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Estimation of the net infiltration rate in the Central Suriname Nature Reserve area using the SWB Model 2.0

by

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A thesis submitted to the Anton de Kom University of Suriname, Faculty of Technology, Suriname, in fulfillment of the requirements for the degree of
Master of Science (MSc) in Sustainable Management of Natural Resources

Supervisor:
R. Nurmohamed Ph.D

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Paramaribo, Suriname

Preface

This thesis is a final work as partial fulfillment for the degree of Master of Science in Sustainable Management of Natural Resources. As I write my final work during this course, I realize that I have gained a significant amount of knowledge, which was my initial goal upon commencing this programme.

My gratitude goes to the Belgian Directorate-General for Development Cooperation (DGDC), the Flemish Interuniversity Council (VLIR-UOS) and the Suriname Conservation Foundation (SCF) for implementing the Master of Science Programme in Sustainable Management of Natural Resources (MSc in SMNR) at the Anton de Kom University of Suriname. Furthermore, I also express thanks to my supervisor Dr. R. Nurmohamed, who is the chairman of SMNR. Thank you for your invaluable guidance during my completion of this study.

My gratitude also goes to Mr. Stephen M. Westenbroek, who is a hydrologist at the United States Geological Survey (USGS). He is also the Soil-Water-Balance software developer and has been a constant support during the completion of this thesis.

Last but certainly not least, I would like to thank my parents for the guidance, love and support which they have given me since the very beginning. I would not be here without your support. Dear Mom and Dad, this one is for you.

Payal Vaishnavi Gangaram-Panday
Paramaribo June 14, 2020

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List of abbreviations

CSNR	Central Suriname Nature Reserve
ET	Evapotranspiration
HSG	Hydrologic Soil Group
Max	Maximum
Max. Net. Infill	Maximum Net Infiltration
Min	Minimum
Mm	Millimeter
RZ	Root Zone
Temp	Temperature
UTM	Universal Transverse Mercator
WGS	World Geodetic System

Executive summary

The Central Suriname Nature Reserve is the largest protected area in Suriname – encompassing 1.6 million hectares. Located in the west-central part of Suriname; it is known for its rich biodiversity. As this area is protected from human impact, this research will investigate how such a habitat functions without human disturbance. Changes in the natural state will definitely alter the reserve to another habitat than the current one. This study aims to estimate the net infiltration and the water balance in this reserve, which will in turn indicate how a system functions in its natural habitat. To estimate the net infiltration rate, the Soil-Water-Balance model 2.0 has been used. This model has been utilized using input of land use and land classification data, climate data, soil data and elevation data. The output provided net infiltration rates and actual evapotranspiration rates. These were then analyzed using Excel and ArcGIS. The model was run for a period of 14 years, from 1972 until 1985. The outputs were as follows: from January to March, a net infiltration between 101.6-127 mm per month can be expected; from May to July, a rate of 177.8-81 mm per month can be expected; from August up to November there is a visible decrease in the values. These range from 0-38.1 mm per month, and in December the infiltration value increases again to 114.3 mm per month. The actual evapotranspiration varies between 101.6-127 mm per month, all year round. It can also be concluded that if there is soil present from group B, which has a higher porosity and permeability, higher infiltration rates can be expected – which will result in lower water balance. Any change in the precipitation will directly impact the water balance and nutrient supply for the ecosystems present in the area. If the area consists mainly of clay rich soil (group C and D), the infiltration will decrease and there will be a surplus in the water balance. Overall, there was a good/logical outcome of the parameters and the relationship between them. Changes in these elements may result in shifts in the existing biological life. A suggestion is to conduct more studies on the water balance using other models and compare the results. If and when there is more data available, these should be incorporated in this model to make the results more reliable. A thorough study should also be done on the habitat preference of the current flora and fauna in the CSNR area to further asses what may happen if changes in the system do occur.

Keywords: Central Suriname Nature Reserve, infiltration, precipitation, actual evapotranspiration, water balance, soil-water-balance

1. Introduction

The Central Suriname Nature Reserve (CSNR) was established in 1988, spanning an area of 1.6 million hectares. Figure 1 shows all protected areas within Suriname, with the CSNR possessing the largest acreage among these reserves. This nature reserve is a combined entity of three pre-existing nature reserves; the Raleighvallen Nature Reserve, the Tafelberg Nature Reserve and the Eilerts de Haan Nature Reserve. The CSNR has a large coverage of pristine rainforest located on the Guiana shield of Suriname. It is home to various species; quite a number of these species are unique to the world (Redjosentono, 1999).

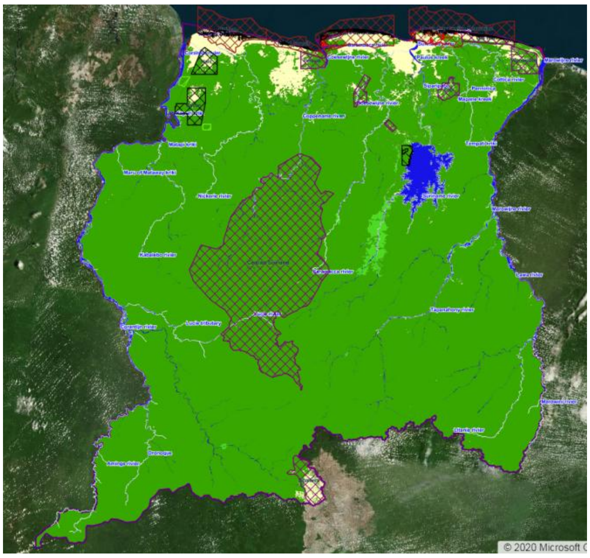

Figure 1: Map of Suriname with all protected areas
Source : GONINI National Land Monitoring System of Suriname, 2020

The CSNR boasts a high plant diversity, as well as many ecosystems. This nature reserve is home to 47 endemic species (CI, WWF, & ACT, 2014). With the exception of bird studies, the fauna diversity in this area has not been fully investigated. There are 30+ amphibians, 54+ reptiles, 452 bird types and 91+ mammals – of which few are endemic (Ouboter, 2002). Biodiversity and ecological life are of global significance. The study area covers a vast area and remains untouched. There is minimal to no human impact in this area, which makes it very unique and worthy of further investigation (Redjosentono, 1999). The Coppename river flows through this reserve, and there are also several waterfalls and rapids to be found in this region (Reichart, 1993). For this area there are no known water balance calculations. A simple hydrological calculation can be made; this can be done by assessing how much water enters the system and how much leaves the system. Due to the fact that this area is protected, no deforestation is expected, but climate change is anticipated to eventually impact this area in the coming few years. The precipitation of Suriname strongly depends on evapotranspiration; it is the most important value in the water balance (Amatali, 1993). Land use and deforestation around the CSNR area may impact the climate and the precipitation. This may in turn affect the vegetation type and the evapotranspiration. Each part is linked to another (Amatali, 1993). The fact that this area is uninhabited, spared from human impact and containing mainly Neotropical Amazonian forest with a rich variety of specimens – makes it more interesting to explore (Redjosentono, 1999).

1.1 Problem statement

Suriname's land consists mostly of tropical rainforest area. Due to the fact that the CSNR area is a preserved area, it is necessary that research is conducted in this area to get a better understanding of how the area's ecosystem works in its natural state. Once there is a clear idea of how nature works in its original state, it will be easier to apply changes to the model – be it in the CSNR area or any other area – and evaluate the outcomes. Research in the CSNR area will facilitate increased knowledge and understanding of the natural processes and features that sustain the reserve's biological richness. One of the major focal points/ aspects that needs to be researched is to determine the water budget components in this area, specifically the net infiltration rate. This will give an indication of the amount of water the soil is able to retain. This will be done according to the rate of precipitation, run-off and evapotranspiration. Determining the water budget will give a good indication of the amount of water that circulates in the nature reserve.

1.2 Research objective

The objective of this study is to determine the net infiltration rate for the CSNR area and to get an indication of the water balance in this area.

1.3 Thesis outline

The first chapter in this thesis provides a broad introduction along with the problem statement and research objective. The second chapter contains more details regarding the study area, previous studies, and the SWB 2.0 model. Chapter three explains the methodology used for this research, followed by a discussion of the results in chapter four and conclusions in chapter five. Chapter six, the last chapter, presents some suggestions for further work.

2. Literature review

2.1 Water balance

In nature, soil moisture plays an important role; it is thought to be connected with climate, vegetation and soil. This is also directly related to the water balance and stresses that are put on the soil. Plants are a major player in the system; as they transpire, they influence the water balance (Fernandez-Illesca, Porporato, Laio, & Rodriguez-Iturb, 2001).
In plant communities derived by nature, a decrease in water will influence the distribution and occurrence of many species. Water deficiency results in a reduction of canopy production. A reduced water availability may interfere with the growth of plants, which is typically exponential. There will be a raeduction of the leaf expansion (Schulze, Robichaux, Grace , Rundel, & Ehleringer, 1987). Deforestation also has an impact on water movement in forest areas; deforestation may increase runoff and infiltration, as well as decrease interception and evapotranspiration (Oliveira, et al., 2015).
It is important to understand the water balance in an area. Moreover, it is crucial to be familiar with the changes which may occur in forested areas in order to sustainably manage the water resources of such areas and assess what could happen if there are other activities in or near the areas which could affect the water resources (Suryatmojo, Fujimoto, Yamakawa, Kosugi, & Mizuyama, 2013). Climate change is a phenomenon which cannot be ignored, because it has great impact on the water balance. The air temperature variation will affect the water balance components such as rainfall and evapotranspiration, and it could also influence the amount of energy that is radiated by the sun, the wind, and the amount of clouds and flora that exist in an area. Climate changes could result in flooding or drought. In the upper Suriname river basin, modelling has been done by varying the temperature and the precipitation. It is shown that if the precipitation rates decrease, the surface runoff and base flow will decrease as well; this reduction in water can cause the tropical rainforest to change into a dry forest. In case of an increase in precipitation, the river discharge will increase. This will result in flooding of the river banks and can cause changes within the river complex (Nurmohamed, Naipal, & De Smedt, 2007).

2.2 The Soil Water Balance Model

The Soil Water Balance (SWB) 2.0 model, used mostly by hydrologists, has been developed by the USGS in order to provide an estimate of the potential recharge. This model has been designed to calculate the various components of the water budget at a daily time step. The main purpose of developing this code was to determine the distribution and timing of the net infiltration based on user provided inputs. This model calculates recharge based on commonly used geographic information system (GIS) data as well as tabular climatologic data. It is important to have an estimation of the spatial and temporal distribution of recharge (Westenbroek, Engott, Kelson, & Hunt, 2018).

This is beneficial for various hydrologic assessments such as:

- Streamflow and riparian ecosystem management
- Aquifer replenishment
- Groundwater-flow modelling
- Contaminant transport

(Westenbroek, et al., 2018)

This model has been used for various projects around the world, such as projects where recharge is estimated throughout basins and aquifers; it is used to build hydrogeologic frameworks, and is also used in agriculture practices (Westenbroek et al, 2018). This model makes use of a modified Thornthwaite-Mather-soil-water-balance approach, which makes calculations based on daily data and gives as output an estimation of the potential recharge. The recharge is calculated separately per grid. The mandatory data required for this model are:

- Precipitation and temperature
- Land-use classification
- Hydrologic soil groups
- Flow direction
- Available water capacity

(Westenbroek, et al., 2018)

<u>Model limitations and assumptions</u>

Just as any other model, the SWB 2.0 model has its limitations and some assumptions. It is most certainly recommended to compare SWB results with other known values (Westenbroek, et al., 2018). The model calculated the net infiltration on a daily basis, but this value tends to be more reliable if it is averaged monthly or annually. In areas where the water table is at a significant depth, there is a time needed for the water to infiltrate to deeper zones to become infiltration. Thus, the daily net infiltration will not be accurate enough. Another limitation is that runoff is assumed to migrate to the next downslope grid where it will infiltrate or will be moved out of the system. If runoff ends up in a depression and evapotranspiration and soil moisture demand are met, the remaining water in the depression will be infiltrated according to the model. This may result in abnormal high infiltration in depressions. Another limitation of the model is the use of the curve number; it is said that the curve number varies in each event. These numbers themselves have some limitations, so this should only be used as a starting point. Also, yearly climate variability causes various recharge rates. By using a larger time frame for the model, the variability can be reduced with more acceptable results (Westenbroek, Kelson, Dripps, Hunt, & Bradbury, 2010). Despite the limitations and assumptions, this code can be reliable if the calculations are done at a monthly or yearly rate. The SWB authors recommend to put monthly/yearly data as input for more reasonable results. (Smith & Westenbroek, 2015)

2.3 Study area

The aforementioned study area is the Central Suriname Nature Reserve, which is located in the Sipaliwini district of Suriname. The geographical coordinates of this reserve are 4º Northern Latitude and 56º30' Western Longitude (Redjosentono, 1999). This area consists of the two-billion-year-old Precambrian formation, a geological stable area. It is a typical hilly to mountain region, where the majority of the region consists of erosional and weathered material. A unique feature in this area are the granite inselbergs, which are bare, dome-shaped granite hills. These features protrude from the forests. Examples of these inselbergs are the Top 1 and 2 of the Voltzberg, which have an elevation of 245m and 209m. The overall geology in this area indicates that the majority of the material that is situated in this area is hard. The major river in this area is the Coppename river, which flows from south to north through the reserve. This area can be accessed through this river. The Rechter-Coppename, Midden-Coppename and the Linker-Coppename are the source of the river. These sources are formed at the slopes of the Tafelberg and Wilhemina Mountains. Along the route, there are various creeks that join the sources. Ultimately these source rivers and creeks form the Coppename river. The largest branches of this river are the Adampada Creek and the Tanjimama creek (Reichart, 1993).

The area has 4 seasons to be distinguished in this area:

- Short rainy season; from December-January
- Long rainy season; from April-July
- Short dry season; from February-March
- Long dry season; from August-November

(Vath, 2008)

With reference to Appendix 1, which displays the climate distribution across Suriname, it is observed that the CSNR area has a monsoon type of climate. Year-round rain can be expected, but in a few months, it will be less than 60 mm. This deficiency is covered by the annual total. Appendix 2 depicts the rainfall distribution across the country. It can be seen that there are larger precipitation rates in the study area compared to the coast area. The rainfall in the study area may vary between 1750 mm and 2500 mm per year (Reichart, 1993). The minimum and maximum temperatures recorded were 23.7 ºC and 28.9 ºC;s these were measured around 18.00hr (Vath, 2008). Figure 2 shows the average rainfall distribution and the temperature data. Approximately 67% of the precipitation in the nature reserve is caused by the evapotranspiration from the rainforest and the remaining 33% is from the Atlantic Ocean (Mol, 2012).

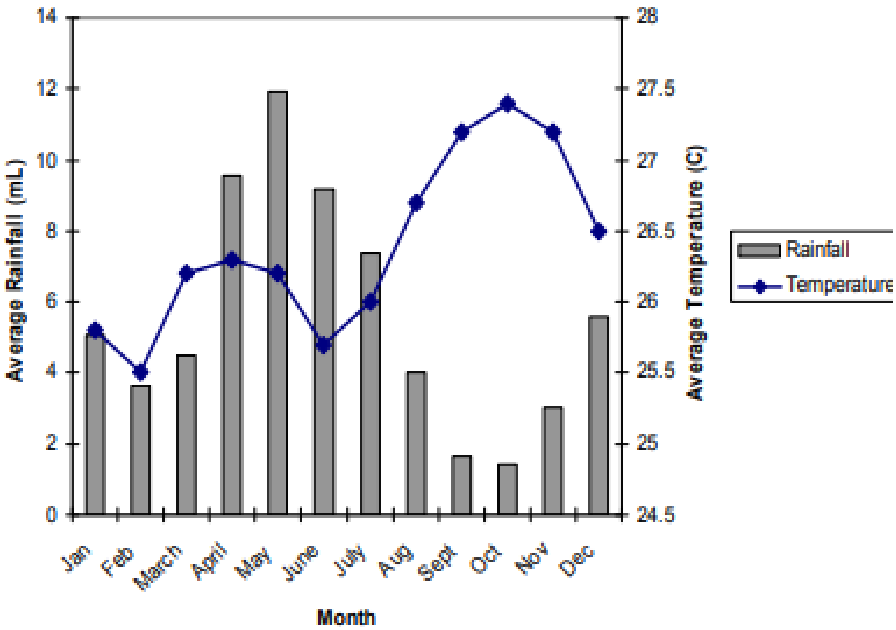

Figure 2: Average rainfall and temperature measured at Raleighvallen in the period 2000-2005
Source : Vath, 2008

Due to heavy weathering in the past, the soil in the CSNR area mainly consists of weathering materials that are poor in nutrients. Quartz, ferrous oxides, aluminum oxides and kaolinite are the main sediments typically found in this area. The soils in this area consists mostly of erosion material, we can expect sandy to heavy loam or clay in this region (Reichart, 1993). Although the study area is claimed to be protected, there are still tangible threats to conservation. For instance, during the gold-mining activities along the Suriname river, small scale gold miners easily move from one location to another; it should not be overlooked that they enter the reserve area. Their presence, as well as the amount of pollution they can cause with mercury, should not be dismissed. There is limited human impact, but there are frequent visits from tourists – this too can result in pollution, vegetation damage etcetera. There is no control on the hunting activities that take place in the Kayser region. In the northern area of the reserve there are villages where there is human impact, mostly hunting that disturbs the ecosystems. In addition, climate change forms a threat to the area. There is also insufficient knowledge/data to understand the natural processes which maintain/support the wealth of biodiversity in the reserve (Conservation International, 2004).

