monthly discharge data
Stondansie	1963 – 1985
Avanavero	1965 – 1980
Maksita	1965 – 1984
Dramhosso	1960 – 1985
Pokigron	1952 – 1985
Tapanahony	1960 - 1985

For the geographical location of these hydrometric stations, see appendix 5 en 6.

A quick glance at the periods of available monthly discharge data reveals that there is an overlapping period which could be distinguished, namely 1960 – 1985. If this period would be chosen for the input of the model, only two hydrometric stations consist of an incomplete data set, and those are the Stondansie and the Maksita station. Hence, these stations required extension of their data series.

4.2 Supplementing missing data

The data series for the Stondansie and Maksita hydrometric station needed to be extended. This has been realized through plotting the monthly data of the hydrometric station under investigation with monthly data from another nearby station for the overlapping period. Consequently, a linear





regression line can be drawn through the scatter of points and the correlation coefficient can be determined. This was considered to be the best solution to fill in the gaps in the data series besides for example the moving average method. The first attempts with the correlation method gave very high correlation coefficients and therefore this method seemed to be satisfactory.

The correlation results of Dramhosso catchment with Maksita were the highest, giving a correlation coefficient of approximately 0.95. Correlating the Avanavero catchment with Dramhosso, Maksita or Pokigron did not give satisfactory results. The value of the correlation coefficient did not exceed a value of 0.6.

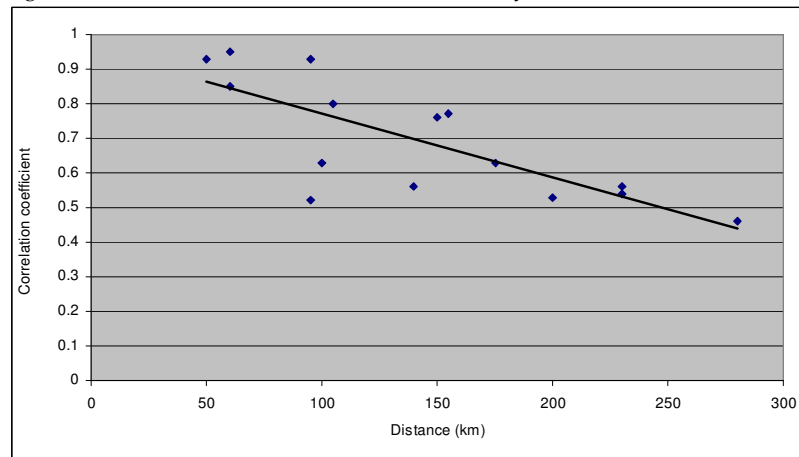
Table 5 The correlation coefficients for monthly discharge data

	Pokigron	Maksita	Dramhosso	Stondansie	Avanavero	Tapanahony
	1952 - 1985	1965 - 1984	1960 - 1985	1963 - 1985	1965 - 1980	1960 - 1985
Pokigron						
Maksita	0.93 (95)					
Dramhosso	0.93 (50)	0.95 (63)				
Stondansie	0.77 (155)	0.85 (60)	0.80 (105)			
Avanavero	0.56 (230)	0.56 (140)	0.53 (200)	0.52 (95)		
Tapanahony	0.63 (100)	0.63 (175)	0.76 (150)	0.54 (230)	0.46 (280)	

In each cell, first the correlation coefficients is given between the two hydrometric stations and the value between the brackets, in blue, is the distance between these two stations in km.

According to the above table the missing data of both the Maksita and the Stondansie data set can be supplemented with the Dramhosso station, since that particular correlation relationship gives in the highest values. The relationship between the correlation coefficient and the distance between the hydrometric stations meets the expectations, as high correlation coefficients correspond with stations which are situated near to each other. This relation can also be witnessed in figure 5.

Figure 5 The correlation function for the hydrometric stations



In figure 5 the distance between the hydrometric stations and the correlation coefficients has been plotted against each other. The correlation witnessed in the figure decreases with increasing distances between the hydrometric stations under investigation. This is according to various literature sources.





5 Rainfall data analysis

Rainfall data were obtainable from the Meteorological Service for the six catchments which have been mentioned earlier. The Meteorological Service falls under the Ministry of Public works. The service maintains and manages all meteorological data of the country. It took some determination and also some cash to obtain the desired data from rainfall stations in the catchments under investigation. Although at some point in history there were 200 rainfall stations (see appendix 5) under operation (W.L.A., 1969) the data received from the meteorological service showed that there are stations with huge gaps between the data or with a very short period of observation, e.g. 2 or 3 years. Correlating the rainfall stations with each other was therefore much more of a challenge than with the discharge stations. At present, the collection of meteorological data, just like the hydrometric observation system, is carried out only at urban areas since lack of finances and trained personnel makes it very difficult to maintain the stations in the rural areas, especially those in the tropical rainforest.

5.1.1 The measurement technique

Rainfall measurements were performed with different methods; manual and automatic raingauge. Due to instrumental failures, absence of observatory and traffic problems not all series are complete. The daily raingauge was emptied each morning at 08:00 am local time. The observation is dated on the day of measurement. Some of the observations were carried out with automatic raingauges, but most were done with a manual raingauge. The receiving area of the instrument is 400 cm². The automatic raingauge gives hourly readings of the rainfall. During the 1960's there were 25 automatic raingauges (out of 200 stations in total) in operation, mainly in isolated areas where no observers are available (W.L.A., 1969).

5.1.2 The data availability

In the previous chapter a corresponding period of discharge data was discussed: 1960 – 1985. The first correspondences with the National Meteorological Service learned that this was also the period during which intensive meteorological measurements were carried out. A great deal of data was made available from the National Meteorological Service in Suriname, but the data was not automatically suitable as model input. Each and every one of the rainfall stations contained gaps of various quantities, sometimes daily, monthly or even annual data was missing. An overview of the different meteorological stations per catchment that have been provided by the National Meteorological Service is as follows:

-  Stondansie catchment – 5 stations
-  Avanavero catchment – 3 stations
-  Dramhosso catchment – 7 stations
-  Pokigron catchment – 8 stations
-  Maksita catchment – 5 stations
-  Tapanahony catchment – 3 stations

See appendix 5 for a graphical representation of the catchment and the meteorological stations.

First, the data series demanded a thorough screening of which stations were worth the effort of filling in the gaps of the data series with a certain degree of reliability. The first screening of the rainfall stations resulted in a limited number of stations which could be used for further research.

The stations considered representative for further analysis passed the following set of criteria:

-  The stations should have at least 10 successive years of measurement data
-  Of these available successive years at least 75% of the daily data per year should be present





- Over the period of 1960 – 1985 at least 50% of the monthly values per meteorological station should be present

Table 6 The meteorological stations used for analysis

Hydrometric station / catchment	Number of rainfall stations located within the catchment	Number/name of the meteorological station	Period of data availability	Location Latitude (N)	Location Longitude (W)
Stondansie	1	216, Baas Bart	1963 - 1985	5 - 04	56 - 40
Avanavero	1	117, Avanavero	1972 - 1980	4 - 50	57 - 24
Dramhosso	2	513, Tafelberg 525, Boslanti	1978 - 1985 1960 - 1985	3 - 47 4 - 20	56 - 09 55 - 47
Pokigron	4	667, Brownsweg 670, Pokigron 671, Nw Aurora 695, Ligorio	1960 - 1985 1955 - 1969 1953 - 1985 1969 - 1985	5 - 01 4 - 30 4 - 22	55 - 09 55 - 22 55 - 24
Maksita	2	414, Maksita 419, Raleighvallen	1974- 1978 1972 - 1985	4 - 55 4 - 49	56 - 07 56 - 10
Tapanahony	2	805, Stoelmanseiland 821, Apetina 820, Drietabbetje 808, Palumeu	1960 - 1985 1972 - 1986 1972 - 1984 1961 - 1986	4 - 21 3 - 31 4 - 07 3 - 21	54 - 25 55 - 03 54 - 40 55 - 27

See appendix 5 and 6 for the geographical locations of the hydrometric and meteorological stations mentioned in table 6 and 7. The meteorological station 667, Brownsweg (indicated with purple in table 6), is not located within the catchment of Pokigron but has been added to the list because this station has a very complete rainfall dataset and later on in this report it will become clear that this station will be of use when filling in the gaps in the rainfall data series from all the other stations mentioned in table 6. All the meteorological stations mentioned in table 6 have one aspect in common: they are all located along the watercourses. This makes sense, as almost all the meteorological stations can be found in villages that have been founded along watercourses for a multitude of reasons.

In the second column the number of stations per catchment is given that are representative for further analysis since these stations are the ones that have an acceptable amount of data. Most of the rainfall stations lacked continuous data and were therefore not suitable for further investigation. The period of availability (table 6, column 4) gives an indication of the inconsistency of the different rainfall data series. It is obvious that it was almost impossible to compare all the catchments with each other since the period of availability (see column 3) differs greatly.

The next step was to fill in the gaps for the data series of the meteorological stations mentioned in table 6. Therefore, further assessment was required concerning the methods of supplementing missing data in the rainfall data series.





Table 7 The percentage (%) of missing monthly data for the period 1960 – 1985

Hydrometric station	Number of the meteorological station	Meteorological station	Period of record	% missing data
Stondansie	216	Baas Bart	1963 - 1985	70%
Avanavero	117	Avanavero	1965 - 1980	46%
Pokigron	670	Pokigron	1953 - 1983	18%
	671	Nw. Aurora	1953 - 1985	16%
	695	Ligorio	1969 - 1985	50%
Dramhosso	513	Tafelberg	1960 - 1985	8%
	525	Boslanti	1960 - 1985	12%
Maksita	414	Maksita	1965 - 1985	65%
	419	Raleighvallen	1972 - 1985	58%
Tapanahony	805	Stoelmanseiland	1960 - 1985	18%
	820	Apetina	1969 - 1985	54%
	821	Drietabbetje	1969 - 1985	60%

The above table gives the percentages of missing monthly data if the whole time period of 1960 – 1985 is taken into account per rainfall station. The Baas Bart, Avanavero, Ligorio, Maksita, Raleighvallen, Apetina and Drietabbetje rainfall stations are very incomplete (the coloured cells in the last column, table 7), since more than half of the monthly data for the period 1960- 1985 had to be supplemented. Thus, the certainty and the reliability of the rainfall data becomes questionable. Nevertheless, since the overall data availability is so poor (the data availability for other stations not mentioned in table 7 is much worse) it has been decided to apply most of these meteorological stations despite their poor availability of data. The only stations which have been discarded in this stage for its very incomplete data set is the Baas Bart (Stondansie) and the Drietabbetje (Tapanahony) meteorological station. In the following chapter a more detailed screening of all the available meteorological and hydro metric data will be discussed.

5.2 Supplementing missing data

It is better to have incomplete rainfall data series than no data series at all. With this in mind, the next steps have been undertaken to supplement the missing data in the rainfall series for all the meteorological stations under investigation (see table 7).

5.2.1 The daily missing data: Interpolation

The method of interpolation has been used where one daily rainfall value is missing in the data set of a month, but the method has been ignored when more than 20% of the daily data within a month is missing. When more than 30% of the daily values are missing in a month then no other steps are being undertaken to supplement the missing daily values except for the next step of supplementing the missing monthly values (see next paragraph). The other criterion was that the method of interpolating could not be used if more than one daily value was missing in a row. Since daily data seemed to be missing frequently, this method has been used extensively to supplement the daily series in order to be able to determine a monthly rainfall value.





Days	Daily rainfall in (mm)
1	15.5
2	27.4
3	0.2
4	9
5	11.5
6	10.25
7	9
8	
9	7.5
10	0.9
11	0.3
12	2.2
13	14.2
14	4.2
15	0.6

The interpolation technique which has been taken into consideration is to calculate the missing daily value (indicated in yellow in the table left, day 8) by interpolating between the daily values before and after the value under investigation. By plotting for example the seven daily values prior to the one under investigation (in the table left, days number 1 to 7) and the seven daily values following the missing daily value (days 9 – 15) a trend-line can be plotted through the scatter of points. Depending on which trend-line fits the scatter of points the best, one can choose between a linear, polynomial or a moving average trend-line, where after the missing value can be calculated.

This rather simple method has been chosen above other, more sophisticated methods, because the daily variations of the rainfall are very large. Hence, it is rather impossible to find any logical trend or mathematical logarithm that defines the value of one or more missing daily rainfall values. Another method of correlating the daily values of the station under investigation with another neighbouring station gave very poor results, varying from 10 – 30% correlation coefficient. Accordingly, this method has been disregarded for further interest.

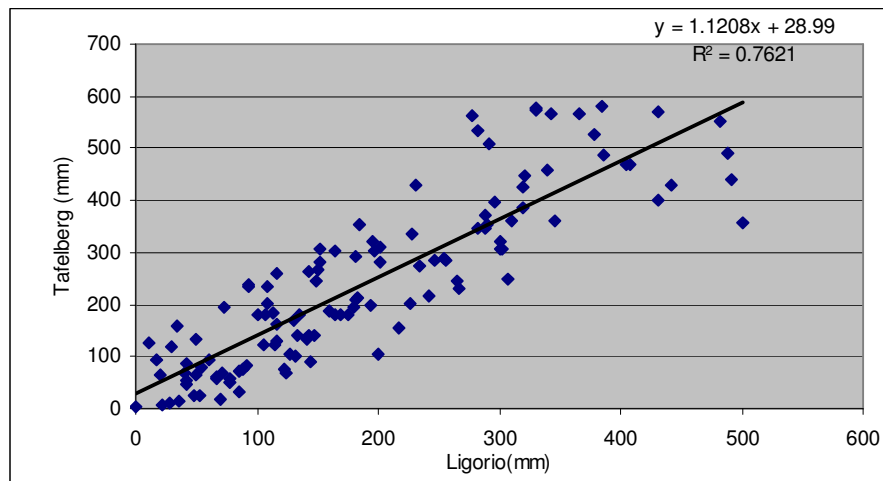
5.2.2 The monthly missing data: Correlation

After all the missing daily values had been supplemented the next step was to examine the missing monthly data. It was often witnessed that in the complete data series some months were completely missing, and also that during some years there were no observations made at all. Since there was not one single rainfall station with a complete data set, all the stations needed to be correlated with each other in order to supplement the missing monthly values. In appendix 7 an overview has been presented for the correlation technique performed. The period of observations which has been used is given in the first row. The green shaded cells correspond with the best correlation results which have been applied to fill in the gaps in the data series. The year 1971 was a unique year for the Brownsweg meteorological station (664), since this was the only station with data available, out of all the other stations mentioned in table 7. Thus, all the other stations are correlated with Brownsweg (664) to be able to supplement for this particular year. In appendix 5 the geographical location of the Brownsweg station (664) is given. Almost all the stations under investigation as given in table 7 have satisfying correlation values with Brownsweg (664). The requirement for the correlation coefficient was set to be at least 50%, and for the few stations that did not meet this requirement, another method has been selected to fill in the gap of 1971. More will be explained in the following paragraph 'Average values'.





Figure 6 The correlation of monthly rainfall for the period 1969 – 1980 between Tafelberg (513) and Ligorio (695)



In the above figure an example is given when the (monthly) rainfall data from the station under investigation (Tafelberg, 513) is plotted against another neighbouring station (Ligorio, 695) with satisfying monthly data availability to define the correlation coefficient. The correlation coefficient is also the highest found for all the other combinations of rainfall stations. The distance between these two meteorological stations is 55 km., and one would expect a higher value for the correlation coefficient.

The results from appendix 7 show that correlation with Nw. Aurora (671), Boslanti (525) and Tafelberg (513) give very high correlation values. The stations Pokigron (670), Nw Aurora (671) and Tafelberg (513) are the ones with the most complete observation records. The year 1970 is marked with the absence of any rainfall measurements for all the stations under investigation, except for the Tafelberg (513) and Brownsweg station (667). The gap of 1970 has thus been filled in according to the best correlation coefficients with either Tafelberg or Brownsweg station. After questioning the personnel of the national meteorological service it became clear that the period of 1970-1972 was characterized by national instability which resulted in strikes all over the country that included the personnel of the meteorological stations of the country.

In appendix 8 the correlation function is given for the distance between the rainfall stations and the corresponding correlation value. Even for rainfall stations which are situated close to each other (distance between 20 – 80 km) the correlation value is somewhat low, one would expect values of around 0.8 and 0.9, just as with the correlation results if the discharge stations are compared with each other (see table 5). The low correlation coefficients could be explained by the very local rainstorms that can occur in Suriname, especially if the daily rainfall data are compared. Another explanation is the measurement technique performed, where the rainfall being caught in the measurement bucket is either not representative enough for the areal rainfall storms. Systematic errors may also occur if the instruments and equipment remain unchanged.

The correlation within the same month was also evaluated for those stations which showed the best correlation coefficient in appendix 7. The best results from the correlation analyses were obtained when performed with the Boslanti (525) data set. But the differences in correlation per month are large and therefore this correlation method will not be discussed in further detail.

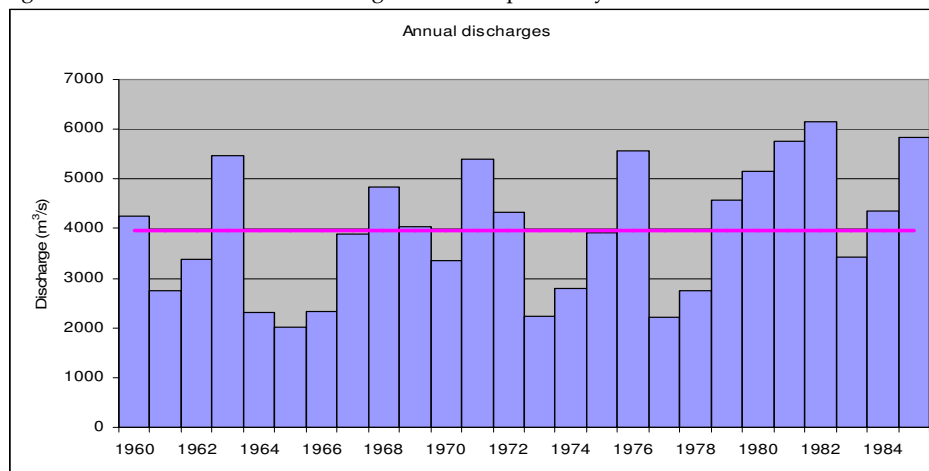




5.2.3 The monthly missing data: Average values

In addition to correlating the rainfall data of the station under investigation with other stations the long term monthly average rainfall values had to be used as well to fill in the gap of the year 1971. The problem with all the rainfall stations was that the year 1971 did not have any measurements at all except for the Brownsweg station (667). For some stations the year 1973 was missing as well. Hence, supplementing the missing monthly average data of 1971 could only be performed through correlation with Brownsweg station (667). There was only a problem if the correlation was not adequate, which is assumed to be if the correlation coefficient was less than 50%. This was only the case for the Palumeu (808), Apetina (820) and Drietabbetje (821) stations which all happen to be located in the Tapanahony catchment. Instead, the long term monthly average rainfall values for the respective stations for the period 1960 – 1985 were an alternative to be used to supplement for the year 1971. The discharge data for the Tapanahony catchment has been checked to see whether the year 1971 had been an extreme dry or wet year. It was clear that in 1971 the discharges were above average for the Tapanahony catchment as plotted in figure 7. Actually, if compared with the respective annual long term averages (pink line) then the annual discharge for the year 1971 was approximately 35% above the long term average. The monthly rainfall data for the year 1971 for the Palumeu (808), Apetina (821) and Drietabbetje (821) rainfall stations have been supplemented by using the long term average data for the respective stations.

Figure 7 The annual discharges for the Tapanahony catchment at Alamandidon sula



See appendix 6 for the geographical location of the Alamandidon sula in the Tapanahony river.

5.2.4 The areal distributed rainfall

In the case when sufficient rainfall stations are present in one catchment interpolation techniques are used to spatially integrate the rainfall over the catchment area. However, in the case of insufficient stations and incomplete data series this is of no use at all. Further in this report it will become clear that only one meteorological station in the whole catchment is available for modelling objectives. In the best scenario (Pokigron catchment) there are three rainfall stations available for modelling purposes. These stations are not evenly distributed over the whole catchment but are located near each other and always along the river. In this case, the arithmetic mean of the rainfall amounts measured in the area is assumed to give a realistic estimate for a relatively uniform rain for the whole catchment.





6 The screening of the input data

After carefully assessing the discharge and rainfall data availability a number of decisions has been made concerning the data required for calibration and validation of the model. First, a region of interest has been identified since it was not realistic to model all the rivers in the interior of Suriname. The large rivers in Suriname can be grouped according to their annual flow regime, and these differences had to be taken into account. The rainfall and discharge data series were not available for the same time period, and therefore one corresponding time period had to be defined for further research. Furthermore, an attempt has been made to check if the rainfall data series contained any measurement error because the correlation functions found are not very satisfactory.

6.1 Defining an area and time period

The following conclusions can be made:

-  The period of overlap for the precipitation and discharge data chosen is 1960 – 1985. This has been decided after evaluating the available rainfall and runoff data as well as the possibility to supplement the missing data with an acceptable degree of accuracy.
-  Supplementing the rainfall data for the Stondansie and Avanavero catchment was much too inaccurate since these rainfall stations had very incomplete data sets (over 60% of the data missing) and correlation of the rainfall and discharge with other stations did not give adequate results.
-  The correlation technique between discharge data and rainfall data have also been performed but with poor results (correlation coefficient values of around 40%) and therefore have not been discussed in further detail.

Initially, the idea was to calibrate and validate the model with all the six different catchment areas as given in table 2. However, after careful investigation and literature study it can be concluded that the Nickerie river and Kabalebo river (both located in West Suriname) cannot be compared with the other catchments (see appendix 4). First of all, they are located further away from the other catchments. Second, differences in the hydrological regime show that these rivers are characterized by low runoff if the average annual unit discharges are compared with other large rivers in Suriname (see figures 8 and 9). According to the W.H.O. report, the seven large basins of Suriname can be divided into two groups. The first group representing high runoff basins for which the median unit discharge is around 25 l/s/km² (the Marowijne, Corantijn, Coppename, Saramacca and the Suriname river) and the second group represents low run-off basins for which the median unit discharge is 15 l/s/km² (the Kabalebo and Nickerie river fall within this group). Although several factors such as the amount and the intensity of rainfall, geology, topography, vegetation and evaporation contribute to the amount of runoff and consequently the unit discharge, it is apparent that the geology in particular and the rainfall contribute most to the differences between the basins. The differences in geology have already been discussed in chapter 1, see table 1. A common feature of the rivers with low runoff is their location along the northern fringe of the basement area on which at least a discontinuous veneer of basin sediments extends beyond the limit of the coastal basin. The Nickerie and Kabalebo basins include part of the Savannah upstream from the gauging stations (W.H.O., Public water supplies and sewerage project). Besides that, the rainfall data for the Stondansie station (Nickerie river) is very incomplete (around 70% of the monthly data are missing for the period 1960 – 1985 is missing). Furthermore, the geological features are such that a mountainous range divides the Corantijn river from the other catchment areas.





