Comparison of the Water Balance of two Forest Stands using the BROOK-90 Model

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Abstract. The objective of this project was to compare the water balance between two forest stands in two different areas regarding the influence of the future climate changes. The two areas are climatically differing; Hartheim forest locates in the southern of Germany with mean annual temperature is 10.3°C and annual precipitation of 627mm, the other site was Norunda forest that locates in the central of Sweden with mean annual air temperature is 5.5°C with annual precipitation of 527mm. The physically-based hydrological BROOK90 model was used in our study. The projected changes in some of the meteorological variables and stand management were determined in four different scenarios. The maximum annual value of the evapotranspiration for Hartheim site was recorded under the scenario of increasing maximum daily air temperature by 1°C with value of 516mm for the year 2007 and 489mm in 2005 for Norunda site for the scenario of increasing daily precipitation by 20%. For the soil water, the amount of water increased by 5% and 6% for Hartheim and Norunda forest respectively in compare to the scenario of control. The study concluded that adding 20% to the amount of forest’s precipitation has a tiny role in maintaining and regulating the water balance of the forest and decreasing the water deficiency that could occur due the projected increase in the future air temperature. The study also concludes that Norunda forest will be more sensitive to the long-term future projected increase in the air temperature than Hartheim forest.

Keywords: Evapotranspiration, Transpiration, BROOK-90 Model, Hydrological Cycle

1. Introduction

Forest ecosystems refer not only to an assembly of trees or providing renewable resources such as timber, food and medicine, they are extremely complex interactions between soil, trees, human being and the atmosphere and play a vital role in our life. Forests represent about 4.1 billion hectares globally which is about 30% of the worlds land area [1], considering the major reserve of carbon stock about 70% of the global terrestrial carbon, which is more than in the entire atmosphere [2].

Forests and hydrological cycle are strongly related to each other in which the forests are highly relying on the amount of the water existing in the soil. Some of the water that comes to the soil will evaporate directly to the atmosphere and some other goes as surface runoff. The remaining portion will be extracted by the plant roots and transported to other parts of the trees, and part of the water will transpire to the atmosphere through their leaves. The forests will be stressed if the proportion of the actual transpiration to the potential transpiration becomes less than one, meaning that there is limited amount of water present in the soil which is not enough for the forests to grow [3].

The hydrological cycle, generally begins with the radiant energy from the sun which heats up the ocean and evaporates water to the atmosphere. Under suitable and favorable conditions; the evaporated water will form clouds and produce precipitation [4]. Some of the precipitation will evaporate directly from water bodies, while a portion will infiltrate in the soil in which the near surface water will evaporate to the
atmosphere and the rest extracted by the plant roots and transported to the plant leaves then transpire to the atmosphere, the remaining water will drain downward and producing groundwater, see figure 1.1.

![Figure 1.1: The hydrological cycle (Zhang et al, 2002)](image)

1.1. Evapotranspiration

Evapotranspiration referred to the combination of two important processes that occurring together in the forest, evaporation where water evaporates from the soil surface and opened areas, and transpiration in which water lost from the plants through their leaves [5]. Many factors affecting the rate of evapotranspiration including weather factors such as air temperature, air humidity, wind speed, global incoming radiation and precipitation. While forest factors are ground cover, soil type and structure, forest roughness and characteristics of the tree roots.

The aim of this study is to analyze the effects of some of the projected changes in the future climate and their effects in water balance of the two forests in two different areas through focusing on analyzing the model output of the model and compared them with some of the measuring data including soil moisture and evapotranspiration.

2. Materials and methods

2.1. Site description

This section illustrates the description of the study area that was covered by our study.

Norunda forest locates in the central Sweden (60°08'N, 17°29'E, altitude 45 m) about 32km north of Uppsala in the southern part of the boreal zone. The forest consists mainly of coniferous trees of both Scots pine (66%) and Norway spruce (33%) and few birch trees [6]. The soil type is glacial till with moderate to high occurrence of large boulders and is covered by mosses and stands by dwarf shrubs [6 and 7]. The mean annual temperature of the area is about 5.5 °C; the annual precipitation is about 527 mm with leaf area index (LAI) varies between 4 and 5 [7].

The other site is Hartheim forest which locates in southern Germany (47°56'N, 7°36'E, altitude 201m) about 24km to the south-west of Freiburg in the southern part of the upper Rhine plain near the village Hartheim. The area is covered with even-aged Scots pine (Pinus sylvestris L.) [8]. Mean annual temperature is 10.3°C and mean annual precipitation of 642mm [10]. The soil of the forest is a carbonate-rich, the upper layer of the soil is sandy loam with depth about 0.4m. Loam soil means that it has a lot of nutrients and having no stones.

