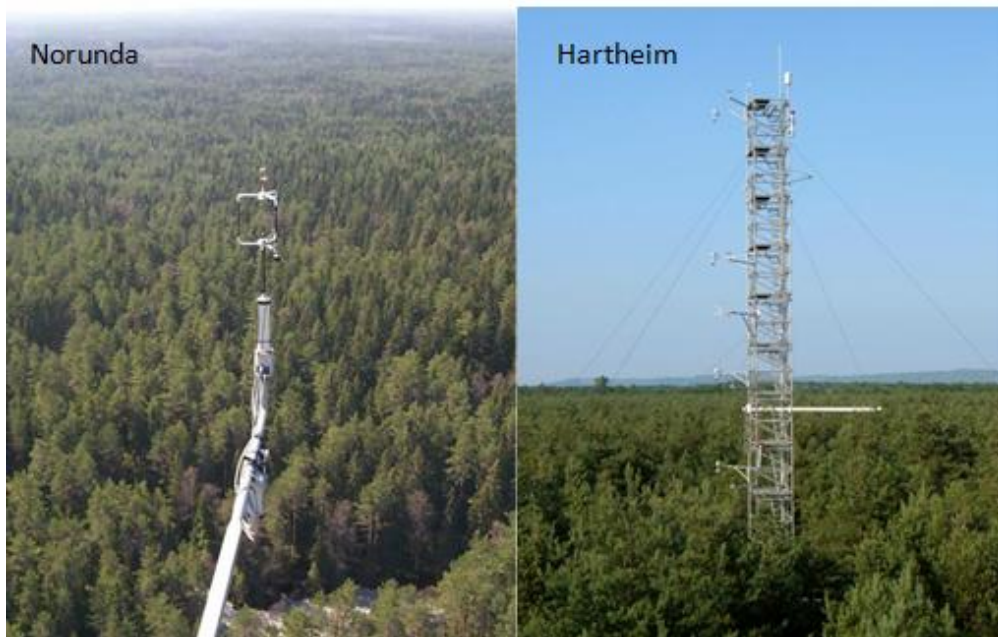# Comparison of the Water Balance of Two Forest Stands using the BROOK90 Model

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Comparison of the Water Balance of Two Forest Stands using the BROOK90 model

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Acknowledgments

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Abstract

Recent studies show that future climate change will have a major influence on the water balance of forests in which the projected increase in air temperature and variation in the precipitation around the world are expected to be among the most important drivers affecting the forest's hydrological cycle.

The objective of this study is to compare the water balance of two forests stands in two different areas. The two areas covered by this study are climatically differing. Hartheim forest locates in the southern Germany about 24km south-west of Freiburg in the southern part of the upper Rhine. Mean annual temperature is 10.3˚C with annual precipitation of 627mm and Leaf Area Index (LAI) of 1.5. The other site is Norunda forest that locates in the southern part of the boreal zone, in the central Sweden about 32km north of Uppsala. Mean annual air temperature is 5.5˚C with annual precipitation of 527mm and LAI 4 to 5. The physically-based, parameter rich hydrological BROOK90 model was used in our study to simulate the water balance through analyzing the outputs data and comparing them with some of the observed data that were measured directly from the forests.

The projected changes in some of the meteorological variables and stand management were determined in four different scenarios. The first scenario is control which simulated the current conditions of the area by using measured data. The second scenario simulated the changes in the stand management through increasing and decreasing the forest's Maximum Leaf Area Index "MAXLAI" by 30% and comparing to control. The third scenario represents the evaluation of the climate change by increasing maximum daily air temperature by 1˚C and total daily precipitation by 20% in two separate sub-scenarios and comparing them with scenario one. Increasing maximum daily air temperature by 1˚C together with increasing MAXLAI by 30% separately with increasing maximum daily air temperature by 1˚C together with decreasing MAXLAI by 30% were covered in the fourth scenario.

The overall results under different scenarios illustrates that both forests under the scenario of removing Leaf Area Index LAI by 30% shows an increase in the amount of water in the soil by 8.8% and 13% for Hartheim and Norunda forest respectively as an average value for the whole studying period. The maximum value of the annual evapotranspiration for the both forests is recorded under the scenario of increasing maximum daily air temperature by 1˚C together with increasing MAXLAI by 30% with value of 571mm for the year 2007 and 501mm in 2005 for Hartheim site and Norunda site respectively.

The study concludes that thinning of the forest has a great 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 mainly through decreasing the competition for water. Norunda forest will be more sensitive to the long-term future projected increase in the air temperature than Hartheim forest.

Contents

List of Acronyms

ALB   Albedo or surface reflectivity without snow

ALBSN   Albedo or surface reflectivity with snow

ASPECT   Degrees through east from north

BYFL   Bypass flow rate from all layers for iteration

CR   Extinction coefficient for photosynthetically-active radiation in the canopy

DSFL   Downslope flow rate from all layers for iteration

DURATN   Average duration of daily precipitation by month

ESLOPE   Slope of the area

EVAP   Evapotranspiration

FLOW   Simulated streamflow

FXYLEM   Fraction of plant resistance that is in the xylem

GLMAX   Maximum leaf conductance

GWFL   Rate from groundwater flow to streamflow

IDEPTH   Depth over which infiltration is distributed

INFEXP   Infiltration exponent

INFL   Infiltration rate into layer

KSNVP   Multiplier to reduce snow evaporation

LAI   Leaf Area Index

LAT   Latitude of the site

LWIDTH   Average leaf width

MAXHT   Maximum canopy height for the year

MAXLAI   Maximum projected leaf area index

MELFAC   Degree day melt factor for open land

MXRTLN   Maximum length of fine roots per unit ground area

NLAYER   Number of soil layers to be used in the study area

RFAL   Rainfall rate

RELHT   Relative height

RELLAI   Relative leaf area index

RINT   Rainfall catch rate

RNET   Rain reaching soil surface

ROOTDEN   Relative root density

PREC   Precipitation

RSNO   Rain added to snowpack

RSTEMP   Base temperature for snow-rain transition

RTHR   Rain throughfall rate

SFAL   Snowfall rate

SINT   Snowfall catch rate

SNOW   Snow water

SLFL   Input rate to soil surface

SMLT   Melt drainage rate from snowpack

SRFL   Source area flow rate

STHR   Snow throughfall rate

SWAT   Soil water for all layers

THICK   Vertical thicknesses of each soil layer

VRFL   Vertical matrix drainage rate from layer

Z0G   Ground surface roughness

1. Introduction

1.1. Background

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, for example: timber as a source of economically products, and also through providing oxygen, cold air temperature in warm days, healthy environment, clean air, beautiful nature and biodiversity of the area. Forests represent about 4.1 billion hectares globally which is about 30% of the worlds land area (FAO, 2005) considering the major reserve of carbon stock which is about 70% of the global terrestrial carbon which is more than in the entire atmosphere (Lai, 2005).

Forests and climate change are strongly linked in which forests have a vital role for the global carbon and climate change. Deforestation has a great role in the climate changes. Many studies show that when all forests around the world are cleared, this will lead to release about 5.9 $GtCO_2$ annually to the atmosphere which is about 17% of all anthropogenic GHG emissions (IPCC, 2007).

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 the parts of the trees, and 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 the water present in the soil which is not enough for the forests to grow (Wellpott et al, 2005).

In our study, we focused on two forests in two different areas that are climatically differing from each other due to the long distance between them. One forest was located in southern west of Germany placed in temperate forest; named Hartheim forest, while the other one was located in sub-boreal forest zone in the middle of Sweden; called Norunda forest. Nevertheless, they are in two kinds of forests as mentioned below:

I. **Temperate Forests**

   They are usually occurred in places characterized by cold winter and dry summer with high annual rainfall. The distribution of temperate forests is wider than boreal forests; they are present in both hemispheres, i.e. north of America, northern Asia and western and central Europe, Argentina, Japan, New Zealand and Australia, with widely distributing in northern hemisphere (FAO, 1999).

   Temperate forest is distinguished by hardwoods, which has trees that lose their leaves Fall (FAO, 1999). As in boreal forest, coniferous trees are widely distributed in temperate forest (Waring, 2002). The trees in this forest are usually used for economical purposes by human activates through forest management. In our study we focused on a temperate forest in the central Europe.

II.   Boreal Forests

They usually refer to a green belt of coniferous forest and is dominated by relatively few tree species, such as spruce, larch, and pine having similar size with a slow rate of production. Boreal forests are frequently present in the northern hemisphere, covering Alaska, USA, Northern Canada, Russia and most of Scandinavia (FAO, 1999) and occupying about 14 per cent of the Earth's vegetation surface (Olsson, 2009).

The presence of coniferous trees in such area is mainly due to their adaptation to the harsh climate with long cold winter and short warm summer and to grow with the slim acidic soil (CFA, 2005). They are recognized by their needle leaves which have a vast role in reducing the loss of water through their narrow surface area.

The two kinds of forests will be subject to the projected future climatic changes in temperature and precipitation and non-climatic change mainly from human activities through altering the distribution, structure and composition of the species.   In Boreal forests, the expected increase in the mean annual air temperature (IPCC, 2007) will highly affect the forests through changing the regional weather conditions as a short term and shifting them northward searching for cold conditions to survive as a long term. The non-climatic impacts have also an essential role in changing forests mainly through land use change by human activities mostly for obtaining food, economical purposes and some other life requirements (Galicia and Leticia, 2010).

1.1.1   Hydrological cycle

It is the movement of water through the hydrological cycle, from land and ocean to the atmosphere and back to the ground from clouds through precipitation in different kinds, Figure 1.1. The hydrological cycle generally begins with the radiant energy from the sun which heats up the Earth surface and evaporates water to the atmosphere, under suitable and favorable conditions; the evaporated water will form clouds and produce precipitation (Zhang et al, 2002). 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. The availability of water in a forest is mainly depends on the abundance and time distribution of the rainfall, forest structure, species of trees and some other meteorological factors. When the rate of precipitation exceed the infiltration rate, overload water builds and produce surface runoff, while the ground water will be produced as long as the potential rate of infiltration exceed the rate of precipitation. The topography, soil type and soil structure and the specific geological features of the area are also affecting the availability of water. Hence, precipitation and the evapotranspiration considering the main control on water balance (Budyko, 1958).
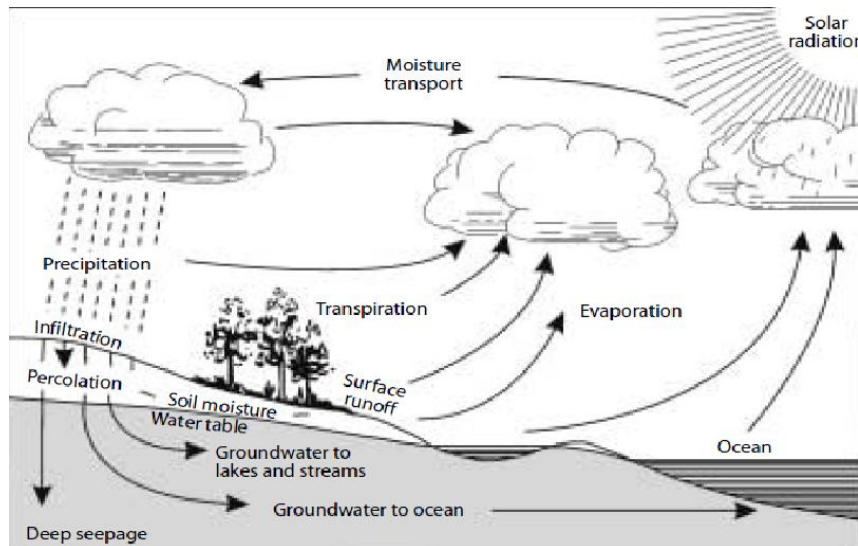
Figure 1.1: The hydrological cycle (Zhang et al, 2002)

1.1.2 Soil moisture

Commonly, it refers to the amount of water held in the soil in any particular area. The amount of the water present in the soil varies from place to place; but usually it depends on the amount of precipitation, type of soil, roots of plants, soil texture, surface runoff, drainage and infiltration and soil evaporation.

Soil is to be at field capacity when maximum amount of water stored in all the soil pores usually after 2 days from raining or wetting the soil by relying on the amount of rainfall, soil type, soil capacity and time of year. The soil will be in wilting point when most of the water lost either by evaporation, transpiration, drainage, and surface runoff. The actual amount of water available for the plant is the amount of water present at field capacity minus the amount at wilting point (FAO, 2003).

The amount of the water available in the soil has a great role in the distribution and growth of plant, soil aeration, the presence and absence of toxic materials in the soil, and uptakes of water from the roots of the plants depending on it is place and the time of the year (Oki and Kana, 2006).

1.1.3 Evapotranspiration

Evapotranspiration refers to the combination of two important processes that occurring together in the forest which is evaporation and transpiration. Many factors affecting the rate of evapotranspiration, weather factors include air temperature, air humidity, wind speed, global incoming radiation and precipitation. While forest factors are ground cover, soil type and soil structure, forest roughness and characteristics of the tree roots. Evapotranspiration includes two important processes:

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I. **Evaporation:** It is one of the fundamental processes occurring on the Earth and has a great role in the Earth's surface energy, regional weather and the water balance. Evaporation is a process where the liquid water from water masses and opened areas convert to it is vapour form and then transferred to the surrounding atmosphere. The rate of evaporation will be maximized if there is high rate of water availability, low air humidity, hot climate, windy and bare surface exposed to sunlight (Stormont and Coonrod, 2004).

II. **Transpiration:** It is a process in which the water in the soil is taken to the plant through the roots and going up to the plant by the aid of xylem and evaporates out of the leaves through stomata; the small openings in the leaf surface surrounded the mesophyll cell (Stroosnijder, 1987). Transpiration uses about 90% of the water that enter the plant, while the rest is used in the process of photosynthesis and plant growth. The regulation of the plant transpiration is mainly depending on the stomata conductance which is the speed at which water evaporates from the pores presents in the plant leaves which is affected by many factor such as size of the pores, sun light, soil moisture, root structure, presence and absence of nutrient in the soil, air temperature, humidity, wind speed and the internal concentration of CO_2 (McDowell et al, 2008).

1.1.4 Solar energy

Solar energy is the energy that derived from the sun's radiation and is fundamental for life in which simply there will be no life without the daily incoming radiation from the sun. It considers the most important drivers affecting the rate of evapotranspiration, water balance of the forest and hydrological modeling studies. The amount of the solar radiation reaches the Earth's surface differs depending on the location and time of the year (FAO, 1998 and Ferenc et al, 2002) and not all the radiation that comes out from the sun can reach the Earth's surface and vaporize the water, for instance, some of the radiation can be absorbed or reflected by clouds and some other aerosols present in the atmosphere.

1.1.5 Transpiration index

According to Hammel and Kennel (2001) it is the ratio of actual transpiration to potential transpiration (T_{act}/T_{pot}) which is an ecophysiologically based indicator for drought occurrence. Potential transpiration is a measure of the ability of the plants to remove water under optimum conditions when there is no water stress, while the actual transpiration is the quantity of water that actually removed from the plant. The forest will be optimally supplied with water if the rate of T_{act}/T_{pot} equal to one, but when the rate is lower than one, there is water deficiency (Wellpott et al, 2005). When the daily value of T_{act}/T_{pot} is below 0.95 for 25% of a year, the site can be considered as frequent dry (Hammel and Kennel, 2001).

1.1.6 Climate change

It is a global issue that has a severe effect on all living organisms on the Earth's surface. Climate change refers to the change in the composition of the atmosphere that can alter the global weather on the long-term. Change in e.g. CO_2 concentration does change the radiation and consequently the air temperature and precipitation over time. This change in concentration is considered to be human induced. Polices should be done to defeat anthropogenic emission, otherwise the global average temperature will rise by further 1.8 to 4.0 C by 2100 (IPCC, 2007).

Forests are very important to address in the climate change and global warming, because of the strong interaction between the climate change and forest ecosystem through the absorption of high amount of carbon in their leaves and. Deforestation is one of the most important factors that linked to the future climate change and usually occurred from several human activities by cutting trees and changing to agriculture (Gorte and Sheikh, 2010) dams-building projects and to land area through human population growth (FAO, 2006). High quantities of carbon and other greenhouse gases will emit from the soil and woods of the plants to the atmosphere because of deforestation, burning of forests, harvesting (IPCC, 2007) and through loss of photosynthesis process (Apps et al, 2006).

Besides affecting on the climate change, deforestation has a vast role on the water balance and hydrological function of the area as well, since large amount of water circulated in the forest ecosystem. Therefore, when trees cut down, the area will lose this circulation and become drier (ACIA, 2004).

1.2. Aim of the study

The aim of this study is to analyze the effects of some of the projected changes in the future climate and their effects in the water balance of the two forests used in the study that occurred in two different areas through focusing on analyzing the model output of the model and compared them with some of the measurement data, for instance, soil moisture, evapotranspiration and plant transpiration. One forest is located in the temperate area which is Hartheim forest, and the other one is located in sub-boreal area called Norunda forest. To do this, a physically based hydrological BROOK90 model has been applied by using a standard equation for evapotranspiration.

1.3. Hypothesis

How do forests react to some aspects of climate change in relation to their water balance? Basically, this is due to many reasons that link forests with the future climate and how they will affect on the water balance of that area. In this thesis, we will try to concentrate on some of the hypothesis that described below and analyze them to find out how the forests will be affected by the future climate change from the expected increase in air temperature, precipitation and some other patterns and how they will affect the water balance of these forests and to try making a comparison between the two forests.

I. Currently, Hartheim forest supposes to have higher transpiration than Norunda forest due to higher temperature in mid Europe than boreal forest.

II. Higher evapotranspiration in Norunda forest in the future than Hartheim forest due to the expected increase of temperature in the future of about 1.4 to 4.8 C by 2100 (**IPCC, 2007**).

III. Higher soil water content in Norunda forest than Hartheim forest due to the increase in the average annual precipitation overall north Europe and decrease in mid-Europe (**IPCC, 2007**).

IV. Hartheim forest will be more stressed in the future than Norunda forest.

To do the experiment, some tests have been done with the simulation of the model by changing some of the input parameters in order to get results comparable with the original model output results. The simulations include:

A. Increasing Leaf Area Index (LAI) by 30%, from 1.5 to 1.95 for Hartheim forest and from 4.0 to 5.2 for Norunda forest.

B. Decreasing Leaf Area Index (LAI) by 30%, LAI from 1.5 of Hartheim Forest to 1.05 and from 4.0 to 2.8 for Norunda forest.

C. Increasing maximum daily air temperature by 1˚C.

D. Increasing total daily precipitation by 20%.

E. Increasing maximum daily air temperature by 1 ˚C combined with increasing LAI 30%.

F. Increasing maximum daily air temperature by 1 ˚C combined with decreasing LAI 30%.

1.4. Disposition

This thesis consists of four chapters. Introduction, aim of the study and hypothesis explained in chapter one where the materials and the methods and model description are illustrated in chapter two. Chapter three presents different scenarios applied to the study and display their results. Discussion and the comparison between the two forests regarding different scenarios are addressed in chapter four.

2. Materials and methods

At both sites, hydro-meteorological variables were available for different periods. For Hartheim forest, the data were taken from Jun-04 to Oct-07, while for Norunda forest; they were taken from Jan-03 to Dec-05.

2.1. BROOK90 model

2.1.1. General description

BROOK90 is a deterministic, 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 (Federer, 1995, Federer et al, 2003). Below the ground, the model includes many soil layers ranging from 1 to 25, each with its own thickness and having different physical properties. The vertical flow through these layers is obtained iteratively. The program can also be used for modeling water balance at forest sites and water movement for a small point of area and to simulate the daily evaporation, as well as to model floods and surface flow (Federer, 1995, Federer et al, 2003 and Wellpott et al, 2005) and to assess the influence of vegetation on some hydrological patterns (Bencokova et al, 2010). The Penman-Monteith equation is used to estimate the rate of evapotranspiration, which is expressed as:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a c_p \frac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)}$$

Where:

> R_n is the net radiation [MJ m^{-2} day^{-1}], G is the soil heat flux [MJ m^{-2} day^{-1}], ρ_a is the mean air density at constant pressure, c_p is the specific heat of the air [MJ kg^{-1} °C^{-1}], (e_s - e_a) represents the saturation vapour pressure deficit of the air [kPa], Δ represents the slope of the saturation vapour pressure temperature relationship, γ is the psychometric constant [kPa °C^{-1}], and r_s and r_a are the (bulk) surface [s m^{-1}] and aerodynamic resistances [s m^{-1}] (FAO, 1998).