Figure 8 Monthly average discharge (1960 – 1985) for the different catchments

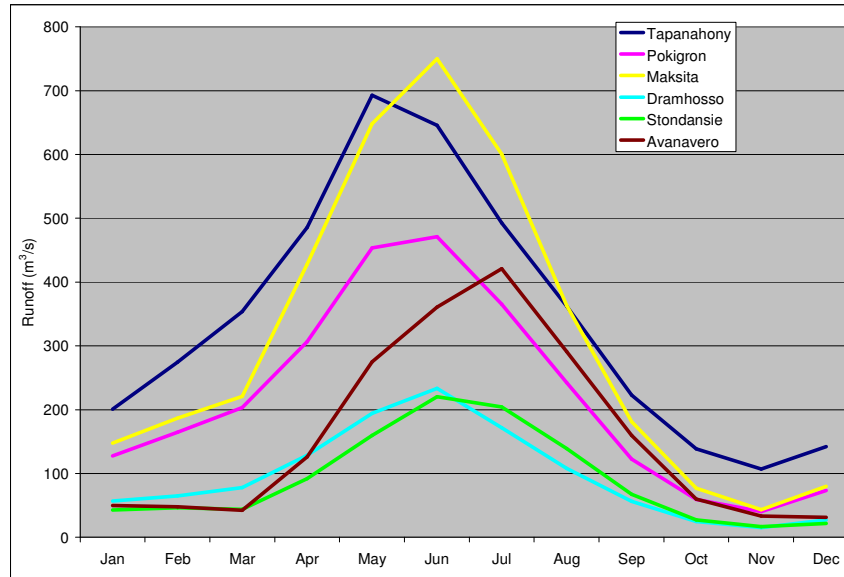
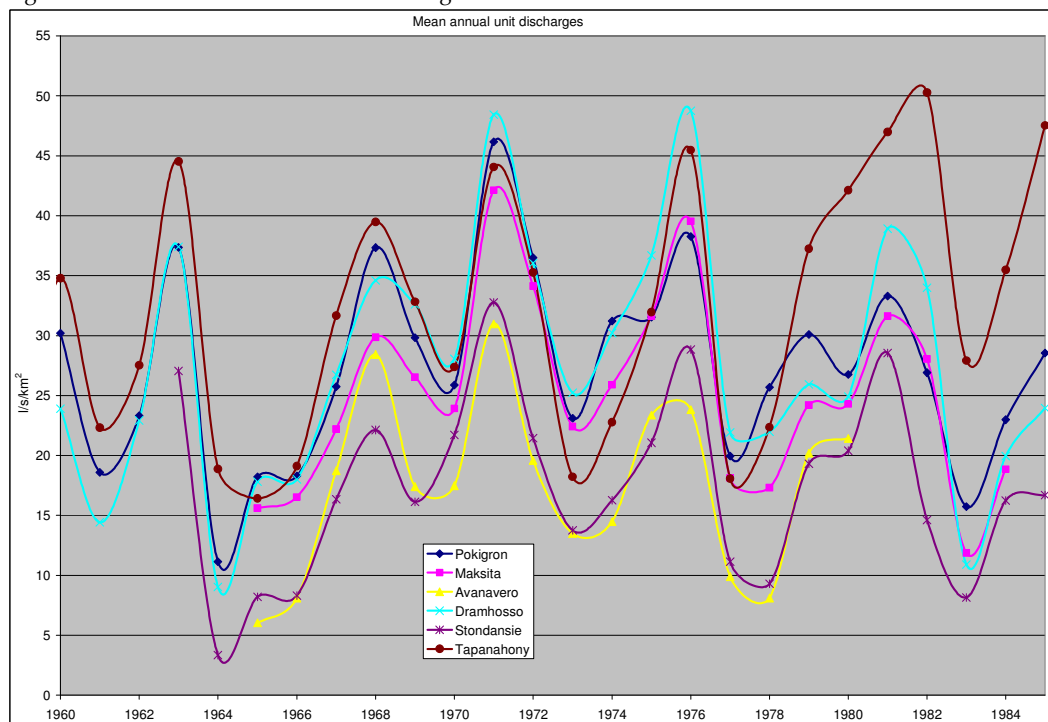


Figure 9 Mean annual unit discharges for the different catchments



In figure 8, the Stondansie and Dramhosso catchments show a similar hydrograph pattern, this corresponds with a small catchment size of respectively 5,160 and 3,520 km². The Maksita and Tapanahony catchments are respectively 12,300 and 10,210 km². However, figure 9 shows that the Stondansie (Nickerie river) and Avanavero (Kabalebo river) catchments are characterized by a low mean annual unit discharge. Table 1 can give an explanation, where it is evident that the Nickerie river flows for 23% through the Savannah Belt where there is a high permeability and infiltration and percolation are high (Ouboter, 1993).



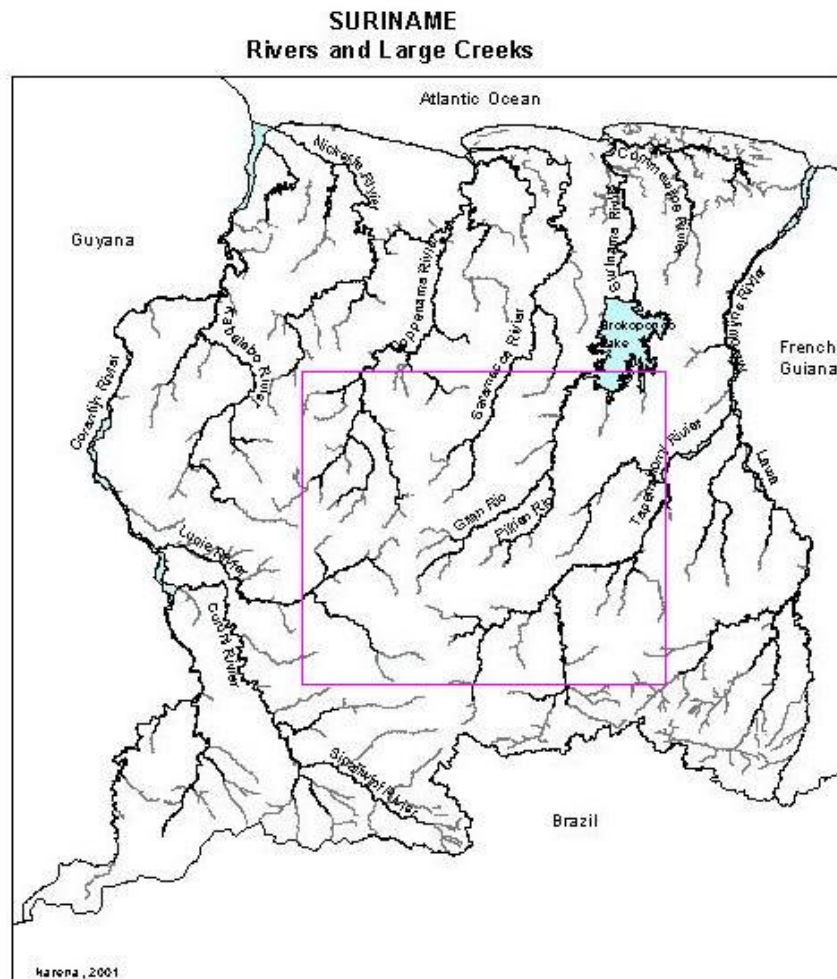


According to the differences between the catchments mentioned above, a specific area has been chosen consisting of the following catchment areas:

-  Maksita catchment (Coppename river),
-  Dramhosso catchment (Saramacca river),
-  Pokigron catchment (Suriname river) and the
-  Tapanahony catchment (is a tributary of the Marowijne river and along which the village Palumeu is located)

The rainfall-runoff model will be calibrated for the area as outlined in figure 10 and hence, an attempt will be made to determine “regional” model coefficients for this area.

Figure 10 The area of specific interest, see pink square



6.2 The data for calibration and validation

The data being used for calibration has been chosen such that per catchment area at least two model runs can be performed with different rainfall input to enhance the reliability of the model output. Hence, the model outputs per catchment can be compared with each other.





Table 8 The data used for calibrating the model

Catchment area	Number of meteorological stations	Number of model calculations
Dramhosso	513, Tafelberg 525, Boslanti Average of 513 and 525	3
Maksita	414, Maksita 419, Raleighvallen Average of 414 and 419	3
Pokigron	670, Pokigron 695, Ligorio Average of 670, 671 and 695 (671 is the Nw Aurora station)	3

For the Maksita catchment there were no other rainfall stations available besides the Maksita (414) and Raleighvallen (419) station. They are located very close to each other and it is expected that with an average rainfall input from these two stations no considerable improvement of the model output will be reached. Nevertheless, a model calculation with an average rainfall input (arithmetic mean) from two stations is preferred above a model calculation with the input from only one rainfall station. The decentralization for the rainfall stations of the other catchments is by far better, and the model output results are expected to be somewhat more accurate.

After supplementing the missing gaps in the data series, the time interval for the hydrometric data sets for the three different catchments (Pokigron, Maksita and Dramhosso) is the same and can be divided into three time periods:

-  1960 – 1968
-  1977 – 1985
-  1960 - 1985

The time periods have been chosen such that each of them consists of at least 8 consecutive years of record as to produce reliable model results. The last time period has been chosen such that it includes the previous two time periods. The period of 1960 – 1985 thus represents an average of the model output of the other two time periods.

One record of time has been left out for validation of the model and that is the period of 1969 – 1976. This period is characterized by very large gaps (the years 1970 and 1971) in the rainfall data series due to economical turmoil in the country. Therefore, this period has been chosen for validation of the model to check if the discharges can be simulated with satisfying results. The catchment of the Tapanahony has been chosen for validation rather than calibration since this catchment is located further away from the other three. And since the Panato is a tributary from this river, and there are no hydrometric flow data obtainable from the Panato creek, it has been assumed that if the model could be validated with the Tapanahony with sufficient results, a reliable output could be expected for the Panato simulations.





Table 9 The data used for validating the model

Catchment area	Number of rainfall stations	Number of model calculations	Time period
Dramhosso	513, Tafelberg 525, Boslanti Average of 513 and 525	3	1969 - 1976
Maksita	414, Maksita 419, Raleighvallen Average of 414 and 419	3	1969 - 1976
Pokigron	670, Pokigron 695, Ligorio 670, 671 and 695 (671 is the Nw Aurora station)	3	1969 - 1976
Tapanahony	805, Stoelmanseiland 820, Apetina Average of 805, 820	3	1960 - 1985

See appendix 5 and 6 for the locations of the hydrometric stations as given in column 1 as well of the locations of the meteorological stations.

Initial model attempts will be performed with time-steps of 6 months ($b_0 - b_6$), which means, according to the rainru model, that the precipitation from the previous 6 months contribute to the discharge of this month. After the model calibration it will become more clear what the memory of the catchments are, meaning after how many months the effects of rain are felt on the river discharge of the respective catchments. Per model simulation the model coefficients $b_0 - b_6$ are calculated with the multiple linear regression function. Varying the threshold value until the correlation between the simulated and the measured discharges has reached its maximum value gives the final output of the model coefficients. The underlying requisite is the net runoff coefficient c , which must have a value between zero and one.

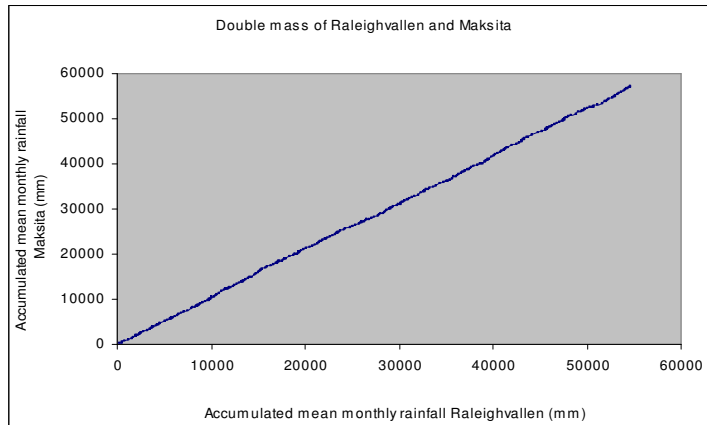
6.2.1 The double mass curve

According to the low correlation coefficients found for the meteorological stations as can be seen in appendix 8, it was desirable to check the data series of these stations for any measurement errors. One method which is easy to perform and where the errors can directly be derived from a graph is the double mass analysis. The double mass analysis can be performed to rule out inhomogeneities in the data series, for example originating from change in observer, rain gauge type etc. This is indicated in the curve of a double mass plot, showing an inflection point in the straight line. The double mass analysis has been realized with accumulated monthly mean rainfall over the period 1960 – 1985 for all the rainfall stations mentioned in table 9. The results were all satisfactory, meaning that there were no visible deflections in the straight line. From this, it can be concluded that the low correlation values in appendix 8 could be the result of very local rainfall storms in Suriname. For an example of the construction of a double mass curve see the following figure. The distance between the Raleighvallen (419) and Maksita (414) meteorological stations is only 20 km., however, the correlation coefficient is only 60%.





Figure 11 The double mass curve of Raleighvallen (419) and Maksita (414) meteorological stations

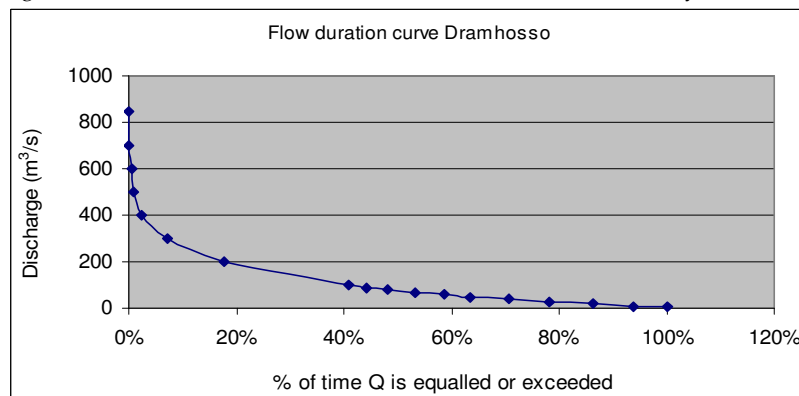


6.2.2 The flow duration curve

A flow duration curve gives the relationship between any given discharge and the percentage of time that the discharge is equaled or exceeded. The flow duration curve only applies for the period for which it was derived. If this is a long period, say more than 10 to 20 years, the flow duration curve may be regarded as a probability curve, which may then be used to estimate the percentage of time that a specified discharge will be equaled or exceeded in the future (Savenije, 2000). As an example, the flow duration curve has been established for the Dramhosso hydrometric station for the period of 1969 – 1979, based upon a daily time basis. The range of discharges is divided into 19 intervals.

The shape of the curve is important as a generally flat curve indicates a river with few floods which is extensively supplied from groundwater, while a steep curve indicates a river with frequent floods and dry periods, having little groundwater flow and being supplied mainly from runoff. (Maidment et al, 1988)

Figure 12 The flow duration curve for Dramhosso hydrometric station



The curve in figure 12 can be described as to have a rather flat curve, which indicates that the flow in the river is dependent on groundwater resources. This can be backed up by the rainfall-runoff regime, when during the dry season (August-December) there is a rainfall deficit. However, the large rivers in Suriname never fall dry. See figure 4 for an example.





7 The model calibration

7.1.1 Introduction

In this chapter the model results for the different simulations of the three catchments will be discussed. The model coefficients b , the threshold value and the net runoff coefficient will be compared with each other for the different simulations during the three time periods. The model is calibrated with the threshold value until the best correlation between the measured and calculated runoff has been found. To be on the safe side, the number of time-steps (memory of the system) for the initial calculations has been set for 6 months. The choice for six months is probably too long, but it is not sure what the memory is of the catchments under investigation. Only after the model calculations have been performed can the number of time-steps be determined. The simulated and measured hydrographs of the different model calculations can be found in appendix 10, 11 and 12.

7.2 The model calculations

As has been explained in the previous chapter, the calibration of the model will be realized with three different time periods for the model calculations. The time periods are:

-  1960 – 1969
-  1977 – 1985
-  1960 - 1985

Pokigron catchment

Pokigron is a Maroon village located along the Suriname river, just south of the van Blommenstein reservoir. Three model calculations regarding the rainfall input were chosen:

-  Calculation with a rainfall data input from station 670, Pokigron. This data set is the most complete when compared with the other rainfall stations. This station is situated just at the border of the catchment area in a Maroon village and the rainfall is most certainly being influenced by the large van Blommenstein reservoir. This reservoir is the result of the construction of the Afobakka dam which is the only hydro-power plant in Suriname.
-  Calculation with a rainfall data input from station 695, Ligorio. This station, located in a Maroon village, is located more or less in the centre of the catchment area of Pokigron and therefore the rainfall data are more representative for the catchment. The distance between Pokigron and the Ligorio station is approximately 70 km.
-  Calculation with an average rainfall data input from all three stations, Pokigron (670), Nw Aurora (671) and Ligorio (695). All the stations are located along the Suriname river and at the same time are the locations for Maroon villages. The distance between Pokigron and Nw Aurora is approximately 260 km (See appendix 5). The distance between Pokigron and Nw. Aurora is approximately 20 km.

Dramhosso catchment

Dramhosso is a place located along the Saramacca river. There were two meteorological stations with sufficient data series. The following calculations have been made:

-  Calculation with a rainfall data input from rainfall station at 513, Tafelberg. The average annual rainfall totals for this station belong to one of the wettest regions of Suriname (See appendix 3 and 5). Tafelberg is the location of a mountain located at the upper reach of the Saramacca river.
-  Calculation with a rainfall data input from station 525, Boslanti. Boslanti is also a Maroon village. The distance between Tafelberg and Boslanti is approximately 130 km.
-  Calculation with an average rainfall data input from the stations Tafelberg (513) and Boslanti (525).





Maksita catchment

Maksita creek is a tributary of the Coppename river. In this catchment two meteorological stations were available for further modelling purposes. The following model calculations will be performed.

-  Calculation with a rainfall data input from station 414, Maksita
-  Calculation with a rainfall data input from station 419, Raleighvallen. Raleighvallen is a location in the river where a number of rapids (in Suriname called sula's) and falls can be found. The distance between Maksita and Raleighvallen is approximately 15 km.
-  Calculation with an average rainfall data input from the stations Maksita (414) and Raleighvallen (419).

The discharge data series of the three catchments are equal for the different simulations (different rainfall data input).

7.3 Analysis of the model output

In this paragraph the model coefficients, correlation coefficient, the threshold value and the net runoff coefficient will be compared with each other. Per catchment the graphical output has been presented with the highest correlation value, the other model simulations have been left out, since the graphical model results are more or less the same (see appendix 10, 11 and 12).

7.3.1 The model variables b_i

In appendix 9 the output of the different model simulations is represented for the three time periods. Overall it can be concluded that the largest influence on the present runoff is influenced by the rainfall from this month and the previous months (b_0 and b_1). It can also be witnessed that the difference between the values of b_0 and b_1 are small. The value of the coefficient b_1 is on average 74% of b_0 , in some cases (Dramhosso catchment for the period 1977 – 1985) the coefficient b_1 is sometimes even larger than b_0 . This is unusual, and occurs only in this particular time period and only for the Dramhosso calculations. The Pokigron calculations (with rainfall input from station 695 and calculation with an average input of 670, 671 and 695) show above average values for the coefficient b_0 (average around 0.35 for all the calculations) if compared with the other calculations. This would mean that the rainfall from this month plays a larger role in the runoff for this month for this particular catchment area.

For each of the three time periods all the model coefficients $b_0 - b_6$ have been compared with each other. It can be seen in appendix 9 that there are great similarities between the different catchment calculations concerning the model coefficients despite the differences in catchment size and runoff magnitude. This is above expectations, and accordingly an average value for each of the b coefficients can be assigned per time period. In table 9 the values of the b coefficients indicate that the memory of the system is, on average, 4 months. This can be concluded out of the results in table 10, where can be seen that the values of b decrease until b_4 , after which the values of b_i either remain constant or increase.

In the following table the different outputs for the model coefficients b_i per time period are presented. It can be noticed that the model coefficients $b_0 - b_4$ show satisfying similarities with each other.





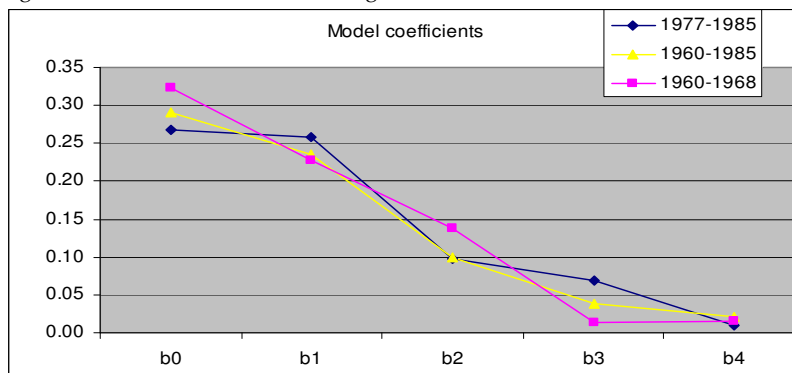
Table 10 The average model coefficients for the different time periods

	1960 - 1968	1977 - 1985	1960 - 1985
b0	0.32	0.27	0.29
b1	0.23	0.26	0.24
b2	0.14	0.10	0.10
b3	0.01	0.07	0.04
b4	0.02	0.01	0.02
b5	0.06	0.00	0.02
b6	-0.04	0.00	-0.03

The last column is the output of the model coefficients for the whole period, 1960 – 1985. If the average value is calculated for the period 1960 – 1968 and 1977 – 1985 then the values for the period 1960 – 1985 can be found. It can be assumed therefore that the values for the model coefficients b_0 – b_4 for this period are the average values for the area under interest and from now on will be addressed as the “regional” model coefficients.