3. Methodology

3.1 Workflow

The initial step to conduct this thesis was to acquire as much knowledge as possible about the study area. After that, data was collected, namely precipitation, temperature, soil, elevation and land use data. All these data were integrated into the model to obtain the output. Figure 3 depicts an overview of the workflow that has been used in this project.

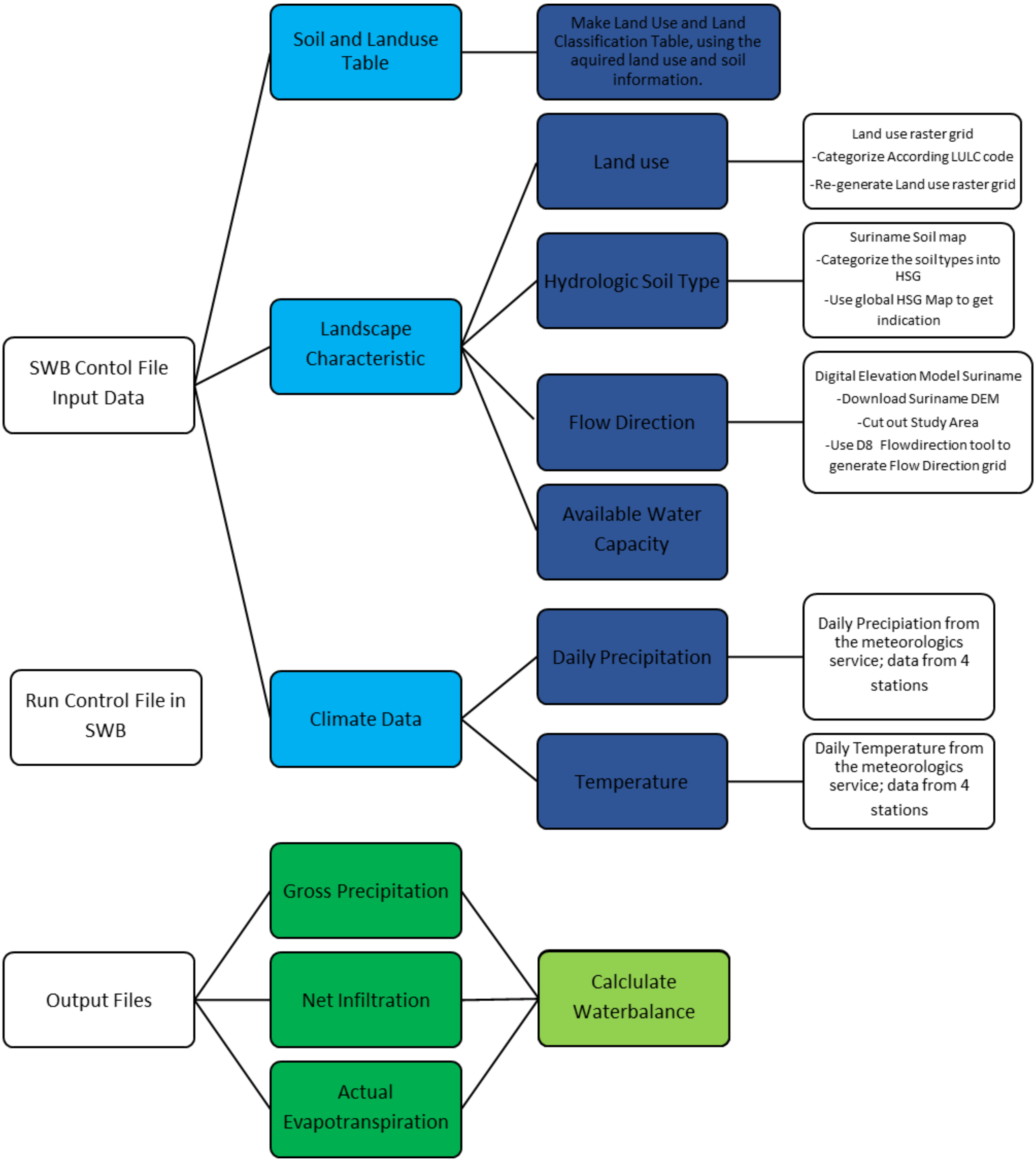

Figure 3: Model workflow

3.2 Input data

Meteorological data

Upon request, precipitation (in mm per day) and temperature data (in degrees Celsius per day) was received from the meteorological survey. For this project, precipitation data was available from 1972 until 1987; 1991 and 1992; and from 2005 until 2017. There were 5 stations located in and around the CSNR area, namely the Tafelberg station, Raleighvallen station, Boslanti station, Poesoegroenoe station and Kayser station. An overview of the CSNR area and the approximate location of the stations is illustrated in Figure 4.

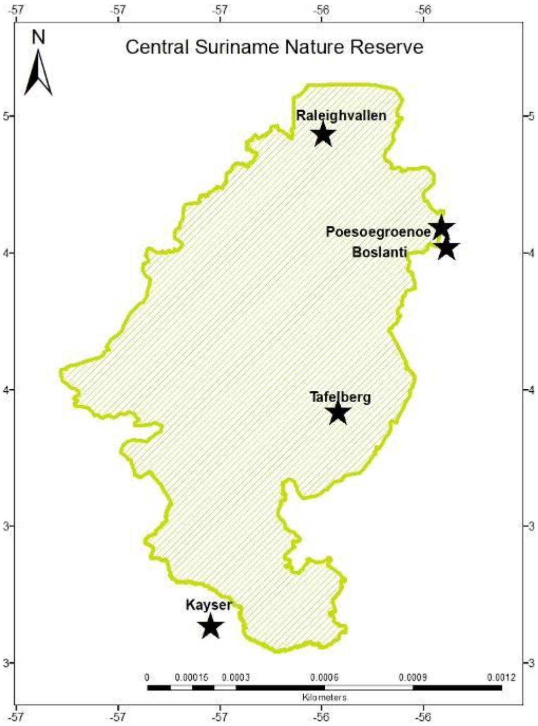

Figure 4: Central Suriname Nature Reserve map with the five data location points

The received datasets for precipitation were not complete for all the stations. Table 1 gives an overview of the available data per station per year. There were also missing data in the tables which were received; these were set to zero. Table 2 gives an overview of the available temperature data for this study. The cross marks indicate that data is available for the specific station in that year. The blank blocks indicate that there was no data for that specific station in that specific year. As can be seen for the years 1991 and 1992 precipitation data was available, but only for the Tafelberg station. Regarding temperature data, it is apparent that only station Tafelberg has temperature measurements and that too for the period 1971-1985.

Table 1:Available precipitation data per station

	BOSLANTI	TAFELBERG	POESOEGROENOE	RALEIGHVALLEN	KAYSER
1959-1970					
1972	X	X		X	X
1973	X	X		X	X
1974	X	X		X	X
1975	X	X		X	X
1976	X	X		X	X
1977	X	X		X	X
1978-1982	X	X	X	X	X
1983	X	X	X		X
1984-1986	X	X	X	X	X
1987			X		X
1991-1992		X			
2005		X		X	
2006		X		X	
2007		X		X	
2008		X			
2009		X		X	
2010		X		X	
2011		X		X	
2012		X		X	
2013		X		X	
2014		X		X	
2015		X		X	
2016		X		X	
2017		X		X	

Table 2: Available temperature data Tafelberg station

	TAFELBERG
1971	X
1972	X
1973	X
1974	X
1975	X
1976	X
1977	X
1978	X
1979	X
1980	X
1981	X
1982	X
1983	X
1984	X
1985	X

For this project, the decision was made to utilize data from 1972 until 1985, because for this period most data were available. The precipitation data for the five stations were plotted into ArcMap; hereafter these datapoints were interpolated through the whole area. Inverse distance weight interpolation was used to gain an idea of what the rainfall might be in the whole area. Figure 5 gives an overview of the monthly precipitation covering the whole dataset. This interpolation method was chosen, due to the fact that this method is widely used in the field of meteorology (Sluiter, 2009).

It is seen that the highest rainfall (approximately 550 mm) occurs around June corresponding with the long rainy season. Around August, the rainfall amount drops significantly to under 100 mm – indicating the start of the long dry season. Around December and January, the precipitation rises a bit up to 200 mm, which indicates the short rainy season. From February to approximately April, the rainfall is between 100-200 mm, which reflects the short dry season. The various seasons can be found back in the dataset. The decision was made to obtain an average net infiltration over the whole study period. An average of the precipitation data, per station per month, was calculated using Excel. To do the calculations, the data was sorted based on station and date. For example, all the precipitation values of 1st of January of one station (e.g. Boslanti), over the period 1972-1985, were averaged. This was done for 365 days and all stations separately. This resulted in a daily average for the period 1972 until 1985 for each station. These averaged points data were then interpolated (using the Inverse Distance Weight Interpolation method) in ArcGIS, to get a distribution for the total area. After the model has been simulated, it gives gross precipitation as an output, which can be used to double check the input precipitation. There were numerous no-data values, which were assumed to be zero. As mentioned previously, precipitation data was received in mm and the SWB 2.0 model uses inches to make calculations. Therefore, an extra line had to be added in the control file to command the program to convert the units from mm to inches. This was done by adding a scale factor of 0.03737008 in the control file. The input precipitation in mm is multiplied by this factor in order to convert to inches. The minimum allowed value model has been set to zero, because we cannot have negative precipitation (these negative values are created in the interpolation process).

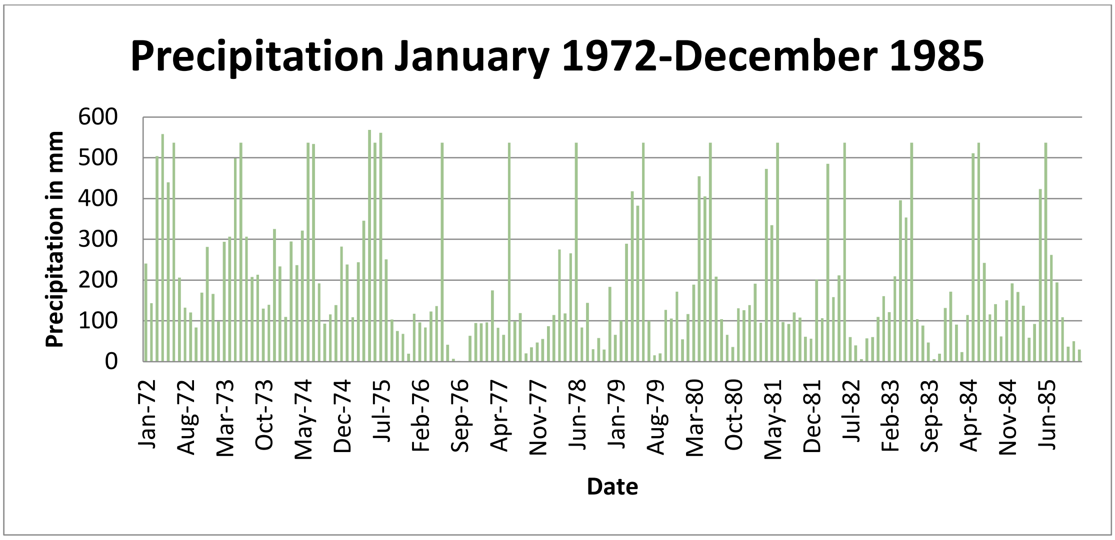

Figure 5: Average monthly precipitation of all stations in mm

Temperature is another required data input for the model. This data was also received from the meteorological service of Suriname. Earlier it was mentioned that temperature data is only available for Tafelberg. This was measured at a daily time step. The model requires an input of minimum and maximum air temperature. Three text files were received; one contained minimum values of temperature, another contained maximum values of temperature and the third one contained the average temperature in degree Celsius. Figure 6 provides an overview of the minimum and maximum air temperature for the study period at daily timesteps.

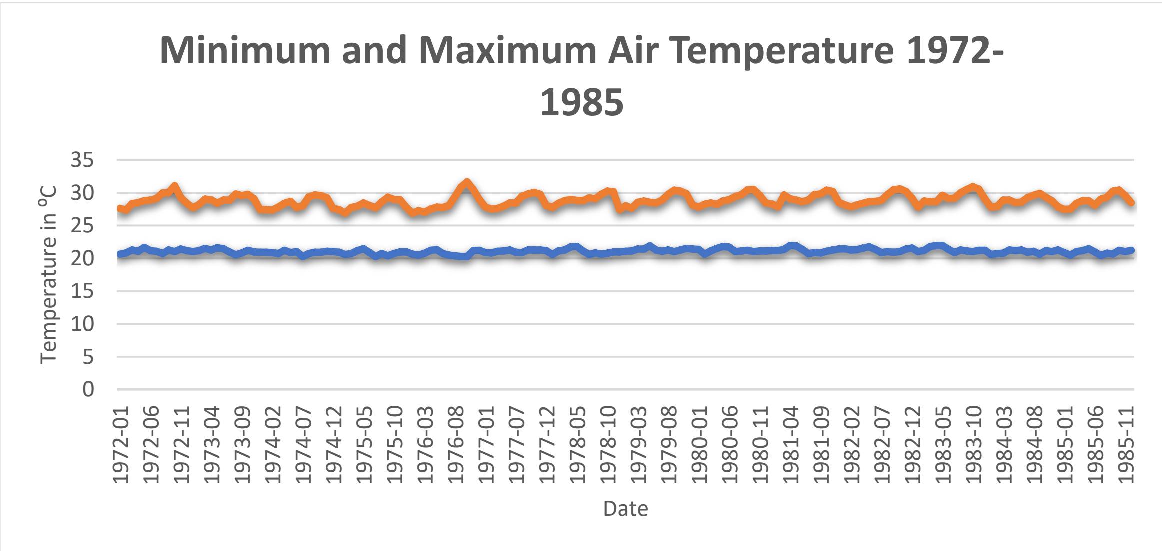

Figure 6: Average daily temperature in degrees Celcius at the Tafelberg station

This is temperature data from one point, Tafelberg. As can be seen, the minimum air temperature varies between 20°C and 21°C. The maximum air temperature varies between 25°C and 29°C. The average of these values was calculated per month for a 14-year period

(1972-1985), which was used as an input for the model. At the end there was minimum and maximum temperature for the 12 months, covering the entire period of 1972-1985 available.

Land-use Data

Land-use is one of the mandatory elements for the Soil Water Balance Model to operate. This area is predominantly covered by pristine forest. Approximately 99% of the area is covered by pristine forest 0.025% is rock, 0.369% are rivers and/or creeks and 0.049% is categorized as open savannah. (GONINI; National Land Monitoring System of Suriname, 2019).

Soils

Along with land use, soil is also required for the SWB model. Figure 7 depicts the major soil types in the CSNR area by percentage. As described in the figure, the majority of soils which occur in this area are mostly kaolinitic, clays or sandy clays. It can be concluded that the major soil types in this area are the clayey type soils, varying from ferritic to kaolinitic to sandy clays. This gives an indication about the soils in this area. Generally, clay has a higher porosity compared with sand, but has a lower permeability compared to the latter. That is the reason that clays hold water rather than infiltrating.

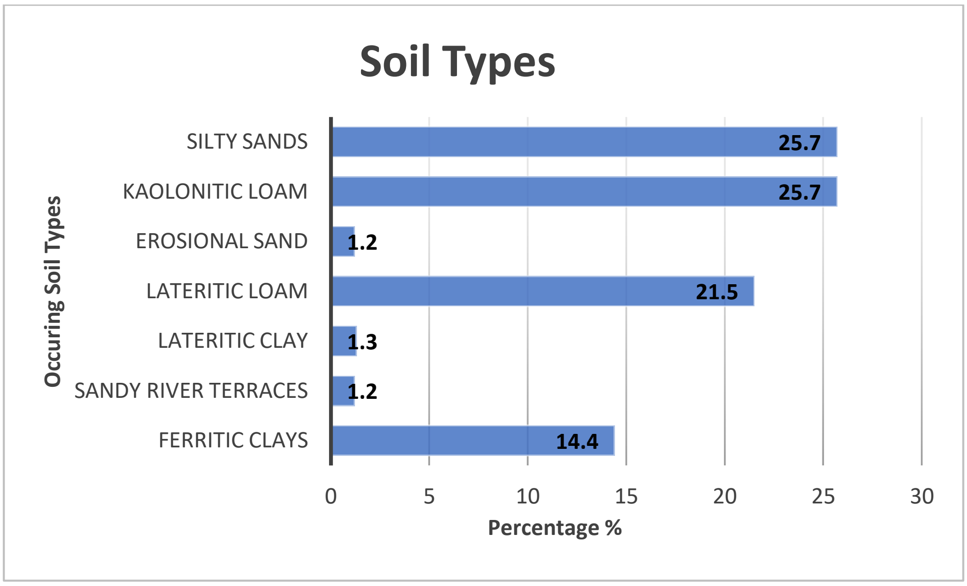

Figure 7: Percentages of the major soil types occuring in the CSNR area

The model requires the soils to be categorized in hydrologic soil groups. For the CSNR area no evaluation has been done regarding the categorization of these soils into hydrologic soil groups. Soils were categorized based on the global hydrologic soil grid, which is represented

in Appendix 3. The majority of the soil types are categorized in group C and group D, which have a relative lower infiltration rate compared to group A and B.
This categorization of soils in the CSNR area can be seen in Table 3. All the soils are categorized into the hydrologic soil groups.