The model uses the Shuttleworth and Wallace (1985) method to separate transpiration and soil evaporation from sparse canopies, and for evaporation of interception the potential transpiration rate is used where the leaf conductance is set to maximum. The Shuttleworth and Wallace equation is expressed as:

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

Where *PMc* and *PMs* are similar to the Penman-Monteith equation which apply to evaporation from a closed canopy and from bare substrate respectively (Shuttleworth and Wallace, 1985). They can be explaining as:

$$PM_c = \frac{\Delta A + \{\rho c_p D - \Delta r_a^c A_s\}/(r_a^a + r_a^c)}{\Delta + \gamma\{1 + r_s^c/(r_a^a + r_a^c)\}}$$

$$PM_s = \frac{\Delta A + \{\rho c_p D - \Delta r_a^s (A - A_s)\}/(r_a^a + r_a^s)}{\Delta + \gamma\{1 + r_s^s/(r_a^a + r_a^s)\}}$$

The coefficients C_c and C_s are given by the expressions

$$C_c = \{1 + R_c R_a/R_s(R_c + R_a)\}^{-1}$$

and

$$C_s = \{1 + R_s R_a/R_c(R_s + R_a)\}^{-1}$$

where

$$R_a = (\Delta + \gamma)r_a^a$$
$$R_s = (\Delta + \gamma)r_a^s + \gamma r_s^s$$
$$R_c = (\Delta + \gamma)r_a^c + \gamma r_s^c.$$

Where:

λE 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 sub canopy vegetation and soil for net radiation (dimensionless), $\triangle$ is the mean rate of change of saturated vapor pressure with temperature, A is the total available energy (W m^{-2}), p is the density of air (kg m^{-3}), c_p is the specific heat at constant pressure (J kg^{-1} K^{-1}), D is the vapor pressure at reference height, is the bulk boundary layer resistance r_a^c of the vegetative element in the canopy, A$_s$ is the total energy flux leaving the complete substrate as sensible latent heat per unit ground area (W m^{-2}), is the aerodynamic resistance between canopy source height and reference level (s m^{-1}), r_s^c is the bulk stomatal resistance of the canopy (s m^{-1}), r_a^s is aerodynamic resistance between the substrate and the canopy source height (s m^{-1}), r_s^s is the surface resistance of the substrate (s m^{-1}), γ is the psychometric constant (mb K^{-1}) (Shuttleworth and Wallace, 1985).

2.1.2. Model parameters

In order to run BROOK90, the program requires six separate parameter files namely, location, flow, canopy, soil, fixed and initial, and the main focus of the calibration and the parameter fitting of the program is focused in only the first four of them, while the other two files are almost fixed parameters. Each of the mentioned files include many values inside them, but some of them are not important to describe either they have a fixed values or they don't have so much effect if their values been changed, so we will try to describe some of the most important parameters which have a great role in the running of the BROOK90 program. All the parameter descriptions have been taken from the official website or the manual of the model, therefore they do not have citation and also they could have some difficulty to follow them.

I.   **Location parameters**: These parameters are site specific, describing information about the study area, LAT is the latitude of the site, degree slope of the area ESLOPE and degrees through east from north ASPECT should be applied by the user, while both base temperature for snow-rain transition (RSTEMP) and degree day melt factor for open land (MELFAC) can be set to -100 and 1.5 respectively. Relative height (RELHT) is relative leaf area index RELLAI is an array of ten pairs of day of the year (DOY) and relative LAI between 0 and 1. (DURATN) refers to the average duration of daily precipitation by month.

II. **Flow parameters:** These parameters are related to the infiltration and drainage. To start with classic top-down infiltration of all water, both infiltration exponent (INFEXP) and depth over which infiltration is distributed (IDEPTH) should set to 0, in which IDEPTH determines the number of soil layers over which infiltration is distributed, while INFEXP controls the distribution of infiltrated water with depth.

III. **Canopy parameters:** These parameters are referring to the canopy and the forest stand and its characteristics important for the rate of transpiration. Albedo or surface reflectivity without snow (ALB) and albedo or surface reflectivity with snow (ALBSN) could be locally known. Relative root density (ROOTDEN) is also an important parameter, together with fraction of plant resistance that is in the xylem (FXYLEM); this program controls the relative transpiration from each soil layer. MAXHT is the maximum canopy height of the forest while MAXLAI refers to the maximum projected leaf area index of the forest which differs from site to site depending on the density of the forest.

IV. **Soil parameters:** These parameters are referring to the soil profile and its soil water properties in which BROOK90 depends almost mainly to number of layers of the study area. NLAYER is soil parameters refers to the number of soil layers to be used while THICK is the vertical thickness of each soil layer. KF refers to the hydraulic conductivity at field capacity mm/d. THETAF refers to the volumetric water content at field capacity. PSIF refers to the matric potential at field capacity. RELDEN is the relative root density per unit volume for soil layers, m3/m3. STONEF is the stone volume fraction in each soil layer. WETINF is the wetness at dry end of near-

saturation range for soil layer. PSIM refers to the matric soil water potential for layer and its initial value, kPa.

V. **Fixed parameters:** They are fixed values which are set by using a variety of sources. No suggestions are made here for changing them.

VI. **Initial parameters:** All the parameters may be set to 0, except for PSIM, which may be -10 kPa. Normally, an initializing period (often a year) is run in order to eliminate initial value effect. Here, BROOK90 facilitates this with "Number of initialize days" on the main screen.

2.1.3. Windows screen

The model has a simple screen in which all the menu items are shown with no confusing buttons (Figure 2.1). The windows versions of BROOK90 are mouse-driven and menu-driven. The green colored texts are active links which can be used to provide more information. Help button on the top right includes adequate information about running the model.
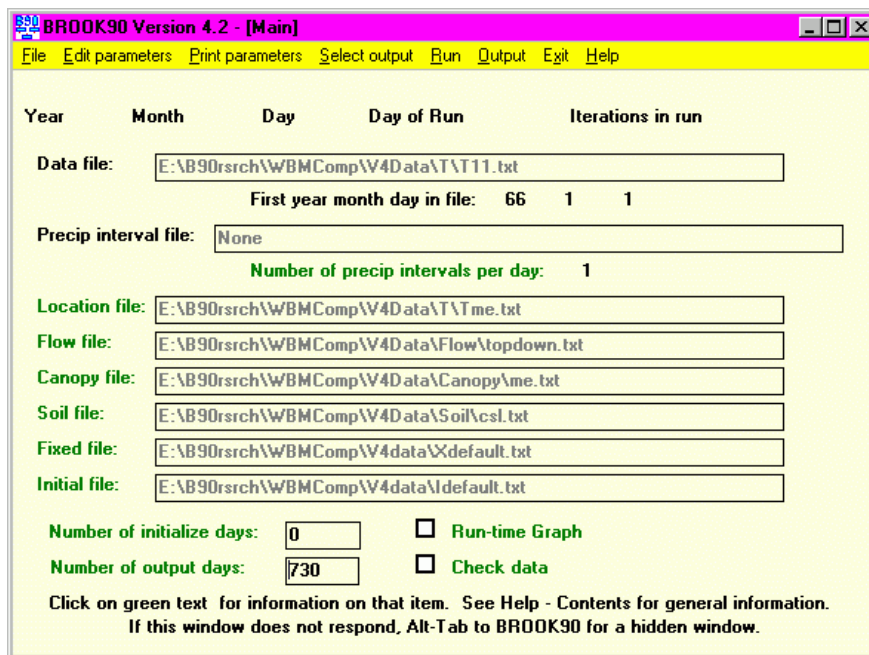

Figure 2.1: The default windows screen for BROOK90 model (BROOK90 website)

2.1.4. Flow chart

The flow chart of the BROOK90 model describes the cycle of water starting from precipitation in the shape of rainfall or snowfall and intercepted rain (INTR), intercepted snow (INTS), snow on the ground (SNOW), soil water in different layers (SWAT) and ground water (GWAT) and circulating through different processes and ends-up with either by evaporation which includes five components: evaporation of intercepted snow (ISVP), evaporation of intercepted rain (IRVP), snowpack (SNVP), soil evaporation (SLVP) and

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transpiration (TRANS) or by deep seepage loss from ground water or by flow that comes from melting snow and the rain from surface flow
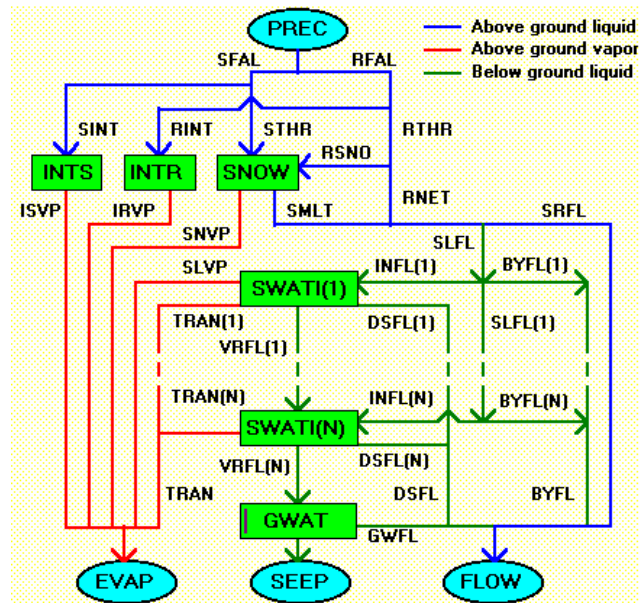

*Figure 2.2: Flow chart of the program BROOK90
(BROOK90 website)*

2.1.5. Constant values

The BROOK90 program has some constant values of some parameters that vary by canopy covers and they consider important values for model parameterization.

Table1.1: Some of the constant parameters that used by BROOK90 model and vary by canopy cover

	evergreen	deciduous	units
ALB	0.14	0.18	-
ALBSN	0.14	0.23	-
KSNVP	0.3	0.3	-
Z0G	0.02	0.02	m
MAXHT	25	25	m
MAXLAI	6	6	-
MXRTLN	2100	3000	mm/m²
FXYLEM	0.5	0.5	-
GLMAX	0.53	0.53	cm/s
LWIDTH	0.004	0.1	m
CR	0.5	0.6	-

2.1.6. Model Inputs

BROOK90 program needs input data in order to run and these data include the summation of daily solar radiation, sums of daily precipitation, daily maximum and minimum temperatures are required, daily average of vapor pressure, and average daily wind speed are desirable. Missing data were filled by linear interpolation. If solar radiation, vapor pressure, or winds speed are not known, they can be approximated. The program can be run if there is only daily precipitation and maximum and minimum temperature.

2.1.7. Model Outputs

Variety of outputs can be selected from the model running, among the most important are: evapotranspiration, transpiration and soil water content for day, month and year. BROOK90 optionally produces graphs at run-time. Each graph show up to one year of daily values of precipitation (PREC), evapotranspiration (EVAP), snow water (SNOW), soil water for all layers (SWAT) and simulated streamflow (FLOW), see figure 2.3. NITSM in the bottom of the graph refers to the number of iterations per month. The graph cannot be saved; it has only the immediate print or saving it through print screen.
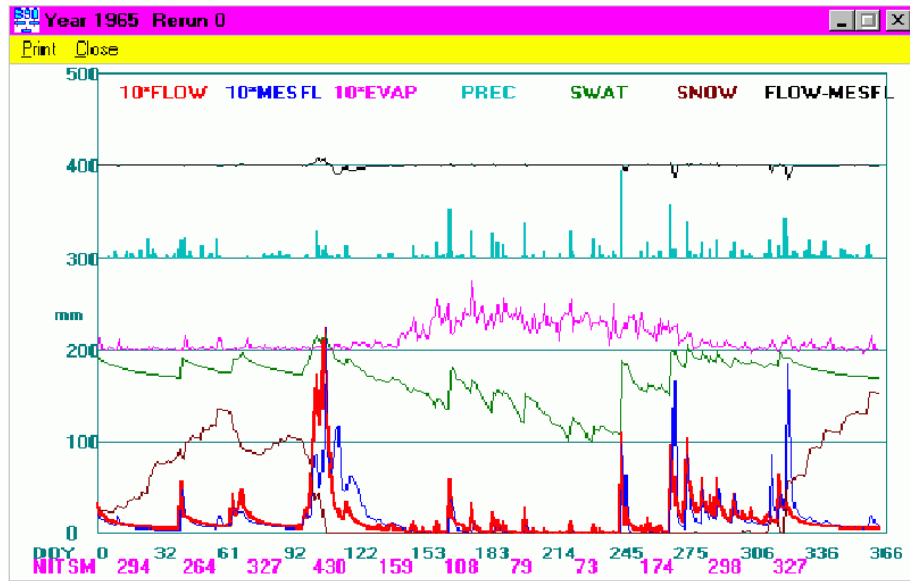

Figure 2.3: The default output graph for BROOK90 model (BROOK90 website)

2.2. Site description

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

2.2.1. Norunda forest

Norunda forest is located 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 has been managed by forestry practice for more than 200 years, and it consist mainly of coniferous trees of both Scots pine (66%) and Norway spruce (33%) (Thum et al, 2008 and Feigenwinter et al, 2010) and few birch trees (Jansson et al, 1999). Figure 2.5 shows the location and the land use of the Norunda forest in which most of the area covered by forest with peat bogs coming after forest, the area has also some lakes and arable lands. The topography of the area is mainly flat having forest spreading about 1km around the area in each direction and more than 20 km headed for the Southwest and the forest has the same frequent in height between 23 to 28m. The forest of Norunda is standing for more than 100 years which is the rotation period for stands (Lindroth, 1998 and Lindroth, 2010) and the soil type is glacial till with moderate to high occurrence of large boulders and is covered by mosses and stands by dwarf shrubs, it's properties and the species composition are differing for both the vegetation and the forest tree (Lagergren et al 2005 and Feigenwinter et al, 2010). The mean annual temperature of the area is about 5.5 ˚C; the annual precipitation is about 527 mm (Lundin et al, 1999 and Lagergren et al, 2008). The projected leaf area index (LAI) varies between 4 and 5 with the higher value of spruce trees (Jansson et al, 1999 and Lundblad and Lindroth, 2001).

Norunda forest has a Central Tower Site (CTS) which is located in dead-end forest road actually build to facilitate vehicles coming to the tower. The tower is 102m tall and holding most of the instruments that measuring almost all the variables in the forest such as atmospheric and within canopy profiles of temperature, humidity and CO_2, precipitation (Lundin et al, 1999).

Figure 2.4: Map of Sweden (scale ca 1: 5 000 000) showing the location of Norunda Common and land use map (scale ca 1: 160 000) showing the area around the tower (marked with a star). The black areas symbolise lakes; dark grey areas are peat bogs; light grey area forests and white areas are arable lands (Lundin et al, 1999)
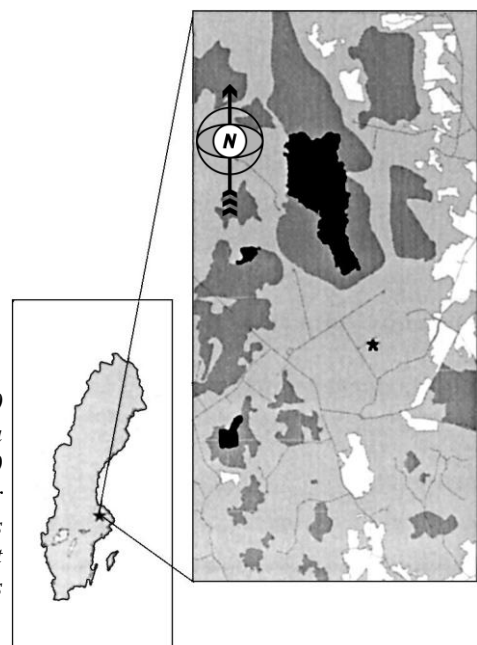
2.2.2. Hartheim forest

Hartheim forest is located in southern Germany (47°56'N, 7°36'E, altitude 201 m) in a slow growing area with mean annual growth rate about 0.3 m^3 $year^{-1}$, 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 sylestris L.*) forest that was planted in 1963 and has trees with approximate mean height of 14m and mean diameter of 0.2m at breast height (Holst et al, 2008 and Schindler et al, 2006). Hartheim differs from Norunda in climate conditions; it locates in one of the warmest and driest region in Germany, because of its location between the Vosges Mountain in the west and the Black Forest Mountain in the east, with mean annual temperature of 10.3°C and mean annual precipitation of 642mm (Wellpott et al, 2005 and Schindler et al, 2006). The topography of the area is flat with forest spreading in 10km North-South and about 1.5km West-East. 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, the water storage capacity is 80mm, hence, the roots of the trees are going to develop very well in this layer (Holst et al, 2008 and Schindler, 2006). The ground water in Hartheim forest dropped to about 7m, and this is mainly due to the river regulation and sealed Rhine bypass channel, see Figure 2.6 in which small amount of water is infiltrate from the surface to the groundwater (Jaeger et al, 1997).

Hartheim forest has two experimental towers with meteorological measurement systems. Figure 2.6 shows the taller tower which is about 30m height and installed for the long-term investigations. Measurements in this tower are: vertical measurement of air temperature, vertical profile of horizontal wind speed, photosynthetically active radiation below and above the canopy, wind direction and gross precipitation. Figure 2.5 describes the location of meteorological experimental site "Hartheim Scots pine forest" in the west of Hartheim village (Mayer et al, 2008).
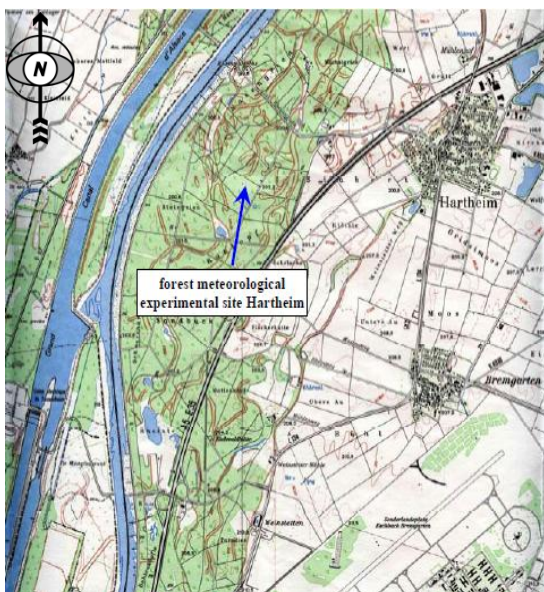

Figure 2.5: Location of the meteorological experimental site "Hartheim Scots pine forest "west to Hartheim village (Mayer et al, 2008).

Figure 2.6: Aerial view of the experimental Hartheim forest showing the meteorological tower (Meteorological Institute, University of Freiburg)

2.3. Variables measurements

This section describes the measurement of different variables used in the study.

I. **Solar radiation:** It is the amount of the energy given from the sun and reached to the earth in all directions and it is the most important factor for the process of photosynthesis inside the plant leaves and evapotranspiration. Pyranometer is the most accurate equipment for measuring the incoming solar irradiance at both sites (Lundin et al, 1999 and Mayer et al, 2008).

II. **Temperature**: Basically, temperature refers to the thermal energy content of matter, which expresses the state of hot and cold of the matter. Temperature has direct and indirect effects on many physiological processes inside the plant. In Hartheim forests, air temperature was measured using vertical profile of air temperature with (19.1 m above ground level "a.g.l.") from the taller meteorological tower above the canopy cover (Mayer et al, 2008). While in Norunda site, it has been measured using thermocouple instrument (Moderow et al, 2009).