The coefficients b_i determine the contribution of the effective rainfall in month $t-i$ to the runoff in month t . For example, the first coefficient b_0 gives an indication that the runoff in the month under investigation depends upon approximately 30% of the net rainfall from this month (see the last column, table 10). The sum of the average b_0 – b_4 coefficients amounts to a total of around 0.7 which means, that eventually, 70% of the net rainfall ends up in the rivers. The other 30% of the net rainfall would incorporate the long-term processes of moisture recycling to the atmosphere. In turn, the net rainfall (total rainfall P – threshold value T) is approximately 20% (average for all the catchments under investigation) of the total rainfall which is received in a catchment. The other 80% (threshold value T), which can amount to 2000 mm/a, is the evaporation term in the hydrological cycle. For comparison, the annual rainfall in Suriname varies between 2200 – 3000 mm (Ouboter, 1993).

Figure 13 The average value for the model coefficients for the different time periods



The average of the coefficient b_0 – b_4 for the period 1960 – 1985 will be regarded as the “regional” model coefficients.

7.3.2 The threshold value

As is the case with the model coefficients, the threshold values for the different simulation runs show significant similarities for the three different time periods. The period 1960 – 1985 represents the average threshold values.

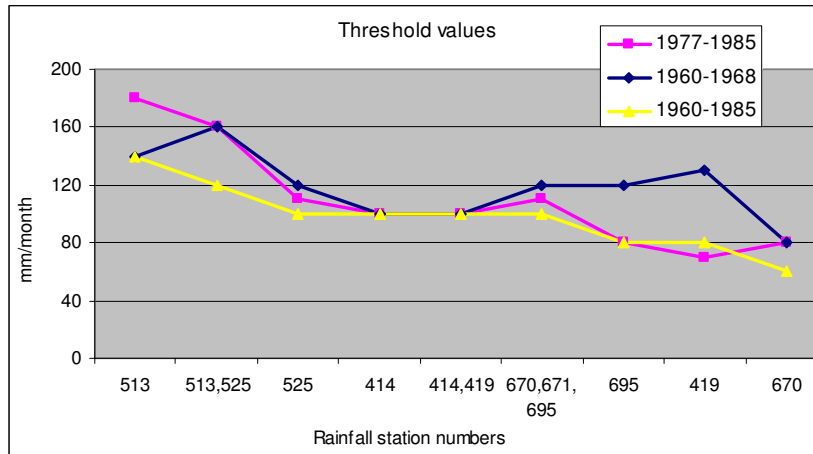
The threshold value is an indication for the amount of rainfall that does not directly result in runoff, but that is a result of interception and an immediate feedback to the atmosphere. In chapter 2 it has





been explained that in a tropical country like Suriname the evaporation is a major element in the hydrological cycle. If one looks at table 3 it can be seen that the annual average evaporation value is in quite agreement with the threshold values found during the calibration process, see figure 14. According to Savenije (1997), the threshold value is the separation between the immediate and the long term processes on the time scale considered.

Figure 14 The average threshold values for the different time periods



The rainfall station numbers correspond with:

- 513 = Tafelberg, Dramhosso catchment, Saramacca river
- 525 = Boslanti, Dramhosso catchment, Saramacca river
- 695 = Ligorio, Pokigron catchment, Suriname river
- 414 = Maksita, Maksita catchment, Coppename river
- 419 = Raleighvallen, Maksita catchment, Coppename river
- 670 = Pokigron, Pokigron catchment, Suriname river
- 671 = Nw Aurora, Pokigron catchment, Suriname river
- 695 = Ligorio, Pokigron catchment, Suriname river

The period 1960 – 1968 shows a rather erratic pattern for a number of calculations, and those are the calculations with the rainfall stations 419 and 695. An explanation for this could not be found.

The threshold value differs greatly for all the calculations, with average values ranging between 80 – 160 mm/month. However, there are calculations with distinguishable higher threshold values.

-  The calculations for the Saramacca catchment for the Tafelberg station and the calculation with an average input of 513 and 525 show high threshold values, ranging between 120 – 180 mm/month.
-  The rest of the calculations for the Coppename and Suriname catchment show an average threshold value ranging between 80 – 120 mm/month.

The high threshold values in the area of the Tafelberg station (Saramacca river) cannot be explained. The topographic and vegetation characteristics (respectively appendix 1 and 2) of this region indicate no specific reason for an increased threshold values which can be assigned to interception, bare soil evaporation or other immediate moisture feedback processes. The input of the rainfall data is probably to blame, since the Tafelberg station shows very high annual rainfall amounts, as can be seen in table 11.





Table 11 The average annual rainfall numbers for 4 meteorological stations

In mm/annual	Ligorio 695	Tafelberg 513	Boslanti 525	Maksita 414
Average annual rainfall 1960 - 1985	2,244	2,897	2,310	2,096
Annual rainfall total 1964	1,164	2,161	1,903	1,857
Annual rainfall total 1968	2,927	3,851	2,584	2,073

Out of the eight rainfall stations used for the calibration, four have been chosen, each from every other catchment area and both station from the Saramacca river, as to compare the Tafelberg (513) station with the Boslanti (525) station in table 11. Different years have been compared, together with the average annual rainfall over the period 1960 -1985. Without doubt the Tafelberg station receives high amounts of rain. This can also be witnessed in appendix 3, where the region with the highest annual rainfall coincides with the geographical location of the Tafelberg station. It is also clear that the differences between the Tafelberg and the Boslanti station are quite noticeable, especially in the year 1968, which can be described as a typically “wet” year. Around 40% more rain fell at Tafelberg compared with Boslanti. The distance between these two is approximately 150 km. This could explain these differences. The point is that the Tafelberg (513) rainfall data is not very representative for the whole catchment area as first has been assumed. A solution to this problem has been found to set a ratio between the monthly rainfall data from Tafelberg and what is assumed to be representative for the Dramhosso catchment:

Representative data for Dramhosso / Tafelberg data = 0.6 – 0.8

If a ratio of 0.7 is chosen and the model calculation with the corrected Tafelberg data is performed, the threshold value results to around 100 mm/month, which is also the average threshold value for all the other model calculations.

7.3.3 The correlation coefficient

Overall, the correlation between the measured and modelled discharge give very satisfactory results. The lowest correlation coefficient is a value around the 0.75 while the highest value is 0.91. See appendix 7 for an overview of the correlation coefficients for the different model calculations.

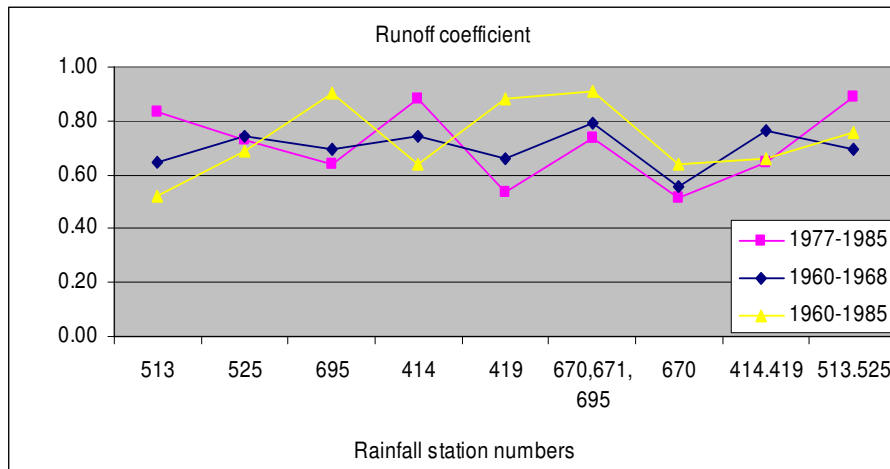
7.3.4 The net runoff coefficient

The net runoff coefficient gives an indication of the percentage of net rainfall - the rainfall which remains after the immediate moisture feedback processes (threshold value) have been subtracted - that results into runoff. Looking at the results from figure 13 one can conclude that the runoff coefficients are quite high, almost all above 60%, with an average value around 70%.





Figure 15 The effective runoff coefficient for the different catchments for the three time periods



In the report of Duba (1971) a correlation value of 0.5 has been found for the catchments that can be described as the high runoff province. This includes the rivers of Coppename, Saramacca and Suriname river. Since these are only 'traditional' runoff coefficients and not a net runoff coefficient the outcome of figure 15 seems quite realistic. The net runoff coefficient is based purely on the net rainfall, the rainfall which remains after the immediate moisture feedback processes (threshold) have been subtracted (Savenije, 1997). Besides, there are specific characteristics for the south of Suriname which could be blamed for such high values for the net runoff coefficient.

The high net runoff coefficient can be explained by the following features:

-  The permeability is not high and the surface is quickly saturated after the onset of the rainy season.
-  The gentle slopes and the low hydraulic conductivity of the soil mantle produces very small groundwater outflow to the rivers. Most of the moisture in the soil mantle is consumed by the forest vegetation during the season. The combination of gentle topography and geology make the contrast between monthly low flows and high flows (a ratio of 200 to 1) quite large (Durrant, 1982).

7.4 Improvement: Introducing a seasonal threshold value

The following improvements have been looked at:

-  Performing the same calculations, but with a variable threshold value for the rainy and dry season. This calculation will be performed with the same rainfall stations as in table 9 but only for one time period: 1960 – 1985. See the next paragraph for the model results.
-  Improvement of the calculation with rainfall data from Tafelberg have been discussed already, and it can be concluded that if a ratio of 0.7 for the monthly rainfall data is applied a more realistic rainfall input is being used and thus the model output is more accurate.
-  Perform the model calculations with mean daily rainfall and discharge data. However, the rainfall and discharge data sets are very incomplete, and filling in these gaps is very difficult and therefore not very realistic. An attempt has been made to model on a daily time basis, for a period of one year for the same catchment areas as have been used up to this point. The model results were not satisfactory, with a correlation output of around 50 and 60%. As for analyzing the availability of the flow of the Panato creek for hydro-power purposes, it has been assumed that it will be sufficient to do so with monthly runoff variations. Therefore, the model attempts on a daily time basis will not be discussed further on.





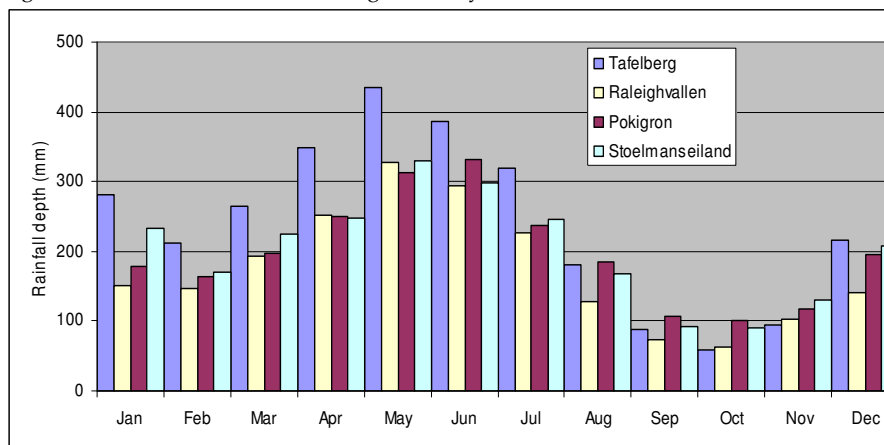
Varying the threshold value is the most realistic representation for taking into account the variable immediate losses of rainfall such as interception and bare soil evaporation and immediate transpiration. The following figures will give a visualization of the variations in the rainy and dry season in Suriname. In the dry season (August, September, October) the rain that occurs will almost immediately infiltrate in the dry soil and the evaporation and transpiration are very high. In figure 4 it was clear that in the dry season there is a net rainfall deficit, however, the Tapanahony river never falls dry. This can be observed for all the large rivers in Suriname. In the long rainy season (April – July), the immediate processes of feed back moisture such as evaporation from bare soil and temporary surfaces (pools) are less pronounced because the soil is saturated and according to the evaporation measurements in figure 3 the evaporation slightly decreases in the rainy season. Therefore, the threshold value during the rainy season is most logical less than during the dry season. To check whether the variation in the threshold value has any influence upon the outcome of the model coefficients, two scenarios will be investigated.

It has been decided to perform the model calculations for two different scenarios:

- ✎ Setting the threshold value (T) to 0 mm/month for the months April – July
- ✎ Setting the threshold value (T) to 40 mm/month for the months April – July. This is approximately 40% of the average threshold value found during the calibration process. The rainfall numbers during the months April – July reveal that almost 40 – 50 % of the annual rainfall occurs in these 4 months.

During the rest of the year, including the period of the long dry season (August – March), the threshold value is set to vary between 80 – 120 mm/month. This is the same interval in which the “regional” threshold value lies that has been found during the calibration process.

Figure 16 The average monthly rainfalls for four different stations for the period 1960 - 1985

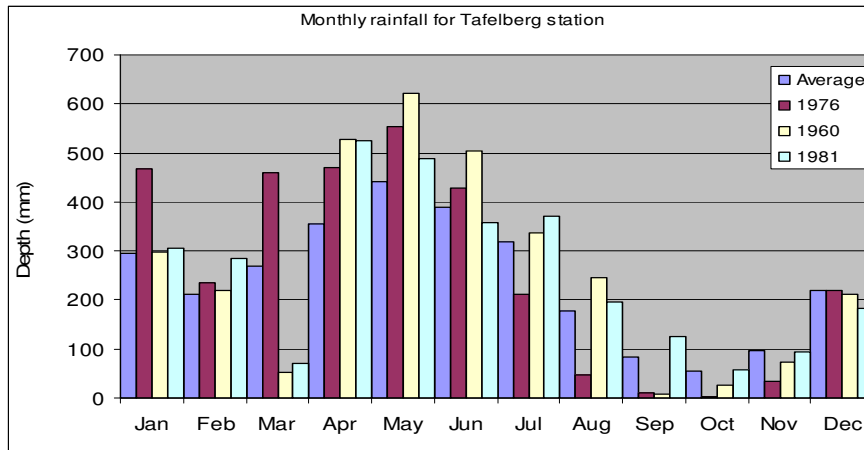


The above figure gives the long term monthly rainfall figures for the period 1960 – 1985 for Tafelberg (513), Raleighvallen (419), Pokigron (670) and Stoelmanseiland (805). As can be seen in figure 16, most of the rain falls in the period of April – July, corresponding with the long rainy season. The monthly variations over the years however can be very pronounced. The following figure illustrates this.





Figure 17 The total monthly rainfall for the period 1960 – 1985 for the Tafelberg station



For the year 1976 around 85% (2,600 mm) of the total annual rainfall (3,142 mm) fell in the first 6 months of the year, from Jan – June (average amount for Tafelberg, for the period 1958 – 1983 is 67%). Similar intensities occurred in the year 1960, where 53% (1,652 mm) of the total annual rainfall (3,120 mm) fell in the months April, May and June (average amount for Tafelberg, for the period 1958 – 1983 is 41%).

7.4.1 Model results

For the two scenarios as mentioned above the model calculations were performed. In table 12 the results are presented when the threshold for the rainy season is set to 0 mm/month. In the last column the results from the earlier calculation (see calibration paragraph) are given where a constant T value is assigned throughout the calculations. The correlation coefficient between these two model runs does not improve noticeably. The same goes for the scenario when the threshold value is 40 mm/month during the rainy season.

Table 12 The output of the model when the threshold value during the rainy season is set to 0 mm/month

Catchment	Rainfall station	Threshold dry season (mm/month)	Runoff coefficient	Correlation coefficient	Correlation coefficient calibration step, Threshold value=constant
Maksita	419, Raleighvallen	100	0.55	0.84	0.82
	414, Maksita	100	0.54	0.84	0.83
	Average 414 and 419	100	0.55	0.85	0.83
Pokigron	670, Pokigron	100	0.56	0.80	0.74
	695, Ligorio	80	0.53	0.89	0.88
	Average 670, 671 and 695	80	0.54	0.88	0.87
Dramhosso	513, Tafelberg	120	0.43	0.86	0.86
	525, Boslanti	80	0.52	0.84	0.85
	Average 513 and 525	100	0.48	0.86	0.88

The correlation coefficients do improve, although the change is minimal except for the Pokigron (670) calculation. For the model calculations of the Dramhosso catchments, the correlation coefficient slightly decreases. The average net runoff coefficient is around 52% when the threshold value is 0 mm/month during the rainy season.

Table 13 The output of the model when the threshold value during the rainy season is set to 40 mm/month

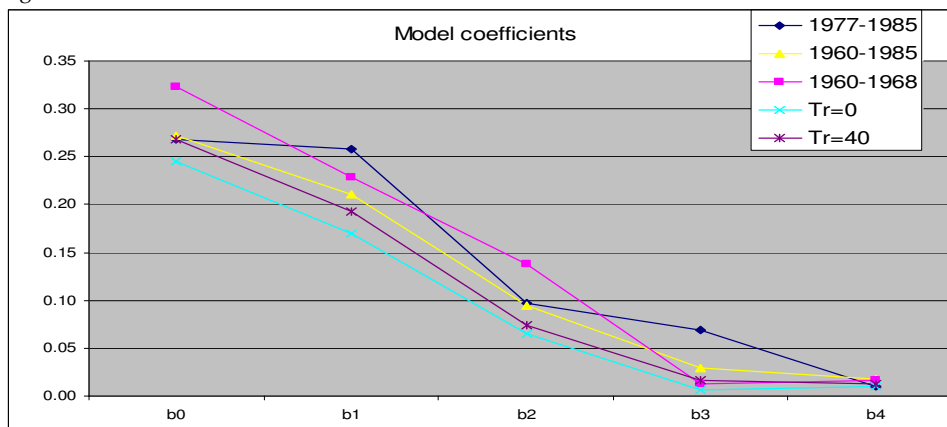




Catchment	Rainfall station	Threshold dry season (mm/month)	Runoff coefficient	Correlation coefficient	Correlation coefficient calibration step, Threshold value =constant
Maksita	419, Raleighvallen	100	0.62	0.84	0.82
	414, Maksita	100	0.65	0.83	0.83
	Average 414 and 419	120	0.62	0.85	0.83
Pokigron	670, Pokigron	120	0.67	0.78	0.74
	695, Ligorio	100	0.67	0.89	0.88
	Average 670, 671 and 695	100	0.60	0.87	0.87
Dramhosso	513, Tafelberg	120	0.47	0.86	0.86
	525, Boslanti	100	0.62	0.85	0.85
	Average 513 and 525	100	0.52	0.87	0.88

Similar to the model results in table 12 when the threshold is 0 mm/month during the rainy season, there is hardly any change in the correlation coefficient when the threshold is 40 mm/month during the rainy season. Here also, the correlation coefficient somewhat improves when they are compared with the earlier calibration calculations where the threshold value is constant throughout the year (last column table 12 and 13). Again, the Pokigron (670) calculation responds very well to the variation introduced for the threshold value. The average net runoff coefficient is around 62% for the scenario when the threshold value is 40 mm/month during the rainy season. If the results of table 12 and 13 are compared with one another, it can be said that the improvements in the correlation coefficients if compared with the earlier calculations (when the threshold value is constant throughout the year) are almost identical.

Figure 18 The model coefficients for variable threshold values

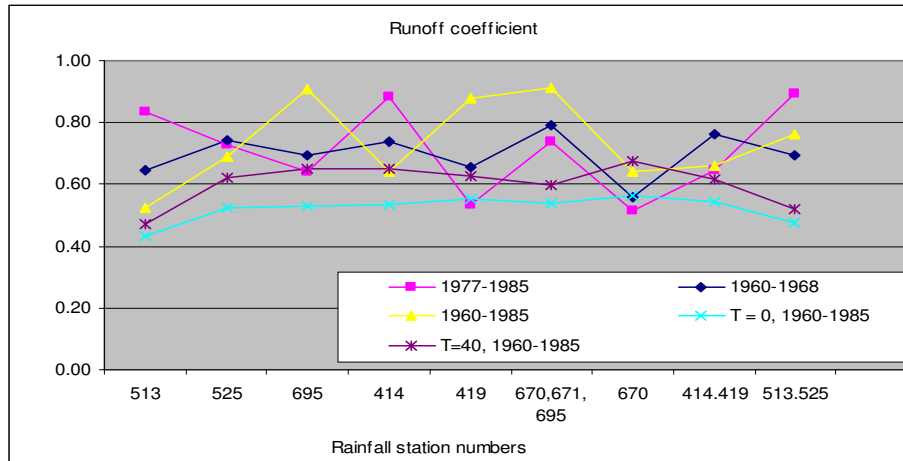


The blue line $Tr=0$ is when the threshold for the rainy season is set to 0 mm/month for the period 1960 – 1985. The brown line $Tr=40$ is when the threshold for the rainy season is set to 40 mm/month for the period 1960 – 1985. If we compare the model coefficients $b_0 - b_4$ for both scenarios with the previous calculations (see paragraph ‘calibration’) for the period 1960 - 1985, then the only difference visible in figure 18 is that the values of the model coefficients is slightly smaller. The pattern however, is similar, and the results are therefore adequate.





Figure 19 The net runoff coefficients for variable threshold values



The average net runoff coefficient decreases when the variable threshold value is introduced. This is no surprise, since during the months in the rainy season (April – July) the total monthly rainfall is applied, subtracted by either 0 or 40 mm/month, for calculating the net runoff coefficient instead of the net monthly rainfall values where the original threshold value of 80 - 100 mm/month is subtracted.