Table 3: Hydrologic Soil group classification of the soils in the CSNR area

Hydrologic soil groups	Hsg	Hsg	Available soil-water capacity
Ferritic Clay Plateau	4	D	3.60
Sandy River Terraces	2	B	1.60
Lateritic Clay	4	D	3.40
Lateritic Loam	3	C	2.40
Kaolinitic Loam	3	C	2.40
Sandy Silt	2	B	1.60

Available water content is also a mandatory requirement for the model to make its calculations. For the CSNR area, this data was also unavailable; according to the SWB handout, if the available soil-water capacity is unknown, we can use the estimated available water capacities assigned for the specific soil textures. The available soil-water capacity is given per inch in Table 3. A grid file of this data was supplied in the control file. The value of the available soil-water capacity was assigned to each soil group, after which this was gridded. The gridded dataset was supplied to the control file. After obtaining soil and land use data, these were incorporated into the land use lookup table which is also a mandatory input data for the model. The lookup table that was used is the land use lookup table, which is a requirement of the model. Four land use types have been identified based on the received data, namely undisturbed forest, rock, river/creek and open savannah. These must be assigned to specific land use categories, which will be created according to USGS land use and land cover classification system, seen in Appendix 4. The Suriname forest has been classified as seasonal Evergreen forest, there are more smaller categories identified in the region of Voltzberg and Raleighvallen (Reichart, 1993). As a result, pristine (undisturbed) forest will be categorized as evergreen forest, with a land use code of 42. There are 2 categories, savannah and barren rock; these are in lesser quantity compared with the undisturbed forest coverage. These 2 will be categorized under barren land with a land use code of 24. Sand, rocks and clays are included in this category. The assumption is that the vegetation on these land types is less than 15% (Mockus, Moody, & NRCS/ARS Work

Group, 2017). Rivers and creeks will be included in the open water category; this will be added to the land use table as open water with a code of 11.

The table is compiled by assigning curve numbers, maximum net infiltration, rootzone and interception data to each combination of land use and hydrologic soil group. These values are not available for the CSNR area, so it was opted to use literature value. The values that have been used are from a study done in Minnesota by Erik Smith and Stephen Westenbroek. These scientists calculated the potential groundwater recharge in the state of Minnesota using the Soil-Water-Balance model for the period 1996-2000.

Table 4 gives an overview of the four soil groups that are linked to runoff curve number. The hydrologic soil groups are not mentioned as A to D, but from 1 to 4. The curve number is a constant in an equation which determines the soil-water balance of an area before a storm event. This parameter is based on the following factors: hydrologic soil groups, land use, land treatment and hydrologic condition. (Suphunvorranop, July 1985)
As can be seen in the table, the 3 land use categories are linked to soil groups. There is a curve number assigned to each soil group for each land use.

Table 4: Land use codes linked with Curve Numbers

LU_Code	**Description**	**CN_1**	**CN_2**	**CN_3**	**CN_4**
42	Evergreen Forest	36	60	73	79
24	Barren land (sand, rock, clay)	90	93	95	96
11	Open Water	100	100	100	100

Table 5 gives an overview of the maximum net infiltration per soil group for each land use type. The maximum net infiltration in the open water area is relatively lower than that of evergreen forest and barren lands. The values are given in inches.

Table 5: Land use codes linked with the maximum net infiltration

LU_Code	***Description***	***max_net_infil_1***	***max_net_infil_2***	***max_net_infil_3***	***max_net_infil_4***
42	Evergreen Forest	6	3.50	2.75	3
24	Barren land	6	3.50	2.75	2
11	Open Water	4.5	2.25	1.50	0.75

Table 6 shows the interception values in inches per day. In this column, values for interception storage are given for the growing season and the dormant season. Our rainforest does not have specific growing seasons or dormant seasons, so the first and last day of growing is set on the first and last day of a year.

Table 6: Land use codes linked with the interception growing season and non growing season

LU_Code	***Description***	***Interception_Growing***	***Interception_Nongrowing***
42	Evergreen Forest	0.02	0.02
24	Barren land (sand, rock, clay)	0.06	0
11	Open Water	0	0

Lastly the rootzone depth per soil group is added for each land use type. This is seen in Table 7. The rootzone depths are defined in feet. According to the table, the roots of the evergreen forest are approximately 1 meter. Barren land and open water have shallower root zones. The rootzone is important because calculations will be made based on this value. Everything below the rootzone will be considered potential recharge.

Table 7: Land use codes linked with the rootzone depths

LU_Code	***Description***	***RZ_1***	***RZ_2***	***RZ_3***	***RZ_4***
42	Evergreen Forest	3.16	2.65	2.12	1.85
24	Barren land	1.00	1.00	1.00	1.00
11	Open Water	1.00	0	0	0

Digital Elevation Model

The flow direction is another mandatory element that has to be added to the model as input. To obtain the flow direction, we first need the digital elevation model of the area. SRTM data for Suriname was obtained from the internet. Figure 8 depicts the Digital Elevation Model for the CSNR area, we can see that this area is not flat, but has quite some relief. From this data CSNR was clipped using ArcGIS; this software was used to create the D8-flowdirection grid.

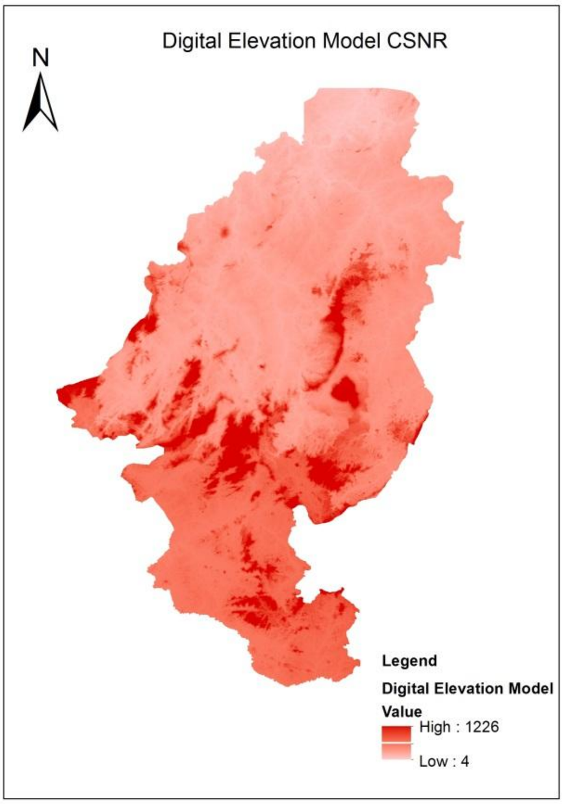

Figure 8: Digital Elevation Model of the CSNR area

Model Definition

The first thing that has to defined in the control file is the grid of the Model. The outline of the Central Suriname area was used to define the boundary of the study area. The value for rows and columns was taken approximate using the Land-use as well as Soil grid extension. The grid of the model has been made slightly bigger so that every other data input lies within this grid. A total of 79 columns and 116 rows have been used. The coordinates of the lower left-hand corner are 489600 and 328000. The grid resolution was set at 1810.

The second step is to set the projection of the area. For this project the projection was set to WGS 1984 UTM Zone 21N.

Other factors

There were a few other factors that had to be chosen for this model. The initial soil moisture content was unknown for this area, so it was decided to use a medium value of 50%. In this model it is also required to put in the initial frozen ground index; for this tropical area, the index was set to 0.

SWB 2.0 Model Methods

The SWB 2.0 model makes use of user-defined methods to make the calculations. The Soil Water Balance Model utilizes a control file in which the location of all input files is given along, with the methods used to make the calculations. After defining the model grid and creating all appropriate input data, the methods for calculation have to be defined. The first method chosen in the control file is for the interception, the bucket method. Interception is defined as part of precipitation which does not reach the ground, because it is stopped by vegetation. The SWB model uses the 'bucket' method. The user gives an amount of precipitation that is intercepted by vegetation; this is done in the land use lookup table. Afterwards the evapotranspiration method was chosen. The following methods are available for evapotranspiration:

- Thornthwaite-Mather
- Jensen-Haise
- Blaney-Criddle (FAO BC)
- Turc
- Hargreaves-Samani

(Westenbroek, Kelson, Dripps, Hunt, & Bradbury, 2010)

Each method has its own data requirement, so that these can be applied. For this project the Hargreaves-Samani method was chosen. The reason for using this method is the available data. There is not enough data available to make use of one of the other calculations' methods. The Hargreaves-Samani equation is defined as follow:

$$\boldsymbol{ET_0 = 0.0135 * (KT) * (Ra) * (TD) * {}^{1}/_{2} * (TC + 178)}$$ ***Equation 1: Hargreaves-Samani***

Where:

-KT is the empirical coefficient

-Ra is the extraterrestrial radiation (mm/day)

-TD is Tmax minus Tmin (ºC)

-TC is the average daily temperature (ºC)

This equation only requires temperature data and the latitude to make its calculations. This equation has been used successfully in some areas where there is limited data available (Samani, 2000). This was verified in Mateca, where the Hargreaves-Samani method with limited data was compared with California Irrigation Management Information System station and Pan data, the values of these three methods did not have significant differences (Orang, Grismer, & Ashktorab, 1 May 1995)

For runoff the curve number method will be used. The curve number will be included in the look up tables. The curve number is a number which is defined by a combination of the available soil group and the land use and landcover of that area. It signifies a hydrologic soil cover complex. This number depicts the runoff potential of a complex. A higher curve number means a higher runoff potential. (Mockus, 2004)

For the water balance a simple equation method will be applied with the available parameter output:

$$\boldsymbol{Water\ balance = P - (net\ infiltration + ET)} \qquad \textit{Equation 2}$$

Where

P = Precipitation (inch)

ET=Evapotranspiration (inch)

The output rasters will be used for this calculation. The raster data is in inches, thus the calculations will be done in inches. Afterwards the outcome will be converted to mm.

4. Results and Discussions

Precipitation has been used as one of the input data for the SWB model. After running the model, this data is reflected back into the output. For this project, the decision has been made to observe a monthly average for the whole time period. From this there is a visible precipitation trend, as is shown in Figure 9. The same peaks are observed around May and June. The extreme lows are also seen from August to November.

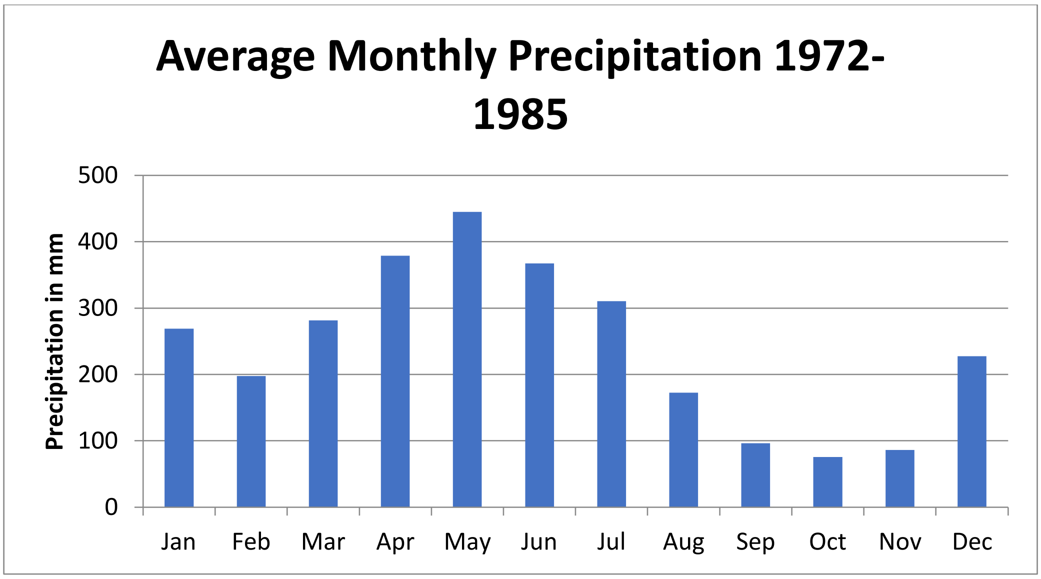

Figure 9: The average montly precipitation in mm for the time period 1972-1985

According to the soil map the area was divided based on the hydrologic soil groups. This is also an input but is generated back in the output. The model gives a raster file in which the division can be more clearly seen. Figure 10 depicts the output of hydrologic soil groups after running the software. It can be observed that most of the area is covered with number 3 (category C) hydrologic soil groups, which have a more claylike/loam texture. Category D is the next prominent soil group, followed by a few patches of category B, which has a sandier texture compared to the other soil groups.

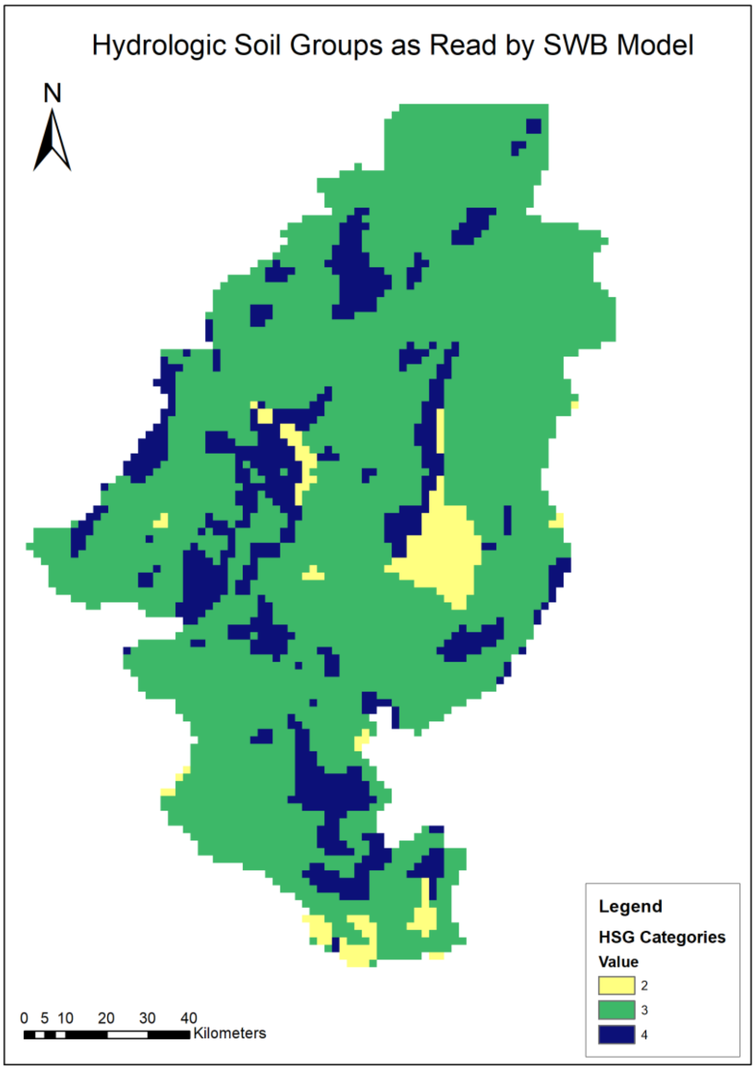

Figure 10: Soil types distribution in the CSNR area

Net infiltration is one of the outputs which is generated through the SWB model.
This model considers water that goes through the soil and beyond the root zone, to be net infiltration or recharge. Recharge does not happen on a daily basis, although the input data is daily data. To get a more representable overview of the recharge in the CSNR area, statistics were run to get the monthly net infiltration rate over the entire study 14 year-period.
Figure 11, Figure 12 and Figure 13 give an overview of the various net infiltration rates per month. It can be seen that in the beginning of the year there is an infiltration rate of approximately 100-130 mm infiltration per month. This is apparent for the months January until March. In May, June and July some higher values of infiltration are observed. These are the highest in the whole year, with values ranging from 170-390 mm of infiltration per month. From August on, there is significant decrease in infiltration to approximately 0-35 mm of infiltration per month. In December the infiltration rate increases again to 101.6 mm of infiltration.