III. **Wind speed:** It is the speed of wind or the movement of air in the atmosphere and expressed in m/s. There are several methods for measuring the wind speed, in both forests, sonic anemometer was chosen for the analysis of the turbulent wind field above and within the forests stand. This kind of instrument used in order to get higher long-term stability of calibration than one achieved by the normal anemometer (Lundin et al, 1999 and Mayer et al, 2008).

IV. **Precipitation:** Is any form of water that falls from the clouds and reaches to the Earth's surface. At both sites, precipitation was measured using rainfall gauge (Lundin et al, 1999 and Mayer et al, 2008).

V. **Soil moisture:** It is the liquid water content of the soil, which determines the availability of water in the soil for specific area. Drying and weighting the samples of soil is the basic method for measuring the moisture of the soil, but this takes time. In both forests, volumetric soil moisture content has been measured using Time Domain Reflectrometry (TDR) (Lundin et al, 1999 and Mayer et al, 2008). This method gives immediate results with more accuracy. Soil water is measured as a volumetric measurement (%vol), but it is converted into mm to be easily compared with model output results. In our study, soil water was named as SWAT.

2.4. Evapotranspiration

Eddy-covariance system that measures the turbulent flux in the atmosphere (Lundin et al, 1999 and Burba and Anderson, 2007) is usually used for the direct measurement of evapotranspiration. Both in Hartheim and Norunda forests, the measurement of evapotranspiration gained directly from the latent heat flux in (W/m^2) converted to values of evapotranspiration with mm to be easily compared with the model outputs values. In our study, evapotranspiration named as EVAP.

2.5. Transpiration

Measurement of tree transpiration is one of the important issues for the indication of water state of the forest. The estimation of tree transpiration for both forests is usually done by sap-flow technique (Cienciala et al, 1997, Jansson et al, 1999 and Wellpott et al, 2005). In our study, transpiration names as TRANS.

2.6. Data collection

The available data has been obtained from two different places. For the Hartheim forest, the data was taken from the Meteorological institute, University of Freiburg, Germany. For the Norunda forest, most of the data have been obtained from the department of Earth and Ecosystem Sciences, division of Physical Geography and Ecosystems Analysis, Lund University, Sweden. These data include topography of the area, soil description, and climate information. Precipitation has been taken from one of the Swedish Meteorological and Hydrological Institute (SMHI) meteorological stations called "Films Kyrkby station" which is about 45km far from Norunda forest to the north-east.

2.7. Limitations

The missing data of many time periods were not available and they were replaced or filled by interpolating them manually. For the short time period for example: minutes, hours or a few days, they have been taken from the closest time period, while for the long time i.e. for more than one week, the data were taken from the same period of the previous or the next year after.

The number of the days or the percentage of the missing data varied from site to site and from parameter to parameter. At both forests, 60% of the missing data were from winter, while the rest distributed to the other time of the year. The missing data were ranged from 30min interval to 17 days.

3. Simulation scenarios and results

The following chapter illustrates various scenarios addressed in the study and displays their results. The scenarios are:

A. 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.

B. Stand management: The goal of the this scenario is to estimate the water state of the two forests through some of anthropogenic event by increasing the forest stand by 30% either by planting more trees, good forest management or through some other practices and decreasing by 30% through either cutting some trees by human activities or naturally through flooding, fire, dryness and some other natural impacts.

C. 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 (IPCC, 2007). 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 (IPCC, 2007).

D. Combination of scenario B and C: This scenario aims to show how the forests respond to the future changes by combining the previous two scenarios.

3.1. Hartheim forest

This section illustrates the ability of the simulated model output to track the actual measurements and display the results.

3.1.1. Scenario 1: Control (under current conditions)

This scenario shows the water balance and the growing conditions of Hartheim forest under current conditions through investigating evapotranspiration, soil water and transpiration index. Figure 3.1 shows measured EVAP (mm/d) and how it correlates with model simulated output EVAP (mm/d). The coefficient of determination R^2 value of 0.6 is a decent value indicating an obvious correlation. While the slope is 1.10 meaning that the model is working well for estimating EVAP for Hartheim forest with 10% overestimation and a very small offset of 0.1mm.

Modeled EVAP (mo) corresponds to measured eddy-flux EVAP (me) for the period Jun-2004 to Oct-2007 Figure 3.2. The slope of 1.10 with offset of 0.1mm (see Figure 3.1) has a great role in the overall consistency between eddy-flux and model output EVAP. One reason behind the high values of simulated EVAP during winter 2007 in comparing to winter 2005 and 2006 was because of the higher mean monthly air temperature in winter 2007 with 5.9˚C compared to 1.7 and 0.5 for the years 2005 and 2006, respectively. Another feasible reason is

higher total daily precipitation in 2007 with 97mm in comparing to 64mm and 61mm for both 2005 and 2006, respectively.
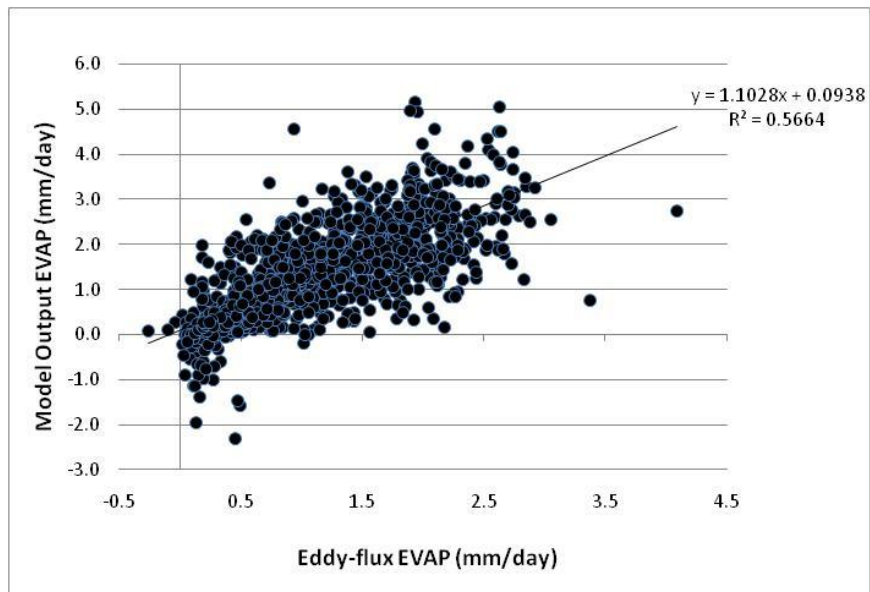

Figure 3.1: Scatterplot between eddy-flux and simulated BROOK90 evapotranspiration at the Hartheim Scots pine forest for the period Jun-2004 to Oct-2007.

Overall the studying period, it is appeared that simulated EVAP increased about 1 % from the measured EVAP, see table 3.1. Figure 3.2 shows daily mean values of eddy-flux and simulated EVAP for the period Jun-04 to Oct-07. The figure shows convergence between measured and simulated value by having almost the same values except in some specific areas for instance, 27th of Feb in 2005 reached the minimum value with -2.5mm. This means that condensation occurred during that period.
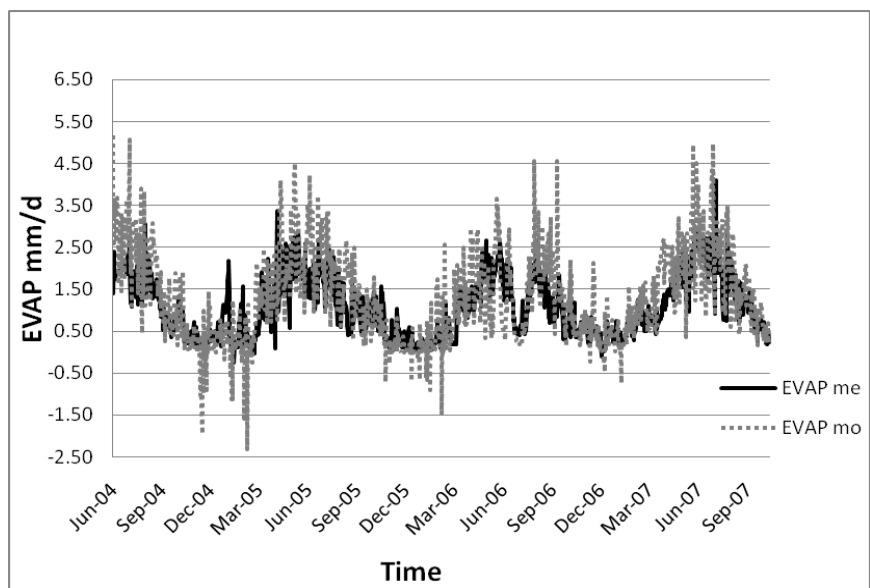

Figure 3.2: Daily means of eddy-flux and simulated EVAP at Hartheim Scots pine forest in the period Jun-2004 to Oct-2007.

Figure 3.3 represents mean monthly temperature *T*, total monthly precipitation *P* and modeled evapotranspiration EVAP at Hartheim site for the period Jun-04 to Oct-07. The monthly rainfall for the studying period was comparable to the long-term 30-year average except in October 2004 and August 2006, which were wetter than the average rate. The highest value of mean monthly temperature scored in July 2006 with value of 24 ˚C while the lowest value was from January 2006 with value of -1˚C. The highest value of the monthly simulated EVAP is recorded with 86mm in July 2004 and this is because of the increasing mean monthly air temperature of that month in compare to the rest of the studying period with value of 19 ˚C, and also a decent value of wind speed in such month which increases the ability of evaporation. The minimum monthly value of the simulated model EVAP during the whole investigation period recorded in December 2004 with only 0.3mm.

Despite agreeable amount of precipitation and adequate air temperature and wind speed, low values of evapotranspiration were recorded in October 2004, August and September 2006, with 31mm, 49mm and 36mm, respectively. This could be due to the poor soil management which limits the development of the forest and the drainage of water into the groundwater which is at 7m depth in this site as mentioned elsewhere. In this case, the roots of the trees will face a great difficulty in accessing to the water. Hence, evapotranspiration will reduce.
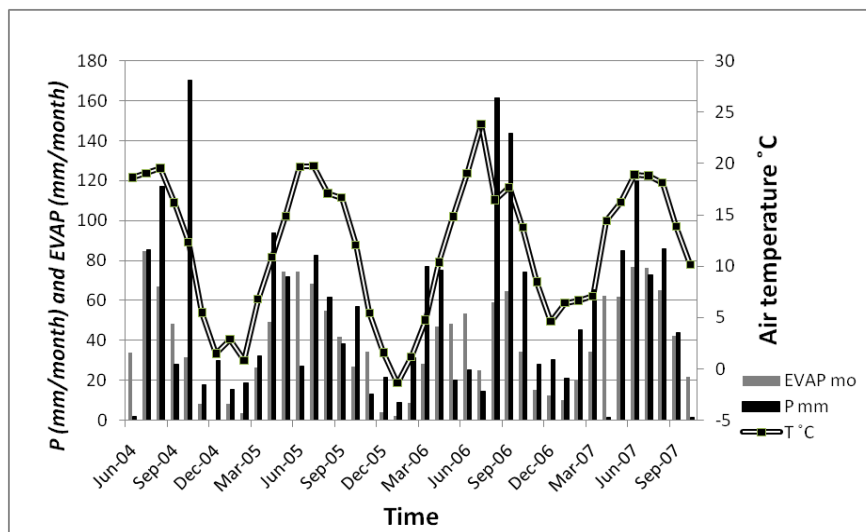

Figure 3.3: Total monthly evapotranspiration E for the scenario of control in comparing to mean monthly air temperature T and total monthly precipitation P at Hartheim Scots pine forest for the period (June 2004 to Oct 2007)

The maximum value of the simulated EVAP during summer recorded in 18th of August in 2006 with 4.6mm/day, while the period between 17th of July 2006 to 25th July 2006 recorded with lowest values of 0.2mm/day. The mean daily value of EVAP in summer 2005 was higher than in summer 2006 with of 2.1mm and 1.5mm respectively, Figure 3.4.
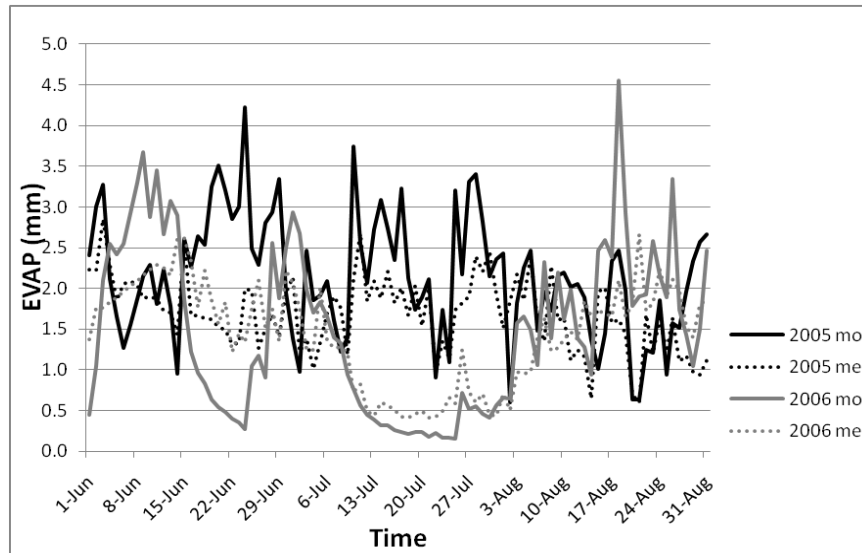
Figure 3.4: Daily summer values of measured and simulated BROOK90 evapotranspiration at Hartheim Scots pine forest for the period (2005-2006). mo means modeled and me is measured.

In winter, the rate of evapotranspiration is likely to decrease compared to summer due to decreasing in daily air temperature, low incoming solar radiation and also the air humidity above the ground and above the canopy cover. While in our investigation period; the rate of evapotranspiration appeared to have more fluctuation than the reality.

Figure 3.5 shows the difference between measured and simulated EVAP for winter 2005 and 2006. The measured values shows an increase in EVAP from the mid to the end of January reaching to its peak in 23rd of January in 2005 with values of 2.2mm. The modeled values show a reduction in the rate of evapotranspiration reaching to their minimum values in 5th Dec-05, 22nd Feb-05 and 27th Feb-05 with values -2.0mm, -1.6mm and -2.3mm respectively.
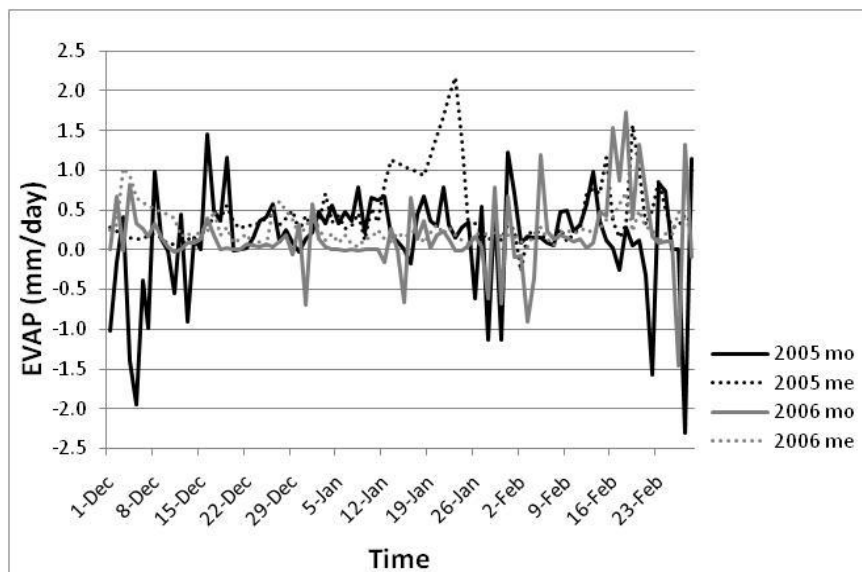

Figure 3.5: Daily winter values of measured and simulated model evapotranspiration at Hartheim Scots pine forest for the period (2005-2006) mo means modeled and me is measured

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To show how the model works for soil water for Hartheim Scot pine forest, Figure 3.6 illustrates how the measured soil water in the upper 40 cm (SWAT) correlates with the model output for the period Jun-04 to Oct-07. R^2 value of 0.54 is an honest value which indicates a closer correspondence compare to the measured SWAT, while the slope of 0.55 meaning of a tendency of underestimating of the values from the programs for estimating SWAT for the Hartheim Scot pine forest.
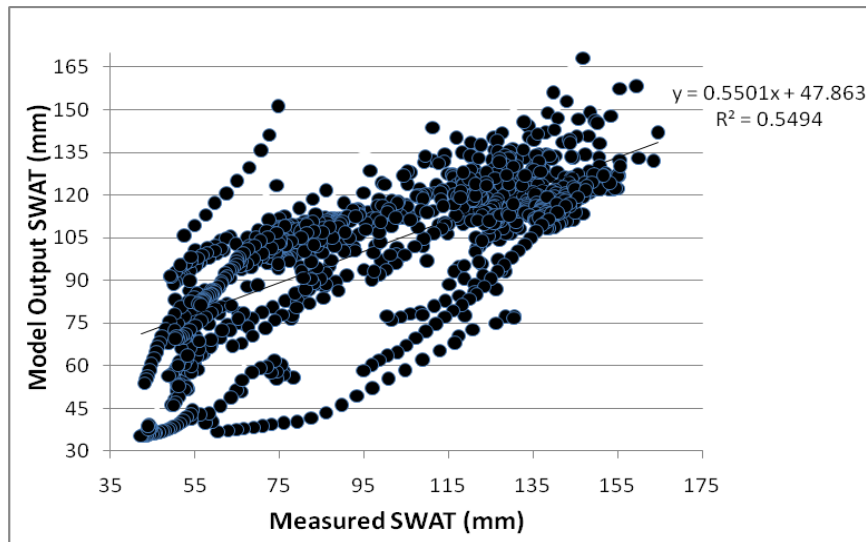

Figure 3.6: Scatterplot between measured and simulated model soil water (SWAT) at Hartheim Scots pine forest for the period (Jun-04 to Oct-07)

Figure 3.7 describes the measurement and the simulated model output of the daily soil water content together with the daily air temperature and total daily precipitation for the period 2005-2006. Generally, the soil water was approximately stable for both years having almost the same amount of water in the soil until the beginning of summer which has a significant downward in both years reaching to their minimum values.