7.5 Conclusions

7.5.1 Conclusions

The following conclusions can be made:

-  The model coefficients ($b_0 - b_4$) for all the calculations show satisfying similarities. The coefficients b_5 and b_6 have been left out because the values for b should show a decreasing trend with increasing system memory, and b_5 and b_6 showed values which were higher than b_4 (see table 11). An average value for the coefficients $b_0 - b_4$ can be calculated, these “regional” values will be used for validating the model.
-  The threshold values for the different calculations shows large variations between 60 and 180 mm/month, but out of all the calculations, the average threshold value for validation of the model is set to vary between 80 – 120 mm/month, which can be described as the average value for the threshold according to the calibration output (see figure 14). After validating the model a fixed value will be assigned to the threshold.
-  Introducing a seasonal threshold value during the long rainy season (April – July) does not lead to remarkable improvements of the model input if compared with the calculations when the threshold value is kept constant throughout the year. Consequently, performing the model simulations with a constant threshold value is found to be reliable.
-  In appendices 10, 11 and 12 the simulated and observed hydrographs have been plotted. For the time period 1960 – 1985 (appendix 12), the year 1971 is badly simulated, but this is also the year when rainfall measurements were not available for any meteorological station. There could also be an error in the discharge measurements, since it is odd that discharge measurements continued when rainfall measurements ceased in this year. Especially during a period of economic turmoil. All the other time periods show very good simulations, except for some cases such as in appendix 11 for the period 1977 – 1985. Here, the Maksita calculation is poorly simulated for the year 1982. This can also be assigned to the poor rainfall data input, which had to be filled up for this particular year for the rainfall station 414, Maksita.





8 The model validation

In this chapter the model validation with the fixed regional model coefficients $b_0 - b_4$ and the fixed threshold value from chapter 7 will be discussed. The ultimate challenge in Suriname remains the availability of reliable data sets for rainfall and runoff. It would have been desirable to validate the model with other, smaller catchments than those used during the calibration process. Especially since the Panato catchment is also comparatively small. However, other rainfall and runoff data could not be obtained for smaller catchments.

The “regional” model coefficients ($b_0 - b_4$) have already been determined with the model calculations for three different periods of observation. Now, calculations can be made with these fixed model coefficients. The only parameter which was not fixed is the threshold value. Earlier it was determined that the threshold value can vary between 80 – 120 mm/month. During the validation runs, the model calculations have been performed with three threshold values: 80, 100 and 120 and afterwards a fixed value has been assigned to the threshold value.

Model validation has been performed with monthly input from the same rainfall stations as with the calibration, but with another time period; 1969 – 1976. See table 14 and 15 for an overview.

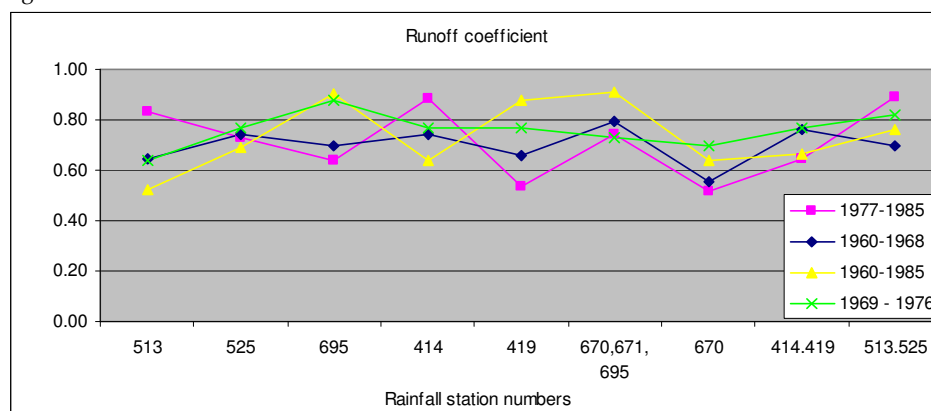
Table 14 The correlation and runoff coefficients, period 1969 – 1977

	Maksita			Dramhosso			Pokigron		
Threshold (mm/month)	419	414	Average 414, 419	525	513	Average 513,525	670	Average 670,671, 695	695
80	0.83	0.81	0.84	0.85	0.82	0.91	0.61	0.81	0.84
100	0.82	0.81	0.84	0.85	0.82	0.91	0.60	0.80	0.84
120	0.82	0.81	0.83	0.84	0.82	0.91	0.59	0.80	0.84
Net runoff coefficient	0.77	0.77	0.77	0.77	0.64	0.82	0.70	0.73	0.88

In the last row, the net runoff coefficient is given which corresponds with the highest correlation coefficient out of the three values.

As can be seen in the table above, the overall correlation coefficients give satisfactory results. The average correlation coefficient can be found with a threshold value of 100 mm/month. Except for the Pokigron calculation the correlation coefficients are all very good. The runoff coefficients show similar results as with the calibration procedure. With an average value varying between 0.7 – 0.8. See the figure below, where the validation period (1969 – 1976) is compared with the other calibration periods.

Figure 20 The net runoff coefficient for the calibration and validation





No abnormalities can be found in the runoff coefficient or the correlation coefficients, and therefore the validation procedure for the period 1969 – 1976 can be concluded to be successful.

8.1.1 Tapanahony calculations

With the support of Mr. Boksteen the monthly streamflow data of two locations in the Tapanahony could be obtained. One of the locations is the Alamandidon sula (see appendix 6). The other location is situated very close by, and therefore only the Alamandidon location has been chosen to validate the model for the Tapanahony catchment. The period of calculation is 1960 – 1985, since both the runoff and rainfall data were available for this period. The model output is as follows.

Table 15 The correlation and runoff coefficients for validation of the model with the Tapanahony catchment, period 1960 - 1985

Threshold value (mm/month)	Tapanahony catchment		
	820 Apetina	805 Stoelmanseiland	Average 805, 820
80	0.69	0.74	0.76
100	0.69	0.74	0.76
120	0.69	0.74	0.77
Net runoff coefficient	0.95	0.81	0.86

An average rainfall data input of the Stoelmanseiland (805) and Apetina (820) station (See appendix 5 for the geographical locations) has been used for the fourth column in table 15. The correlation coefficients for the model calculation with input from Apetina (820) differs much from the other two calculations. An explanation could be the numerous gaps in the rainfall data set for Apetina (820), where 54% of the monthly data was missing for the period 1960 – 1985. The meteorological station of Stoelmanseiland (805) on the other hand, had to be supplemented with only 17% of the monthly data over the same period of time.

The model validation has given satisfactory results and the model coefficients as have been determined with the calibration are therefore correct. A threshold value of 100 mm/month is given to be representative for the region of interest (as can be seen in figure 3). Now the model is calibrated and validated, the flow in the Panato creek can be predicted.

In appendix 12 the graphical output of the simulated and measured discharge from every catchment has been given. The model output with the best correlation value per catchment has been presented, instead of the graphs from all the model calculations. The year 1971 is again poorly simulated, but an explanation has already been discussed in the previous paragraph “conclusions”.





9 The model performance for the Panato creek

The final area of interest is the catchment area of the Tapanahony and especially the catchment of the Panato creek. The rainfall data from the meteorological station Palumeu (808) are available for a period of 1975 – 1986. Correlating the data series from this rainfall station with other rainfall stations show good results, especially with the Tafelberg and Boslanti rainfall station (see appendix 7). Since there are no discharge measurements available for the Panato creek, another method has been discussed as to attempt to validate the simulated hydrograph. Also, the input of the model variables has been changed to witness the sensitivity of the model output.

As a first indication towards modelling the discharge fluctuations in the Panato creek the rainfall data from the Palumeu rainfall station (808) have been used. This station is located only 5 km away from the Panato creek and is therefore assumed to be representative to be used as model input for the Panato catchment. The regional model coefficients have already been determined, as well as the threshold value of 100 mm/month. Discharge measurements of the Panato creek are not obtainable except for three measurements performed by Mr. Naipal. Discharge and water-level measurements of the Tapanahony can be obtained, but only for stations which are located further away downstream from the confluence of the Tapanahony and Palumeu river. Water-levels have been measured for the past two years. One waterlevel gauge is located approximately 200 m. downstream of the dam location and the other gauge has been placed 200 m. upstream of the dam location.

Mr. Naipal has carried out a few discharge measurements with an ott current meter in the Panato creek during several visits. The results of these measurements are:

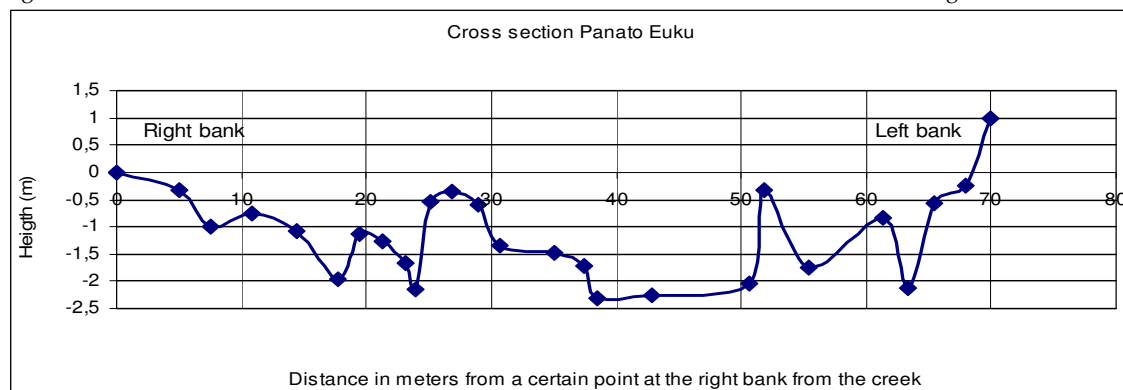
 Q on 14 September 2003 = 0.5 m³/s

 Q on 17 February 2003 = 0.414 m³/s

 Q on 6 September 2003 = 4 m³/s (v=1.9 m/s)

It should be noted that the difference between the first and the last measurement is such that one of these measurements most likely contain an error. According to the simulated runoff in figure 20 the average discharge in September varies between 3 and 4 m³/s. Hence, the first measurement of 14 September 2002 is probably incorrect. The cross section of the Panato creek shows a very irregular pattern, which makes discharge measurements very difficult. During my observational visit in November, it was impossible to perform any discharge measurements since there was no flow at all.

Figure 21 The cross section of the Panato creek at the location where the dam is being constructed



Mr. Naipal (the supervisor in Suriname) has measured the above cross section of the Panato euku (euku means creek in Trio language) as can be seen in figure 21. The heights in figure 21 are





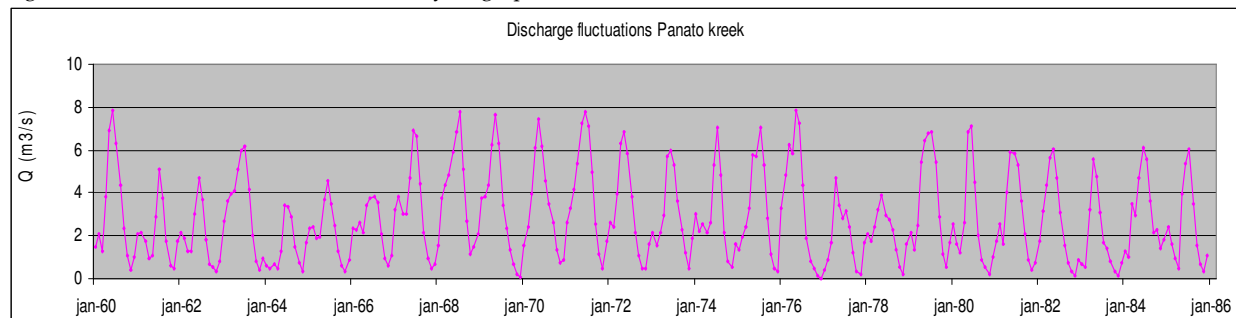
referenced from a certain point at the right bank. This point is probably chosen such that it is the highest point at the right bank.

It is planned that the top of the dam will be at a height of approximately 0.5 m above the large rock situated at 30 m from the right bank. The location of the outlet of the dam is next to the large rock at the right side and the top of the outlet is right below (approximately 30 – 40 cm) the highest point of the rock. See also figure 25, where the effective storage is made possible by an additional 0.5 m construction, indicated with a grey colour.

See appendix 15 for a few pictures of the location in the Panato creek where the dam is being constructed. The differences in water-level observed for November and February are significant. At the time of writing this report, construction of the dam had not been finished. The difficult accessibility of the project site for deliverance of construction materials and the rainy season impede the construction schedules.

9.1 The model output

Figure 22 The simulated hydrograph of the Panato creek for 1960 - 1985



During the observational period in November 2004 it was witnessed that the creek falls dry during the long dry season, which is from August – November. It should be mentioned however that the year 2004 was an extreme year: in May there was a period of more than average heavy rains and in the period of October – January there hardly fell any rain at all in the interior. These phenomena cannot be backed up with meteorological or hydrometric data but by oral communication with the local people at the village Palumeu and other villages in the interior (the upper reach of the Suriname river at Ligorio and Pokigron). It is suspected that the creek falls dry during any normal year around the long dry season, since this creek is only very small and the flow not very substantial.

Since the discharge measurements in the Panato creek are not available except for the three occasional measurements performed by Mr. Naipal, another method had to be found to be able to validate the simulated runoffs for their reliability. The choice has fallen upon the usage of the annual unit discharges for the different catchments. The use of unit discharge (unit flow), seems to be an exceedingly convenient approach to compare the water resources potential of catchments (surface and subsurface) of highly variable size. Further, if the unit discharge is determined for a given type of environment, it can be used to assess the water resources potential of a basin in a similar environment where metering data are not available but the area of the catchment is known (Dubá, 1971). A comparison has been made of the annual unit discharge of all the catchments under investigation. The unit discharge represents average conditions within a basin. It tends to decrease with increasing area, but in Suriname this is not necessarily the case (W.H.O., Public water supplies and sewerage).



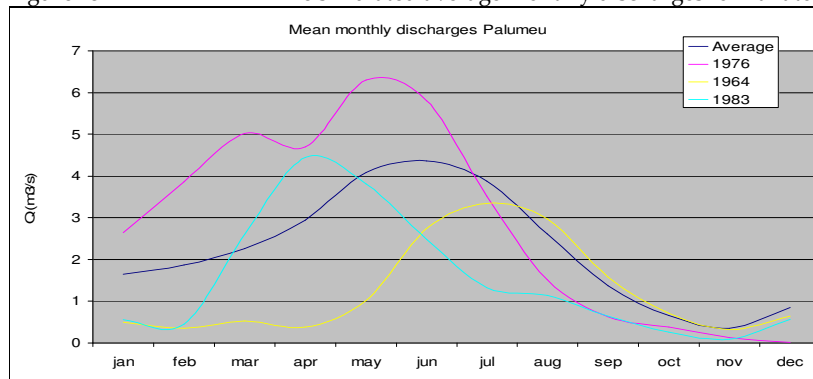


Table 16 The annual unit discharges for different catchments

	Period of record	Catchment size	Annual unit discharge	Annual rainfall
		(km ²)	l/s/km ²	(mm/year)
Tapanahony	1952 - 1985	10,212	34	2,610
Pokigron	1952 - 1985	7,750	28	2,267
Maksita	1965 - 1985	12,300	25	2,122
Dramhosso	1960 - 1985	3,520	27	2,898
Stondansie	1963 - 1985	5,160	17	not available
Avanavero	1965 - 1980	9,020	17	2,267

The Panato streamflow calculations have an annual unit discharge value of 34 l/s/km². The average annual rainfall total is 2295 mm for the period 1960 – 1985 for the rainfall station located at Palumeu. The value for the annual unit discharge for Panato and Tapanahony is similar, and therefore it can be concluded that there is some reliability in the Panato creek model output.

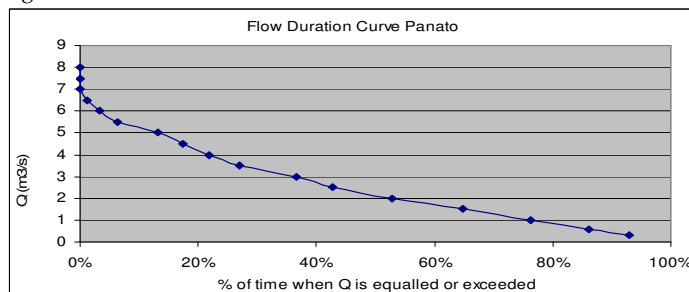
Figure 23 The simulated average monthly discharges for Panato creek



The above figure presents the simulated hydrographs for different years, and also the long term average discharge over the simulated period of 1960 – 1985. In the following paragraph when calculations will be made of the storage in the Panato creek two alternatives will be discussed; one with the average discharge variation and one with the year 1964, which can be described as a dry year. The total annual discharge for this year is the lowest in the period of 1960 – 1985. In the year 1976 the annual discharge is the highest for the period 1960 – 1985. However, for the objective of this research it is not interesting to analyze the high runoffs. These are of interest for the design and construction of the dam which is not within the scope of this research.

Next, a flow duration curve has been established based on a monthly time basis for the period of 1960 – 1985 for the simulated runoffs. Daily discharge data were not available.

Figure 24 The flow duration curve for the Panato creek for 1960 - 1985





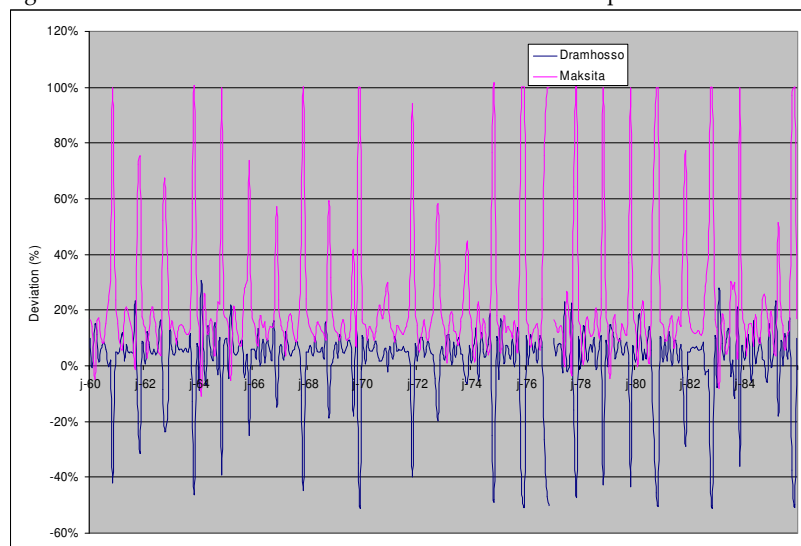
As can be seen in the flow duration curve of the Panato creek an average outflow for hydro generation of 1 m³/s is equalled or exceeded during 75% of the time. This sounds very promising for the hydro-power capacity, but the other criterion in the energy output formula (see page 50) is the head, which in this case of Panato is the decisive factor for the hydro-power generation. In the next chapter a more detailed analysis of the hydro-power capacities will be discussed.

9.2 Sensitivity analysis

To determine the sensitivity of the model output, the input of the model variables $b_0 - b_4$ has been varied. Two alternative inputs for the model variables $b_0 - b_4$ have been used, one input with the smallest catchment (Dramhosso) and one with the largest catchment (Maksita), see appendix 9. For the geographical location see appendix 5. Those model variables have been chosen for the calculation with the highest correlation output (see appendix 9). For the Dramhosso input, the rainfall input for 513 and 525 has been used, for the period 1960 – 1985. For the Maksita input, an average rainfall input of 414 and 419 has been used, for the period 1960 – 1985.

In figure 25 the deviations (in percentage) of the original simulated discharges of the Panato creek when compared with the two alternative calculations are plotted for the period 1960 – 1985. The deviation from the Dramhosso calculation is smaller than that of the Maksita calculation. This is probably due to the difference in catchment size; Dramhosso is 3,520 km² and Maksita is 12,300 km². It is evident that the largest deviation (for both scenarios) with the original calculations of the Panato creek runoffs (see previous paragraph) are during the last two or three months of the year: Oktober, November and December. Also, the values of the original discharge output if compared with the calculation of the Maksita input is, except for a few months, always larger. When the input of the model variables of Dramhosso is used, the opposite occurs, but only during the month November and occasionally also during October and December. Apart from these months, the deviation of the two alternative simulations is small when compared with the original calculation. November is usually the month with the lowest monthly discharge in a year, see figure 3, 4 and 23. The month October is usually the month with the lowest rainfall depth (figures 3, 4, 14 and 15). These results could mean that there are different mechanisms (such as groundwater storages and flows) per catchment resulting in runoff during the month with the largest rainfall deficit (November). Overall, the deviation when compared with the original calculation is not so large.

Figure 25 The deviation for two scenarios when compared with the simulated runoff of the Panato creek





10 The availability of water for hydro-power

The next and final step for my research is the evaluation of the hydro-power generation in the Panato creek. For this, a water balance of the reservoir is required. The availability of water for hydro-power purposes will be evaluated on the basis of monthly runoff data. The expectations for the energy output of the dam are approximately 5 – 10 kW, according to a preliminary analysis of the availability of water and the present need of the village by Mr. Naipal (supervisor from the Anton de Kom University in Suriname). However, the stakeholders of the Palumeu project have no idea of the fluctuations when it comes to the hydro-power generation throughout the year. It is not difficult to predict that during the long dry season (August – November) the continuation of the hydro-power generation is very vulnerable. It is during this period that the operation of the dam needs to be expressly tailored to the fluctuations of water availability.

The following water balance equation can be applied:

$$S_1 = S_0 + (I - Q + A \cdot (P - E)) \cdot (t_1 + t_0) \quad \text{VI}$$

Where by:

S = storage (m³)

I = inflow of the Panato creek (m³/s)

Q = reservoir release (m³/s)

A = surface area of the reservoir (m²)

P = precipitation (m)

E = evaporation (m)

As was described in chapter 1, the formula for the energy output from hydro generation is as follows:

$$P_{\text{Wat}} = H_n \cdot Q \cdot g \cdot \rho \cdot \eta_{\text{tot}} = H_n \cdot Q \cdot \eta_{\text{tot}} \cdot 9.81 \cdot 1000 \quad \text{I}$$

To determine the energy output of the dam, the variables Q and H in formula I should be calculated first. To be able to do so, the storage of the reservoir should be calculated. In this way, the variable water-levels upstream of the dam can be calculated, which in turn determine the net head H in formula I.

10.1 Criteria

The following figure 25 gives a simplified schematisation of the water balance in the Panato creek as a result of the construction of the dam. Henceforth, the reference level for discussing all measures of the dam and all relevant water-tables is the downstream situated water level gauge. The top of the highest rock according to this downstream water level gauge is then located at 3.69 m.