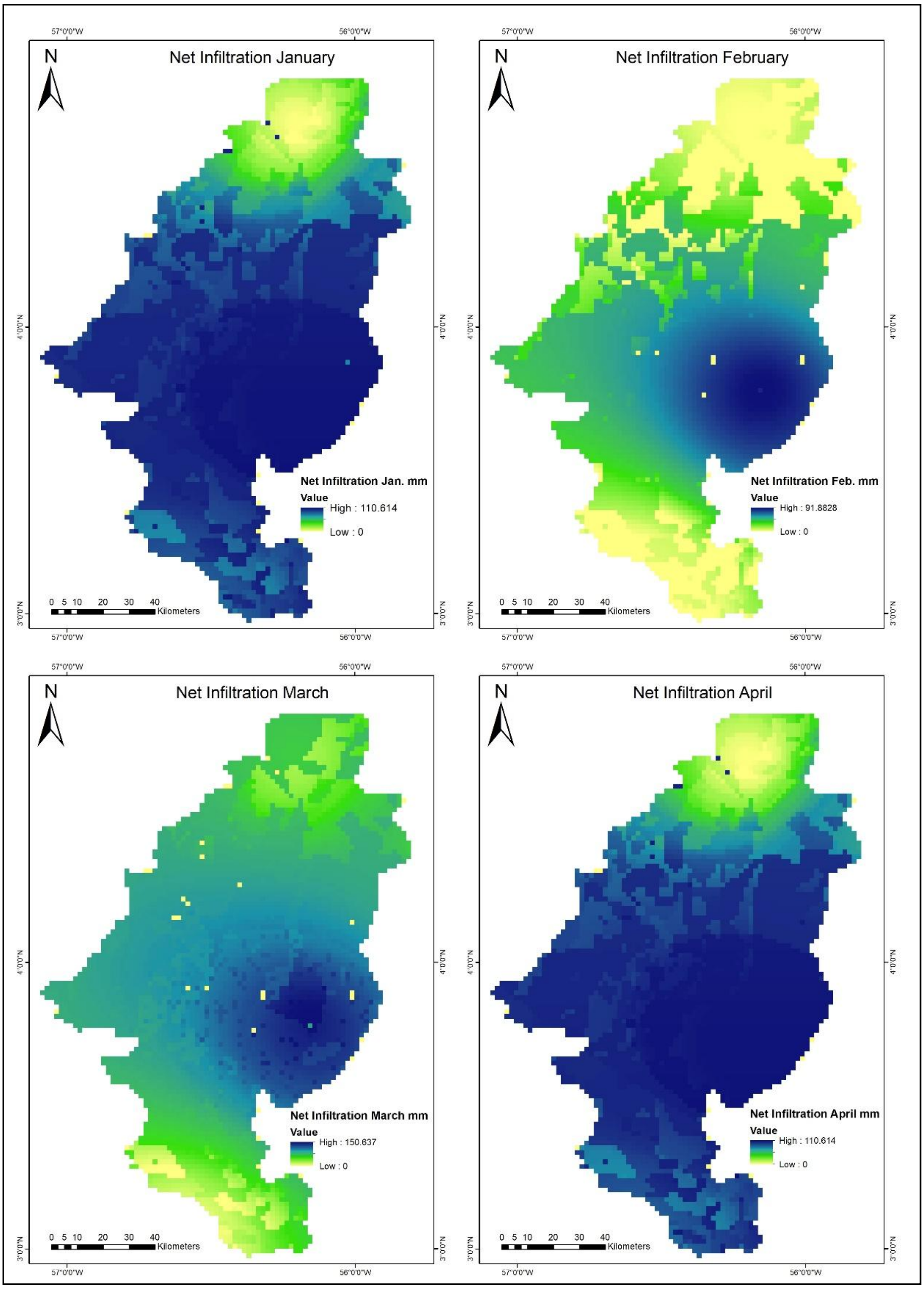

Figure 11: Average monthly net infiltration (1972-1985;CSNR) in mm for the months January, February, March and April, for the CSNR area

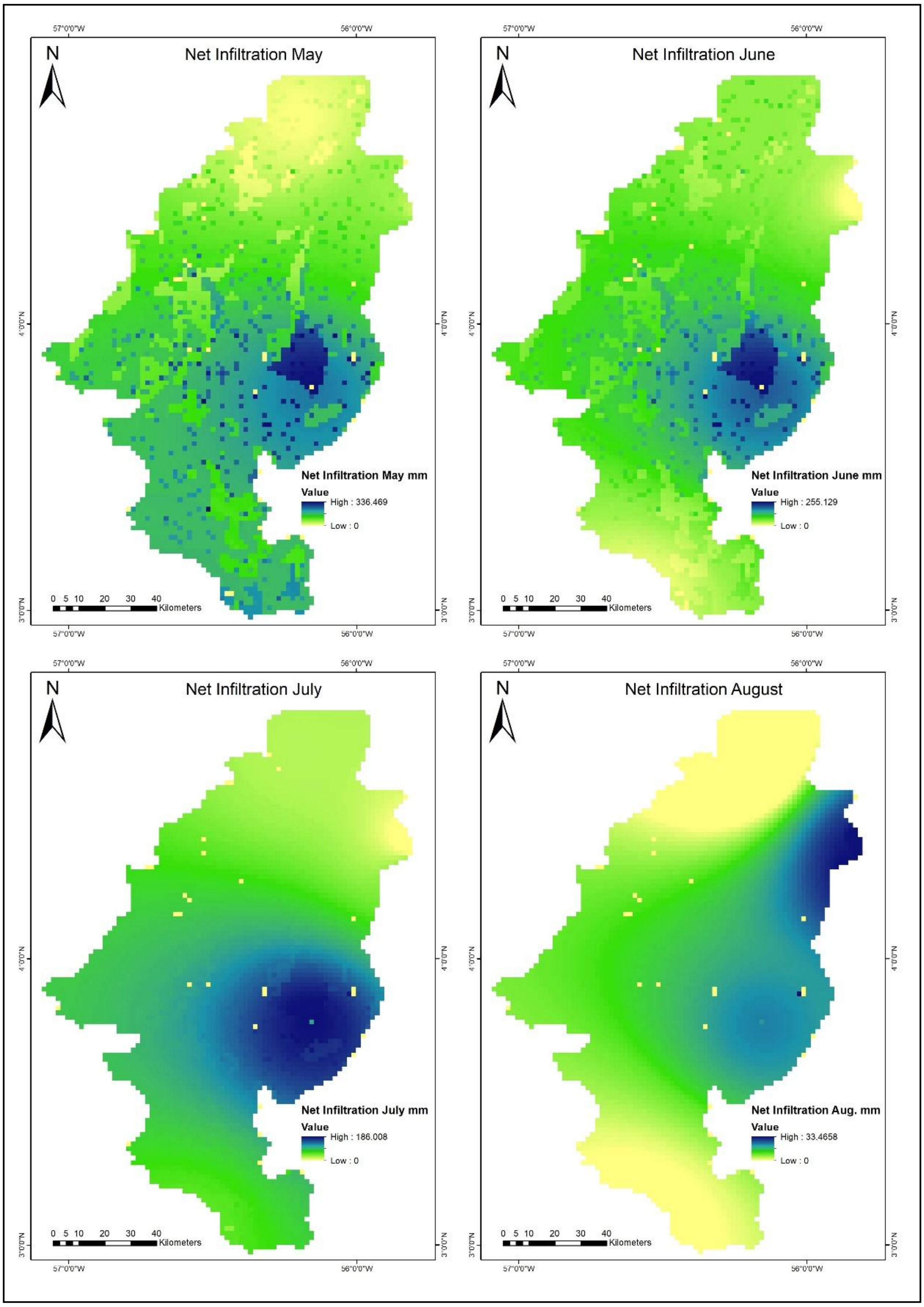

Figure 12: Average monthly net infiltration (1972-1985;CSNR) in mm for the months May, June, July and August in the CSNR area

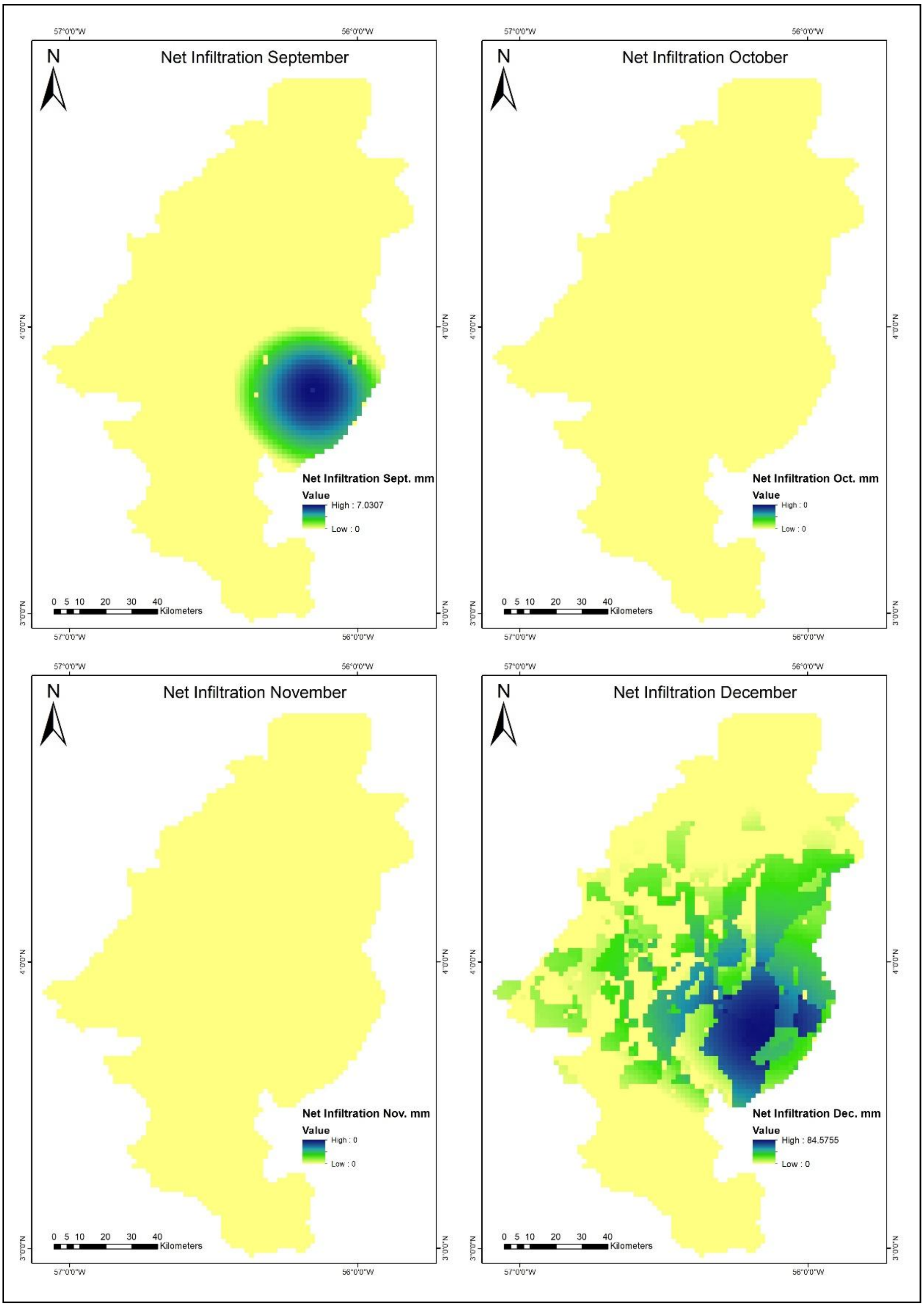

Figure 13: Average monthly net infiltration (1972-1985;CSNR) in mm for the months September, October, November and December in the CSNR area

A monthly average temperature has been used for the model to run. Figure 14 gives an overview of the monthly average temperature for the CSNR study area. In terms of the seasons we can see a rise around August and a slight raise in temperature from February to April. These periods are also referred to as the dry seasons, and higher temperatures are expected. The rainy seasons have a relative lower temperature than the dry seasons.

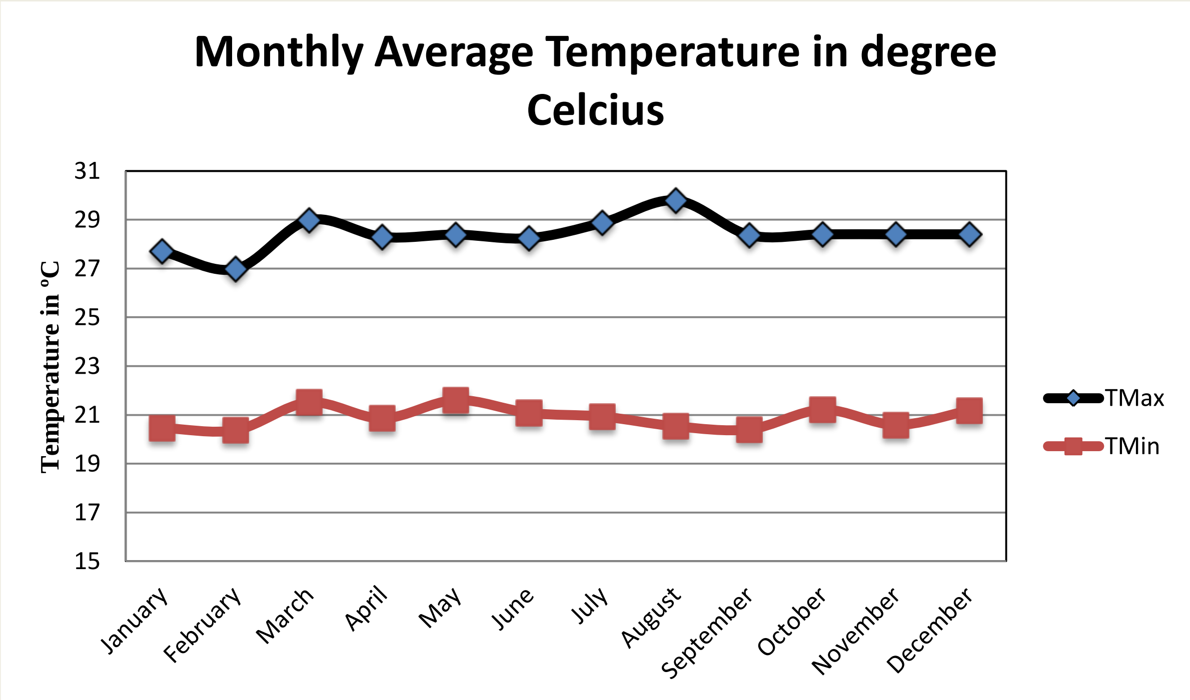

Figure 14: Average daily temperature in °C per month

After running the model, the ET values are computed. Figure 15, Figure 16 and Figure 17 give an overview of the generated monthly ET-maps. The actual evapotranspiration is not only subject to rainfall or soil, but it is also dependent on the vegetation cover. It is the sum of evaporation and transpiration. This area is covered with tropical rainforest for the whole year round. The ET rates are more or less the same throughout the whole year, with values that range between 100-130 mm of monthly evapotranspiration.