From the beginning of autumn, after the transpiration lean to stop; the amount of the soil water is increasing reaching to the highest values with 113mm and 158mm in 3rd of October 2005 and 1st of October 2006, respectively for the simulated modeled. While the highest values for the measured SWAT was recorded in 5th of October 2005 and 1st of October 2006 with values 92mm and 159mm. Later on, the soil becomes in a steady state having nearly the same amount of soil water until the end of the year.
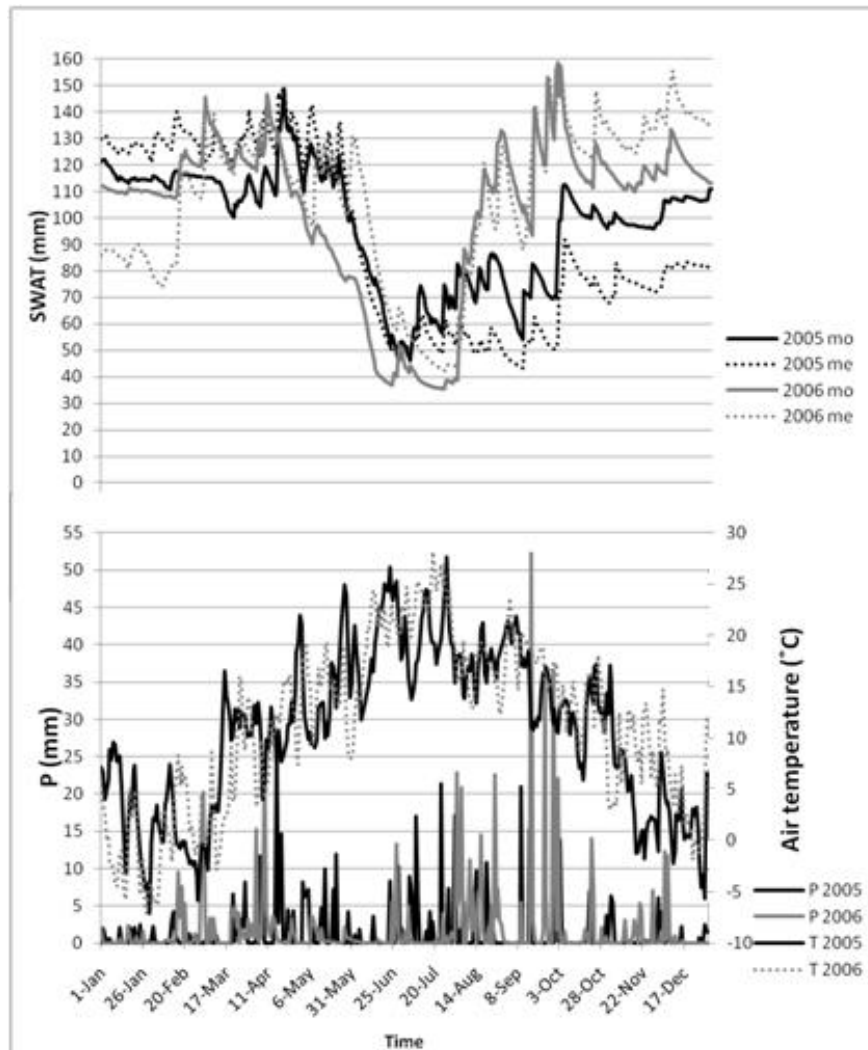
Figure 3.7: Daily values of measured and model output soil water SWAT in comparing with mean daily air temperature T and total daily precipitation P at Hartheim Scots pine forest for the period (2005-2006)

The distribution of the soil water in summer of both 2005 and 2006 is shown Figure 3.8. The figure shows a significant decreasing of the soil water in summer that has a steeper descending. This is mainly due to the sharp increasing in the air temperature combining with low rainfall during summer, and also because the forest is in growing season which needs more water.

In our investigation period, Hartheim forest suffered from water shortage for 2 and 48 days in 2005 and 2006, respectively. This mean that in 2005, only 2 days have the soil water content below the wilting point which is 48mm according to Wellpott et al (2005) which is the point where plant roots face difficulty in taking water from the soil due to the deficiency of the water. In 2006, the forest suffered from water deficiency for 48 days. Low rainfall during summer 2006 (see Figure 3.7) was one of the main reasons behind this scarcity of water.
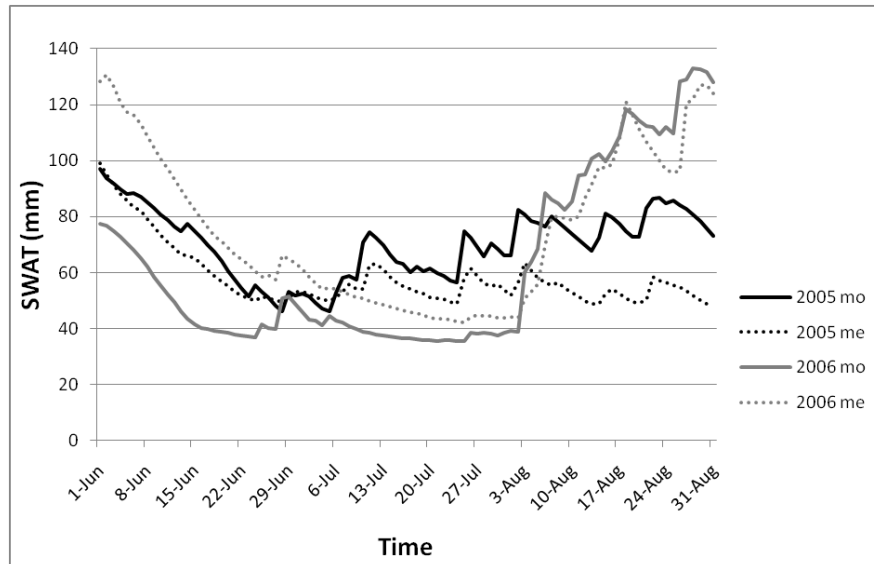
Figure 3.8: Daily summer values of measured and simulated BROOK90 soil water at Hartheim Scots pine forest for the period (2005-2006)

In winter, the amount of soil water at Hartheim Scots pine forest was approximately constant having the nearly the same amount of water in the soil.

Figure 3.9 describes daily values of transpiration index (T_{act}/T_{pot}) of each year from 2004 to 2007. (T_{act}/T_{pot}) is used to evaluate the water availability of the forest. The annual plots start from 1st of May until the 31st of August, which represents the period where draught is more frequent under current conditions by relying in the growing season.

In our studying period, the number of the days with transpiration index less than 1 is ranged between 0 days in 2004, 2005 and 2007 and 51 days in 2006. The Hartheim Scots pine forest was thinned in 2003 (Wellpott et al, 2005) resulting in lowering LAI value through removing trees. Hence, T_{pot} reduced as a result of the thinning leading to increase the value of transpiration index in the next two years showing no days with T_{act}/T_{pot} less than 1 despite the regional weather conditions changing or the availability of the water in the soil.
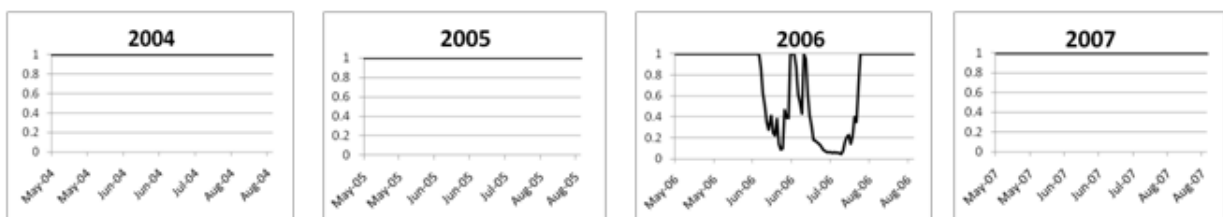

Figure 3.9: Daily values (May to September) of transpiration index (T_{act}/T_{pot}) at Hartheim Scots pine forest for the period 2004-2007. X- axis (Time), Y-axis (T_{act}/T_{pot})

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3.1.2. Scenario 2: Management conditions

This scenario shows how soil water content at Hartheim forest will react under management conditions which have been divided into two categories:

I. **Increasing LAI by 30 %**

This scenario describes the water balance of the forest through determining the soil water content and the rate of evapotranspiration by increasing LAI which could be as a result of increasing plant density, more water in the soil from different sources, good management practice, excellent irrigation, soil management via good application of fertilizer and by controlling the forest diseases and pests. Nevertheless, there will be a water limitation due to increase the demand and competition for water by plants.
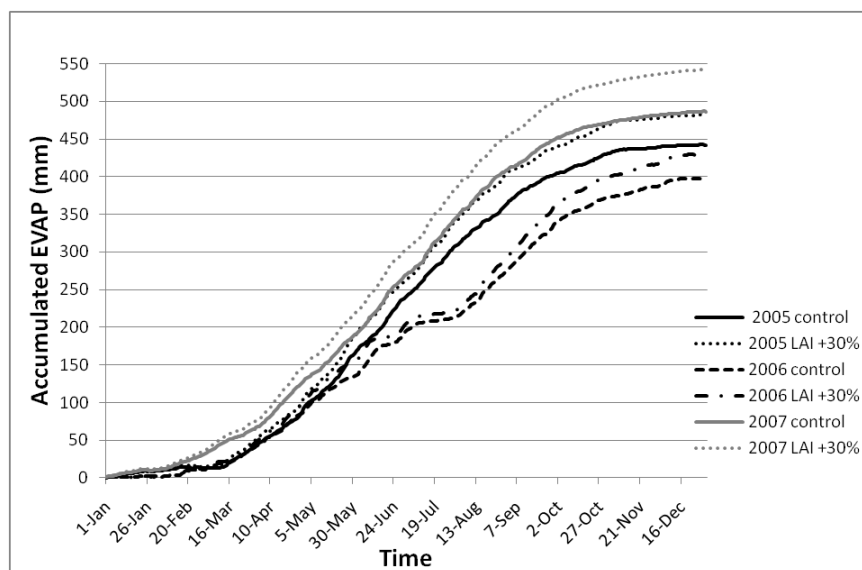

Figure 3.10: Summation of the daily values of evapotranspiration under increasing LAI by 30% and simulated model output EVAP under original conditions at Hartheim Scots pine forest for the period (2005-2007)

Increasing the forest LAI by 30% shows a significant difference between the simulated model outputs EVAP compared to EVAP under original conditions (Figure 3.10). The figure shows a clear difference between both scenarios in the whole studying period in which increasing LAI has more effects on increasing the rate of transpiration leading to more evapotranspiration. The maximum value of EVAP was recorded in the year 2007 with 543mm indicating 57mm higher than the control. 2006 showed the minimum rate of annual simulated EVAP with 398mm, probably because of the low precipitation during the growing season compared to the other years, see Figure 3.3.

In the whole studying period, there is a clear dissimilarity between the simulated model soil water under original conditions and the scenario of increasing LAI by 30%, showing significant lower values of soil water content under the current scenario compare to the scenario of control (Figure 3.11). The high values of soil water content in summer 2007 compared to the other two years (2005 and 2006) are mainly due to the high rainfall in that period, see Figure 3.3.

The forest under this scenario shows a significant difference in the frequency of drought occurrence in comparing to the scenario of original conditions. In 2005, under this scenario; the forest suffered for 48 days compared to only 2 days in the scenario of control. This means that increasing LAI by 30% will be highly affecting on the water balance of the area.

In 2006, the number of the days in frequency of drought increase from 48 days for control to 55 days for this scenario, while in 2007, the number of the days increased from 0 in control to 12 days with increasing LAI by 30%. Overall, 2006 showed highest value, possibly because of the very low amount of rainfall during summer, see Figure 3.3.
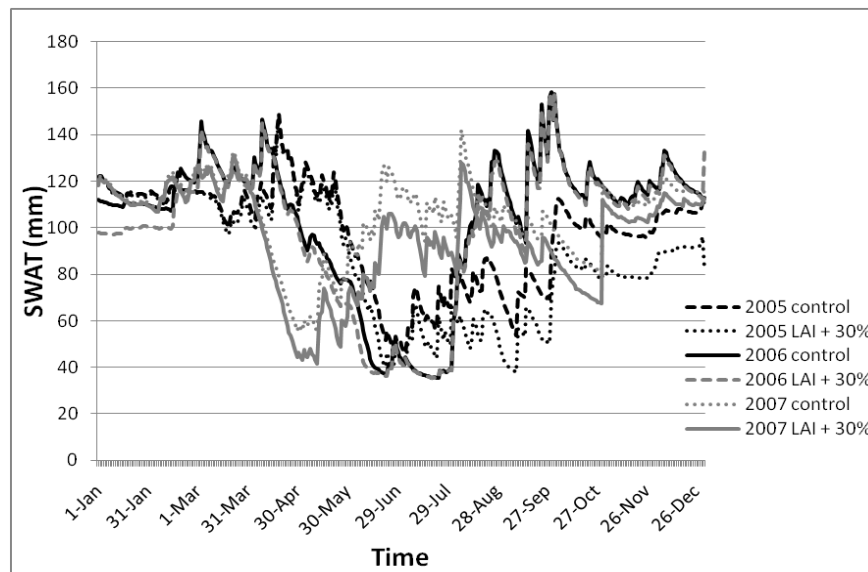

Figure 3.11: Daily values of model output soil water under the original conditions and simulated model SWAT with increasing LAI by 30% at Hartheim Scots pine forest for the period (2005-2007)

II. Decreasing LAI by 30%

This scenario shows the soil water content of Hartheim scot pine forest under the effect of decreasing forest stand by 30%. The aim is to describe the impact of thinning on the forest's water balance as thinning acts to reduce the vulnerability of drought occurrence and decreasing the competition on water by trees. Another purpose of this scenario is to show the effect of human activities with forest management usually for economical purposes and also the indirect effect of plant diseases and pests on the soil water content and hydrological cycle of the areas. When a forest suffered from a certain diseases, this could lead to kill many trees. Hence, more water will be available in the soil.

Figure 3.12 illustrates the difference in the rates of EVAP for the simulated model outputs both for the original conditions and with decreasing LAI by 30% scenarios. The figure shows a clear difference between the two scenarios in the whole studying period. Under the current scenario, 2007 showed 70mm reduction in the rate of EVAP compared to the scenario of control from 489mm to 419mm indicating high value,

while 2006 has the lowest values with the reduction of 36mm from 398mm to 362mm. In 2005, the rate decreased from 442mm to 380mm indicating 62mm decline.
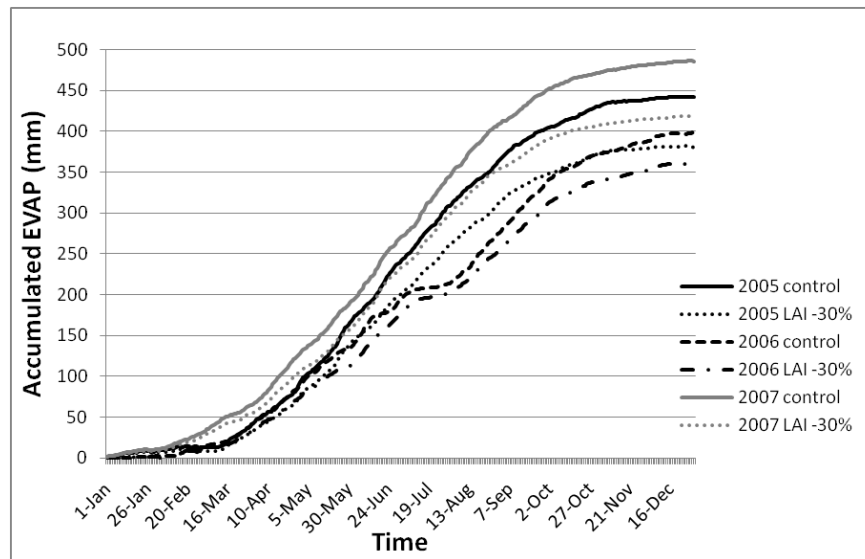

Figure 3.12: Summation of the daily values of evapotranspiration under decreasing LAI by 30% and simulated EVAP of original conditions at Hartheim Scots pine forest for the period (2005-2007)

Under decreasing LAI by 30%, the soil water content tends to increase in comparing to the previous scenario Figure 3.13. In the entire investigation period, there is a clear increase of the soil water content under this scenario in comparing to the scenario of original conditions.

Increasing in the amount soil water content of Hartheim forest under this scenario is mainly due to the less numbers of trees leading to more water available for the remaining trees. Hence, this will decrease the competition for water by trees.

The frequent of drought vary from year to year. Both in 2005 and 2007, the reduction of the water in the soil did not reach the wilting point, while in 2006, despite having mean annual precipitation of 688mm and decreasing LAI by 30%, but the forest still suffered from water shortage for 32 days during summer, this is because of the low amount of rainfall during that specific period compare to the other two years (see Figure 3.3).
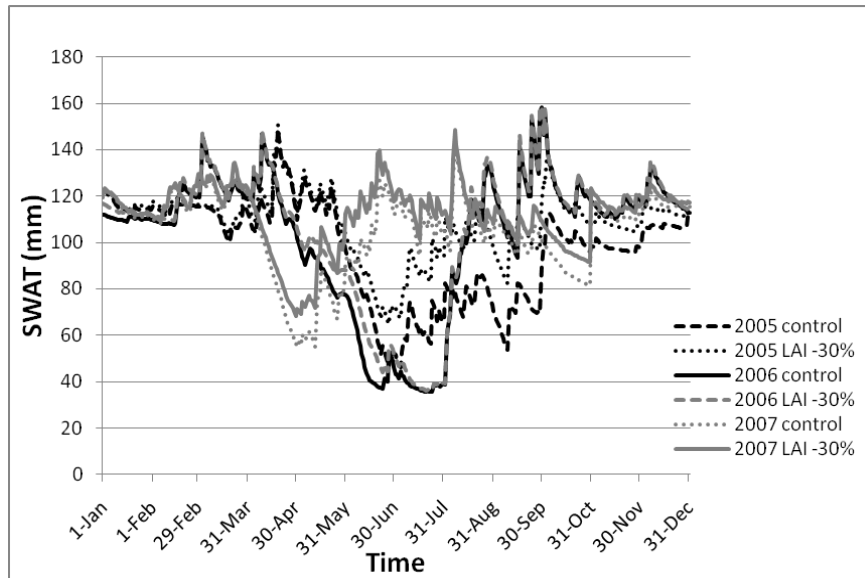
30

Figure 3.13: Daily values of model output soil water under original conditions and simulated model SWAT with decreasing LAI by 30% at Hartheim Scots pine forest for the period (2005-2007)

3.1.3. Scenario 3: Climate change

This scenario aims to describe the influence of the climate change on the rate of evapotranspiration and the amount of the soil water content of the forest and how this will link to the water balance of Hartheim Scots pine forest.

I. Increasing daily maximum air temperature by 1˚C

The simulation was run to show the effect of increasing 1˚C on the daily maximum air temperature due to the projected increase in air temperature from 1.8 to 4.0˚C at the end of this century (IPCC, 2007) as a try to perceive how forest will adapt to the future climate changes with focusing on the hydrological cycle of the forest.

The maximum value of the annual evapotranspiration for the investigation period was recorded in 2007 with 516mm (Figure 3.14). In the whole studying period, there is a slight difference between the model output evapotranspiration under the original conditions and with increasing maximum daily air temperature by 1˚C. The agreeable explanation for this fact is that increasing air temperature will accelerate the rate of evapotranspiration through warming the air surround the plant. So, the stomata "A tiny openings presents mostly on the bottom of a plant leaf and has a main function of gas exchange and releasing of water" (Grant et al, 2004) will open leading to evaporate more water from the leaves, guiding to more transpiration and as transpiration is a part from evapotranspiration, so too does evapotranspiration.
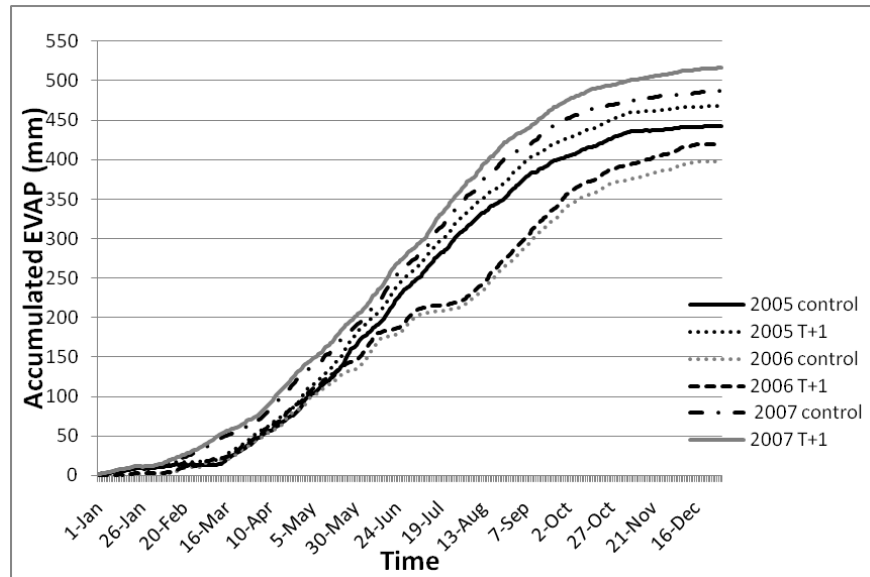
Figure 3.14: Summation of the daily values of evapotranspiration under increasing air temperature by 1˚C and simulated EVAP of original conditions at Hartheim Scots pine forest for the period (2005-2007)

As the air temperature increase, it will affect the amount of the soil water content in the forest through increasing the rate of evapotranspiration, guiding to lose high amount of water from both the soil and plant canopy and evaporating it to the atmosphere leaving the ground to by more drier and the leaves with less water in comparing to original conditions (Figure 3.15). The figure shows a small difference between measured and simulated SWAT, this is because only the maximum daily air temperature increased by 1˚C meaning that only 0.5 ˚C daily air temperature increased. So, in order to show the effect of increasing air temperature by 1˚C, the minimum daily air temperature should also be increased by 1˚C.