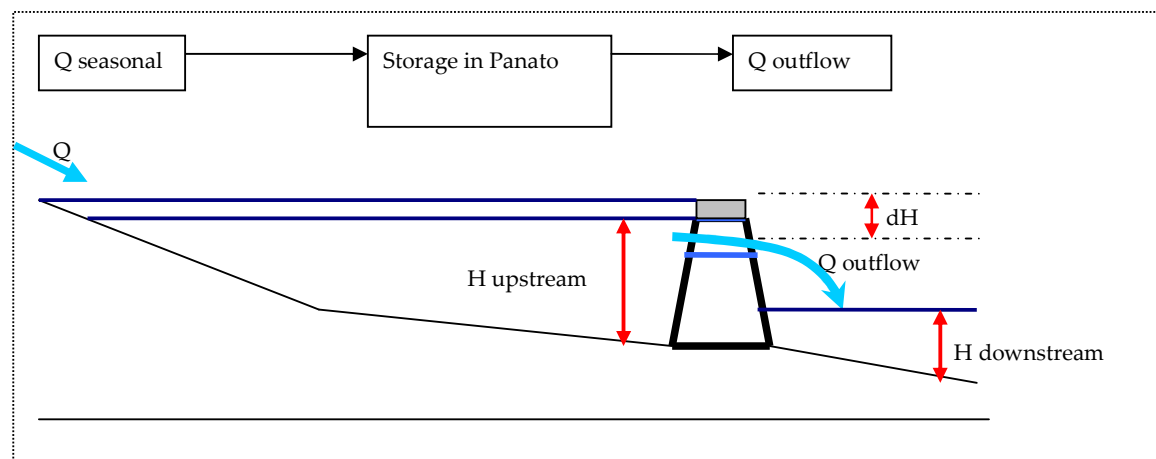
The following dimensions of the dam have been fixed, although the dam construction is not yet completed and changes might occur in the design:

-  The centre of the outflow of the turbine is at a height of 3.0 m. The diameter of the turbine outlet is approximately 80 cm.
-  The top of the dam will be constructed at a height of 4.2 m.
-  The effective storage of the dam, indicated in figure 25, is the volume enclosed between the two blue lines and is the result of an additional construction height of 0.5 m (grey rectangle) above the top of the highest rock as can be seen in figure 21. The rock is situated 30 metres from the right bank.





Figure 26 Schematisation of the water balance of the reservoir in the Panato creek



As can be seen in formula I for calculating the hydro-power potential, there are two variables in the formula which determine the energy output:

- 📖 A Q outflow, which according to Mr. Naipal has a minimum of $0.5 - 1.0 \text{ m}^3/\text{s}$
- 📖 A head dH , which according to Mr. Naipal has a minimum of 0.5 m

The first variable, the Q outflow, is dependent upon the natural inflow of the Panato creek. The second variable however, depends upon two other variable quantities, the water-level upstream of the dam and the water-level downstream of the dam. The water level upstream depends upon the storage volume, and therefore the inflow of the Panato creek and the Q outflow. The water-level downstream is influenced by the Q outflow, but also by the flow in the Tapanahony river. That is because the location of the dam is only about 200 metres away from the confluence of the Tapanahony and the Panato creek (see appendix 14).

A minimum head dH can only be realized if,

- 📖 In the rainy season, the downstream water-levels in the Tapanahony (and thus the Panato) have not reached critical high values (3 m. and higher) or if
- 📖 In the dry season, the water-levels upstream are at a minimum. Hence the water-levels should not reach critical low values of beneath the outflow turbine (3 m. and lower)

In the formula for calculating the net power of the hydro-turbine, the varying magnitude of the Q outflow and the head H can be used to compensate one another so as to realize a rather constant net power output of $5 - 10 \text{ kW}$. For example, in the rainy season, when the Q outflow can reach values above $1 \text{ m}^3/\text{s}$, the minimum energy output of 5 kW can be realized with a minimum head value of 0.64 m . In the dry season, when the head can reach values of above 1 m , the minimum energy output of 5 kW can be realized with a minimum Q outflow of $0.64 \text{ m}^3/\text{s}$.

10.2 Assumptions

The first step towards calculating the storage in order to determine the fluctuations of the water-level upstream of the dam is to look at the catchment size of the Panato creek. Since detailed geographic or topographic maps of this area do not exist, the only way of finding out more of the area is through oral communication with the local people and my supervisor in Suriname, Mr. Naipal. The following assumptions have been made for calculating the storage:

- 📖 The availability of water for the hydro-power generation will be analyzed with monthly discharge data from Panato. One of the motives is that the daily fluctuations in discharge could not be simulated due to lack of reliable daily rainfall data for the calibration and





validation of the model. The other reason is that the daily fluctuations of the discharge are such that it would be better to look at the overall availability of water within one month, since the daily fluctuations can be flattened out by the storage in the reservoir.

-  The total length of the catchment is approximately 10 km with a total catchment size of 80 km².
-  The in and outflow components of rainfall and evaporation in the water balance equation have been left out since their influence, if compared with the inflow of the Panato creek (Q inflow), is marginal. For example, if the average monthly rainfall is 200 mm., and the average natural flow from Panato is 1 m³/s = 1*3600*24*30 = 2,592,000 m³/month. Then the surface area of the reservoir is, according to calculations 300,000 m² and hence, the rainfall contribution in the reservoir would amount to 30,000 m³/month. That is only 10% of the contribution due to the natural inflow of the Panato, and that without taken into account the evaporation factor
-  In the longitudinal section of the catchment two sections can be distinguished. One upstream section, located at the source of the creek, which can be described as to have a small width and steep slopes. The slope (alpha) is assumed to be around 1:800. The average width of this section is set to 5 meters. The other section is located at the downstream section of the Panato creek and is therefore very flat and broad. The average width for this section, with a length of 6 km is 50 m (see figure 27). Consequently, the storage volume can be calculated for different values of the waterlevel upstream of the dam.
-  From January 2003 - January 2004 the water levels both upstream and downstream of the dam location have been measured by local people. The water levels upstream of the dam will be used to calculate the effective head dH. It is also assumed that the dam regulations have no noticeable effect on the downstream water-levels because the storage of the dam is small and all excess runoff from the Panato will spill over the dam. The water levels should have been measured with a three day interval. However, gaps in the data series indicate a regular absence of the observer. The average of all the performed calculations (the number of measurements within one month differs) in a month is taken to be the representative average monthly value for the water level in that particular month. Furthermore it has been assumed that although the water level measurements have been carried out for a short period of time, these values are representative for performing the water availability calculations with a considerable reliability.
-  The Q outflow varies according to the variations in the water-levels upstream (dH) of the dam. To calculate the discharge as a result of the dH, the following formula will be used for a Rehbock weir (Battjes, 2002).

$$Q = 0.45 \left(\tan \frac{\theta}{2} \right) g^{1/2} dH^{5/2}$$

VII

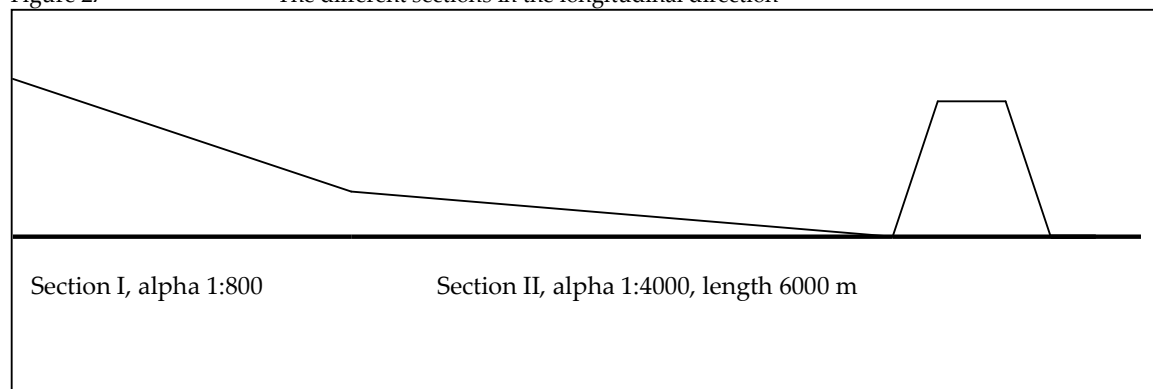
where $\theta = 1/2\pi$

dH is the upstream water-level as can be seen in figure 25 and can be calculated with the monthly simulated inflow discharges of the Panato creek. The fluctuations in the upstream water-levels of the reservoir depend upon the natural inflow of the Panato creek. With the dimensions and slopes of the catchment the water-levels in the reservoir can be calculated according to the natural inflow of the Panato creek. With the monthly fluctuations of the water-levels, the Q outflow can be determined with formula VII. Consequently, the Q outflow and the net head dH can be used to calculate the energy output according to formula I, page 51.





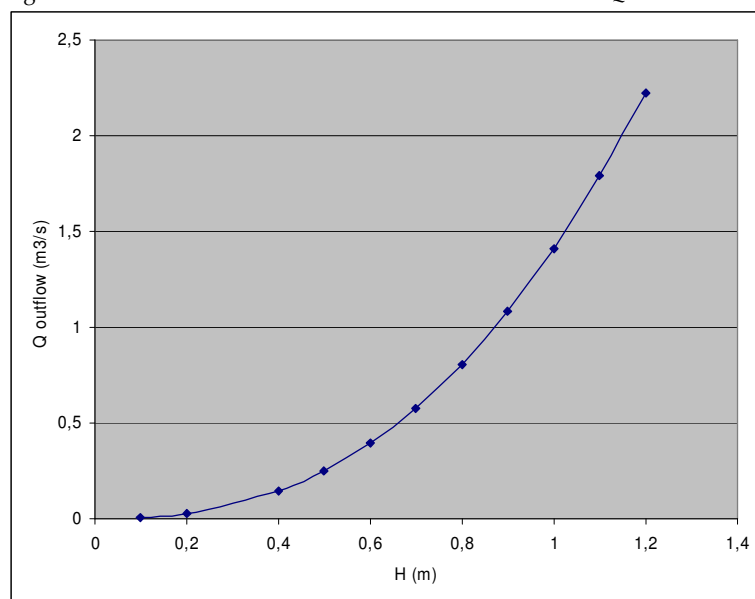
Figure 27 The different sections in the longitudinal direction



10.3 Storage calculations

In this paragraph, the results of the storage calculations will be discussed. First, with the simulated hydrograph for the Panato creek, a relationship between the upstream water-level head H and the Q outflow can be determined with formula VII (page 53) for the period 1960 – 1985. Furthermore, there are two 'runoff' years which have been discussed separately, one year consisting of the long term average simulated discharges for the Panato creek and another year, which has been chosen because the simulated annual discharges are the lowest for the period 1960 – 1985.

The following figure has been plotted by using equation VII (page 53). The maximum dH (see figure 26) is 1.2 m. If the natural inflow of the Panato creek is such, that the waterlevel dH of 1.2 metres is exceeded, it means that the maximum reservoir capacity is reached and the excess water will spill over the dam.

Figure 28 Relation between the net head dH and the Q outflow of the dam

The minimum head required for generating hydro-power is 0.5 m, according to Mr. Naipal (supervisor Anton de Kom university in Suriname). Furthermore, the average Q outflow which Mr. Naipal expects is 1.0 m³/s.





The monthly storage volume has been calculated with two different runoff scenarios (for one year each) for the natural inflow of the Panato creek. These two scenarios will be compared with one another, all the way through determining the availability of water for the generation of hydro-power.

 Calculation with a long term average inflow (average calculated for the period (1960 – 1985) of the Panato and

 Calculation with a low inflow of the Panato, corresponding with a “dry” year.

As can be seen in table 17, the differences in the inflows are rather large. The discharge in the dry year is on average 56% of the discharge of an average year.

The storage volume fluctuations for a “wet” year are not interesting, since this research aims to give insights in the availability of water for generation of hydro-power and therefore the periods when there is a scarcity of water are the most interesting. An average year is a year where the simulated average long term inflow data for the period 1960 – 1985 of the Panato creek is used. The year 1964 shows the lowest annual discharge and on average the lowest monthly discharges. A dry year consists thus of the simulated discharge data for the year 1964. For the downstream water-levels, an average year consists of the average water-level measurements during the only observational period of 2003/2004. For a dry year, the downstream monthly water levels have been set to 80% of the average monthly water-levels.

Table 17 The simulated monthly discharge data for Panato creek

	Dry year	Average year
jan	1.22	1.91
feb	1.18	2.21
mar	0.63	2.64
apr	0.70	3.34
may	1.68	4.50
jun	2.56	4.73
jul	2.07	4.23
aug	1.05	2.95
sep	0.44	1.56
oct	0.39	0.71
nov	0.19	0.35
dec	0.47	0.98
Average	1.05	2.51
Total	12.57	30.09

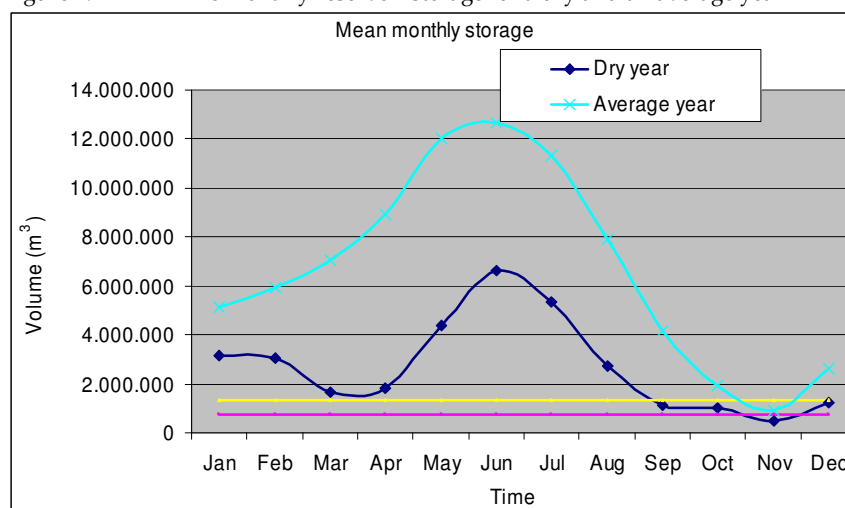
In table 17, the availability of water from the natural inflow of the Panato creek is evident. If the absolute minimum of the Q outflow is 0.5 m³/s, then the purple shaded cells indicate the months during which the requisite of the Q outflow cannot be fulfilled. In figure 24 it also showed that a Q outflow of 1 m³/s is equalled or exceeded during 70% of the time. Hence, it can be concluded that the natural inflow of Panato meets the requirements for the Q outflow of the dam. Now, the net head will be analyzed.

According to the assumptions for the size of the catchment and the topographic features, the monthly storage can be calculated. According to a natural inflow of the Panato creek for a dry and average year, the following results have been obtained, see figure 29.





Figure 29 The monthly reservoir storage for a dry and an average year



The differences in natural inflow of the Panato creek between an average and normal year can be very large, as is the case for all the rivers in Suriname. The monthly storages for the dry and average year in figure 28 are the results of the storage due to the natural inflow of the Panato. The yellow line in figure 29 indicates the maximum storage capacity, if the water-levels upstream of the dam are just below the top of the dam. Everything above this yellow line is water in excess and hence will spill over the dam. This is a considerable amount, especially in the average year. The pink line indicates the dead storage volume of the dam. The relatively small volume that is enclosed between the pink and yellow line is the effective storage of the dam which can be used in times when the monthly natural inflow of the Panato is smaller than the monthly outflow of the dam. The effective storage reservoir is actually very small, just 360,000 m³ and this is very clear from figure 29. As can be seen in table 17, in a dry year, the discharges in the months September - December (4 months) are below the minimum required Q outflow for the purpose of hydro- power generation. In an average year, only during the month November can the minimum Q outflow not be realized.

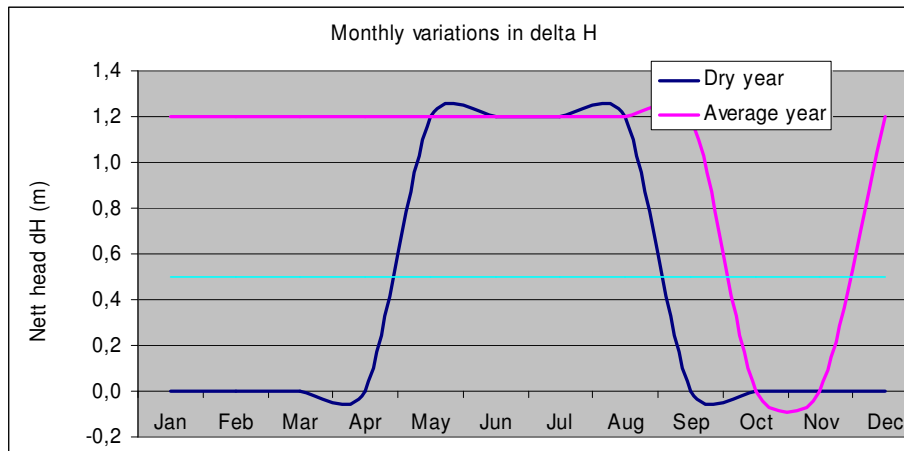
In figure 29 it can be seen that in a dry year only 4 months (September – December) out of a year the effective storage can be fully utilized. For an average year, only in the month November the effective storage cannot be replenished.

Next, if the monthly variations in the storage have been calculated, the water-levels upstream of the dam can be derived from the fixed relationship between the reservoir volume and the water-levels in the reservoir. With these levels the head can be calculated. The monthly water-levels downstream of the dam are determined by the average of all the measurements performed in the corresponding month. To take into account the decrease in outflow as a result of the dam, the downstream water-levels for a dry year have been reduced to 80% of the water-levels during an average year. In an average year, the natural inflow of the Panato creek is sufficient enough to replenish the reservoir, and at the same time maintain the natural downstream water-levels. The latter can be realized because on average, more than 70% of the time the monthly natural inflow exceeds a Q outflow of 1 m³/s (see figure 24), and then the excess water is spilled over the dam.





Figure 30 The monthly variations in the head H



The blue line in figure 30 gives an indication of the approximate minimum head H which is required for generation of hydro-power. It can be seen that in a dry year, during a period of 4 months (May – August) the minimum head H is exceeded. For an average year the minimum head is realized for 10 months. The net head of the two years has been determined after subtracting an average Q outflow of $1 \text{ m}^3/\text{s}$ from the simulated Q inflow from the Panato creek.

10.4 Hydro-power generation

In this chapter, the energy output of the dam will be presented for the period 1960 - 1985 and alternative solutions for the periods of low inflow of the Panato creek will be discussed. Applying the output energy equation (see page 53, equation I) for the monthly variations in net head gives the following figure. The overall efficiency η in the energy output formula is assumed to have a value of 0.8 (Duivenijck van, 2001) because the efficiency of the hydro-power dam has not yet been determined by my supervisors in Suriname.

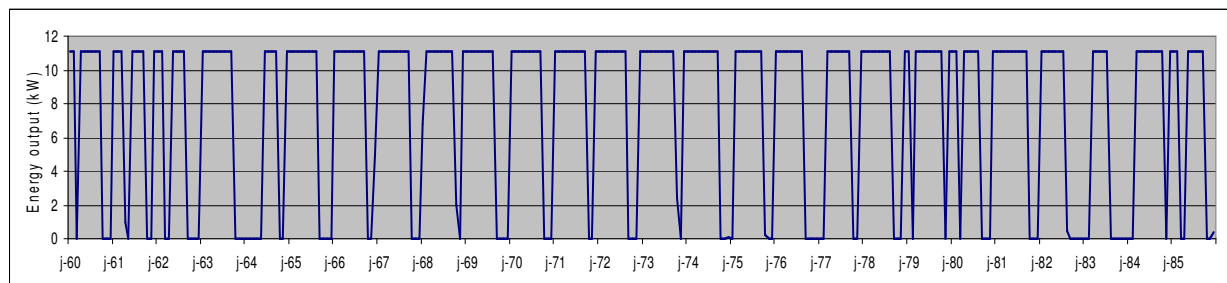
With the results of figure 28, the monthly energy output can be calculated for the period 1960 – 1985. Also, the critical water-levels downstream of the dam have been taken into account. The results of the high downstream water-levels are that during the months May and June (long rainy season) the downstream water-levels have reached levels up to the outlet of the turbine, and hence, generation of energy cannot be continued. Furthermore, for the period 1960 – 1985 (312 months in total), it can be concluded that during 179 months generation of hydro-power is no longer possible (either because of low inflow of the Panato or high downstream water-levels). This amounts to 57% of the period 1960 – 1985. See also figure 31.

Since the effective storage of the dam is very small, the upstream water-levels will response very quickly as a result of the Q outflow, and hence, the Q outflow will vary within short periods of time, probably within days. The effective storage volume is such that with a constant Q outflow of $0.5 \text{ m}^3/\text{s}$ the storage is depleted within 10 days. To take into account these quick responses (on a time scale of days) of the reservoir, the monthly energy output of the dam has been reduced. The maximum energy output if calculated with formula VII results into 21kW. In figure 31, it can be witnessed that the monthly maximum energy output is reduced with 50% to approximately 11 kW. The monthly energy output is also reduced because the actual monthly Q outflow has not been subtracted from the monthly Q inflow when calculating the net head in the reservoir and hence when calculating the output power of the dam.



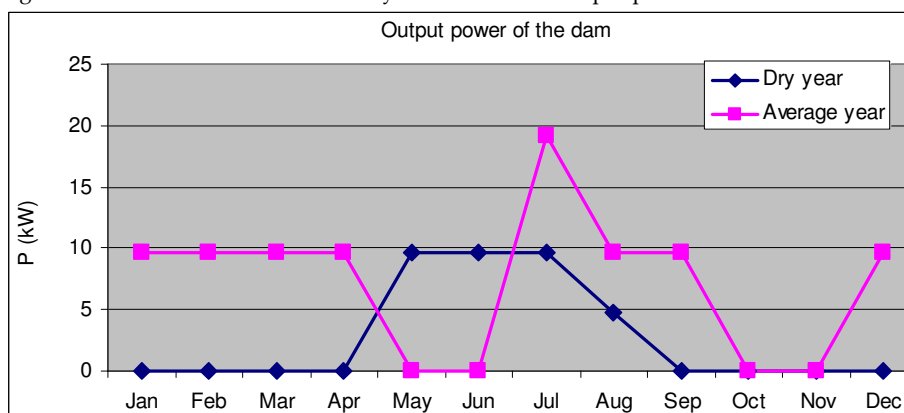


Figure 31 The simulated energy output of the dam for 1960 - 1985



Just as with the previous paragraph, the two different 'runoff' years which have dealt with are now again discussed. This time to give an idea of the monthly variations within an average and a dry year. In figure 32, a constant monthly Q outflow of $1 \text{ m}^3/\text{s}$ has been subtracted from the simulated monthly Q inflow before calculating the output power of the dam. The monthly Q outflow of $1 \text{ m}^3/\text{s}$ is equaled or exceeded for around 75% of the time, according to the flow duration curve in figure 24. Thus, a monthly Q outflow of $1 \text{ m}^3/\text{s}$ seems realistic to achieve, and is according to the expectations of Mr. Naipal.