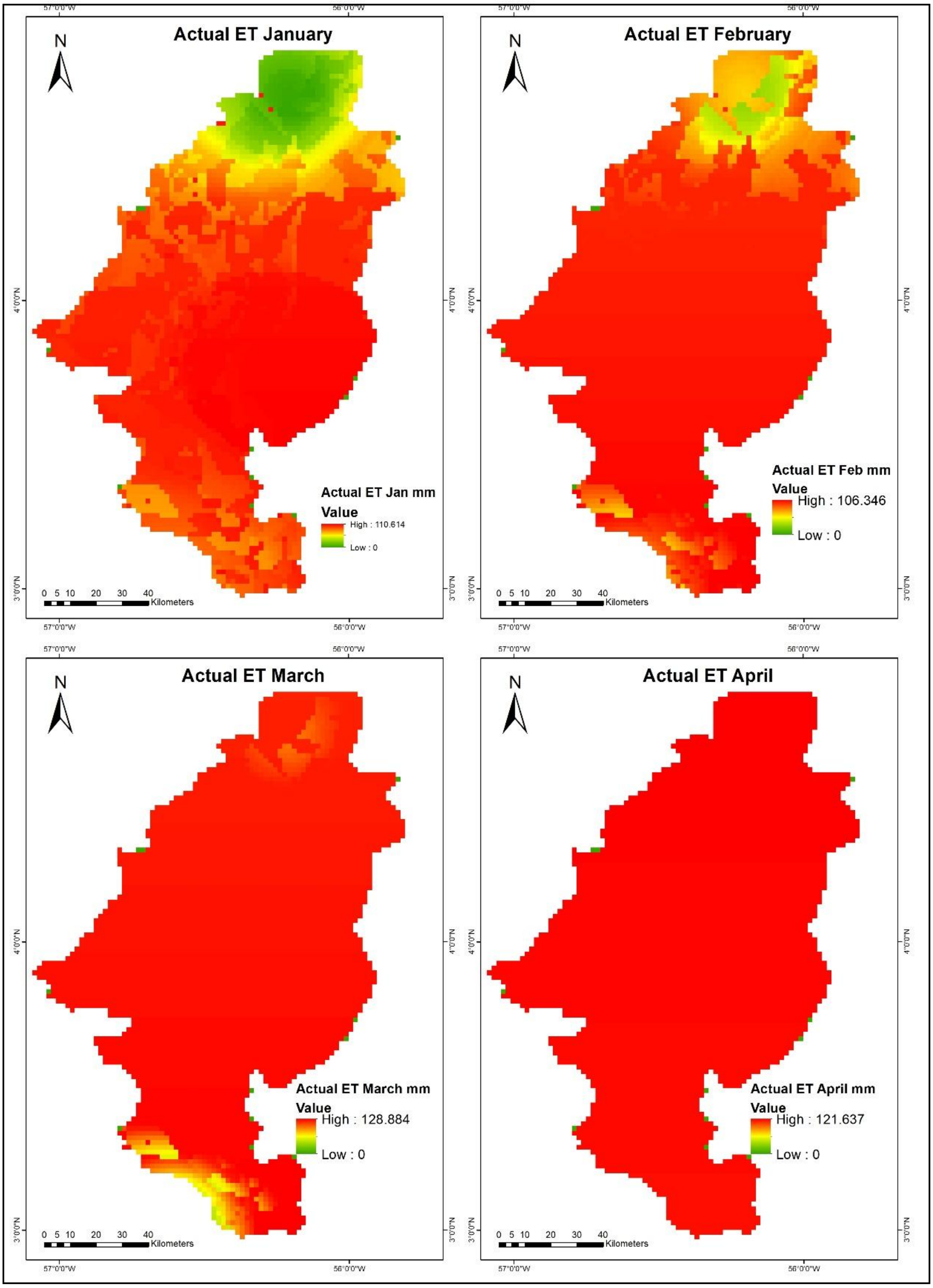

Figure 15: Average monthly ET (1972-1985;CSNR) in inches for the months Januray, February, March and April in the CSNR area

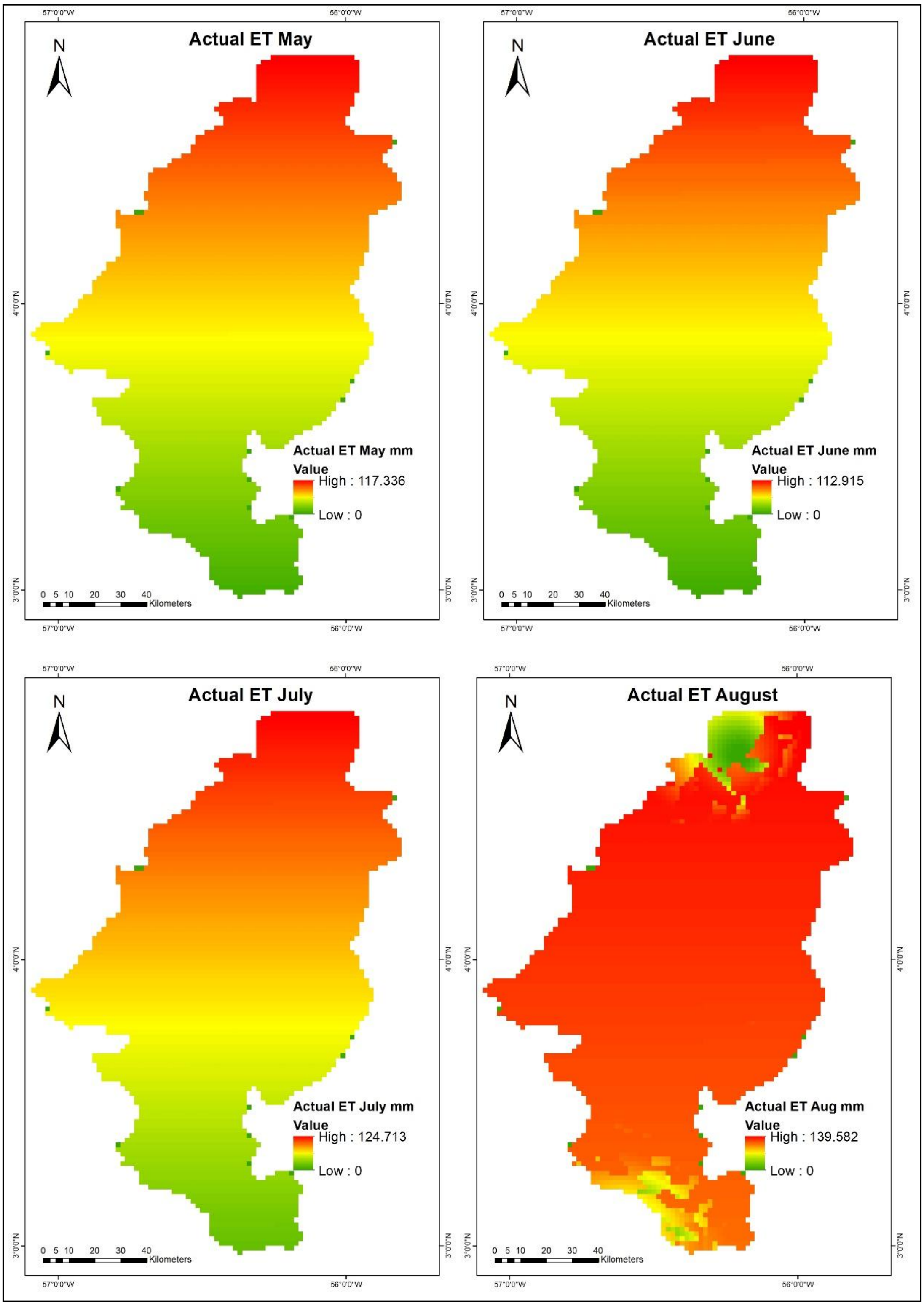

Figure 16: Average daily ET (1972-1985;CSNR) in mm for the months May, June, July and August in the CSNR area

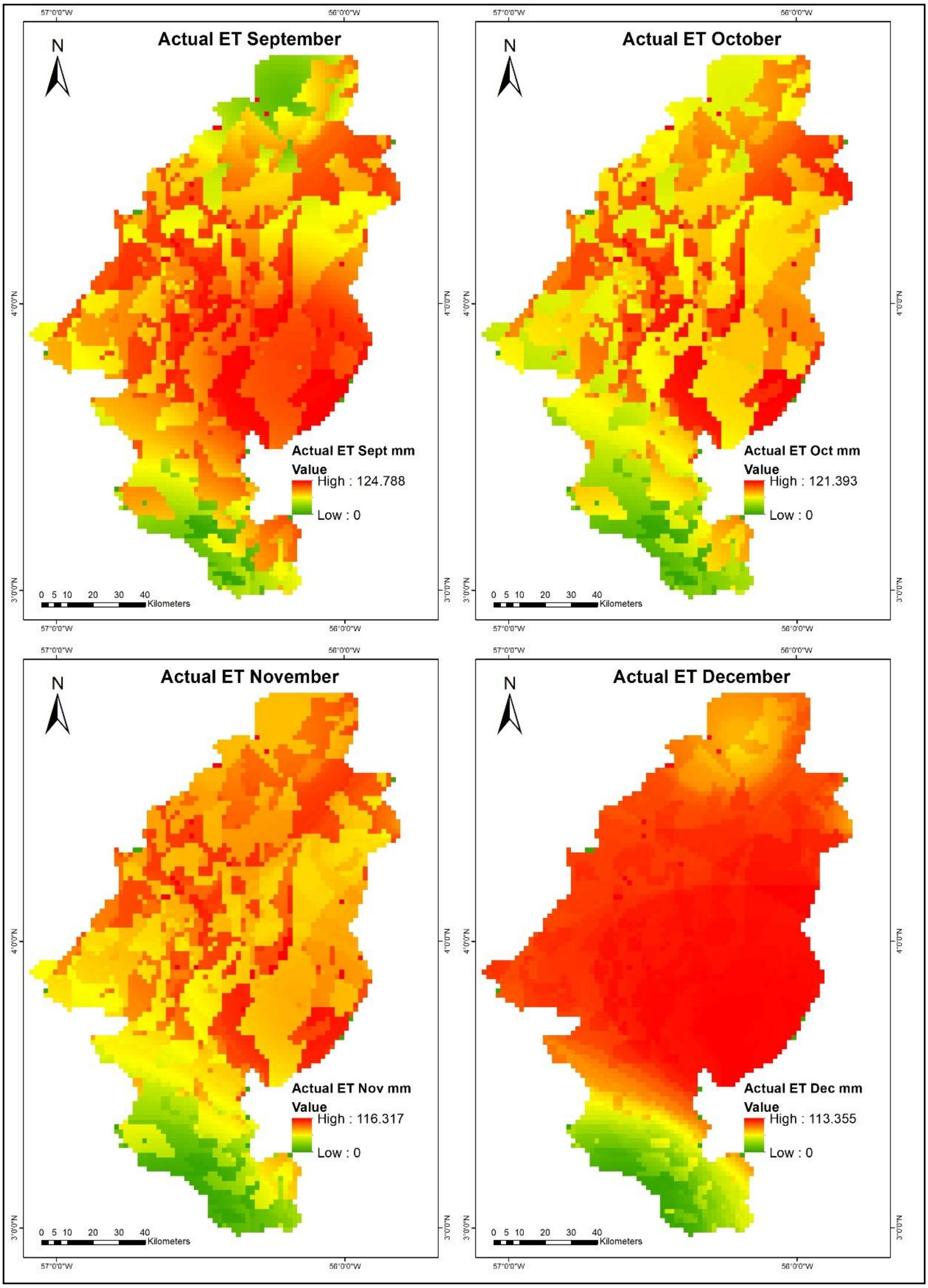

Figure 17: Average daily ET (1972-1985;CSNR) in mm for the months September, October, November and December in the CSNR area

After getting all the outputs and maps, Figure 18 was compiled to compare the gross precipitation with the net infiltration and the actual ET. This figure shows that the net infiltration is related to the precipitation. The peaks of net infiltration are seen in May and June, which indicate the long rainy season. In the months October and November, we have the long dry season (from mid-August). Thus, it is clearly seen that the lowest infiltration rates as well as the lowest precipitation rates have been obtained. In December and January, we encounter the short rainy season with a rise in the precipitation and infiltration. In February we encounter the short dry season with a lower precipitation and infiltration rate. The actual ET remains more or less constant during the whole year. In the months September, October and November, the actual ET values are larger than the precipitation rate, resulting in a deficiency instead of a surplus in the water budget. It should be noted that in this period we are dealing with the long dry season, marking lower precipitation and higher temperatures overall. There are more inputs, such as fog ratio, impervious land etc., into the system which have not been taken into account due to lack of data.

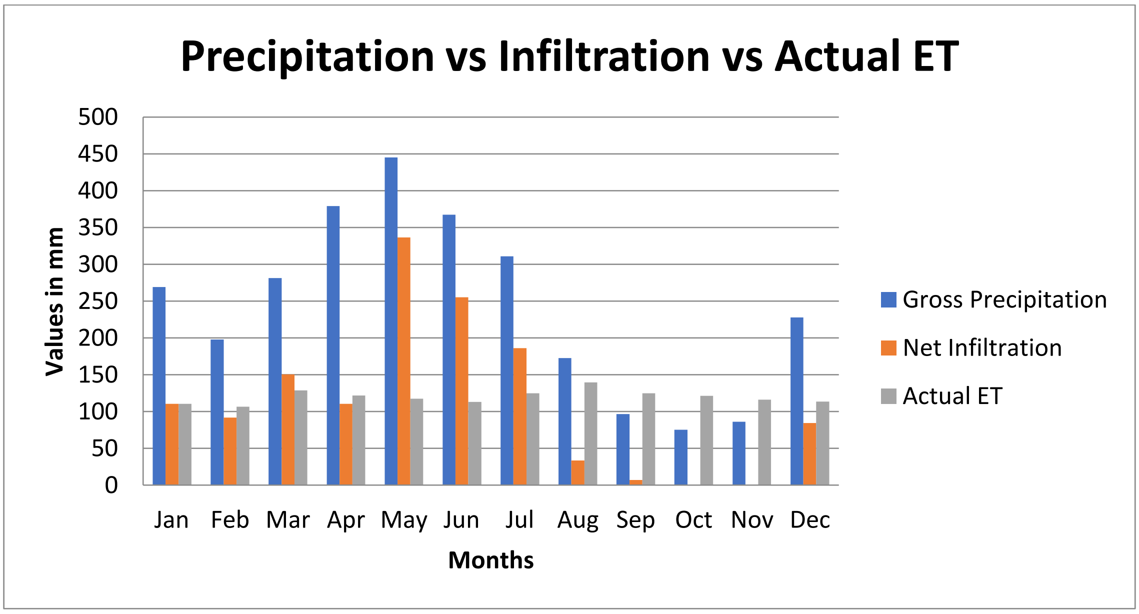

Figure 18: Monthly precipitation vs the infiltration and the actual ET in mm

Figure 19 depicts an annual overview, which is calculated with the swbstats2 module. The annual precipitation is about 2800 mm rainfall per year.

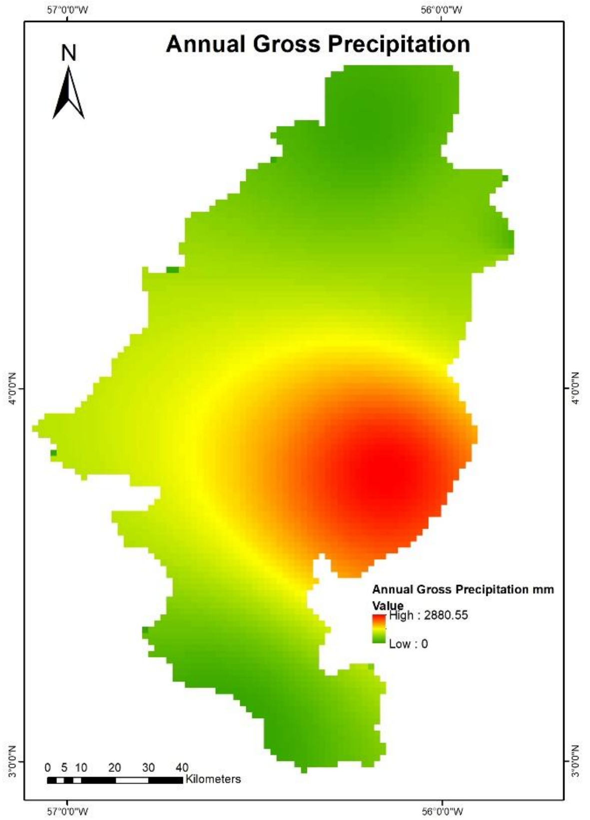

Figure 19: Annual precipitation (1972-1985;CSNR) in mm for the CSNR area

The actual ET, displayed by Figure 20, has a maximum value of approximately 1430 mm evapotranspiration per year. These extreme values are only seen in a few grids. If we look at the annual net infiltration, Figure 21, we see a maximum value around 1470 mm of infiltration per year. On top of the net infiltration map, the soil map is placed. There were 3 soil types identified earlier, soil group 2,3 and 4. These are the same as group B, C and D. ranging from sands to clays, from higher infiltration to lower infiltration levels. It is observed that the highest infiltration rates are encountered where soil type B (2) is assigned. Where there are lower infiltration values, we see soil group D. The remainder of the area consists of soil group C.