Despite the effect of the air temperature in decreasing soil water content, our simulation shows a slight difference between the model output soil water under the original conditions and this scenario indicating a small effect of this scenario on the availability of the soil water and the forest's water balance. This may be due to some other reasons, for instance, sufficient amount of rainfall in certain times of the year that prevent the forest from water shortage or drought occurrence, and compensate the water lost under the influence of increasing air temperature, and also low solar energy and high air humidity.

The forest under this scenario shows that the number of the days with water deficiency in 2005 is increased from 2 days under control into 7 days in this scenario which is only 5 days increasing. This is due to the sufficient amount of rainfall during summer 2005; see figure 3.3 that compensates the loss of water either by increasing air temperature or from the infiltration and drainage to the groundwater.

Summer 2006 under this scenario shows 51 days with water deficiency from 11th of June until the 1st of August, which is only 3 days higher than with original conditions and these three days rely in the mid of the growing period. 2007 shows no days with low water availability in the soil neither in control nor in this scenario due to the very

high amount of rainfall during summer 2007 in comparing to the rest of our investigation period leading to more water in the soil and decreasing the risk of drought occurrence.
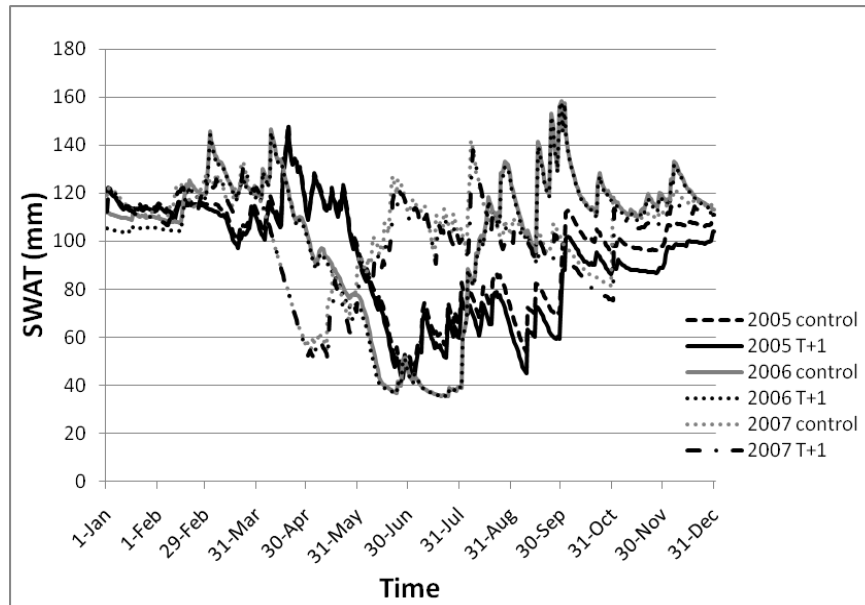

Figure 3.15: Daily values of model output soil water under the original conditions and simulated model SWAT with increasing maximum daily air temperature by 1˚C at Hartheim Scots pine forest for the period (2005-2007)

II. Increasing total daily precipitation by 20%

In this scenario, the rate of evapotranspiration and the soil water content were explained under increasing total daily precipitation by 20%. The aim is to show how the projected future increase in rainfall will affect the water balance of the forest due to very likely increase in the future precipitation in high and mid-latitudes (IPCC, 2007).

Simulations have been done with increasing precipitation by 5% and 10% and compared to the measured data to show the effect of precipitation on the rate of evapotranspiration and soil water content to estimate the forests water balance. However, the difference between the measured and simulated model output results was too small and having no effects; therefore the rate was increased to 20%.

The simulation of the model under increasing precipitation by 20% shows an increase in the annual rate of evapotranspiration in comparing to the model output with original conditions (Figure 3.16). The maximum annual value of the evapotranspiration for this scenario recorded in 2007 with 507mm which is 21mm higher than control. While the rate of evapotranspiration in both 2005 and 2006 increased by 29mm and 20mm respectively, from 398mm to 427mm in 2005 and 442mm to 462mm in 2006.

The increased values of evapotranspiration are due to more precipitation. As the precipitation increased there was more water available on the ground and in the soil. Under optimal conditions, trees will not transpire more, but increasing in precipitation means more rainfall interception, so more evapotranspiration, More rainfall will also

increases the amount of water in the soil which leads to more evaporation from the soil. Hence, increasing the total annual evapotranspiration.
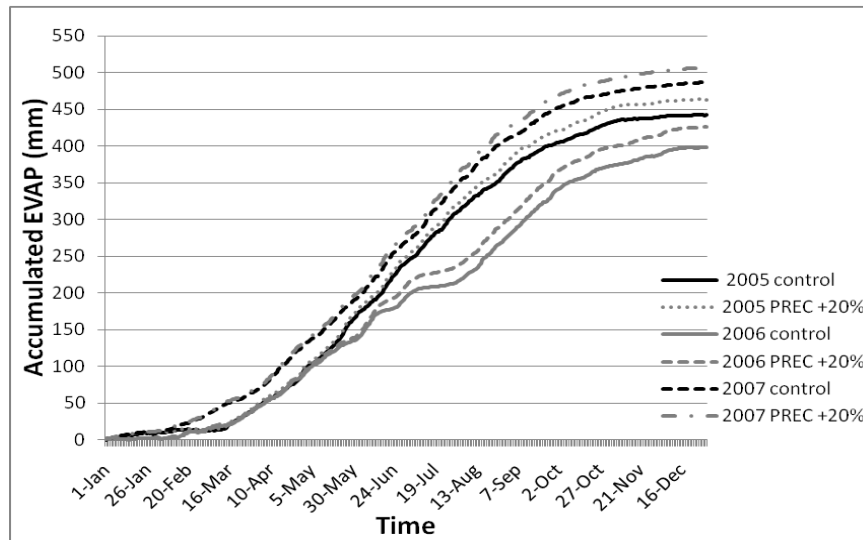

Figure 3.16: Summation of the daily values of evapotranspiration under increasing total daily precipitation by 20% and simulated EVAP of original conditions at Hartheim Scots pine forest for the period (2005-2007)

Figure 3.17 shows the change in the soil water content under the effect of increasing precipitation by 20%. A very small change occurred after adding more rainfall to the model in comparing to the model output under original conditions. The tiny change and especially in summer 2006 could be because most of the days during summer period recorded with no rainfall; therefore, no changes occurred during summer 2006, so, when adding rainfall by 20%; it will make small change to the soil water content indicating less effect of increasing rainfall for preserving forest from water shortage

Furthermore, the forest still suffered from water deficiency and especially in 2006 in which 45 days leant to have water deficiency which was below the wilting point of this area, indicating only 3 days less than the scenario of original conditions. Whilst in 2005, the forest became a way from the threat of water shortage from 2 days under control into 0 days under this scenario. 2007 remained unchanged having 0 days with water deficiency under the both scenarios.
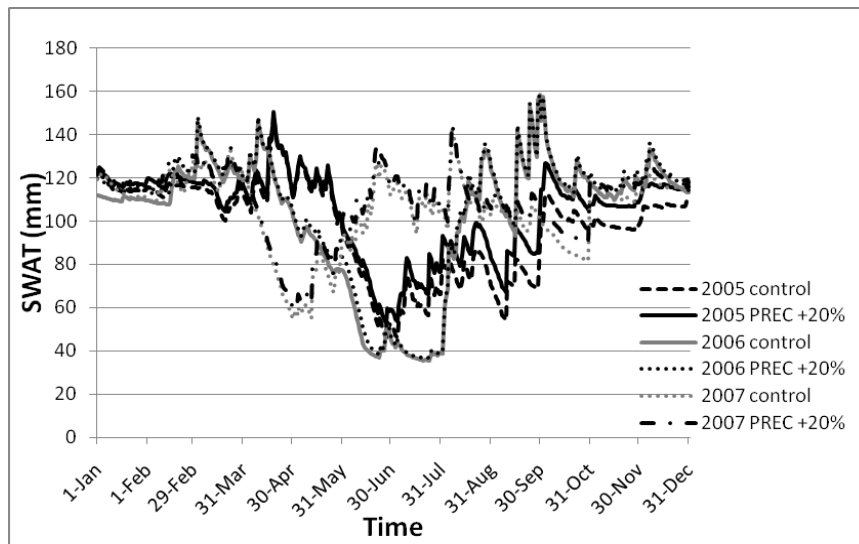
Figure 3.17: Daily values of model output soil water under original conditions and simulated SWAT with increasing total daily precipitation by 20% at Hartheim Scots pine forest for the period (2005-2007)

3.1.4. Scenario 4: Combination of scenario 2 and 3

The purpose of this scenario is to illustrate the influence of the combination of the previous two scenarios on the future forests water balance.

I.   Increasing temperature by 1°C with increasing LAI by 30 %

The scenario's aim is to show the projected increase in the future air temperature together with an increase in the forest stand and describing their consequences on the forest's water balance through evapotranspiration and soil water content.

This scenario explains an observable increase in the annual rate of evapotranspiration in comparing to the scenario of original conditions (Figure 3.18). The maximum value recorded in 2007 with 571mm about 85mm higher than control, while 2006 shows less change with 57mm increase from 398mm to 455mm. In 2005, the rate increased from 442mm to 500mm.
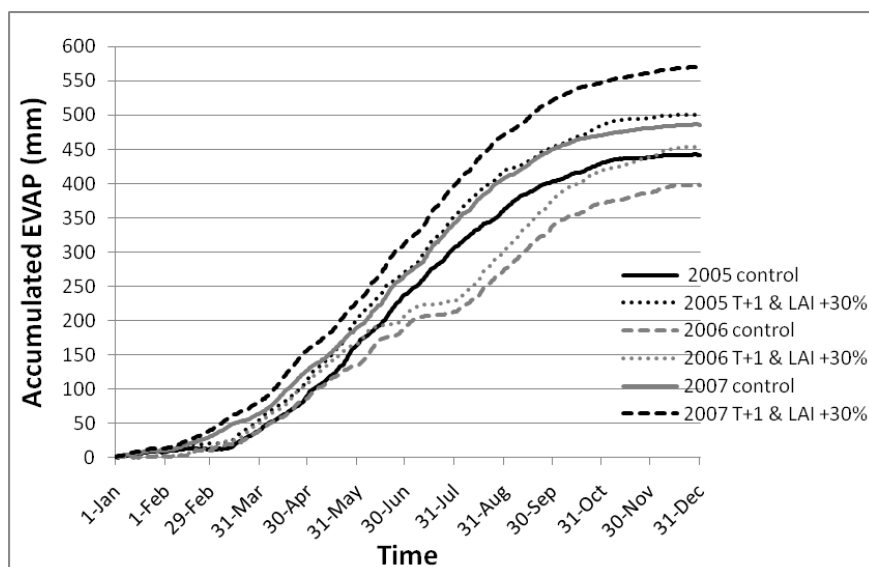

Figure 3.18: Summation of the daily values of evapotranspiration under increasing of air temperature by 1°C together with increasing LAI by 30% and simulated EVAP of original conditions at Hartheim Scots pine forest for the period (2005-2007)

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Figure 3.19 shows the significant difference in soil water between the model output of original conditions and under increasing daily maximum air temperature by 1˚C together with increasing LAI by 30%. Logically, soil water content reduced in the forest under this scenario.

Soil water deficiency under this scenario varies from year to year due to the variation in the regional weather conditions. In 2005, the number of the days with water shortage increased from 2 days in control into to 41days in the current scenario starting from the 18th of June until 9th of September having some days no water shortage in between. This indicating a very significant effect of increasing the two factors on the water reservoir inside the soil casing many turbulent to the water balance of the area.

In 2006, the number of the days with water deficiency increased from 48 days under original conditions to 59 days, from 7th of June reaching to the 1st of August. While in 2007, 0 days of water shortage raised to 16 days starting from the 27th of April until the 12th of May which the forest suffered from a severe lack of rainfall during that period, see Figure 3.3.
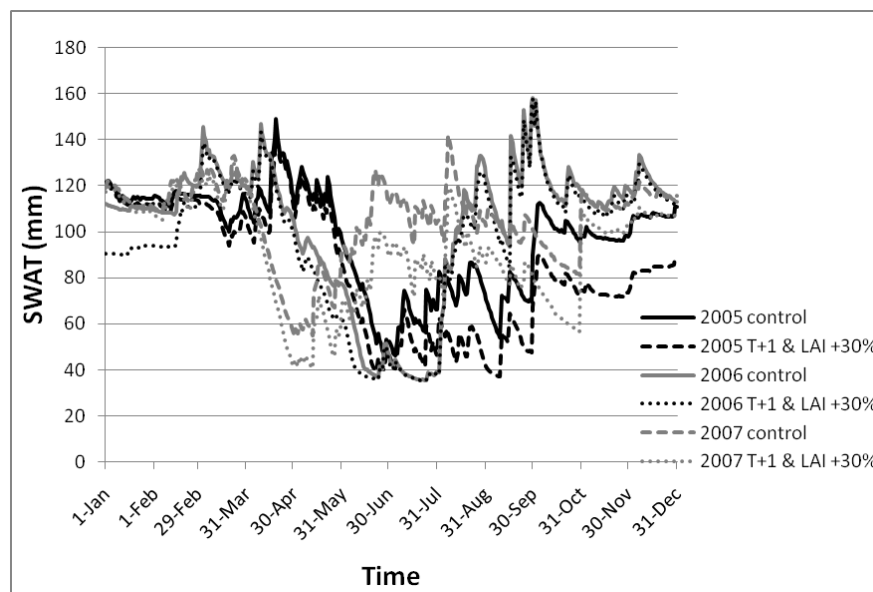

Figure 3.19: Daily values of model output soil water under increasing of air temperature by 1˚C together with increasing LAI by 30% and simulated model output evapotranspiration under original conditions at Hartheim Scots pine forest for the period (2005-2007)

II. Increasing temperature by 1 ˚C and decreasing LAI by 30 %

The scenario's aim is to illustrate the effect of these two factors on the forest water balance through evapotranspiration and soil water content.

Compared to the previous scenario, the rate of evapotranspiration is expected to reduce due to decreasing the forest's LAI by 30% through declining the rate of transpiration, the less the number of trees, the less the leaves to evaporate water from their stomata, Figure (3.20).

The maximum rate of evapotranspiration was in 2007 with 486 for the scenario of control and minimized to 446mm under the current scenario indicating 40mm reduction. In 2006, the rate decreased from 398mm to 382, while 2005 showed a reduction of 37mm in the rate of annual EVAP with 442mm into 405mm.
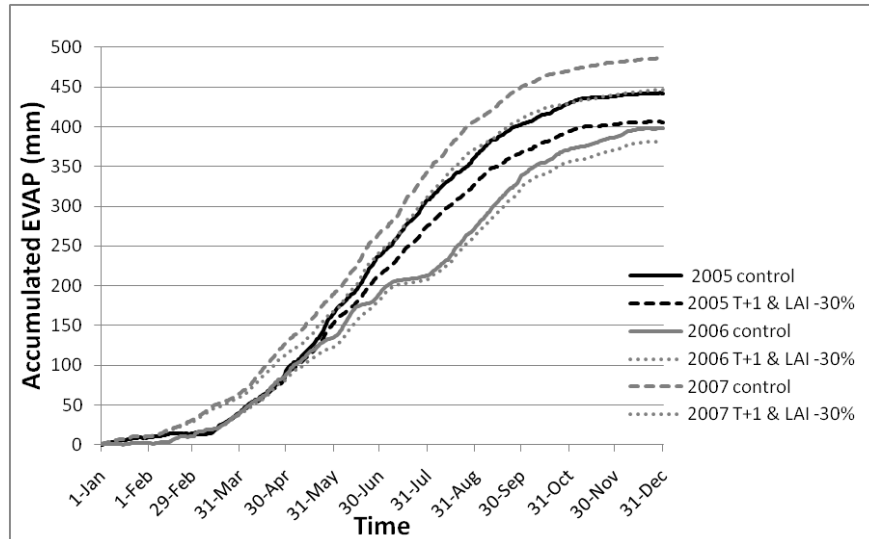

Figure 3.20: Summation of the daily values of evapotranspiration under increasing of air temperature by 1˚C together with decreasing LAI by 30% and simulated EVAP of the scenario of control at Hartheim Scots pine forest for the period (2005-2007)

This scenario shows an increase in soil water content compared to model output under original conditions (Figure 3.21). Both in 2005 and 2007, the forest has sufficient amount of water in the soil and including no days with water deficiency during the whole year due to forest' leaf area index LAI by 30% and getting more water to the rest of the trees despite increasing daily temperature by 1˚C. Nevertheless, the number of the days with water shortage decreased from 48 for the original conditions to 40 days in 2006 indicating only 8 days lees. Therefore, the forest still suffered from water deficiency in 2006 and especially during summer period, because of the very low amount of precipitation during summer 2006.
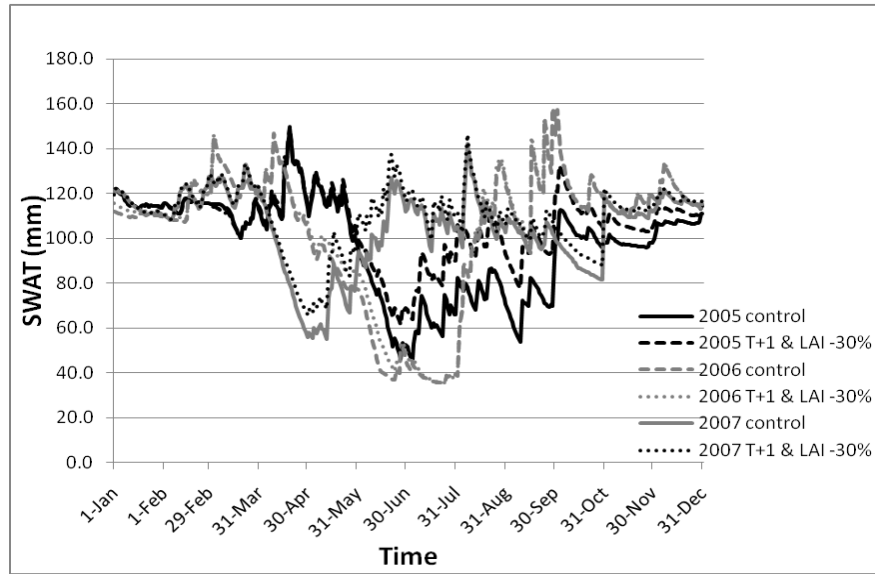
Figure 3.21: Daily values of model output soil water under increasing of air temperature by 1˚C together with decreasing LAI by 30% and simulated model SWAT under the original conditions at Hartheim Scots pine forest for the period (2005-2007)

3.1.5. Transpiration index under all scenarios

BROOK90 has been applied to simulate the transpiration index (T_{act}/T_{pot}) with different scenarios to investigate the probability of drought occurrence and water shortage at Hartheim Scot pine forest. Figure 3.22 shows daily values of transpiration index for different scenarios for the period 2004 to 2007s. The annual plots for all scenarios varied, in 2005 and 2006 the plots start from the 1st of May until the 31st of August, while in 2007 the plots start in the 1st of April to the 30th of June and this is mainly due to the difference in weather conditions for each year, availability of the water in the soil and the vegetation cover.
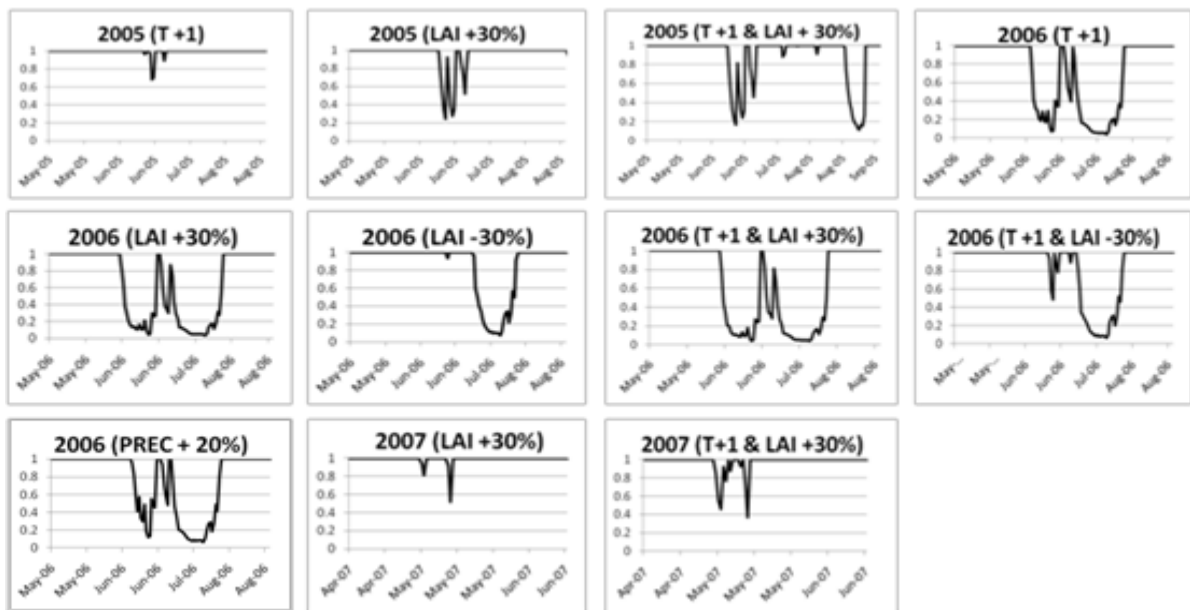

Figure 3.22: Daily values of the transpiration index T_{act}/T_{pot} for Hartheim Scots pine forest under all scenarios, period: (2005-2007). X- axis (Time), Y-axis (T_{act}/T_{pot}).