Figure 32 The monthly variation of the output power of the dam



As can be seen, the hydro-power generation can only be guaranteed for 4 months in a dry year and 8 months in an average year. In an average year, the water-level downstreams have reached critical high levels and generation of hydro-power is no longer possible. In a dry year, the water-levels downstream are affected by the absence of any rain at all and therefore stay below the critical levels. The minimum energy output is 5 kW and the maximum energy output is 18 kW. The preliminary expectations for the energy output of the dam were 5 – 10 kW. In an average year the actual output can exceed these expectations during one month of a year, with a potential energy output of 20 kW. Losses such as transmission losses have not been taken into account, since this falls beyond the scope of this research and information concerning these transmission losses is not available.

For those months when the energy generation cannot be realized according to figure 32, the solution is to generate during intervals rather than around the clock. Especially since the effective storage is rather small, although rainfall storms can fall regularly, even in the dry season. The other alternative when the energy can be temporarily stored during periods of excess energy generation, is not taken into consideration because this alternative seems not very feasible for the village since it requires much more technical support and therefore requires more finances which are not available.



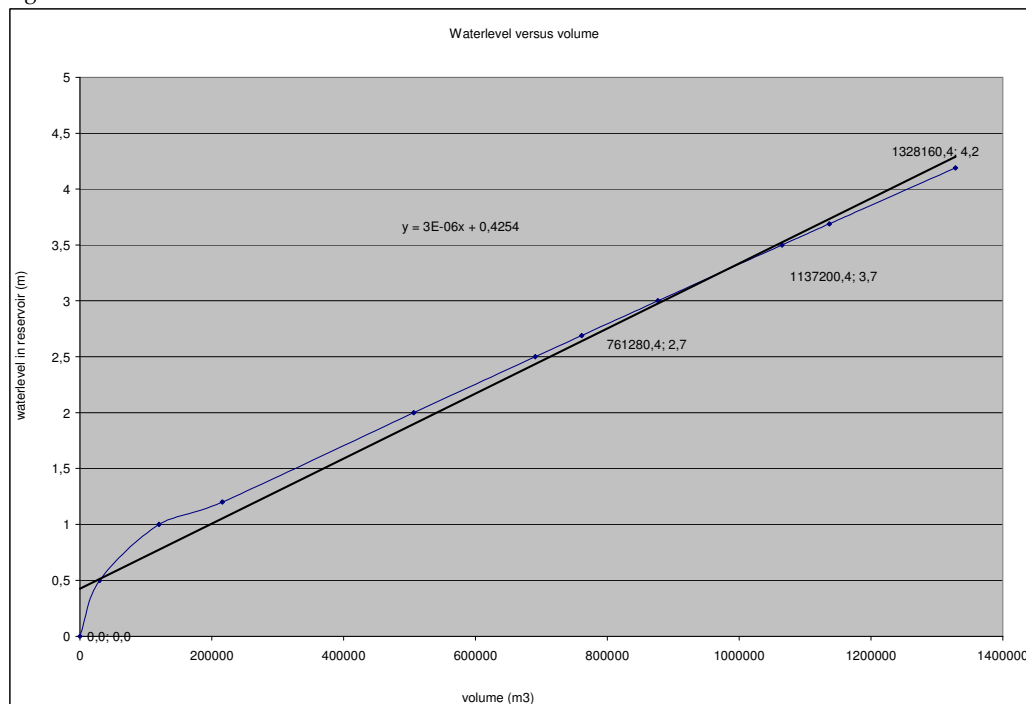


The following figures have been calculated:

	Volume in m ³
Dead storage	750,000
Maximum storage	1,112,000
The effective storage of the dam	360,000

In figure 33 the corresponding reservoir water-levels can be looked up for the different volumes mentioned in the table above. The effective storage is very small, and thus the variations in the reservoir water-level are small as well.

Figure 33 The reservoir water-level versus reservoir volume



A quick calculation gives us that if the natural inflow of the Panato creek is 0.3 m³/s the dead storage volume is reached within one month. The effective storage only is realized with a flow of 0.14 m³/s in one month. If, with a minimum outflow of 0.5 m³/s, during a 24 hour power generation, and without any substantial rain, the effective storage would last for approximately 10 days (360,000/(0.5*24*3600)).

If per day only 5 hours of hydro-power are generated, than the effective storage would last for around 50 days (almost 2 months). Hence, the power generation would last the whole year if the natural inflow of the Panato creek is at average (see figure 32). In an average year, only during the month October and November the energy supply needs to be rationed.

During a dry year (see figure 32), there would still be 8 months without any hydro generation. During these dry months, the daily rainfall fluctuations are crucial as the reservoir is quickly emptied due to the small effective storage. Informing the villagers for the occurrence of such black outs is important because their expectations of this project are high.





11 Conclusions and recommendations

11.1 Conclusions

-  The Rainru model has been successfully regionalized for the area under interest, on a monthly time basis. Fixed values for the model coefficients $b_0 - b_4$ and the threshold value have been realized. The regional threshold value amounts to 100 mm/month, while the net runoff coefficient is around 0.7.
-  The performance of the Rainru model does not improve significantly when a season threshold value (meaning that the threshold value is not constant during the time period) is introduced. The model results are just the same when the threshold value is kept constant throughout the year.
-  The availability of detailed hydrometric and meteorological data (especially on a daily basis) puts a constraint upon the modelling possibilities. Therefore, the model has been calibrated and validated with data on a monthly time basis. For analyzing the availability of water for hydro-power purposes however, it is assumed adequate to model on a monthly time basis, since the daily fluctuations in runoff are not obtainable and the reservoir provides some sort of buffer for these daily fluctuations.
-  The simulated discharges of the Panato creek could not be validated with actual discharge observations, but instead an alternative method has been used: comparing the annual unit discharge for all the catchments under investigation. According to this method, the model performance for the Panato creek is quite satisfactory. The Panato catchment shows the same annual unit discharge value as for the Tapanahony catchment: 34 l/s/km².
-  The decisive factor for the generation of hydropower is the net head (formula I). The other criterion, the discharge, puts less constraint upon the hydro-power generation mainly because in an average year the monthly natural inflow of the Panato creek exceeds the required monthly outflow of the dam during 80% of the time. If the dam was located more upstream of the Panato creek, than the Tapanahony flows would have less influence on the downstream water-levels of the dam and hence the direct results of the dam on the water head would be more pronounced.
-  The availability of water for the hydro power generation is reasonably good, especially during an average year. The minimum requirement of the power of 5 – 10 kW is fairly feasible. The problem in a dry year is the low natural inflow of the Panato creek. The occurrence of periods without any possibility of hydro-power generation was expected by the Anton de Kom University. In a dry year, approximately during 75% of the time generation of hydro-power is no longer possible. This period coincides with the long dry period in a year, from September – December. In an average year, generation is possible during 8 months, while during the periods of water scarcity the electricity will only be available at fixed intervals, for example during nocturnal hours only, when the need for electricity is the greatest. During the periods of high downstream water-levels, generation is not possible. Another alternative is the possibility to store excess energy during those hours when the need for electricity is lower than the generation capacity. However, this requires additional finances and technical knowledge which is not available for this project.
-  The reservoir which is created as a direct result of constructing the dam provides a very small buffer. With a continuous minimum outflow of the dam of 0.5 m³/s the effective storage of the dam would last for only 10 days.





11.2 Recommendations

-  The model will yet have to proof its capabilities for the region for which it has been calibrated and validated. If, in the future, more micro hydro-power works will be realized in the hinterlands of Suriname, the model can be extremely useful to predict the availability of water for the generation of hydro-power on a monthly time basis.
-  To ensure that the calibrated model will generate reliable model outputs, the model needs to be recalibrated and validated if any major change occurs in land-use or climate.
-  The rainru model can also be calibrated and validated on a daily time basis. A practical application could be the simulations of the daily discharge fluctuations at Pokigron, which is located just upstream of the van Blommenstein reservoir. Here, insights in daily fluctuations are desirable for the continuation of the most important source of energy for the country.
-  A prerequisite to validate model results is ultimately, the availability of hydrometric and meteorological data. The gathering of such data needs more attention in the hinterlands of Suriname. The measurements could for example be carried out in those remote areas which have a tourism centre or a public school. Many of the remote villages in the South of Suriname have either one of these, for example Palumeu and Raleighvallen. Cooperation of the meteorological centre and the Hydraulic Research Division (responsible for respectively gathering of meteorological and hydrometric data) with the local people and the tourism organization or public school could lead to a renewed data gathering network.
-  Carrying out such projects in the hinterlands of Suriname is extremely difficult since it requires proper communication with the locals, all stakeholders and the grantees. As many problems have been dealt with thus far during the implementation of the Palumeu hydro-power project, it would be very wise to learn from these mistakes and the experiences before realizing yet another project of a kind. The main issue concerns not the technical preparations, but also consideration of the social impacts on the community involved. One of the decisive factors is the understanding of the community regarding the financial issues of such projects. Are the villagers even capable to actually pay for the energy provided by these projects?





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Maps

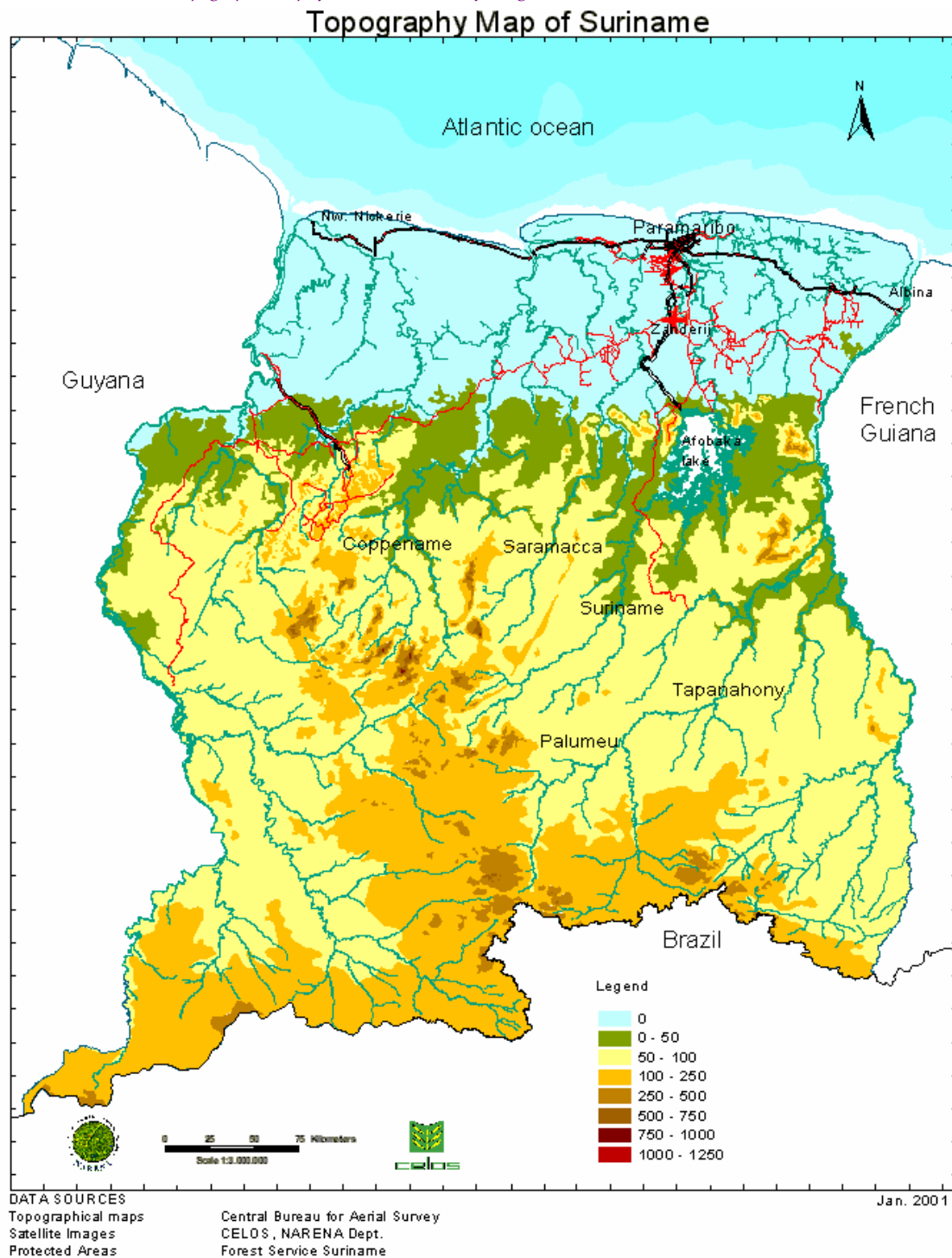
-  Centre for Agricultural Research in Suriname (Celos), department Nareena, Leysweg
-  Bureau Luchtkartering in Suriname





13 Appendices

1. The topographic map of Suriname (Centre for Agricultural Research)

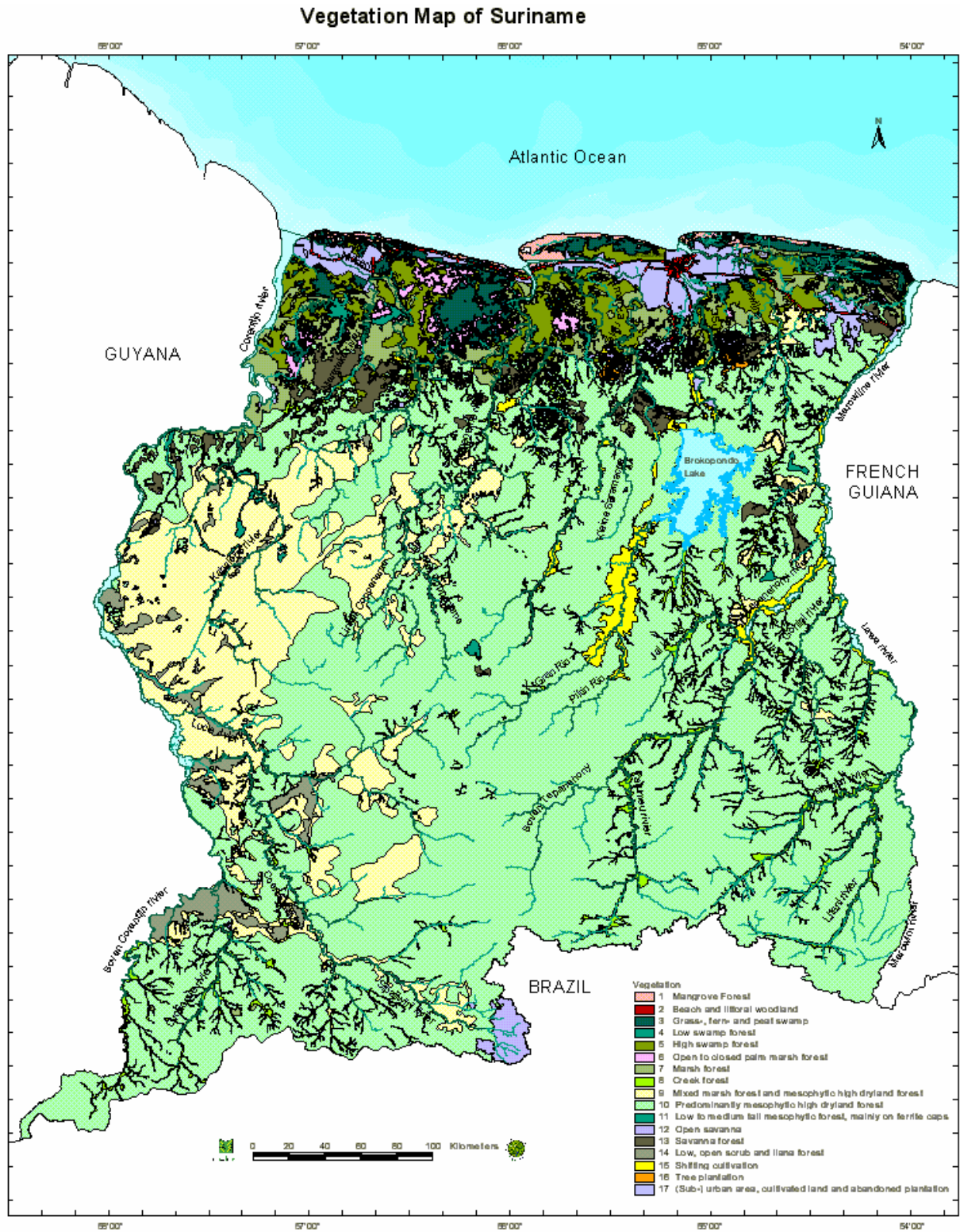


The four rivers: Coppename, Saramacca, Suriname and the Tapanahony (used for calibration and validation of the model) and the location of the village Palumeu.