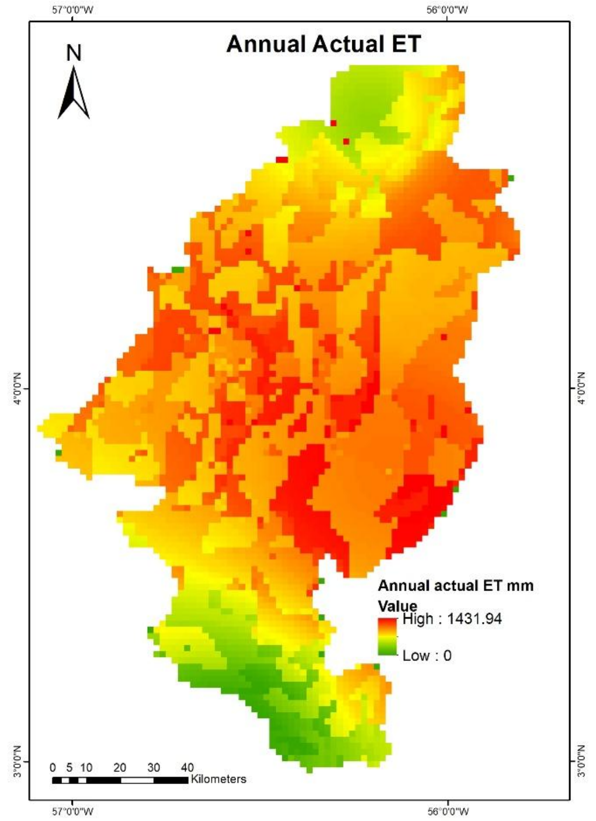

Figure 20: Annual actual ET (1972-1985;CSNR) in mm for the CSNR area

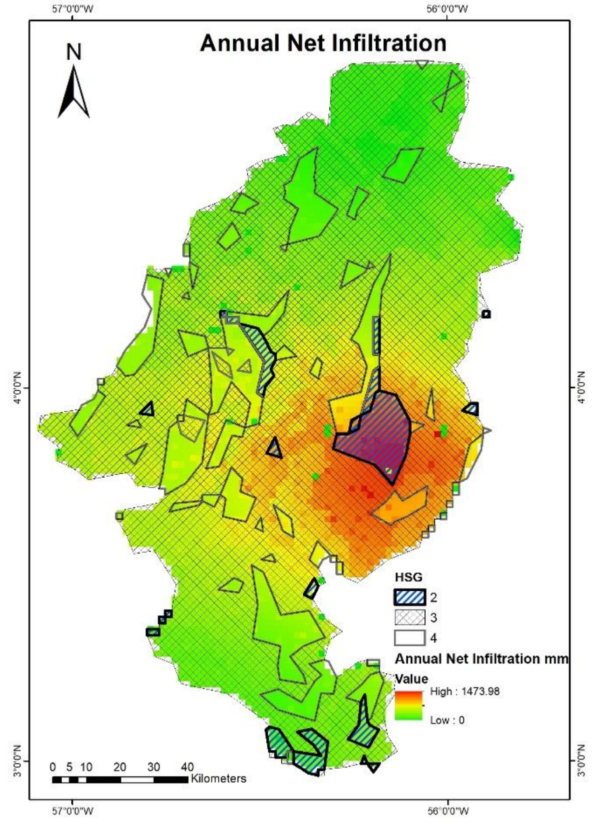

Figure 21: Annual net infiltration (1972-1985;CSNR) in mm overlaied by the HSG for the CSNR area

Figure 22 gives a gross overview of the water balance in this area. The water balance is calculated by subtracting the net infiltration and actual ET grids from the gross precipitation. This resulted in the figure above. We see a surplus of about 2700 mm of water and there is a deficiency of approximately 1260 mm. The extreme values are only seen in a few cells; the brightest yellow indicates the negative values, and the stronger purple grids indicate the highest value of 2700 per year. The majority of the values of the water balance lies between 0 to 330 mm. The water balance is related to the soil groups; it is observed that the lowest value in water balance coincides with the higher soil group, group B, and the higher water balance values coincides with the lower soil groups, group C and D

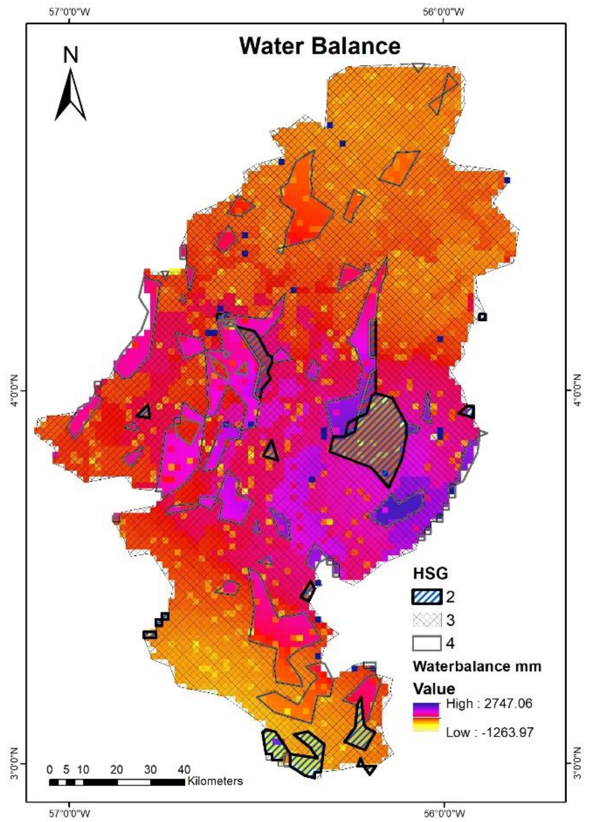

Figure 22: Annual results of the waterbalance (1972-1985;CSNR) in inches for the CSNR area

Figure 23 depicts a comparison between the 3 hydrologic soil groups, the water balance and the net infiltration rate. This figure shows the mean values of the infiltration rate and the water balance. HSG 2,3 and 4 correspond with soil groups B, C and D. It is clearly seen that the higher net infiltration rates correspond with soil group B, which is more permeable. This results in a lower water balance in the end. A closer look at soil type C and D reveals lower the infiltration rates due to the soil properties. Group C and D have a more clay like structure which is not very permeable – resulting in less infiltration. This will result in a surplus of water. That is the reason why we have higher amounts in the water balance.

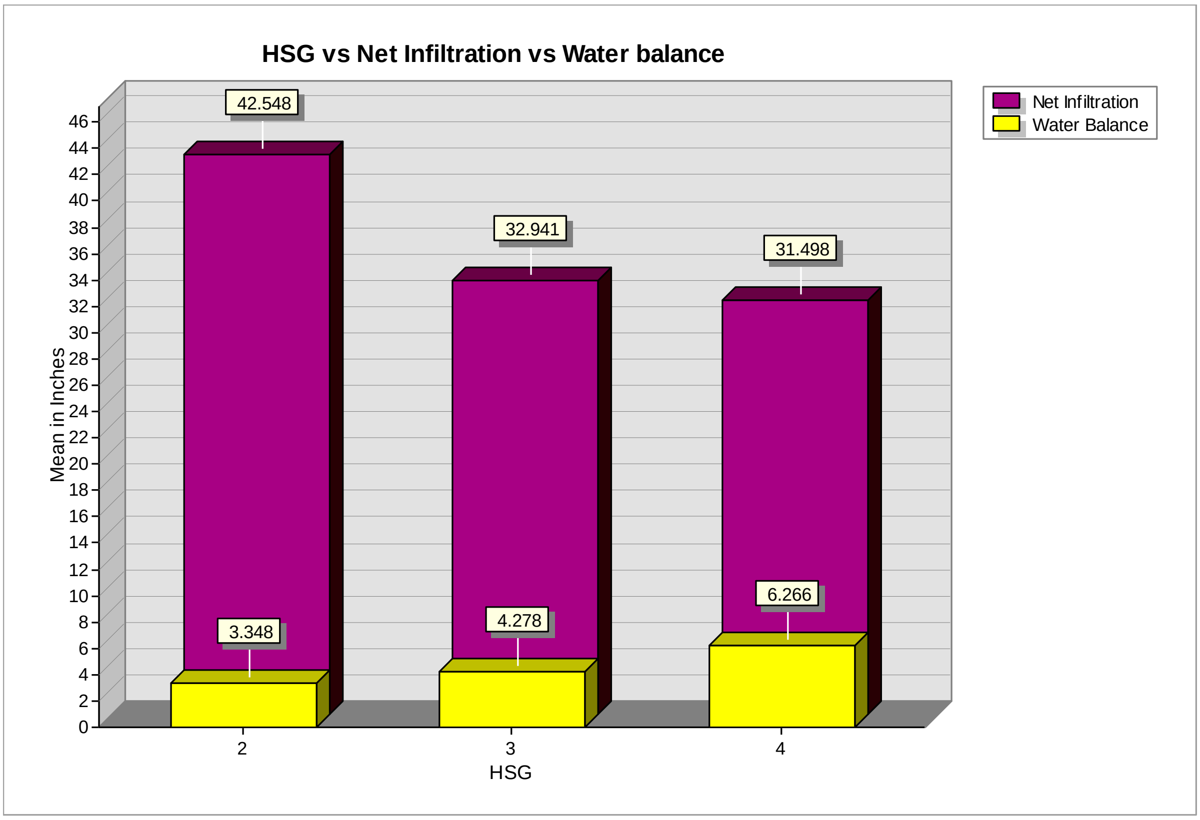

Figure 23: Relationship between the HSG, net infiltration and the water balance

5. Conclusions

The aim of this study was to obtain an indication of the recharge rates in the Central Suriname Nature Reserve with the SWB 2.0 model. After running the model, it can be concluded that the recharge in January is connected to the amount of precipitation. The infiltration rate is higher in rainy seasons than in the dry season. It can also be concluded that the minimum precipitation needs to be 90 mm per day for recharge to occur.
The resulting actual evapotranspiration does not vary significantly throughout the whole year. Results show that the actual ET ranges between 100-130 mm each month. This is because evapotranspiration accounts for the evaporation as well as the transpiration, which is related to the vegetation in the area. The study area is mainly covered with tropical rainforest year-round, which contributes to the actual ET.

The annual water balance shows a clear relation between the factors, infiltration, hydrologic soil group and water balance. The output of the model and water balance calculations show that where permeable soils were present (such as sands, category B), higher infiltration rates were encountered. On the other hand, in clayey areas water will tend to seep slower into the subsurface. This may have an impact on the area, as the CSNR area consists mainly of clay/loam type of soils, restricting the recharge into the subsurface. In the event of phenomena such as floods, such as the 2006 flooding, this factor should be considered. Soil will not absorb a significant amount of moisture.

There is no other data to compare the results of this model, the model is accurate as your data. Currently the model contains the required input data. If more data is added the results will be more accurate.

The overall results show a good relationship between the soil and the parameters of the water balance such as the precipitation, the net infiltration and the evapotranspiration. Climate change or land use changes in this area will have an impact on these parameters as well as the infiltration rate. Groundwater acts as a carrier of nutrients which is used by the trees. Changes in the groundwater will create an alteration in nutrient supply for the plant and aquatic life in the reserve, resulting in possible change in the variation of the species which occur in this area.

6. Recommendations

During this project, the SWB 2.0 model has been run with the basic required data. This was also the only available data. To solidify the outcome of the model, it is recommended that future studies/evaluations are carried out to obtain the missing parameters. The more accurate the data, the more reliable the results. Some key parameters that should be studied are the Curve Number and the root zone depth of the trees existing in that area.
The Curve Number will categorize the soils into groups, based on the characteristics of that type of soil. Knowing the true root zone depth will give a better understanding of the soil profiles and the percolation depth of water.

The current results of the SWB 2.0 model cannot be calibrated, because there is no existing recharge data in this area. Recharge or infiltration measurements should be done in this area. The output data from the SWB 2.0 model should then be compared to gain an indication of the quality of the recharge outputs.

Further studies can be done in this area using datasets with other time ranges, e.g. 2000-2009. The results can be compared to make future prediction of the water balance in the CSNR area. This model can also be applied to other areas.

Studies should be conducted to assess the preferred habitats of the species native to this area, as well as investigate how environmental changes will alter the habitat and occurrence of said species.

It is also recommended to stay in touch with the USGS for further software updates and/or changes to the model – which will ultimately improve the results.

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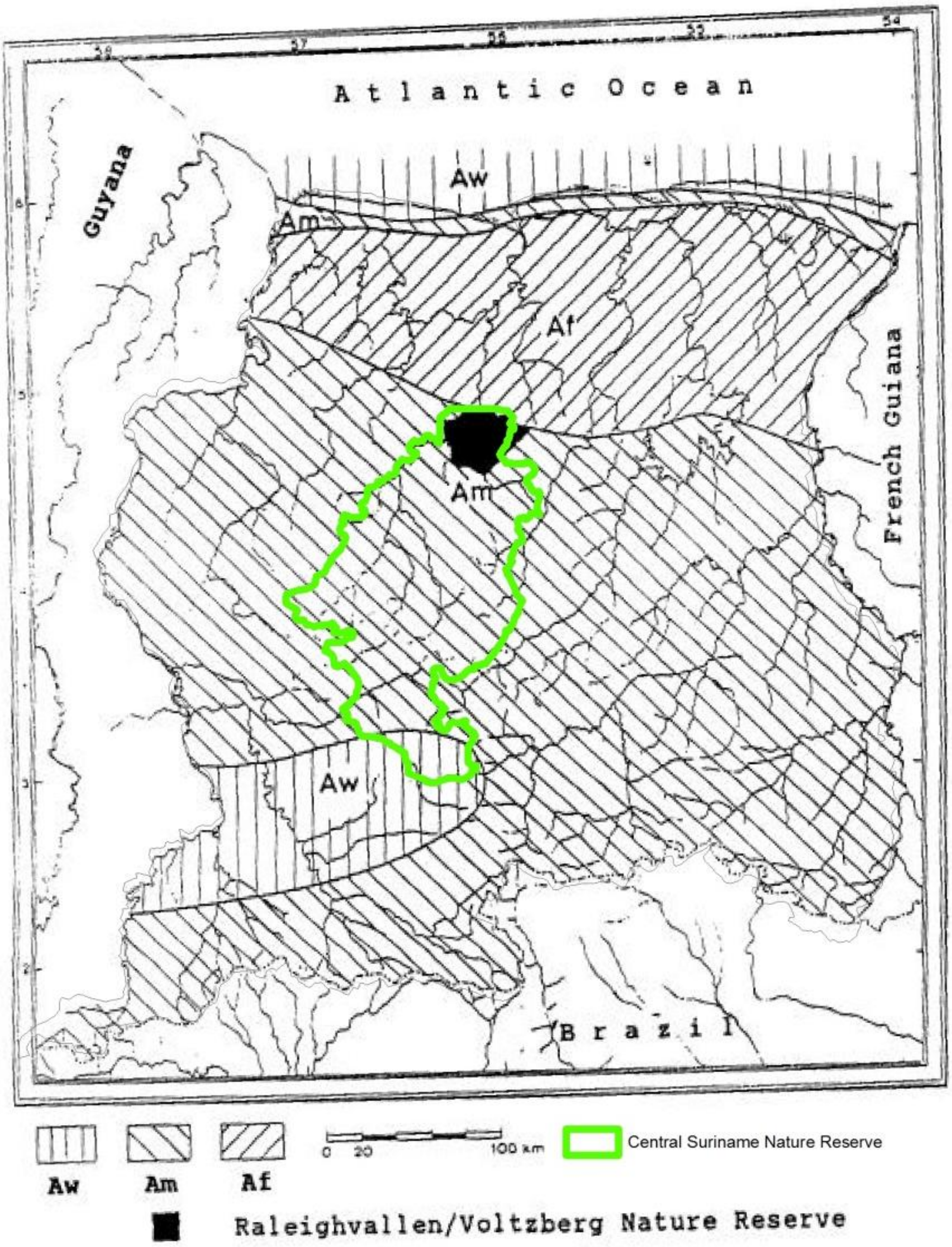
Appendices

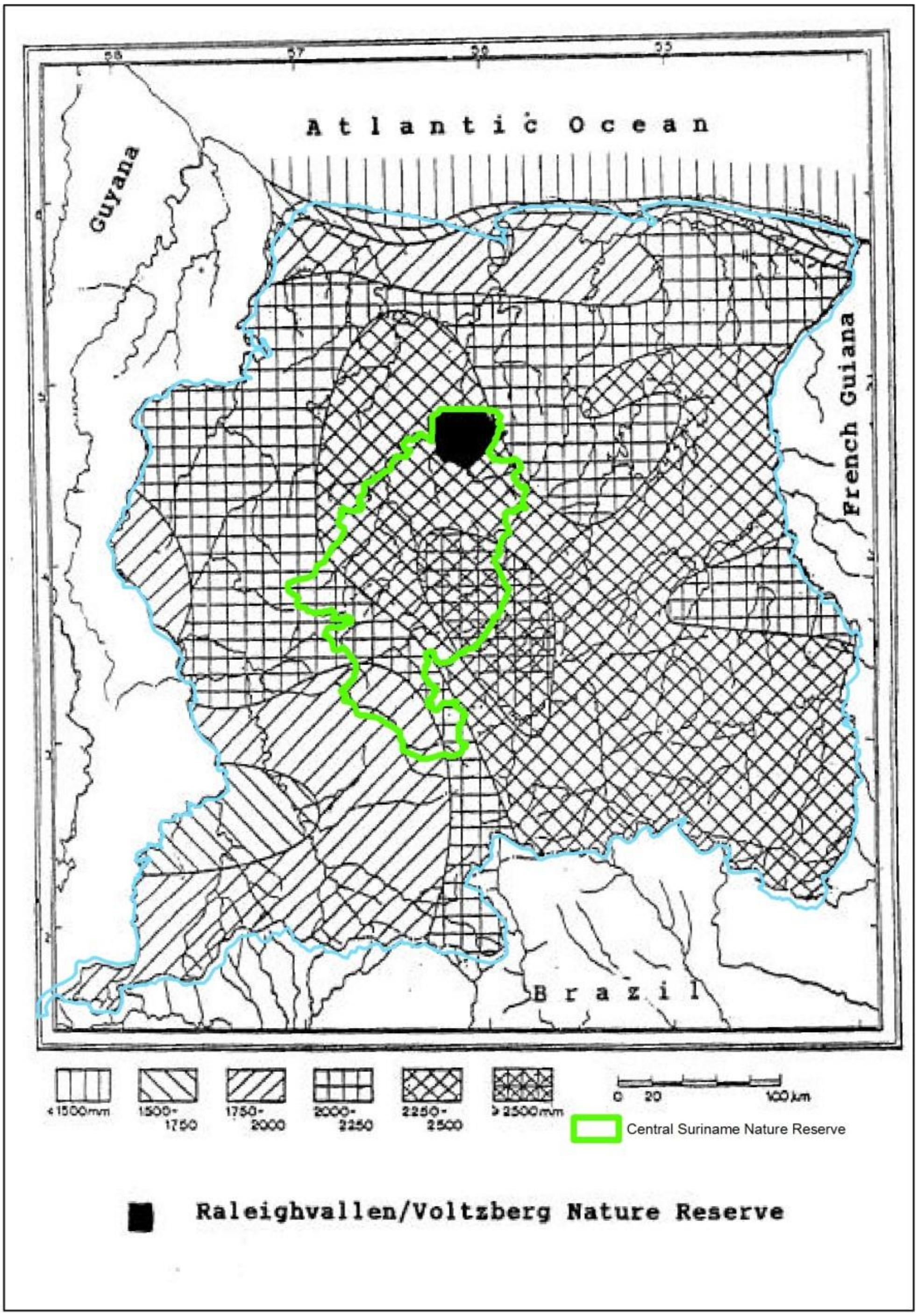
Appendix 1: Climate zones in Suriname

Figure showing the climate zones across Suriname. The study area, CSNR is highlighted (Reichart, 1993).