Because of the thinning of the Hartheim forest about 58% in 2003 (Wellpott et al, 2005) there was no threatened for drought to occur in 2004, and it's obvious from the figure 3.9 that 2004 would have stressed if the forest would not have been thinned and indicating a great role of thinning in maintaining of water in the soil. The forest returned already in the second year after applying the 30% thinning scenario to the same level as before thinning. The number of the days with Tact/Tpot <1 for different scenarios ranged between 0 days in 2004 for the whole scenarios into 85 days for the scenario of increasing daily maximum air temperature by 1°C combined with increasing MAXLAI by 30% for the year 2006. The higher number of the days T_{act}/T_{pot} <1 is mainly because of the very limited amount of rainfall during the beginning of the growing season from (April to July) in 2006 with only 135mm during that period; see Figures 3.3 and 3.8.

Although the number of the days with T_{act}/T_{pot} < 1 in 2006 fors the scenario of increasing temperature by 1°C combined with increasing MAXLAI by 30% reached to 85 days, the year is still not suffering from drought occurrence, because of the percentage of the days with T_{act}/T_{pot} < 1 was less than the threaten value according to Wellpott et al (2005).

Table 3.1: Total annual values of the simulated EVAP (E_{mod}), actual EVAP (E_{act}), and the all different scenarios plus mean annual global incoming irradiation (G), total annual precipitation (P) and mean annual air temperature (T) at Hartheim Scots pine forest for the period (2004 to 2007).

Date	E_{mod}	E_{act}	E LAI +30%	E LAI -30%	E T+1 °C	E PREC+20%	E T+1 & LAI +30%	E T+1 & LAI -30%	G (Mj/m²)	P (mm)	T (°C)
2004	485	395	541	417	519	503	576	450	12	706	11.2
2005	422	387	482	381	467	462	500	405	12.7	543	10.8
2006	399	344	431	362	421	427	455	382	13.1	688	11.2
2007	387	414	543	419	516	507	571	446	12.4	592	11.7

3.2. Norunda forest:

All the scenarios covered in Hartheim Scot pine forest were repeated for Norunda forest in order to compare them with Hartheim forest. Therefore, each scenario will display its results directly without any descriptions about the scenario.

3.2.1. Scenario 1: Control (Under current conditions)

The correlation between measured EVAP in x-axis and simulated BROOK90 EVAP in y-axis is shown in Figure 3.23. The figure shows a significant difference between the measured and simulated EVAP with slope of 1.2 representing an overestimation of the values from the model for estimating EVAP for the Norunda forest with offset of 0.6mm.

The coefficient of determination R^2 for the relationship between measured and simulated EVAP was 0.26 indicating an imperceptible correspondence. Most of the high values of EVAP were recorded during the summer with peak on 19th of June in 2004 with value of 7.38mm. Feasible reasons behind the high values are high amount of incoming solar

irradiation, high daily air temperature (see figure 3.25 and appendix A.2), low humidity and high transpiration.

Most of the maximum values of simulated EVAP lie between 3mm and 6mm, while for the eddy-flux EVAP, they occurred between 1.5mm and 3mm indicating a large discrepancy between the measured and model outputs.
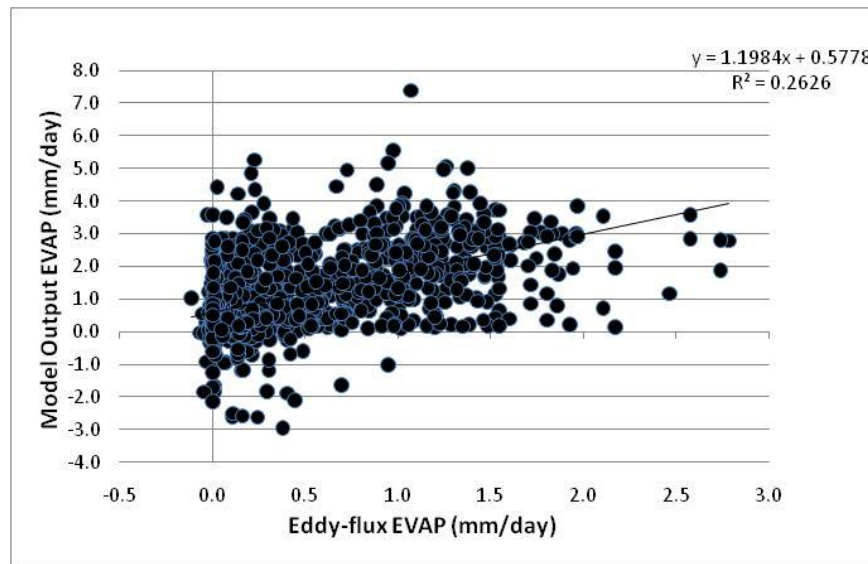

Figure 3.23: Scatterplot between eddy-flux and the simulated BROOK90 evapotranspiration at Norunda forest for the period 2003 to 2005.

Figure 3.24 describes the annual values of eddy-flux EVAP "the measured EVAP" compared to the modeled EVAP. The figure shows a significant inconsistency between the measured and simulated EVAP.

The highest value of the simulated evapotranspiration was estimated in 2005 with 459mm, while the highest annual value of eddy-flux EVAP was for 2003 with 214mm. The annual rate of the modeled EVAP in 2004 reached to 426mm, while the measured value reached to 194mm. In 2005, accumulated measured EVAP reached it is maximum value at the beginning of September with 150mm and stayed at the same level until the end of the year.
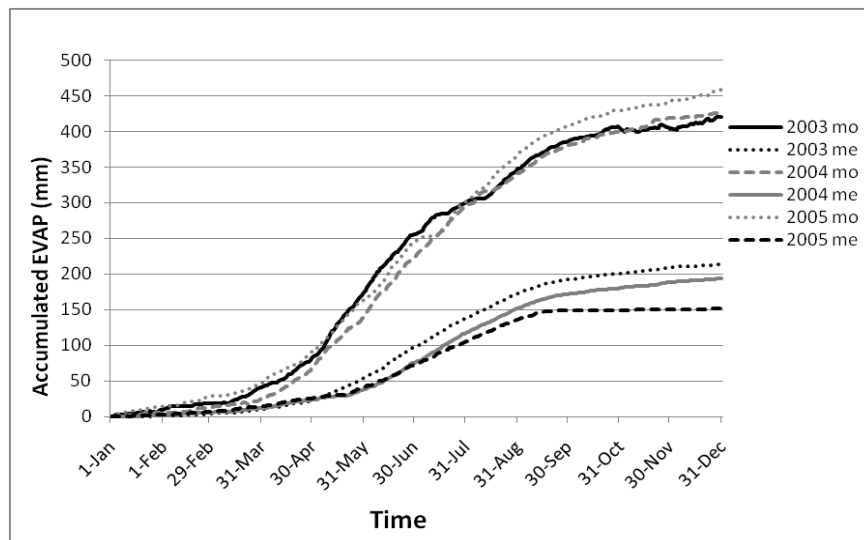
Figure 3.24: Summation of the daily values of measured evapotranspiration and simulated model output evapotranspiration under original conditions at Norunda forest for the period (2003-2005).

Mean monthly temperature, monthly total precipitation and simulated evapotranspiration are shown in Figure 3.25. The maximum monthly value of the modeled EVAP was for May 2003 with value of 92mm. The highest value of the mean monthly air temperature was recorded in August 2003 with 18.8°C with minimum value recording in March 2003 with -5.6°C. The minimum value of the monthly modeled EVAP was for November 2003 with value of -1.7mm.
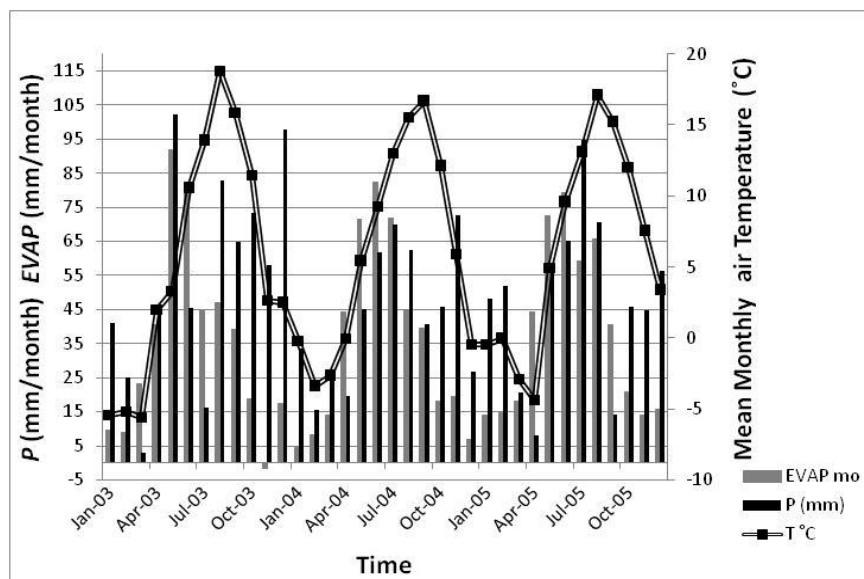

Figure 3.25: Total monthly evapotranspiration E for the scenario of control in comparing to mean monthly air temperature T and total monthly precipitation P at Norunda forest for the period (2003 to 2005)

May 2003 was recorded with highest value of total monthly precipitation with 102mm, while the minimum value was for March 2003 with only 3mm.
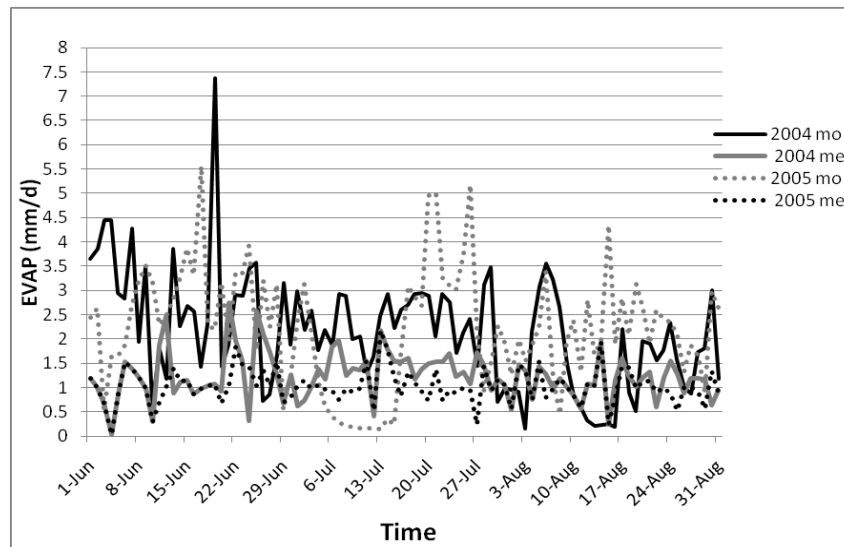
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Figure 3.26: Daily summer values of eddy-flux and simulated evapotranspiration at Norunda forest for the period (2004-2005)

The fluctuation of the distribution of the simulated and measured EVAP for summer 2004 and 2005 is shown in Figure 3.26. The figure shows a significant difference between the measured and model output EVAP. The maximum value of the simulated EVAP has been estimted in 19th of Jun 2004 with 7.4mm. 4th of Jun, both in 2004 and 2005 showed the minimum value of the eddy-flux EVAP with value of 0.03mm.

Figure 3.27 shows the fluctuation of both the measured and the simulated BROOK90 evapotranspiration in winter. In reality, the rate should be more or less stable due to the limited amount of incoming irradiation and high humidity accompanied with low daily air temperature. But in our study, there is a significant variation of simulated EVAP during winter. The maximum value of the simulated EVAP was recorded in the 5th of December 2004 with value of 4.22mm. While the minimum value of the modeled EVAP was recorded in 9th of January 2004 with value of -2.13mm.
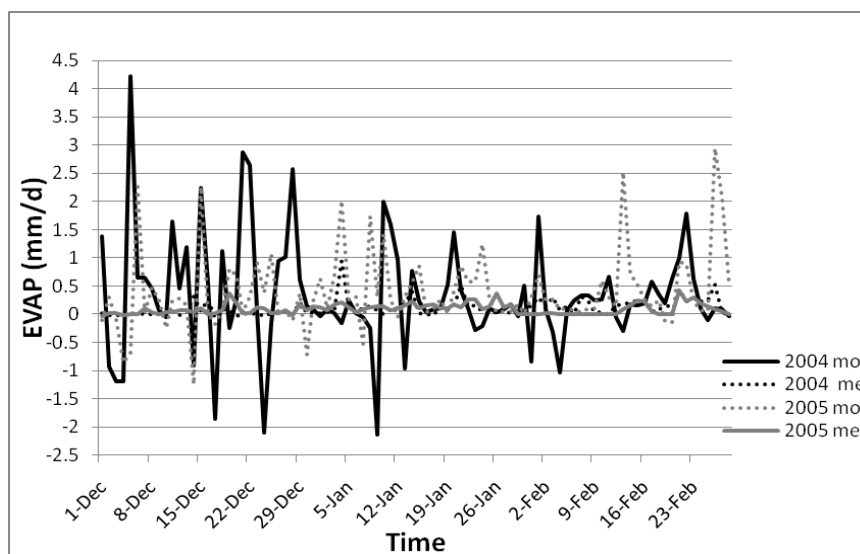

Figure 3.27: Daily winter values of eddy-flux and simulated model outputs evapotranspiration at Norunda forest for the period (2005-2006)

The correlation between measured and simulated model output SWAT for the upper (40cm) soil layer shown in Figure 3.28. R^2 of 0.4 indicating an agreeable correlation between measured and simulated SWAT. The slope of 0.6 represents an underestimation of the values from the model for estimating SWAT for Norunda forest as most of the highest values of the measured SWAT were occurred between 100mm and 130mm, while for the simulated SWAT, they were occurred between 80mm and 100mm. The figure shows an offset of 18 L/m^2.
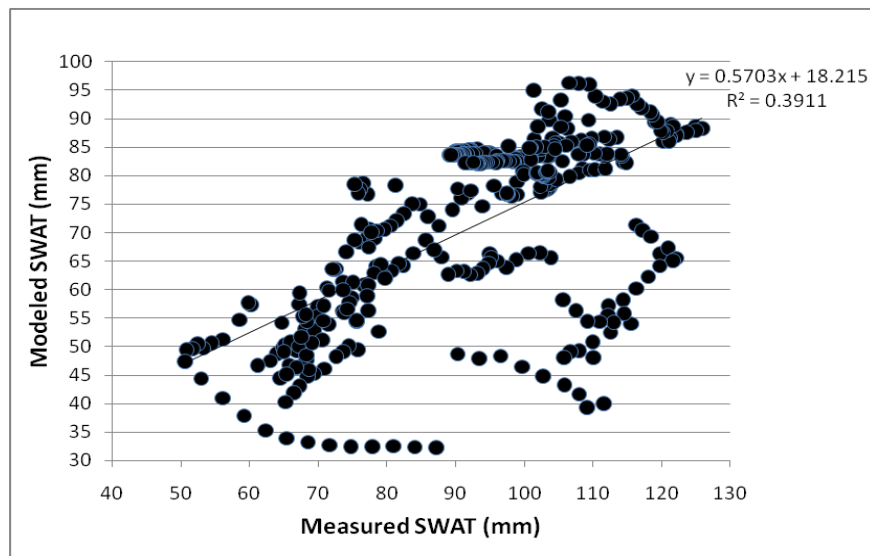
Figure 3.28: Scatterplot between measured soil water (SWAT) and simulated model soil water from the model at Norunda forest for the year 2004

The comparison between total daily precipitation and the soil water content is shown in Figure 3.29. The soil water content for the modeled SWAT was more or less stable from the beginning of the year until March, then started fluctuating and dropping reaching to its minimum value in 12th and 13th of August during the whole year with 32mm. Despite this low value, but it does not reach to the wilting point which was 22mm for the depth 40cm by (Lundin et al, 1999). Soon after that, the amount raises and reached to 85mm by the end of the year (Figure 3.29).

The figure shows that measured SWAT fluctuated more and reached its peak at 22nd of March with 126mm. This value is about 29mm less than the field capacity of Norunda forest which is 158mm. Later on, the amount of the water dropped reaching to its minimum value with 51mm in 3rd and 4th of August, soon after that, the amount of water content in the soil increased as a sharp line reaching to its highest value in 31st of August with 122mm.
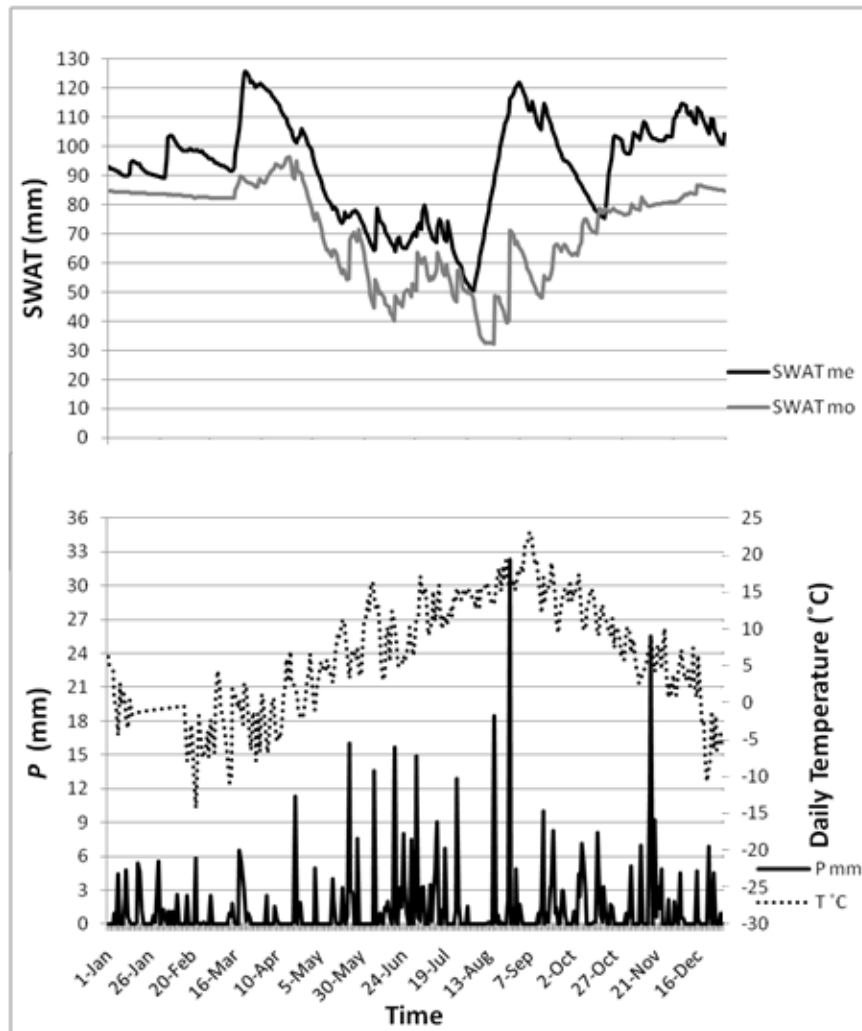
Figure 3.29: Daily values of measured and model output soil water for the upper (40cm) in comparing with total daily precipitation and mean daily air temperature at Norunda forest for the year 2004.