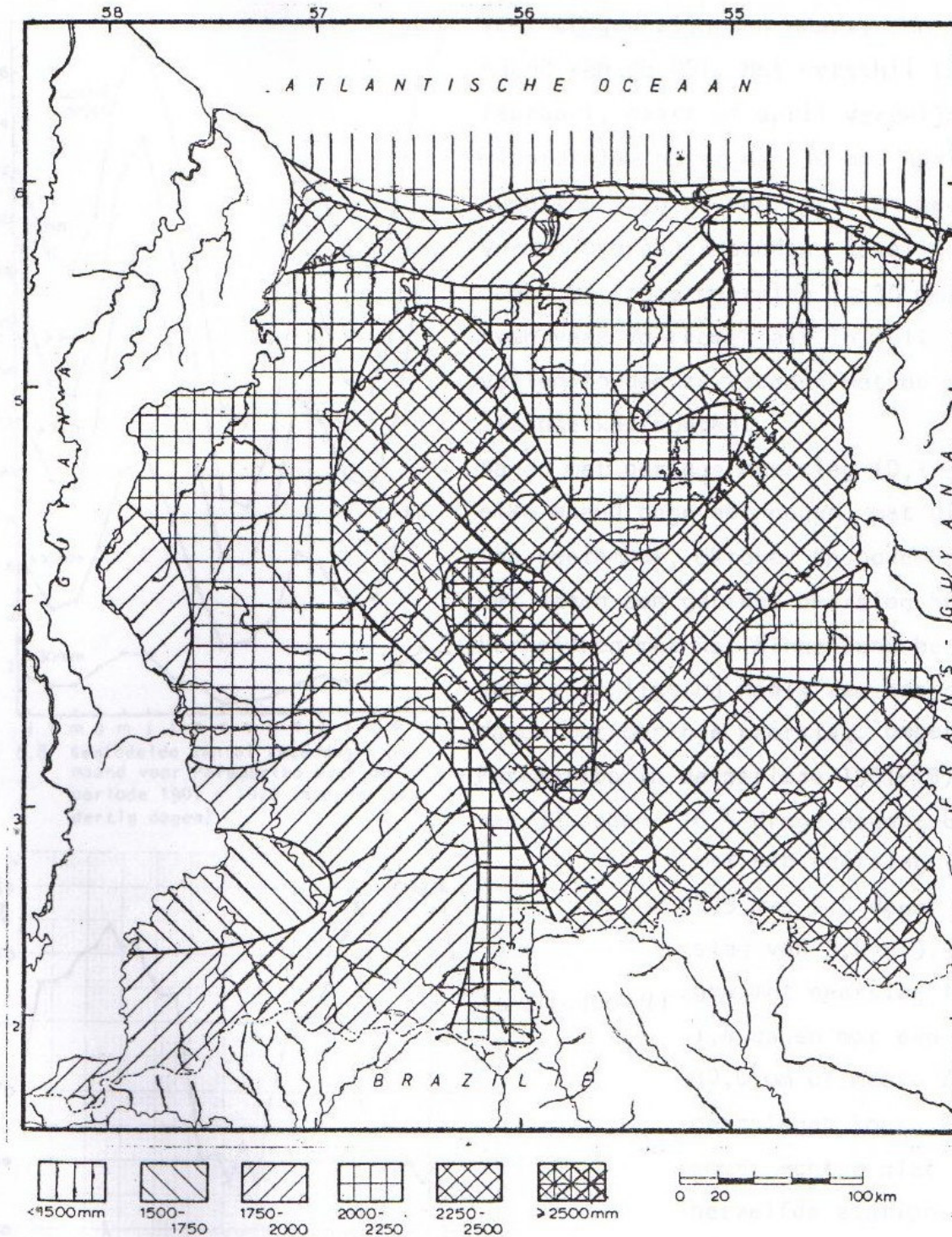


2. *The Vegetation map of Suriname (Centre for Agricultural Research)*



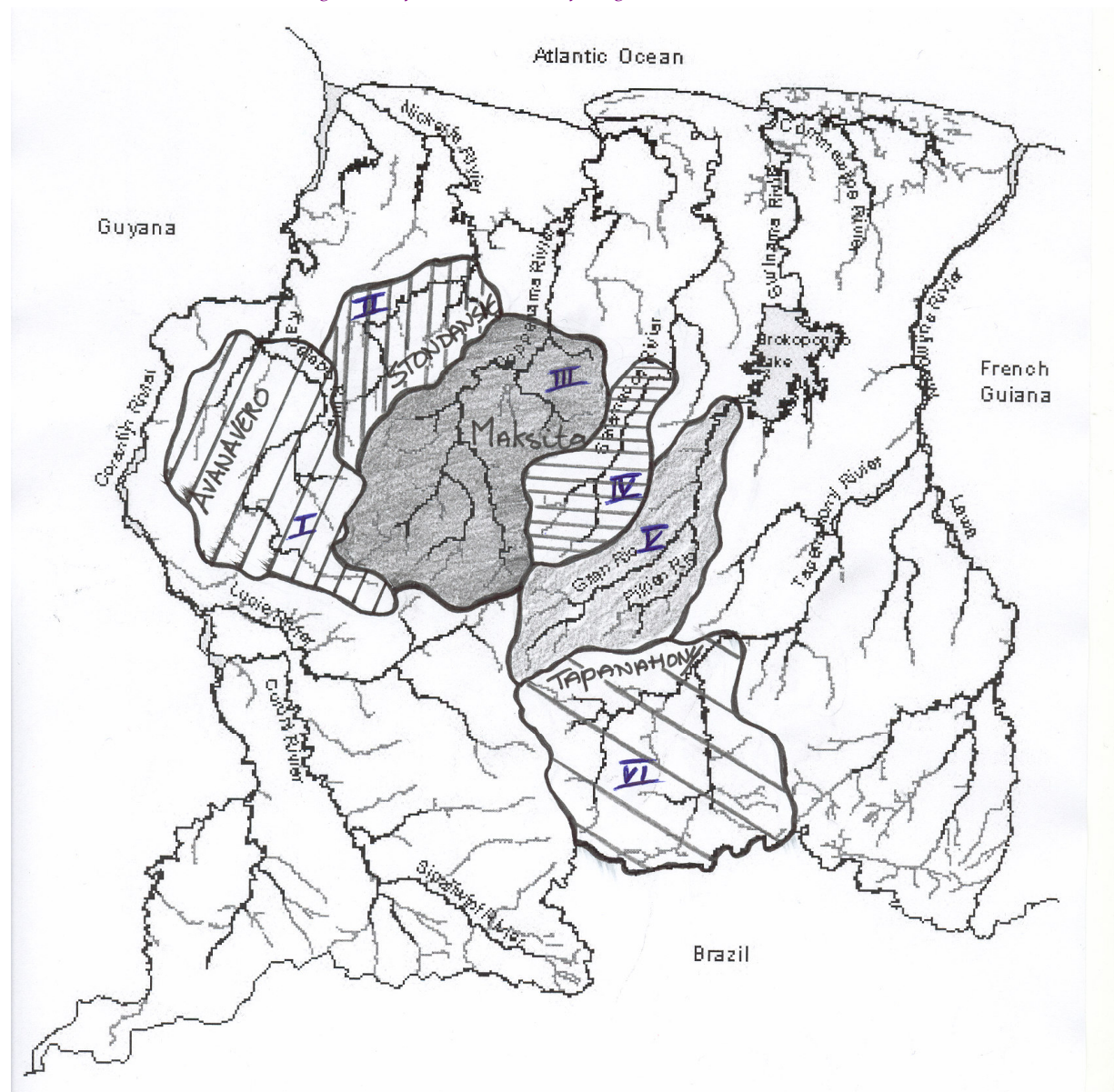


3. *The mean annual rainfall of Suriname, period 1961 - 1970 (Tan, 1989)*





4. *The rivers and large creeks of Suriname (Centre for Agricultural Research)*

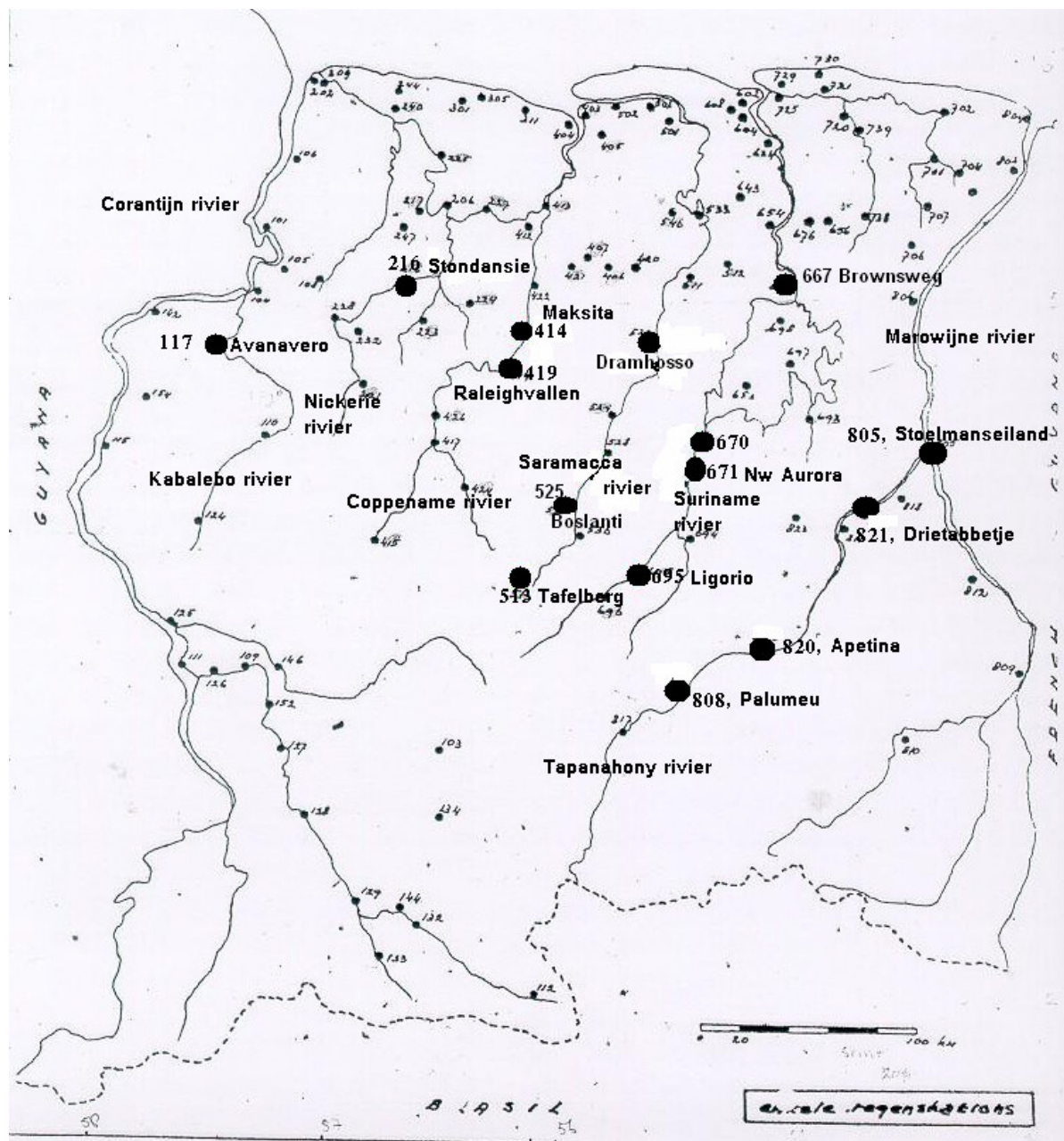


Number	Hydrometric station	River	Catchment size (km ²) ¹
I	Avanavero boven	Kabalebo	9,020
II	Stondansie	Nickerie	5,160
III	Maksita	Coppename	12,300
IV	Dramhosso	Saramacca	3,520
V	Pokigron	Suriname	7,750
VI	Alamandidon sula	Tapanahony	10,210





5. The different catchment areas and rainfall stations



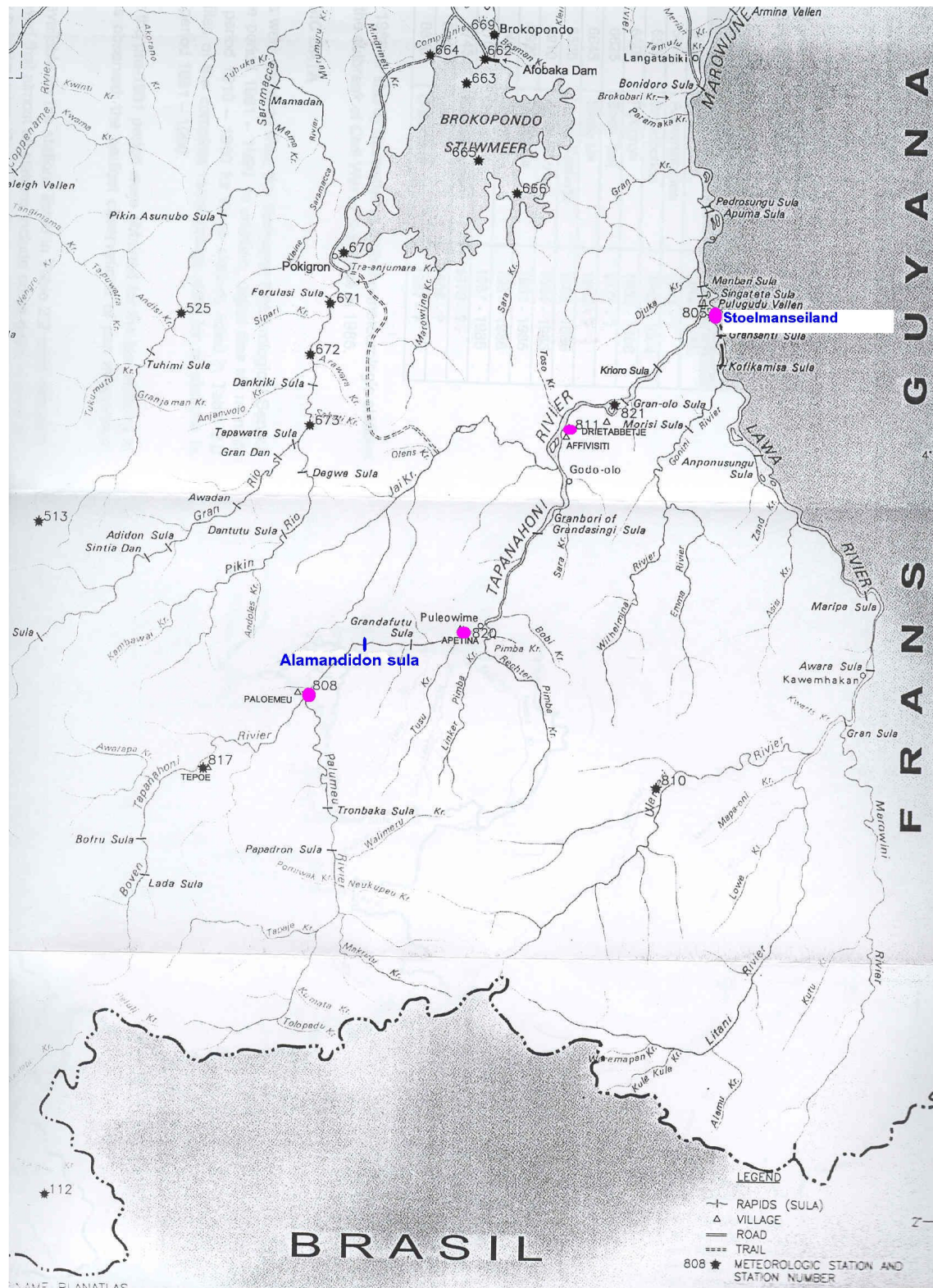
Note:

All the dots in the picture indicate the location of a meteorological station where either the rainfall and/or other meteorological characteristics (windspeed, evaporation, humidity) have been observed. Nearly all meteorological measurements ceased with the outbreak of a civil war and the revolutionary period. Nowadays the meteorological measurements in the coastal area are still carried out. Except for a few stations the measurements in the interior of Suriname have never been continued.





6. The geographical location of the Tapanahony catchment





7. The correlation coefficients for monthly rainfall data

	670	671	695	667	419	513	525	414	117	808	805	820	821
	Pokigron	Nw Aurora	Ligorio	Brownsweg	Raleighvallen	Tafelberg	Boslanti	Maksita	Avanavero	Palumeu	Stoelmanseiland	Apetina	Drietabbetje
	1953-1983	1953-1985	1969-1985	1969-1985	1972-1985	1960-1985	1960-1985	1965-1980	1965-1980	1975-1986	1960 - 1985	1969 - 1985	1969 - 1985
Pokigron		0.64 (18)	0.47 (70)	0.57 (80)	0.43 (95)	0.52 (110)	0.55 (48)	0.47 (95)	0.46 (230)	0.40 (120)	0.49 (110)	0.24 (100)	0.30 (80)
Nw Aurora			0.63 (56)	0.54 (100)	0.67 (98)	0.54 (98)	0.68 (42)	0.65 (100)	0.54 (232)	0.53 (110)	0.61 (115)	0.38 (90)	0.41 (80)
Ligorio				0.50 (158)	0.63 (120)	0.76 (55)	0.73 (55)	0.63 (130)	0.53 (235)	0.56 (60)	0.61 (150)	0.48 (65)	0.54 (110)
Brownsweg					0.48 (135)	0.50 (192)	0.55 (130)	0.59 (135)	0.45 (265)	0.42 (195)	0.60 (100)	0.31 (170)	0.40 (120)
Raleighvallen						0.61 (100)	0.64 (68)	0.61 (20)	0.50 (140)	0.44 (175)	0.59 (200)	0.32 (180)	0.49 (180)
Tafelberg							0.72 (64)	0.59 (100)	0.58 (180)	0.69 (100)	0.63 (200)	0.58 (120)	0.52 (165)
Boslanti								0.62 (75)	0.60 (195)	0.62 (18)	0.62 (160)	0.46 (120)	0.57 (130)
Maksita									0.48 (140)	0.57 (180)	0.61 (200)	0.49 (180)	0.37 (180)
Avanavero										0.48 (250)	0.46 (330)	0.36 (300)	0.40 (310)
Palumeu											0.66 (160)	0.43 (40)	0.32 (120)
Stoelmans-eiland												0.41 (125)	0.64 (40)
Apetina													0.35 (75)
Drietabbetje													

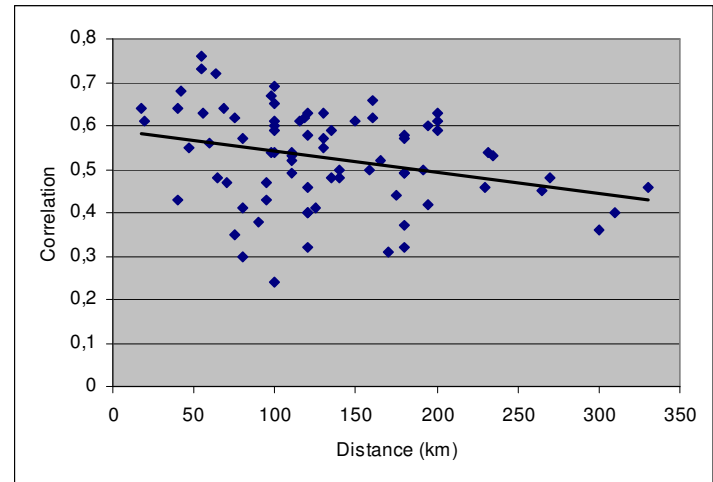
The first value in each cell is the correlation coefficient, the value in between brackets and in blue is the distance between the two rainfall stations in km.





8. The correlation function for the meteorological stations

	Distance (km)	Correlation
Ligorio-Tafelberg	55	0.76
Ligorio-Boslanti	55	0.73
Tafelberg-Boslanti	64	0.72
Tafelberg-Palumeu	100	0.69
Nw Aurora-Boslanti	42	0.68
Palumeu-Stoelmanseiland	160	0.66
Nw Aurora-Maksita	100	0.65
Pokigron-Nw Aurora	18	0.64
Stoelmanseiland-Drietabbetje	40	0.64
Raleighvallen-Boslanti	68	0.64
Nw Aurora-Ligorio	56	0.63
Tafelberg-Stoelmanseiland	200	0.63
Boslanti-Maksita	75	0.62
Maksita-Stoelmanseiland	200	0.61
Raleighvallen-Maksita	20	0.61
Tafelberg-Maksita	100	0.59
Brownsweeg-Maksita	135	0.59
Raleighvallen-Stoelmanseiland	200	0.59
Tafelberg-Avanavero	180	0.58
Tafelberg-Apetina	120	0.58
Pokigron-Brownsweeg	80	0.57
Maksita-Palumeu	180	0.57
Ligorio-Palumeu	60	0.56
Pokigron-Boslanti	47	0.55
Nw Aurora-Avanavero	232	0.54
Ligorio-Drietabbetje	110	0.54
Nw Aurora-Palumeu	110	0.53
Ligorio-Avanavero	235	0.53
Avanavero-Palumeu	270	0.48
Avanavero-Stoelmanseiland	330	0.46
Apetina-Drietabbetje	75	0.35
Palumeu-Drietabbetje	120	0.32



The list of stations and their corresponding correlation coefficients is not the complete list, but is just part of it. The examples indicated in the table are the ones which stand out the most, either because the stations are situated close to each other but the correlation coefficient is small or the other way around.





9. *The output of the model coefficients after the calibration procedure*

Output of the model coefficients for the period 1960 – 1968

Station #	Maksita			Dramhosso			Pokigron		
	419	414	Average 414 en 419	525	513	Average 513 en 525	670	Average 670,671, 694	695
b0	0.34	0.33	0.30	0.33	0.23	0.27	0.29	0.42	0.41
b1	0.28	0.24	0.23	0.23	0.20	0.22	0.18	0.23	0.26
b2	0.19	0.14	0.15	0.11	0.09	0.10	0.12	0.18	0.16
b3	0.02	0.04	0.00	0.01	-0.02	-0.02	0.04	0.03	0.03
b4	0.01	0.02	0.00	0.05	0.01	0.02	0.02	0.02	0.00
Correlation	0.86	0.84	0.86	0.89	0.90	0.92	0.83	0.93	0.91
Threshold value (mm/month)	130	100	100	120	140	160	80	120	120
Net runoff coefficient	0.88	0.64	0.66	0.69	0.52	0.76	0.64	0.91	0.91

Output of the model coefficients for the period 1977 – 1985

Station #	Maksita			Dramhosso			Pokigron		
	419	414	Average 414 en 419	525	513	Average 513 en 525	670	Average 670,671, 695	695
b0	0.21	0.31	0.25	0.26	0.25	0.29	0.25	0.33	0.35
b1	0.17	0.28	0.21	0.27	0.32	0.34	0.19	0.23	0.24
b2	0.11	0.20	0.15	0.06	0.12	0.08	0.02	0.03	0.06
b3	0.04	0.07	0.05	0.07	0.08	0.10	0.04	0.08	0.10
b4	0.00	-0.04	0.00	0.02	0.03	0.03	0.00	0.01	0.04
Correlation	0.82	0.86	0.86	0.85	0.91	0.90	0.83	0.92	0.87
Threshold value (mm/month)	70	140	100	110	180	160	80	110	80
Net runoff coefficient	0.54	0.88	0.65	0.73	0.83	0.89	0.51	0.74	0.64

Output of the model coefficients for the period 1960 – 1985

Station #	Maksita			Dramhosso			Pokigron		
	419	414	Average 414 en 419	525	513	Average 513 en 525	670	Average 670,671, 695	695
b0	0.25	0.32	0.32	0.31	0.23	0.27	0.26	0.36	0.30
b1	0.22	0.24	0.24	0.26	0.24	0.26	0.19	0.24	0.23
b2	0.12	0.15	0.15	0.08	0.08	0.07	0.07	0.09	0.08
b3	0.04	0.05	0.04	0.05	0.04	0.04	0.02	0.03	0.04
b4	0.01	-0.01	0.00	0.04	0.02	0.03	0.01	0.03	0.03
Correlation	0.82	0.81	0.83	0.85	0.86	0.88	0.74	0.87	0.88
Threshold value (mm/month)	80	100	100	100	140	120	60	100	80
Net runoff coefficient	0.66	0.74	0.76	0.75	0.64	0.69	0.56	0.79	0.69

Names of the meteorological stations

419 = Raleighvallen

414 = Maksita

525 = Boslanti

513 = Tafelberg

670 = Pokigron

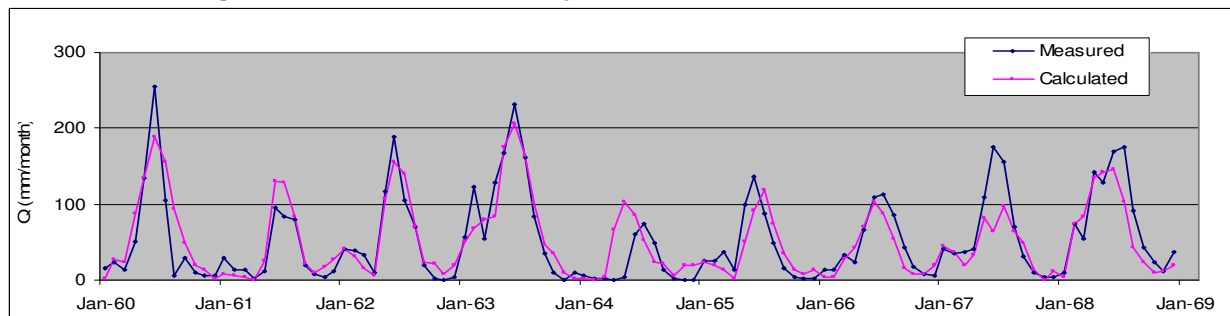
695 = Ligorio



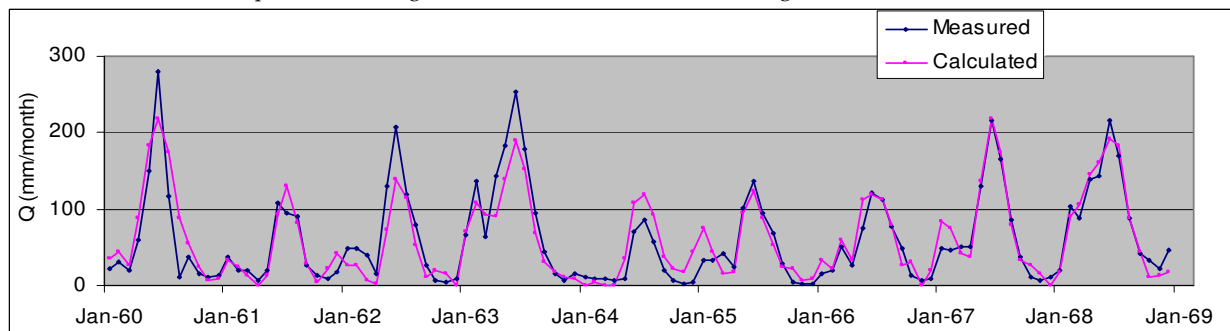


10. The hydrographs for the calibration procedure for the period 1960 - 1968

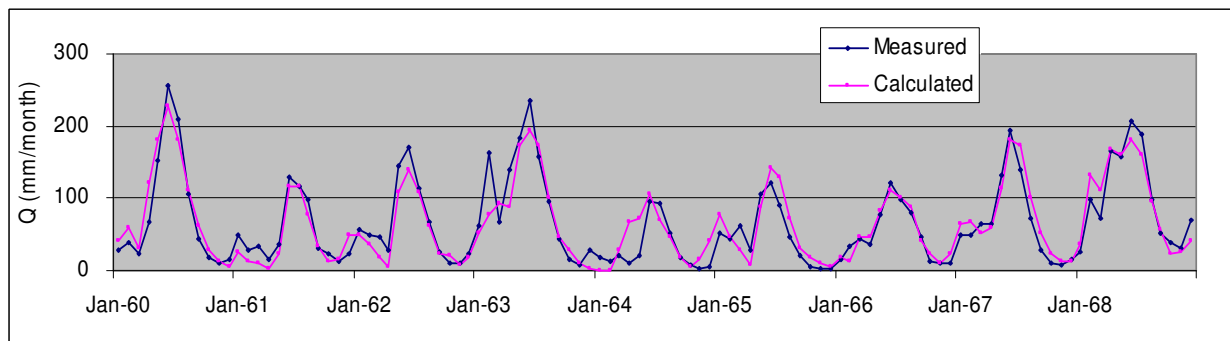
Maksita catchment, input from rainfall station 419, Raleighvallen