2.2. The model

BROOK90 model is a physically-based, parameter-rich, hydrologic model written and supported by Anthony C. Federer and designed primarily to study the processes of daily evapotranspiration, soil water movement at a certain point of a selected land area and for land use having different features with some stipulations of streamflow generation by different flow paths [9]. Below the ground, the model includes many soil layers ranging from 1 to 25, each with its own thickness and having different physical properties [9]. The Penman-Monteith equation is used to estimate the rate of evapotranspiration, which is expressed as:
Where: $R_n$ is the net radiation, $G$ is the soil heat flux, $\rho_a$ is the mean air density at constant pressure, $c_p$ is the specific heat of the air, $(e_s - e_a)$ represents the vapor pressure deficit of the air, $\Delta$ represents the slope of the saturation vapor pressure temperature relationship, $\gamma$ is the psychometric constant, and $r_s$ and $r_a$ are the (bulk) surface and aerodynamic resistances [10].

The model uses the Shuttleworth and Wallace (1985) method to separate transpiration and soil evaporation from sparse canopies which expressed as:

$$\lambda E = C_c PM_c + C_s PM_s$$

Where: $\lambda E$ is the Latent heat from complete crop (W m^{-2}), PM_c is the Penman-Monteith equation of the crop, PM_s is the Penman-Monteith equation of the substrate, $C_c$ is the extinction coefficient of the crop for net radiation (dimensionless), $C_s$ is the extinction coefficient of the substrate for net radiation (dimensionless) [11].

3. Results and Discussion

This part illustrates the scenarios addressed in the study and displays their results:

- **Control**: It is the investigation of the water balance and the growing conditions of the two forests under the current conditions. The aim of this scenario is to show how this system works with measured data for both forests and to compare them with the other scenarios.

- **Climate change**: The main purpose behind this scenario is to show how the forest will react with future climate change by increasing daily maximum air temperature by 1°C due to the projected increase in the temperature by from 1.8 to 4.0°C [12], here it means that we increased air temperature by 0.5°C, for the future, daily minimum air temperature should also be increased in order to increase 1°C. Precipitation increased by 20 % due to very likely increasing future precipitation in high latitude [12].

At Hartheim forest, the maximum value of the annual evapotranspiration (EVAP) was recorded in 2007 with the scenario of increasing daily maximum temperature by 1°C with value of 506mm compare to 487mm in control, figure 3.1. While the maximum value of EVAP at Norunda site was 489mm in 2005 with scenario of increasing precipitation by 20%, figure 3.2.

By looking to the both figures, it is obvious that there is a difference between the scenario of control and the other two scenarios in which the amount of evapotranspiration increased compared to the control, mainly because increasing air temperature will help the stand productivity to transpire more and the ground to evaporate more water to the atmosphere. The more water in the soil, the more water will evaporate by the plants under optimum conditions.

The amount of EVAP increased by 23mm as an average values for the entire investigation period at Hartheim forest which equals to 6% increase compared to control while at Norunda site, the amount increased by 22mm as a mean value for the years 2004 and 2005, which is equal to 5.5% increase in comparing to the scenario of original conditions. By comparison, they are almost equal, but there is an indication that this value could increase in the long-term increase of the daily air temperature.
Figure 3.1 Summation of the daily values of simulated model output evapotranspiration and EVAP of increasing daily maximum air temperature by 1°C and increasing daily precipitation by 20% at Hartheim forest for the period (2006-2007).

At both forests, small difference appeared between the scenario of control and the other two scenarios and especially at Hartheim forest regarding the amount of water in the soil, figures (3.3 and 3.4). The small difference and particularly in summer 2006 at Hartheim forest could be that only the maximum daily air temperature increased by 1°C which means 0.5°C in total and also because most of the days during summer period recorded with no rainfall; therefore, no changes occurred when 20% added to the daily precipitation.

There is a clear difference between 2006 and 2007 at Hartheim forest regarding the amount of water in the soil, figure (3.3). The difference is mainly due to the very low amount of precipitation during summer 2006 compared to summer 2007 accompanied by higher temperatures during the same period in 2006, see figure [A] in Appendix.

4. Conclusions
• The study concluded that increasing daily precipitation by 20% to the forest has a small influence in regulating the water balance of the forest and decreasing the water deficiency that could occur due to the projected increase in the future air temperature.

• The study also concludes that Norunda forest will be more sensitive to the long-term future projected increase in the air temperature than Hartheim forest.

5. References


Appendix

A:Total monthly evapotranspiration E for the scenario of control in comparing to mean monthly air temperature T and total monthly precipitation P at Hartheim forest for the period (June 2004 to Oct 2007)