Figure 3.30 show that the modeled SWAT has lowest values than measured SWAT during the whole summer period. The figure shows that no days were recorded with water deficiency as no day has water content in the soil below the wilting point neither for simulated, nor for measured SWAT.
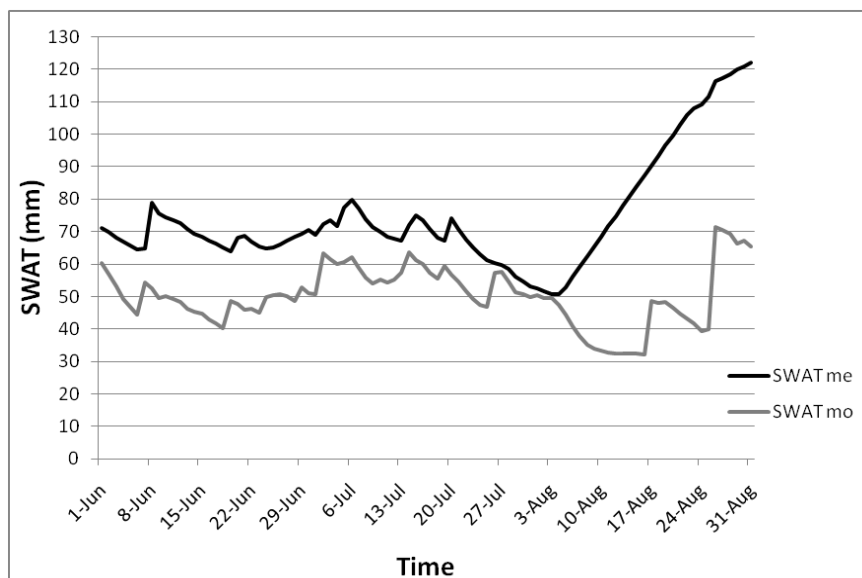
Figure 3.30: Daily summer values of measured and the simulated model soil water at Norunda forest for the year 2004

Figure 3.31 shows the relation between sap-flow and modeled BROOK90 transpiration for the period 2004-2005. The Figure shows stronger correlation in 2004 compared to 2005 with R^2 of 0.4 and 0.3 for the years 2004 and 2005 respectively. The figure shows an overestimating of the values from the model for estimating TRANS for Norunda forest with 1.7 and 1.1 for the years 2004 and 2005, respectively.
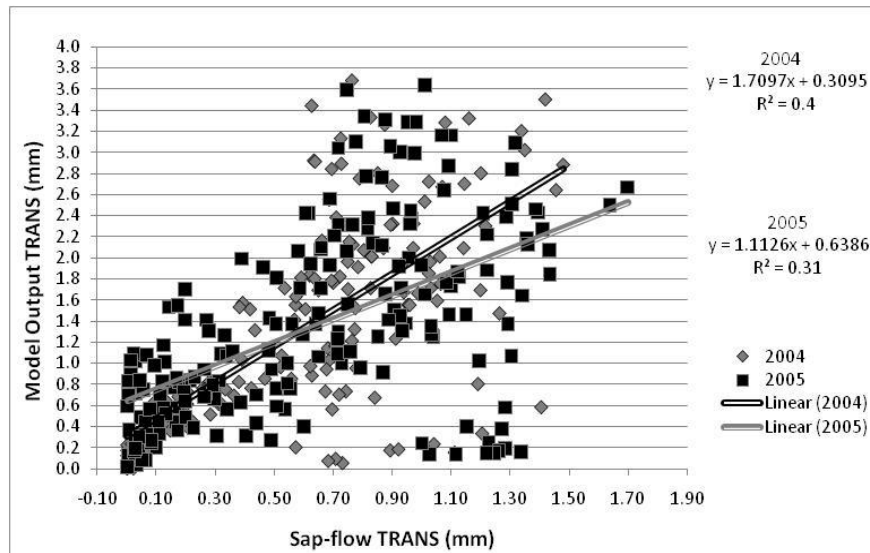
Figure 3.31: Scatterplot between measured and simulated BROOK90 transpiration at Norunda forest for the period (2004 to 2005).

The difference in the amount of transpiration rate during the growing season between sap-flow and simulated TRANS is shown in Figure 3.32. In 2004, the measurement of transpiration started on 6th of May compared to 6th of April in 2005 and stopped earlier in 2004, on 18th of October compared to 22nd in 2005. The figure shows a variation between the total rate of the measured and modeled TRANS in which for the modeled transpiration, it reached to 224mm and 266mm for the years 2004 and 2005 respectively. While for sap-flow TRANS, it reached 101mm and 125mm for the years 2004 and 2005 respectively. By comparison and for both measured and modeled TRANS, 2005 characterized by having more transpiration than 2004.
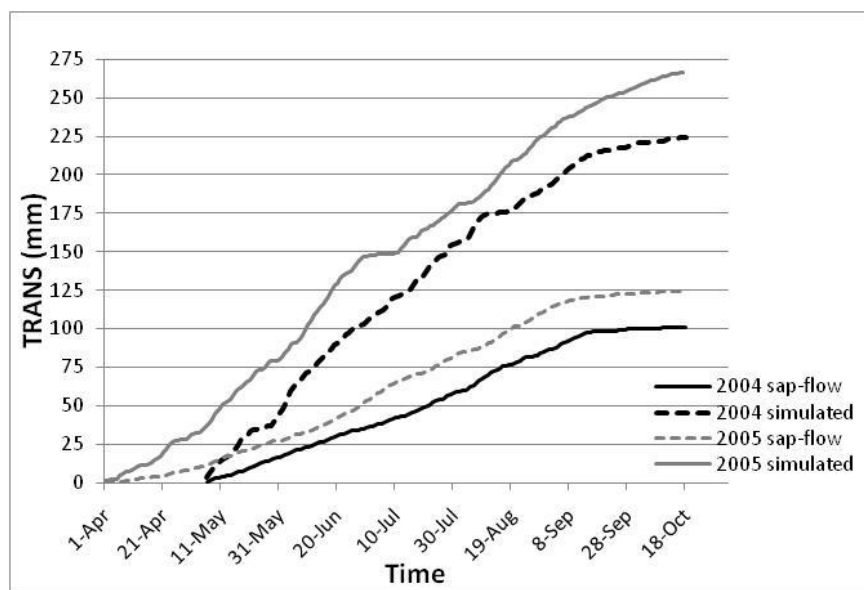

Figure 3.32: Summation of the daily values of sap-flow compared to simulated BROOK90 transpiration at Norunda forest for the period (2003-2005).

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The daily values of transpiration index of each year from 2003 to 2005 is shown in Figure 3.33. The annual plots started from the 1st of June to the 31st of August which reperesnt the period where water deficiency is more common under current conditions.

The number of the days with T_{act}/T_{pot} less than 1 were ranged between 12 days in 2004 and 33 days in 2003. In the studying period, 2004 and 2005 showed less water defficiency than 2003.
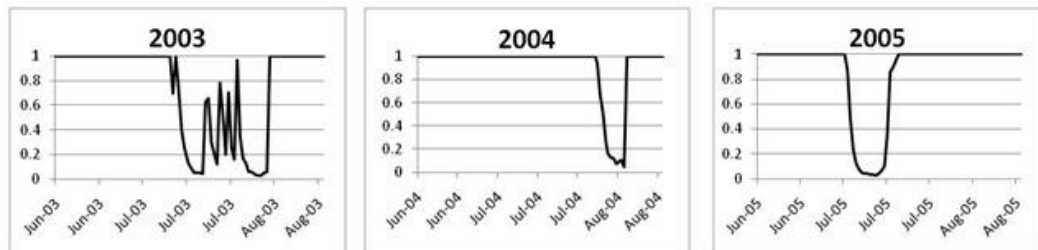
Figure 3.33: Daily values (June to December) of transpiration index T_{act}/T_{pot} at Norunda forest for the period (2003-2005).

3.2.2. Scenario 2: Management conditions

By considering the values of total daily precipitation that was used in the model as an input data for the control scenario and the following scenarios has been taken from the meteorological station inside the forest, we will try to compare the results of simulated scenarios applied in our study with scenario of original conditions.

I. Increasing LAI by 30%

Figure 3.34 shows a slight difference between the model output EVAP under original conditions and with increasing the LAI by 30%. By looking to the graph, it is obvious that all the lines have converged during the whole year, in other word; most of them approximately have values between 400mm to 450mm except for 2005 with the scenario of increasing LAI by 30% having maximum annual EVAP of 489mm.
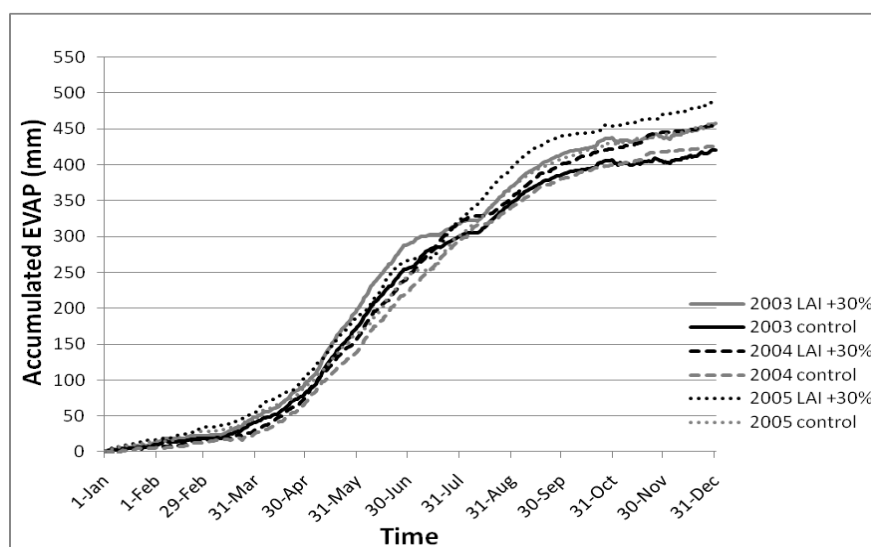
Figure 3.34: Summation of the daily values of evapotranspiration under increasing LAI by 30% and simulated model output evapotranspiration under original conditions at Norunda forest for the period (2003-2005)

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Figure 3.35 illustrates soil water content for the upper soil layers of (40cm) for the year 2004 of the modeled SWAT under increasing LAI by 30% against control. In both scenarios, the soil water content fairly has the same fluctuation until the beginning of summer and then a small difference occurred in which the scenario of increasing LAI by 30% has lower soil water content due to increase the number of trees which increase the demand of water. Later on, the amount of the water in the soil tends to rise as the summer ends, reduction in evaporation and transpiration, increasing of rainfall, decreasing daily air temperature and increasing humidity.

Generally, the water content in the soil decreased by 7% compared to control. Despite increasing LAI by 30%, in which the demand of the water will increase as more roots will distribute in the soil, no days were recorded with water shortage as the minimum value of the soil water content under the current scenario was recorded in 12th of August with value of 32mm, which is about 10mm above the wilting point.

Figure 3.35: Daily values of model output soil water under original conditions and simulated model soil water with increasing LAI by 30% at Norunda forest for the year 2004.

II. Decreasing LAI by 30%

The difference in the annual values of the evapotranspiration for both the scenario of control and the scenario of decreasing LAI by 30% is shown in Figure 3.36. The figure shows a slight decreasing in the annual rate of EVAP under this scenario compared to control. The highest value of the simulated EVAP under the current scenario was recorded in 2005 with value of 411mm indicating 47mm declining. Both in 2003 and 2004, the rate decreased about 48mm and 49mm respectively from 420mm into 372mm in 2003 and from 425mm into 376mm in 2004.

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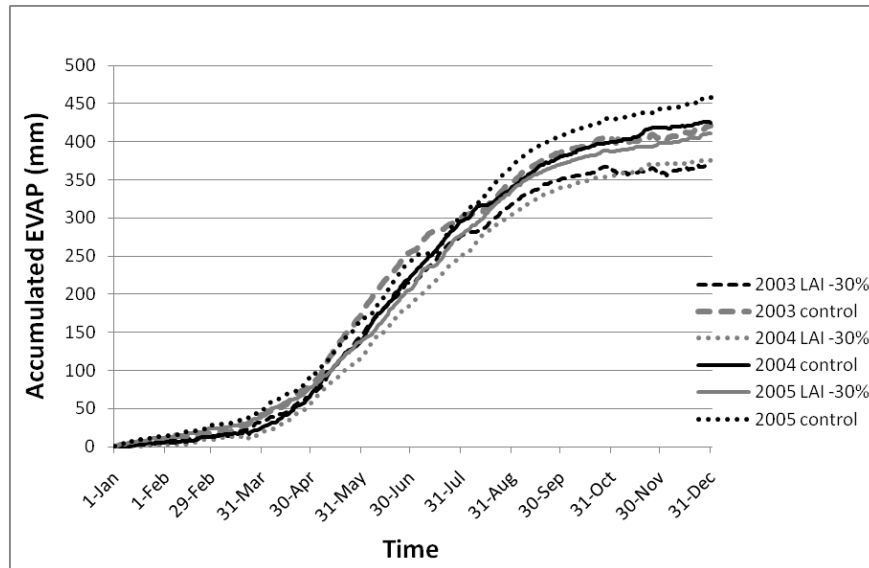
Figure 3.36: Summation of the daily values of evapotranspiration under decreasing LAI by 30% and simulated model output EVAP under original conditions at Norunda forest for the period (2003-2005).

Soil water content tends to increase under this scenario, Figure 3.37. The variation between measured and simulated model output under this scenario started from the beginning of summer. Figure 3.37 shows a significant increasing in the amount of soil water content during summer; this is mainly because decreasing LAI by 30% results the reduction in the transpiration and the rainfall interception which is the water evaporates from the canopy vegetation directly before it reaches to the ground. Hence, declining of the competition from the tree roots for water and helps the soil to accumulate more water.

Under the current scenario, the water content in the soil increased by 13% as average. Under the current scenario, the minimum value of the water content that was recorded in 12th and 13th of August was increased by 18mm reaching to approximately 50mm for both days. Despite this increasing, the forest still does not reached to the point where the soil has its maximum amount of water content, In other words, the field capacity.

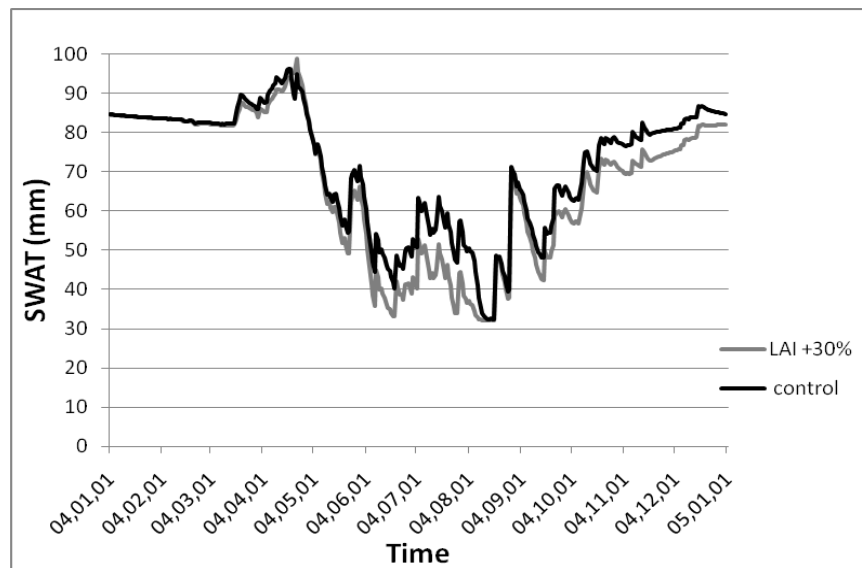*Figure 3.37: Daily values of model output soil water under original conditions and simulated SWAT with decreasing LAI by 30% at Norunda forest for the year 2004.*

3.2.3. Scenario 3: Climate change
I.   Increasing maximum daily air temperature by 1 °C

The influence of increasing daily maximum temperature by 1°C on the rate of evapotranspiration in compare to the scenario of original conditions is given in Figure 3.38. Generally, not much difference occurred between the both scenarios in the whole investigated period. The maximum value of evapotranspiration under this was recorded in 2005 with value of 477mm compared to 455mm and 445mm for the years 2003 and 2004 respectively, indicating only 19mm increasing in 2005, while 2003 and 2004 showed rising of 35mm and 25mm respectively in comparing to the scenario of original conditions.
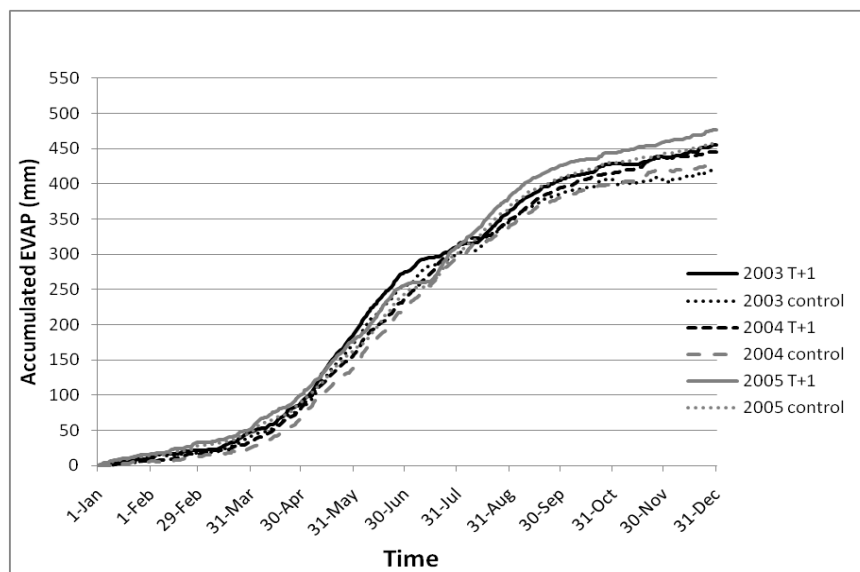
Figure 3.38: Summation of the daily values of evapotranspiration under increasing daily maximum air temperature by 1°C and simulated model outputs EVAP under the original conditions at Norunda forest for the period (2003-2005)

The difference between the current scenario and the scenario of control in the amount of water content in the soil is shown in Figure 3.39. It is clear from the figure that the quantity of soil water content diminished by 7% compared to control. Just a 7% reduction in soil water content and with soil moisture above wilting point is no reason for any limitation in transpiration. An increase in maximum daily air temperature by 1°C affects vapor pressure deficit and thus increases transpiration which then decreases soil water content. Consequently, it will influence on the water balance of the forest.