Dramhosso catchment, input is the average from rainfall stations 513, Tafelberg and 525, Boslanti



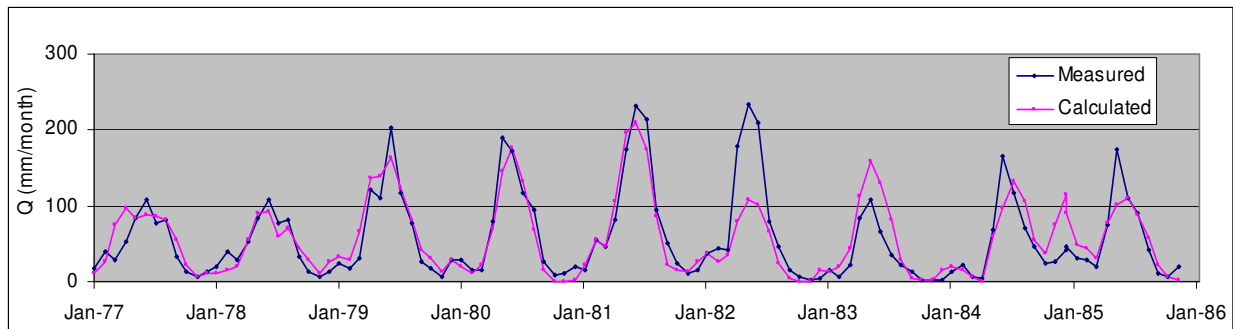
Pokigron catchment, input is the average from rainfall stations 670 (Pokigron), 671 (Nw Aurora) and 695 (Ligorio)



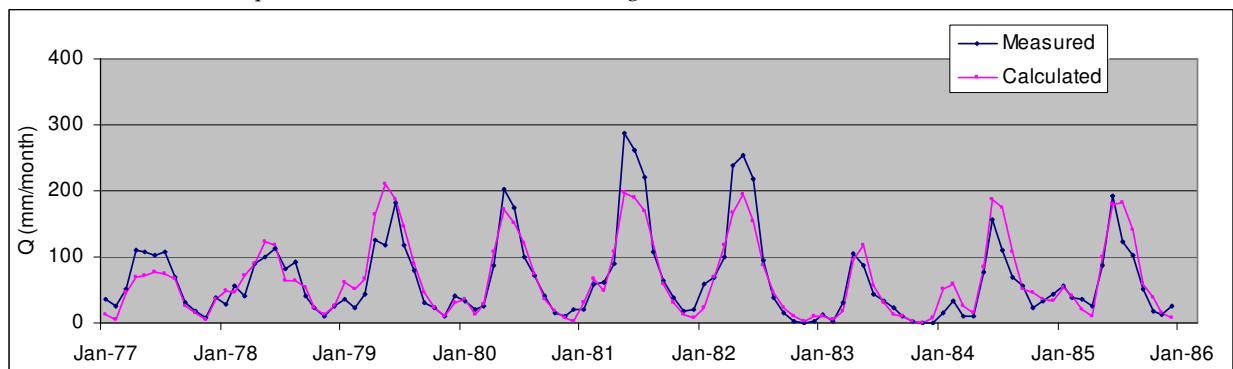


11. The hydrographs for the calibration procedure for the period 1977 – 1985

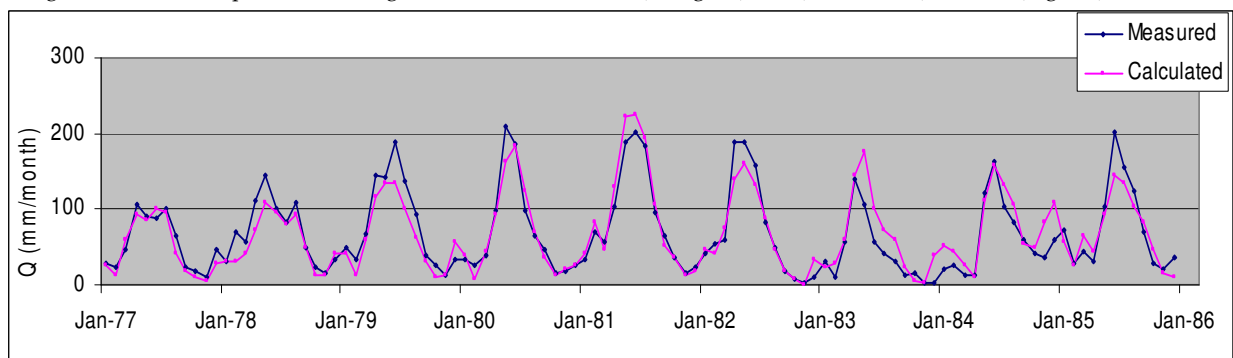
Maksita catchment, input from rainfall station 414, Maksita



Dramhosso catchment, input from rainfall station 513, Tafelberg



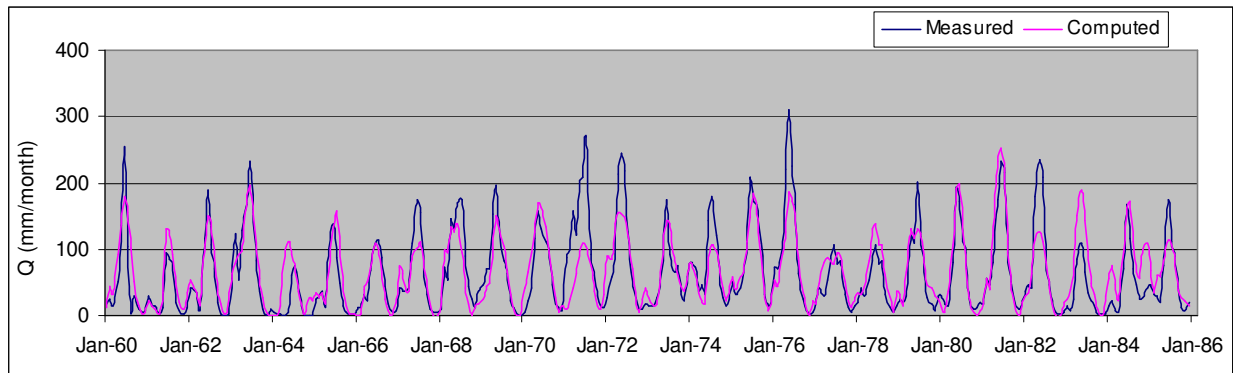
Pokigron catchment, input is the average of rainfall stations 670 (Pokigron), 671 (Nw Aurora) and 695 (Ligorio)



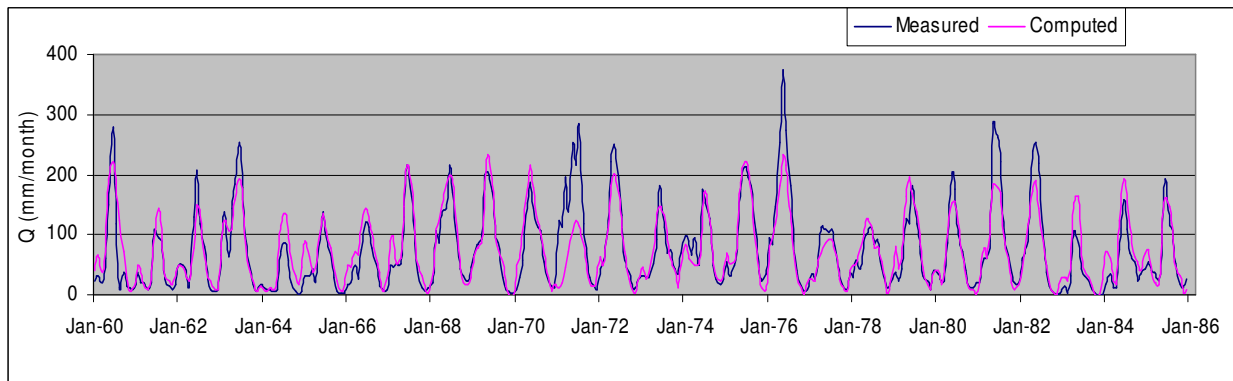


12. The hydrographs for the calibration procedure for the period 1960 – 1985

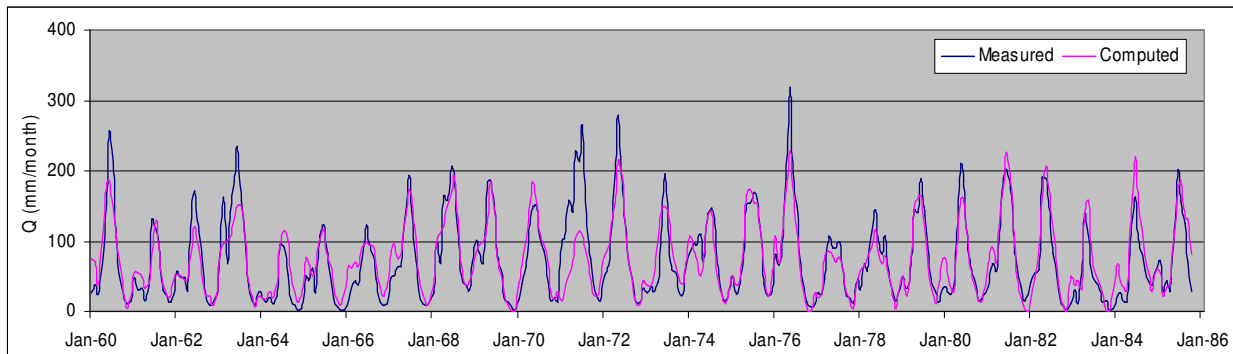
Maksita catchment, input is the average of rainfall stations 414, Maksita and 419, Raleighvallen



Dramhosso catchment, input is the average of rainfall stations 513, Tafelberg and 525, Boslanti



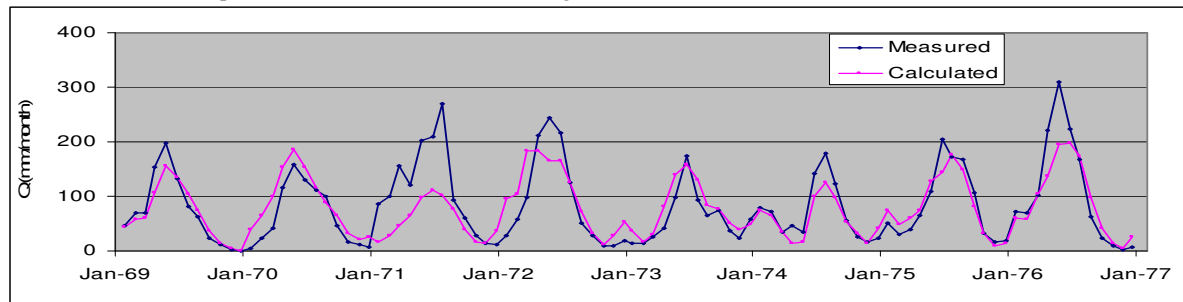
Pokigron catchment, input from rainfall station 695, Ligorio



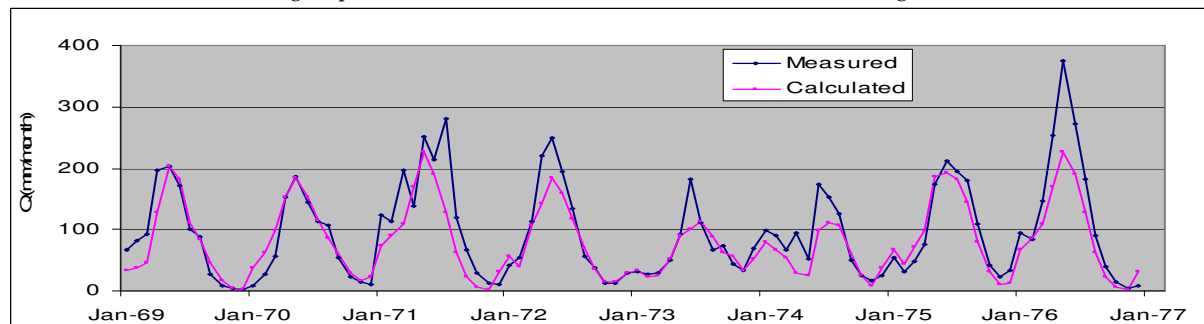


13. The hydrographs for the validation procedure for the period 1969 - 1976

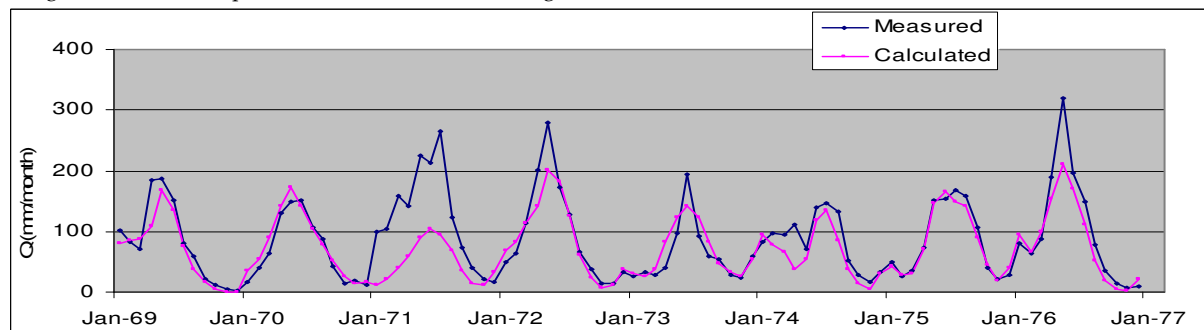
Maksita catchment, input from rainfall station 419, Raleighvallen



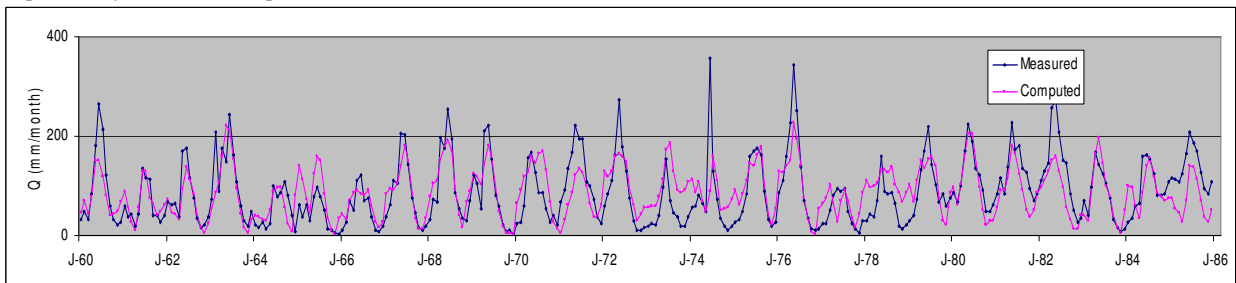
Dramhosso catchment, average input from rainfall stations 525, Boslanti and 513, Tafelberg

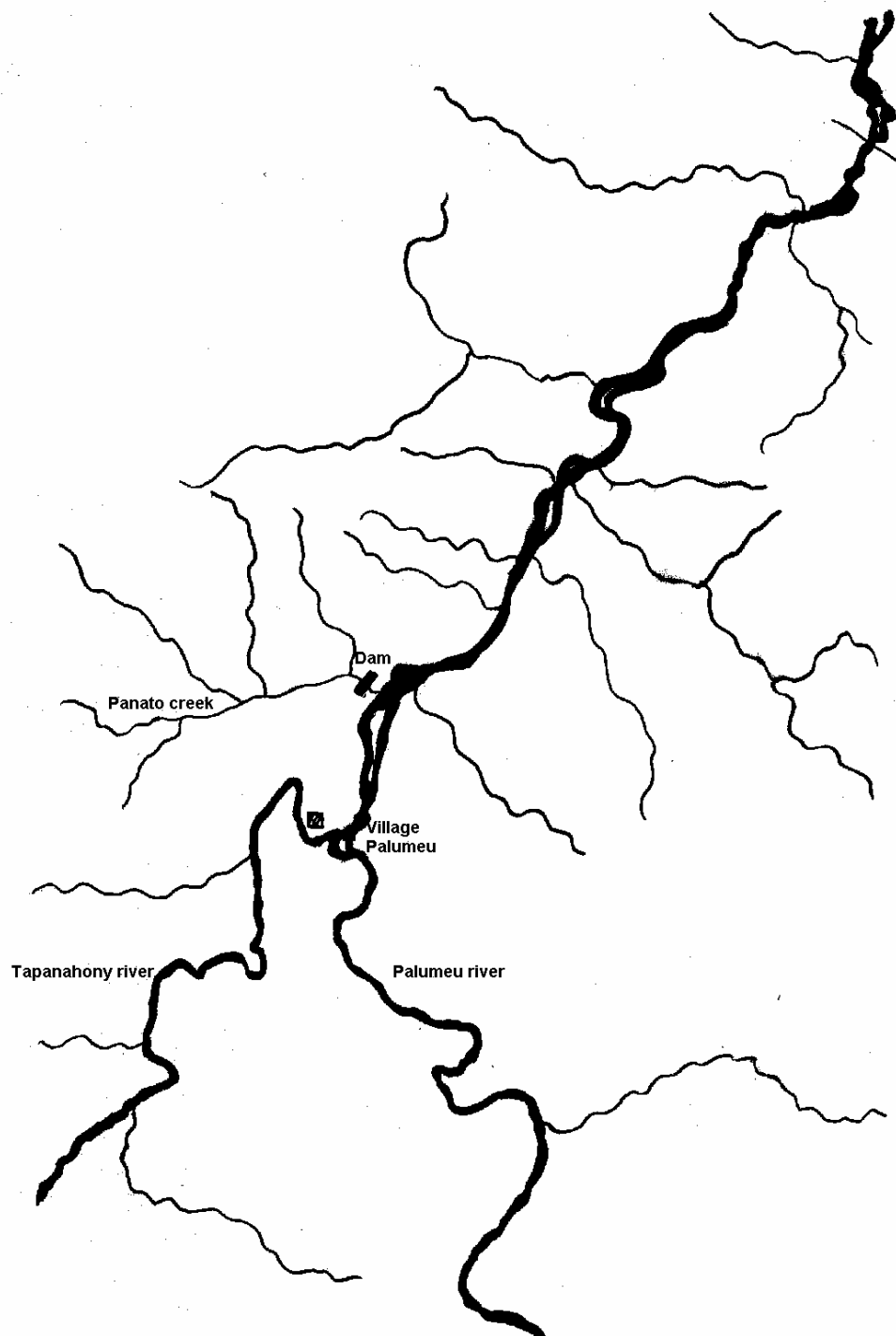


Pokigron catchment, input from rainfall station 695, Ligorio



Tapanahony catchment, input from rainfall station 805, Stoelmanseiland



14. *The map of the Tapanahony river and the Panato creek*

Note: the distance between the village Palumeu (square) and the confluence of the Tapanahony with the Panato creek is approximately 4 km. The distance from the confluence of the Tapanahony with the Panato creek to the construction site of the dam is approximately 200 m.





15. *Pictures of the location in the Panato creek where dam construction has begun*

The pictures have been taken in the last week of November 2004, in the long dry season

Right: placement of the first part of the outlet. Notice the large rock at the left

Left: construction surrounding the outlet has started.



Right: Many villagers attended the daily construction activities to give their support since all work had to be done by hand. The villagers are standing upon the large boulder. The ultimate dam height will be 0.5 m higher than the boulder.





The pictures have been taken in the first week of February, 2005. Rains have started just a week ago.





16. *List of people with who have been contacted in Suriname*

Name	Institute / organization	Contact information	Email address / remarks
S. Naipal R. Nurmohamed Mr. Kisoen Misier	All three are lecturers at the Anton de Kom University of Suriname, Leysweg	+597465558 Idem	naipals@yahoo.com r.nurmohamed@uvs.edu
Mr. Bekker	National Meteorological Service, Suriname, Titanium straat	+597491143 +597493819	All meteorological data used have been retrieved from this institute. There is also a library with all sorts of very old and interesting literature on Suriname. Literature from the hydraulic division of the Ministry of public works is also available.
Mr. Hardien Mr. Amataali	Hydraulic Division, Ministry of Public Works, Titanium straat	+597490963 +597492039	The Hydraulic Division is responsible for gathering hydrometric data.
	Centre for Agricultural Research, department Nareena, Leysweg		The department Nareena produces all sorts of maps of Suriname and detailed parts of it.
Mr. Chin	Integrated Computer Services, Suriname straat	+597401444	Ricardo.chin@isgroup.sr Mr. Chin is supervised with the library of the former consultancy Sescon, which holds very old reports and all sorts of other interesting literature which are difficult to obtain in ordinary libraries in Suriname
Mr. Frijmerssum	Primary Health Care Centres, Rust en Vredestraat		Is the co-founder of a former civil consultancy bureau named Sescon
Mr. Boksteen	Surinaamse Waterleiding Maatschappij, Andirastraat		Is a private civil consultant and is still involved in many projects, such as the Tapanahony Diversion Project.
Mr. Tsai Meu Chong		+597476854	Is a consultant whose primary attention is for groundwater projects all over Suriname
Mr. Monsels	Part-time lecturer at the Anton de Kom University	+597538393	Former director of Bureau Waterkracht Werken which unfortunately does not exist anymore for several years now and of which all the valuable data is lost somehow