Appendix 2: Precipitation distribution Suriname

Figure showing the rainfall distribution across Suriname, with the highlighted study area, CSNR (Reichart, 1993).

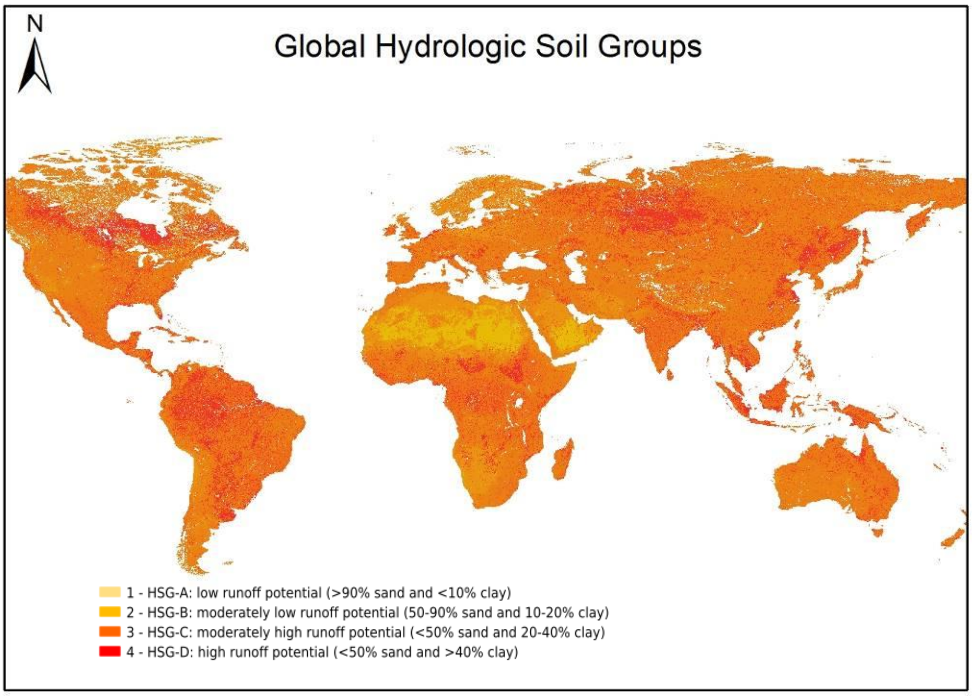


Appendix 3: Hydrologic soil groups

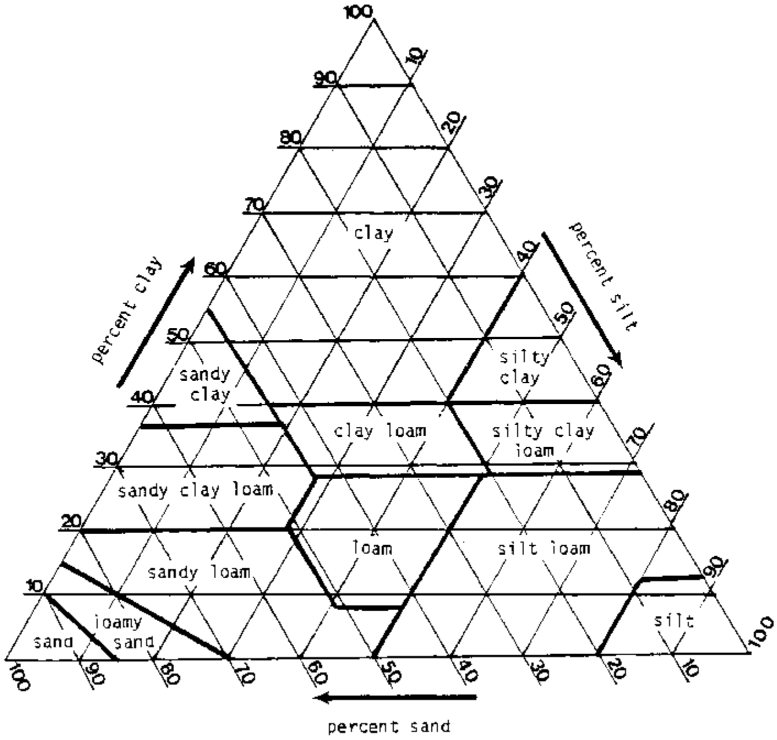
The four hydrologic soil groups are:

- Group A: water is transmitted freely in these types of soils. Meaning a high porosity and permeability in these soils. These types of soils have less than 10% of clay and more than 90% of sand and gravel. Water movement is not restricted in these types of soils.
- Group B: water can run through these soils unobstructed. With clay content between 10-20% and sand or gravel particles at a ratio of 50-90% of sand. In these soils we can also fine loamy sand or silty sands/clays.
- Group C: from here on water is a bit restricted to flow in the soil. These soil types have 20-40% of clay and less than 50% of sand. We get to see more clay, silt, clay loam types of textures.
- Group D: the last group of the hydrologic soil groups is the one which is least permeable. Flow of water here is restricted, because the soil consists of clay larger than 40% and less than 50% sands. The soil has a clayey texture. Clay tends to swell when water is in it, so it will close the pores, due to which water movement is restricted to very restricted in these types of soils.

(Mockus, 2004)



Soil type	Infiltration rate in mm per hour
Clay	1-5
Clay Loam	5-10
Silt Loam	10-20
Sandy Loam	20-30
Sand	Over 30



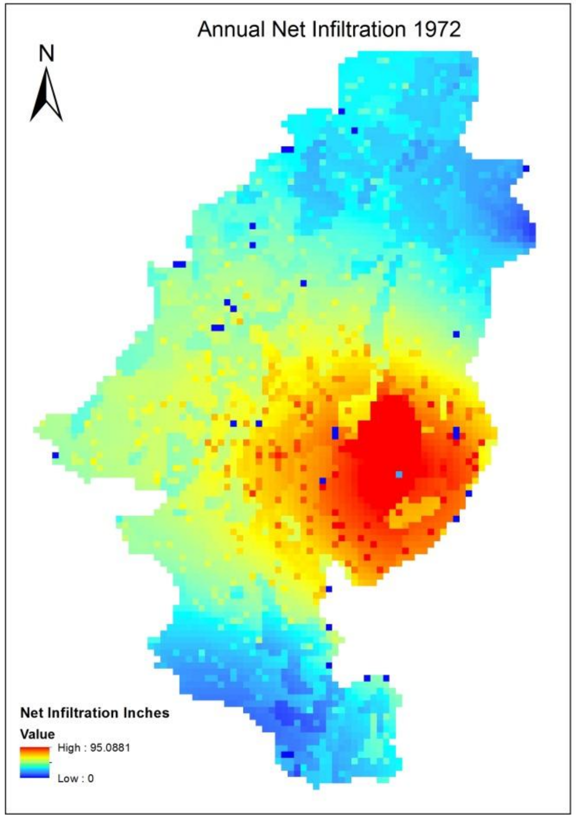
The soil texture triangle gives an overview of the various soil textures. The percentage silt, clay and sand define what type of soil we are dealing with. These textures are categorized in 3 groups. There are the sands, loamy sands and sandy loams, which have a coarse texture. Then we have the loams and silt loams which have a medium texture. And lastly we have the clay, clay loams, silty clay loams, which have a very fine texture compared with the others. Looking at the table beside we can see that the infiltration rate varies per soil type. The more clay the slower the infiltration (Volunteers, 1983).

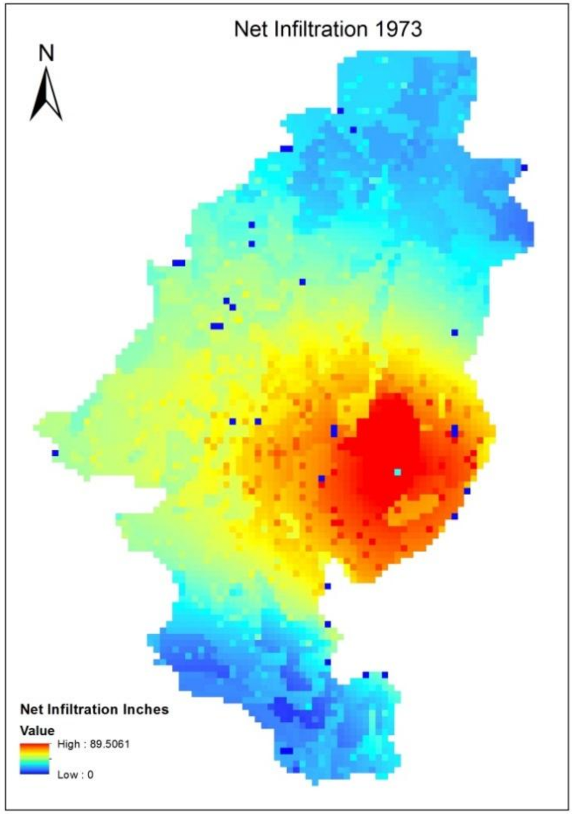
Appendix 4: USGS landuse classification

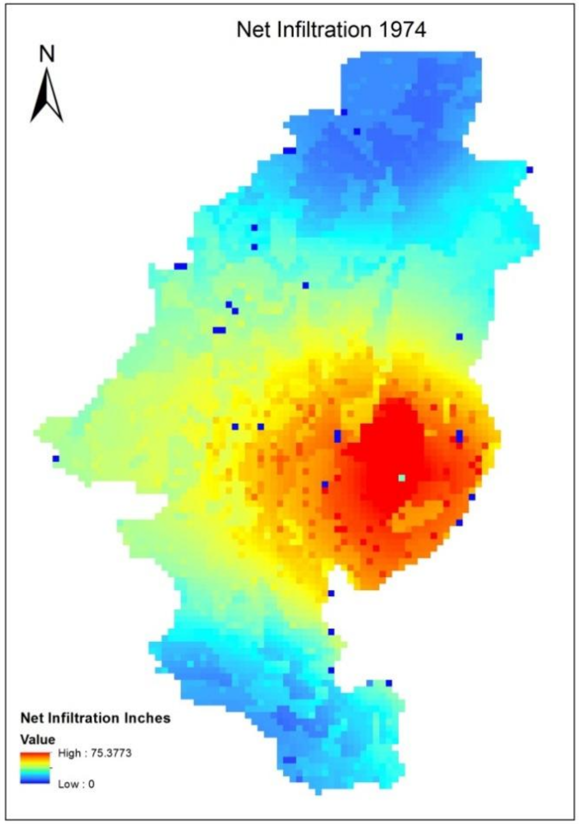
USGS land use and land cover classification system

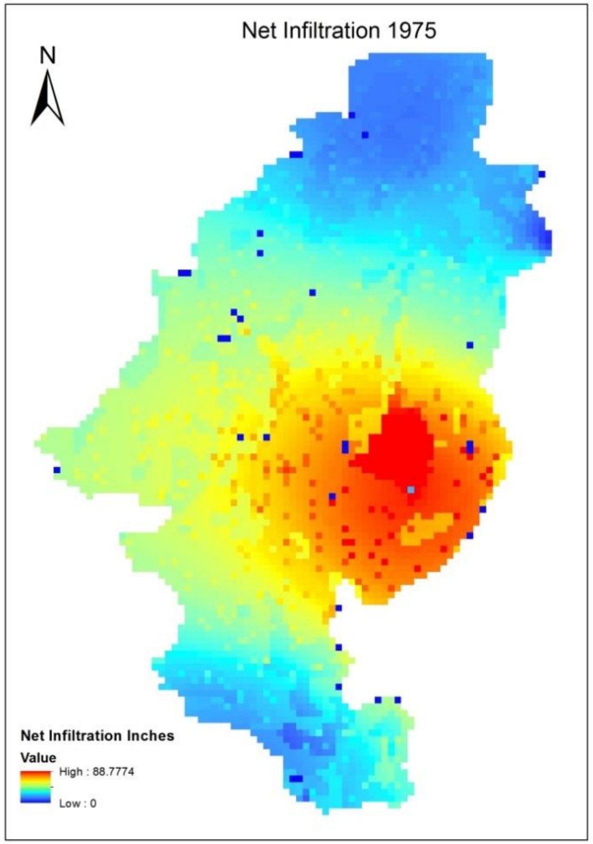
Level I	Level II
1 Urban or Built-up Land	11 Residential 12 Commercial and Services 13 Industrial 14 Transportation, Communications and Utilities 15 Industrial and Commercial Complexes 16 Mixed Urban or Built-up Land 17 Other Urban or Built-up Land
2 Agricultural Land	21 Cropland and Pasture 22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas 23 Confined Feeding Operations 24 Other Agricultural Land
3 Rangeland	31 Herbaceous Rangeland 32 Shrub and Brush Rangeland 33 Mixed Rangeland
4 Forest Land	41 Deciduous Forest Land 42 Evergreen Forest Land 43 Mixed Forest Land
5 Water	51 Streams and Canals 52 Lakes 53 Reservoirs 54 Bays and Estuaries
6 Wetland	61 Forested Wetland 62 Nonforested Wetland
7 Barren Land	71 Dry Salt Flats 72 Beaches 73 Sandy Areas Other than Beaches 74 Bare Exposed Rock 75 Strip Mines, Quarries, and Gravel Pits 76 Transitional Areas 77 Mixed Barren Land
8 Tundra	81 Shrub and Brush Tundra 82 Herbaceous Tundra 83 Bare Ground 84 Wet Tundra 85 Mixed Tundra
9 Perennial Snow or Ice	91 Perennial Snowfields 92 Glaciers

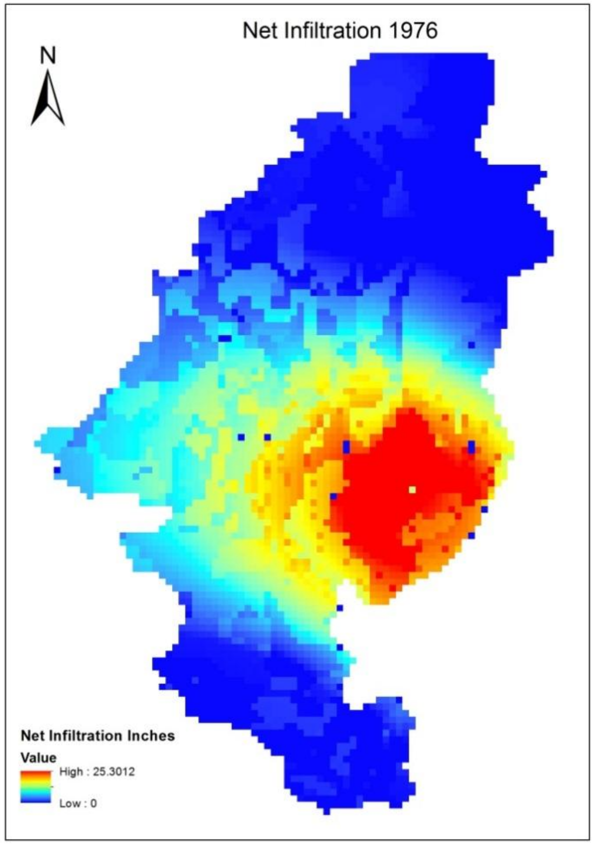
Appendix 5: Annual net infiltrations for the years 1972 until 1985

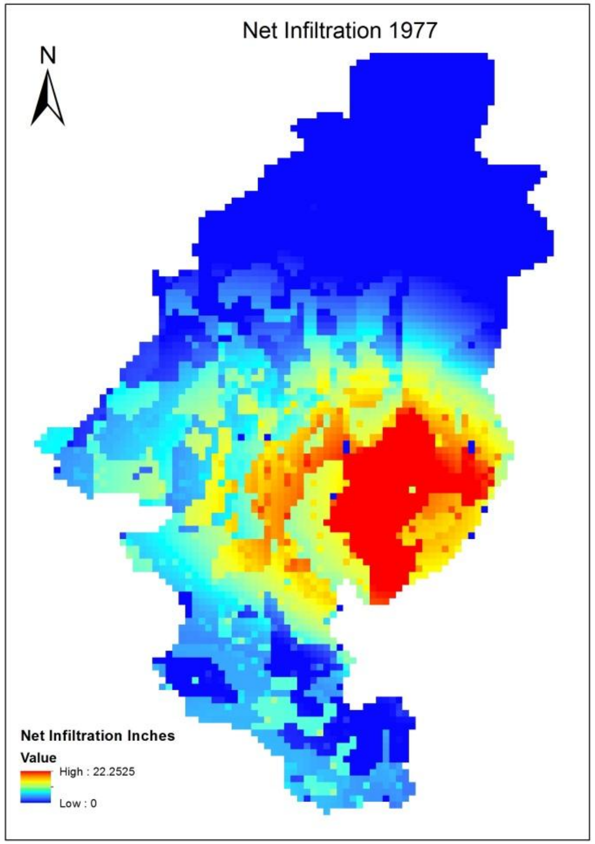


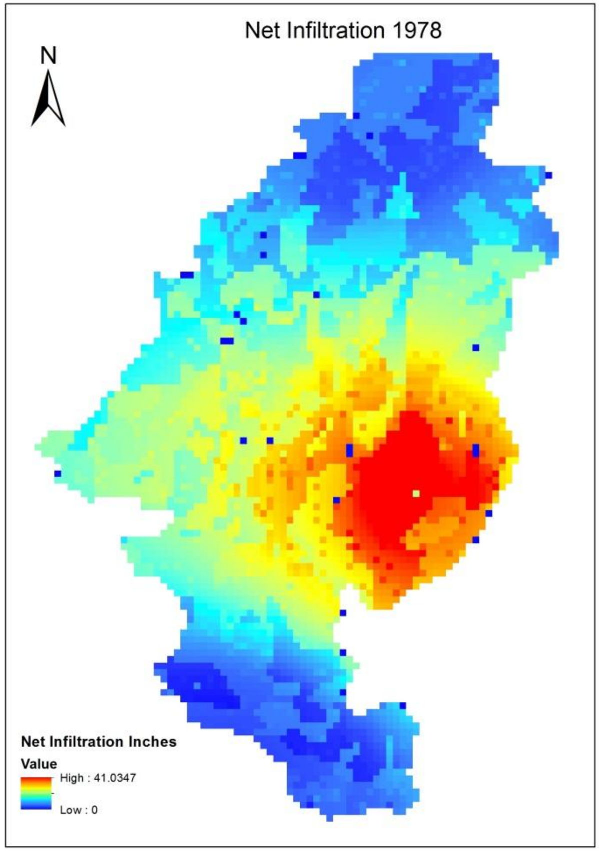


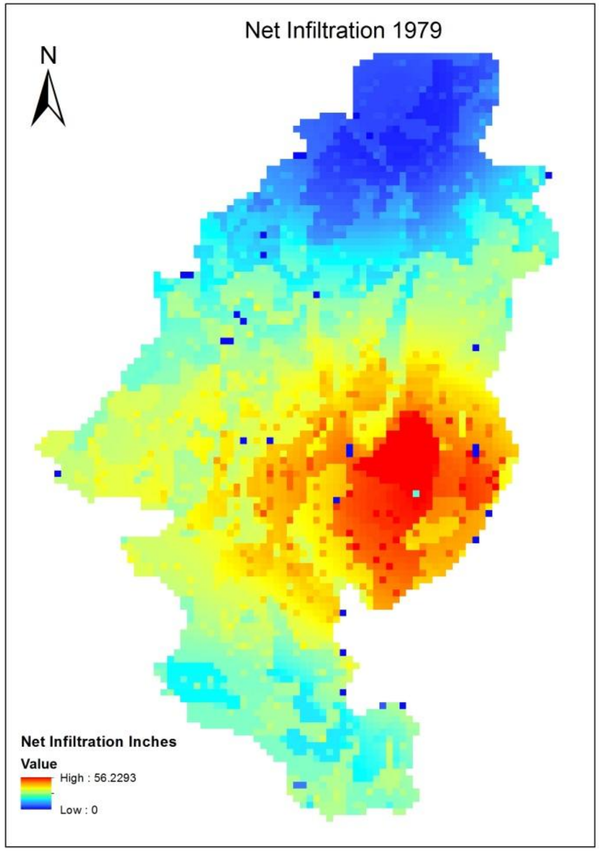


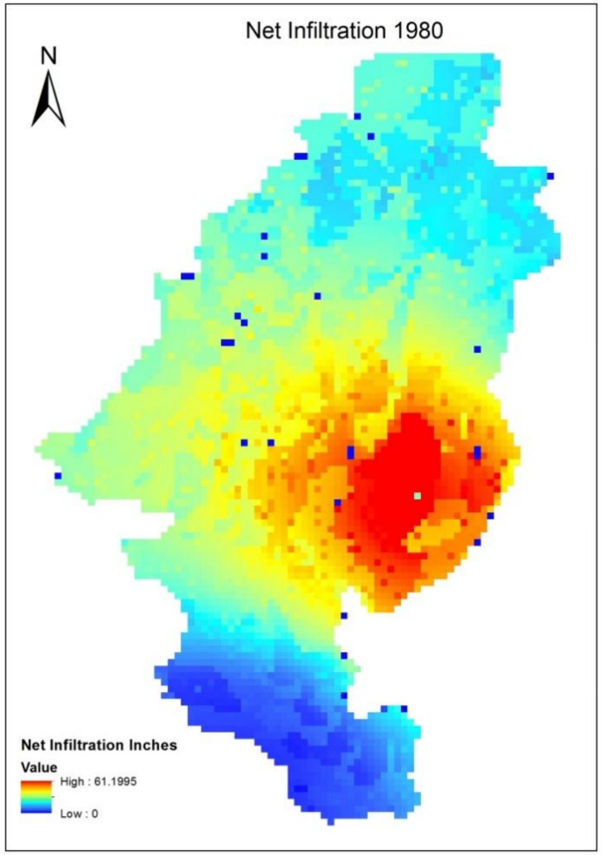

Net Infiltration 1975
N
Net Infiltration Inches
Value
High : 88.7774
Low : 0

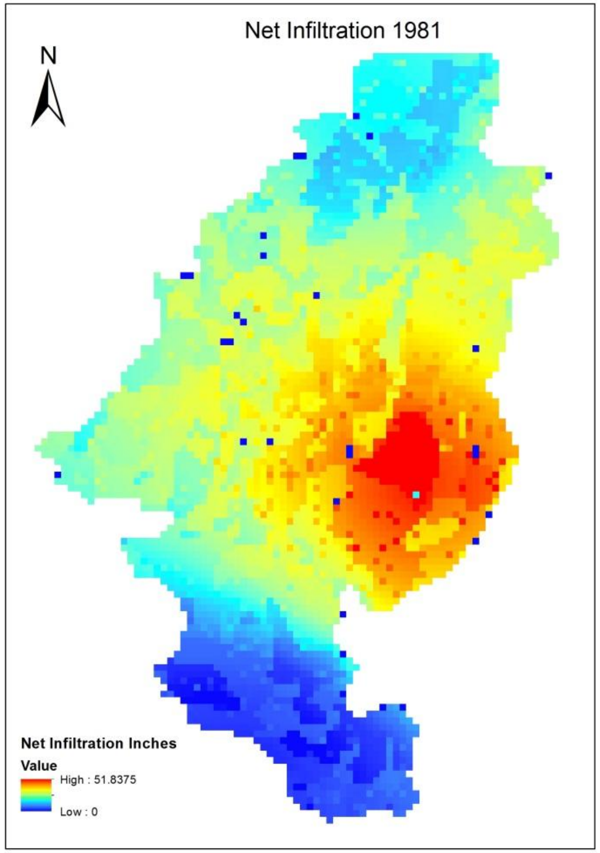

Net Infiltration 1976
N
Net Infiltration Inches
Value
High : 25.3012
Low : 0


Net Infiltration 1977
N
Net Infiltration Inches
Value
High : 22.2525
Low : 0

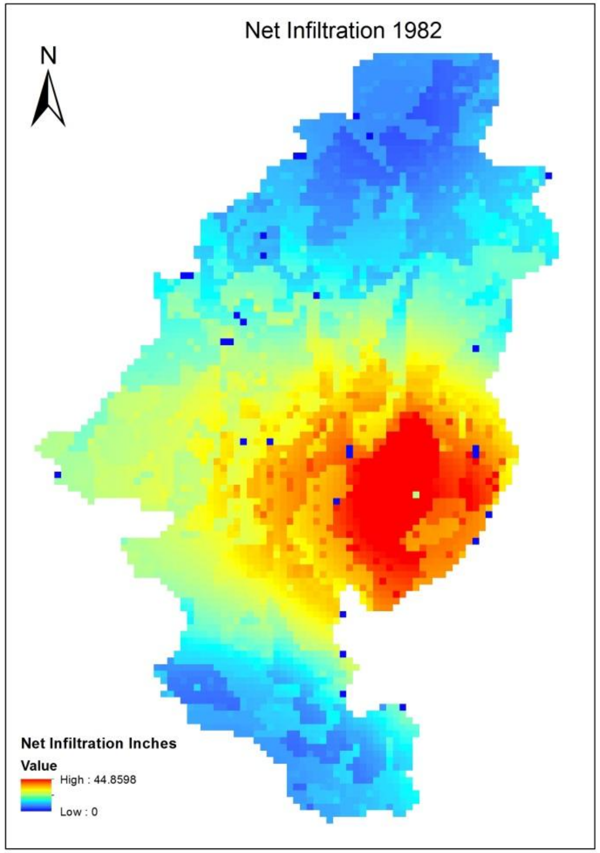

Net Infiltration 1978
N
Net Infiltration Inches
Value
High : 41.0347
Low : 0


Net Infiltration 1979
N
Net Infiltration Inches
Value
High : 56.2293
Low : 0

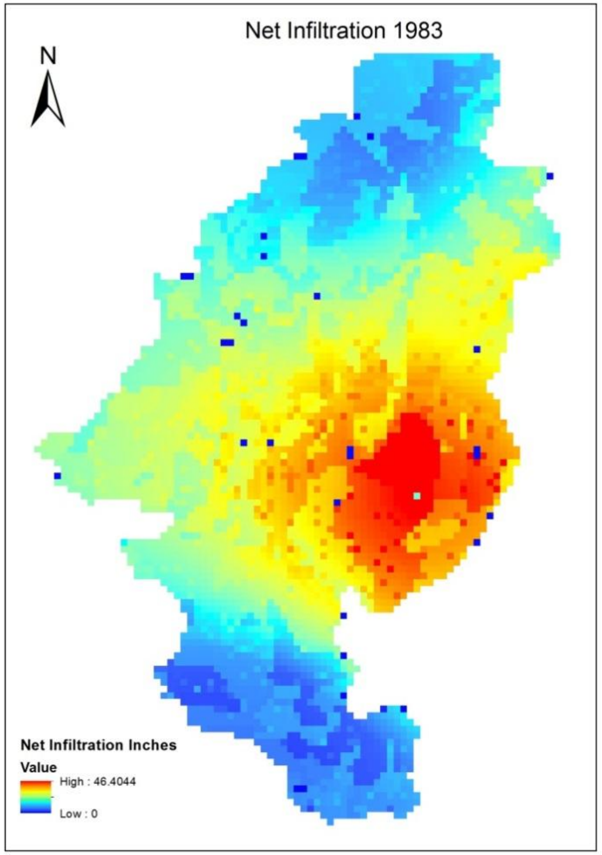

Net Infiltration 1980
N
Net Infiltration Inches
Value
High : 61.1995
Low : 0



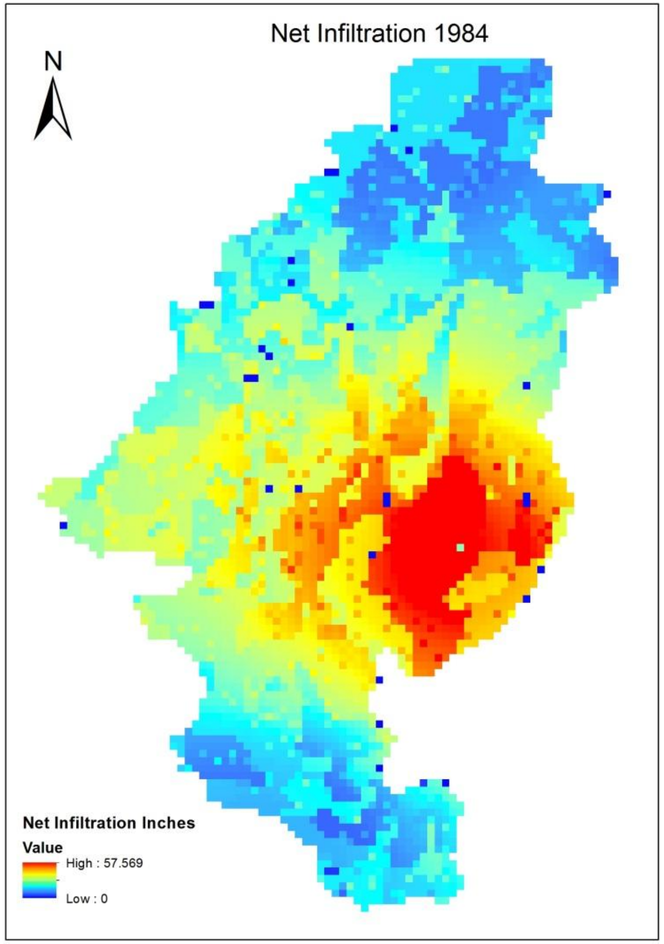
Net Infiltration 1981
N
Net Infiltration Inches
Value
High : 51.8375
Low : 0

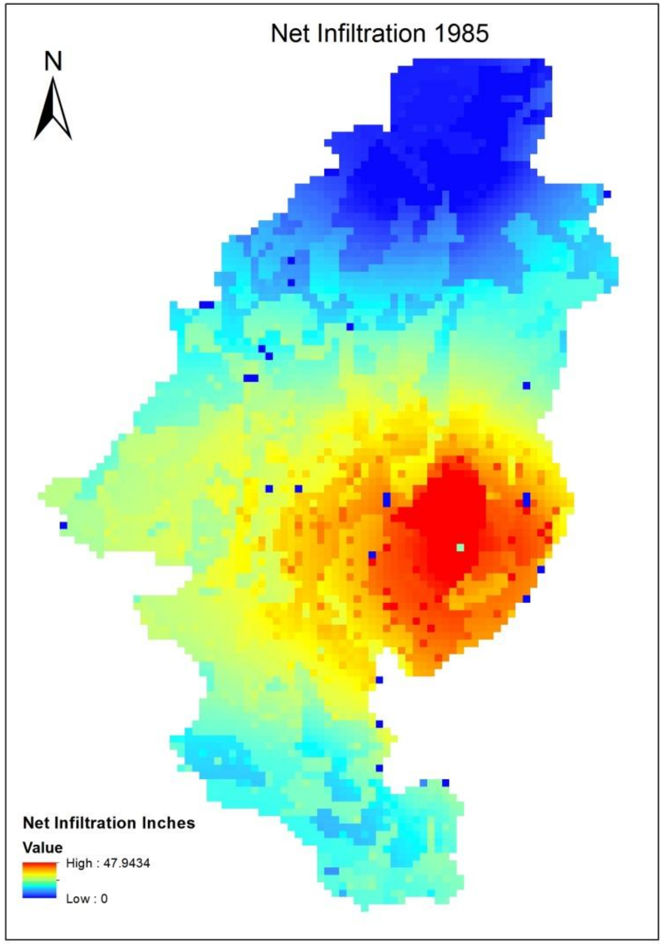


Net Infiltration 1982
N
Net Infiltration Inches
Value
High : 44.8598
Low : 0



Net Infiltration 1983
N
Net Infiltration Inches
Value
High : 46.4044
Low : 0


Net Infiltration 1984
N
Net Infiltration Inches
Value
High : 57.569
Low : 0


Net Infiltration 1985
N
Net Infiltration Inches
Value
High : 47.9434
Low : 0