Despite this reduction in the soil water content, the forest still has sufficient amount of water and the minimum value does not reached to the wilting point and even does not passed the minimum value of control indicating no days with water shortage.
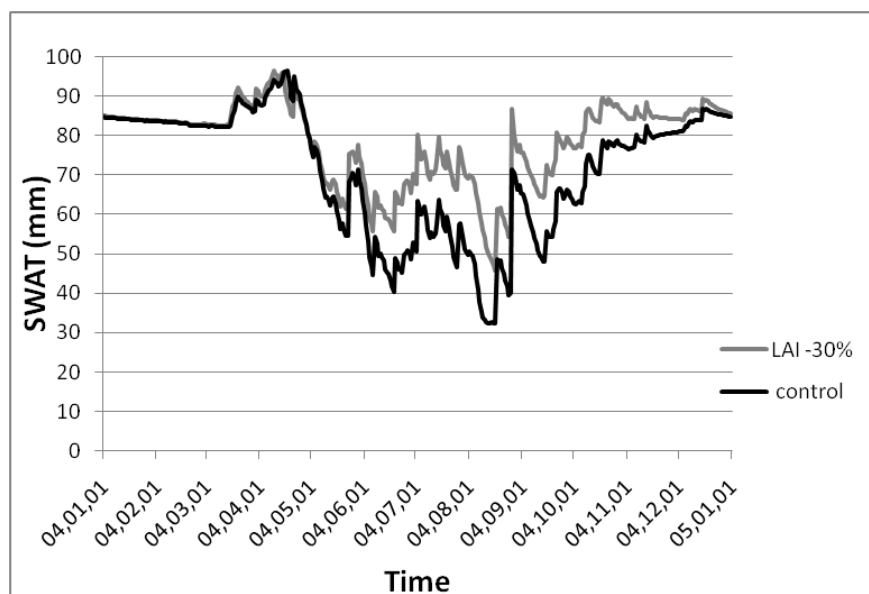
Figure 3.39: Daily values of model output soil water under original conditions and simulated SWAT with increasing daily maximum air temperature by 1˚C at Norunda forest for the year 2004.

II. Increasing total daily precipitation by 20 %

Increasing total daily rainfall by 20% and its impacts on the rate of evapotranspiration is shown in Figure 3.40. The figure clarifies a small distinction between both this scenario and the scenario of control. The annual rate of EVAP increased by 20mm, 30mm and 31mm for the years 2003, 2004 and 2005 respectively in comparing to control with highest value in 2005 reaching 489mm. The increase in the rate of EVAP is also due to increase in interception due to more rainfall.
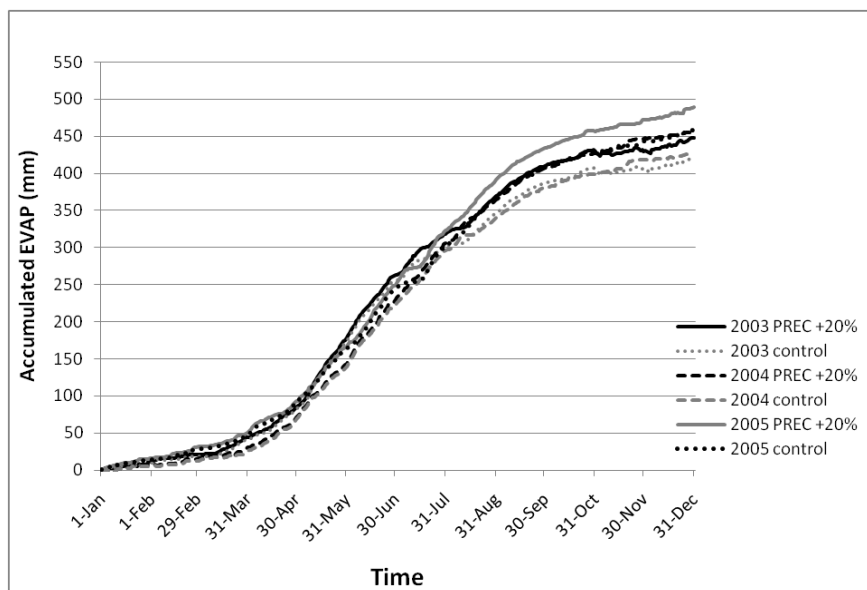
Figure 3.40: Summation of the daily values of evapotranspiration under increasing total daily precipitation by 20% and simulated EVAP of the scenario of control at Norunda forest for the period (2003-2005)

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Figure 3.41 shows the comparison in soil water content between this scenario and the scenario of control. A very small difference occurred between the two scenarios indicating that the increased in the daily precipitation by 20% will not lead to waterlogging or soil erosion since little amount of water raised expressed by 5.5% as average. Despite this increasing, the water in the soil does not reach the field capacity "the maximum amount of water that soil can hold" which is 158mm for the depth 40cm at Norunda site.

Though, increasing rainfall by 20% and adding more water to the forest to prevent the forest from water shortage, approximately no change happened in the minimum value of water content as it increased by only 2mm. on the other side, the highest value reached to 100mm indicating 5mm increase compared to control.
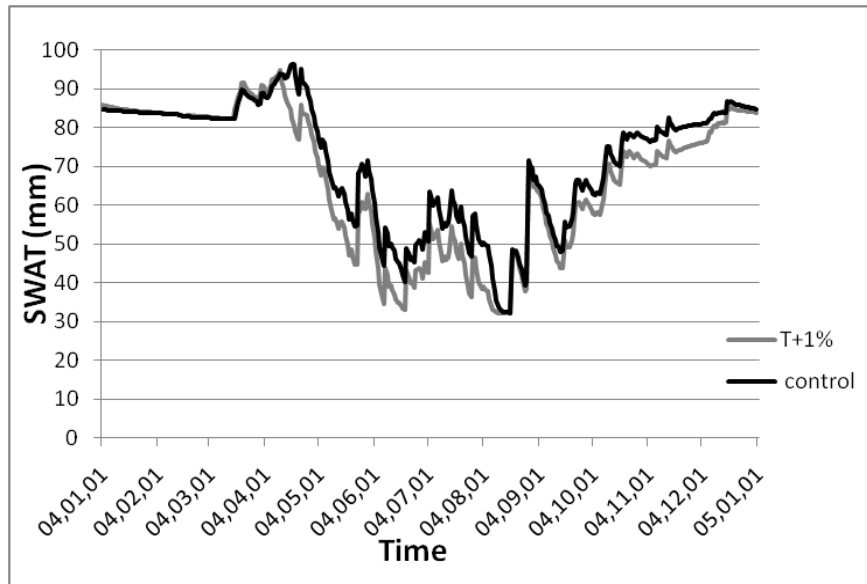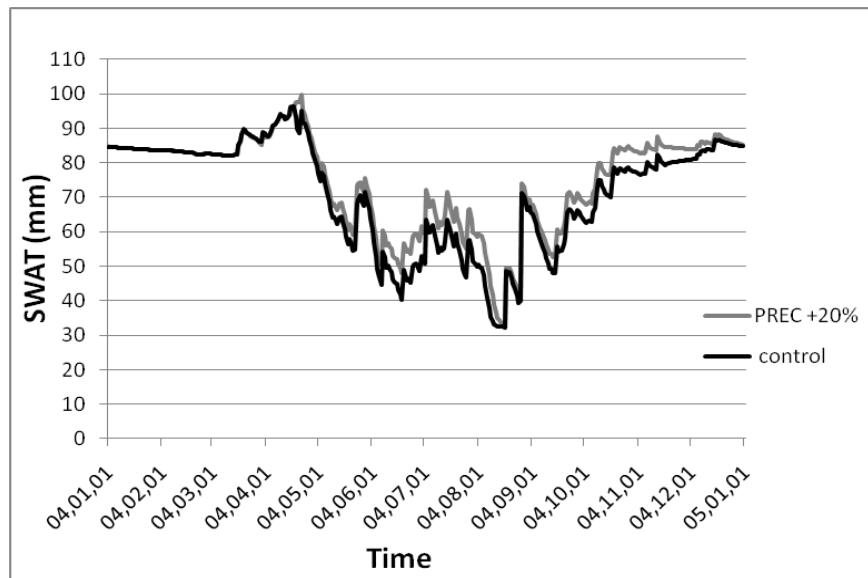

Figure 3.41: Daily values of model output soil water under original conditions and simulated SWAT with increasing total daily precipitation by 20% at Norunda forest for the year 2004.

3.2.4. Scenario 4: Combination of scenario 2 and 3

I. Increasing daily maximum temperature by 1 ˚C with increasing LAI by 30 %

This scenario describes the influence of the combination of two factors together which are increasing daily maximum temperature combining with increasing LAI by 30% on the rate of evapotranspiration and soil water content of the forest. Figure 3.42 below shows the summation of the daily values of EVAP for the current scenario against the scenario of control.

In the whole our investigating periods, a small change occurred between the two scenarios and having approximately the same amount of evapotranspiration during summer despite increasing air temperature and LAI by 30%, mainly because of the limitation of water in the soil due low amount of rainfall during summer. Once it rain again, the rate of evapotranspiration tends to increase. The rate of annual EVAP increased by 64mm, 53mm and 43mm for the years 2003, 2004 and 2005, respectively in comparing to the scenario of control with maximum value of EVAP recorded in

2005 with value of 501mm, while 2003 and 2004 showed annual EVAP of 478mm and 484 respectively.

During the beginning of summer, both 2003 and 2005 were recorded with higher values of EVAP under the current scenario in comparing to 2004 reached to value of above 216mm and 210mm for the years 2003 and 2005 respectively with 184mm for the year 2004.

Figure 3.42: Summation of the daily values of evapotranspiration under increasing daily maximum temperature by 1˚C and LAI by 30% and simulated model output EVAP under original conditions at Norunda forest for the period (2003-2005)

Figure 3.43 explains the comparison in soil water content between this scenario and the scenario of original conditions. The figure shows a significant decreasing in soil compared to the original conditions. Possible reason is because two main factors combined together and facilitated the rate of evapotranspiration to increase. Therefore more water was lost and the soil became with less water content. Hence, the competition for water will increase leading to increase the possibility of drought occurrence.

As the summer started, the amount of water in the soil under the current scenario tended to drop reaching to its minimum values in the beginning of June and fluctuated until the end of September then increased reaching to 78mm by the end of the year.

Despite that two factor combined together, no days were recorded with water shortage as no day was reached below the wilting point.

Figure 3.43: Daily values of model output soil water under the original conditions and simulated SWAT with increasing daily maximum temperature 1˚C together with LAI by 30% at Norunda forest for the year 2004.

II. Increasing daily maximum temperature by 1˚C with decreasing LAI by 30 %

The annual ratios of evapotranspiration under this scenario in comparing to the scenario of control are given in Figure 3.44. Despite increasing 1˚C to the daily maximum air temperature, the ratio of EVAP became stable having approximately the same amount as in control, because of the removing of 30% of the forest stand. So, in this case EVAP will depend mainly on soil evaporation since the forest thinned and the transpiration will have low rate.

In general, our investigation period and under both scenario, the forest has approximately the same amount of evapotranspiration and following the same line. The annual rate of EVAP decreased by 12mm, 19mm and 21mm for the years 2003, 2004 and 2005 respectively in comparing control. This indicates that thinning of the forest by 30% has greater effect on the rate of EVAP than increasing air temperature by 1˚C.
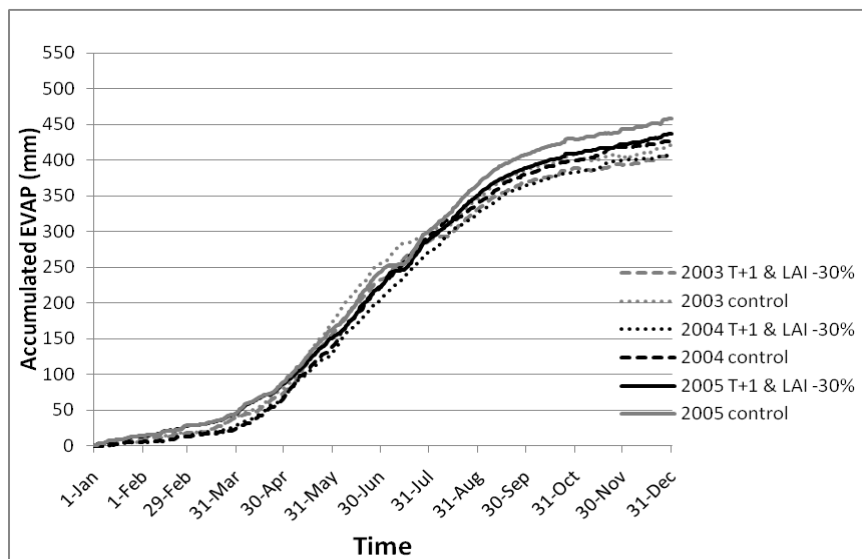
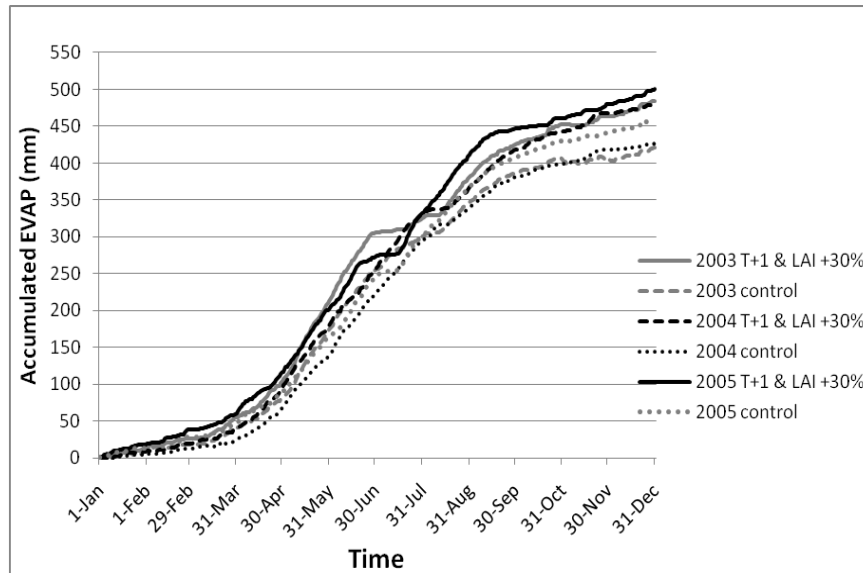*Figure 3.44: Summation of the daily values of evapotranspiration under increasing daily maximum temperature by 1˚C together with decreasing LAI by 30% and EVAP of control at Norunda forest for the period (2003-2005)*

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Figure 3.45 describes the comparison of soil water content between this scenario and the scenario of control for the upper 40cm soil layer. The Figure shows a small increasing in the amount of the water in the soil indicating 4.5% as an average during the whole year compared to the scenario of control.

The amount of water content in the soil tended to decrease from the beginning of the growing season despite decreasing 30% of forest's LAI and continued until the early summer having approximately the same amount as control. Later on, the amount increased until the end of summer then became the same as control with small difference until the end of the year.
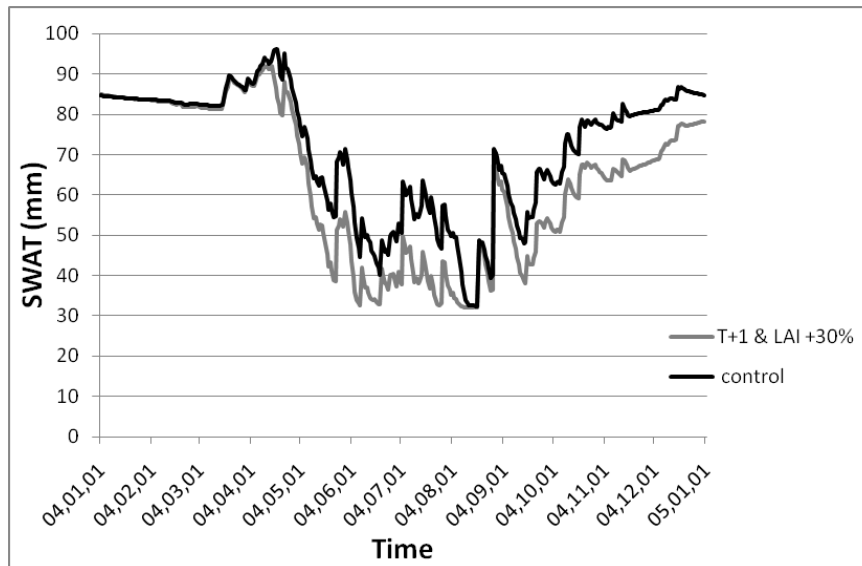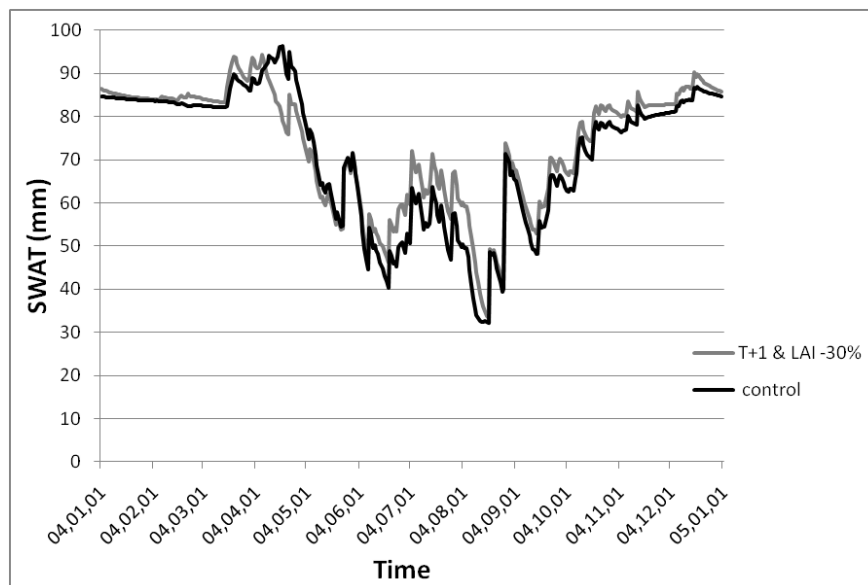

Figure 3.45: Daily values of model output soil water under the original conditions and simulated SWAT with increasing daily maximum temperature 1˚C together with decreasing LAI by 30% at Norunda forest for the year 2004.

3.2.5. Transpiration index under all scenarios

Daily values of transpiration index (T_{act}/T_{pot}) with different scenarios at Norunda forest for the period 2003-2005 are shown in Figure 3.46. Under the whole scenarios, the possibility of drought occurrence varies from year to year and from scenario to scenario. The number of the days with $T_{act}/T_{pot} <1$ for all scenarios ranged between 7 days for the scenario of increasing daily maximum temperature by 1˚C combined with decreasing LAI by 30% for the year 2004 to 136 days for the scenario of increasing daily maximum temperature by 1˚C combined with increasing LAI by 30% for the year 2005.

In our investigation study and under all scenarios, 2005 has the longest period with $T_{act}/T_{pot} <1$ which was for the scenario of increasing daily maximum temperature by 1˚C combined with increasing LAI by 30% with 136 days starting from the 9th of June until the 22nd of October, while 2004 shows the shortest period of $T_{act}/T_{pot} <1$ for the scenario of increasing daily maximum air temperature by 1˚C combined with decreasing LAI by 30% with only 7 days.

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The results showed that both in 2003 and 2005, the percentage of the days with values of T_{act}/T_{pot} <1 for the scenario of increasing daily maximum air temperature by 1˚C combined with increasing LAI by 30% in 2003 (32%) and the scenario of increasing daily maximum air temperature by 1˚C (33%), increasing LAI by 30% (33%) and increasing daily maximum air temperature by 1˚C combined with increasing LAI by 30% in 2005 (37%) were exceeded the threshold values which is 25% (Wellpott et al, 2005) indicating drought occurrence in that scenarios.
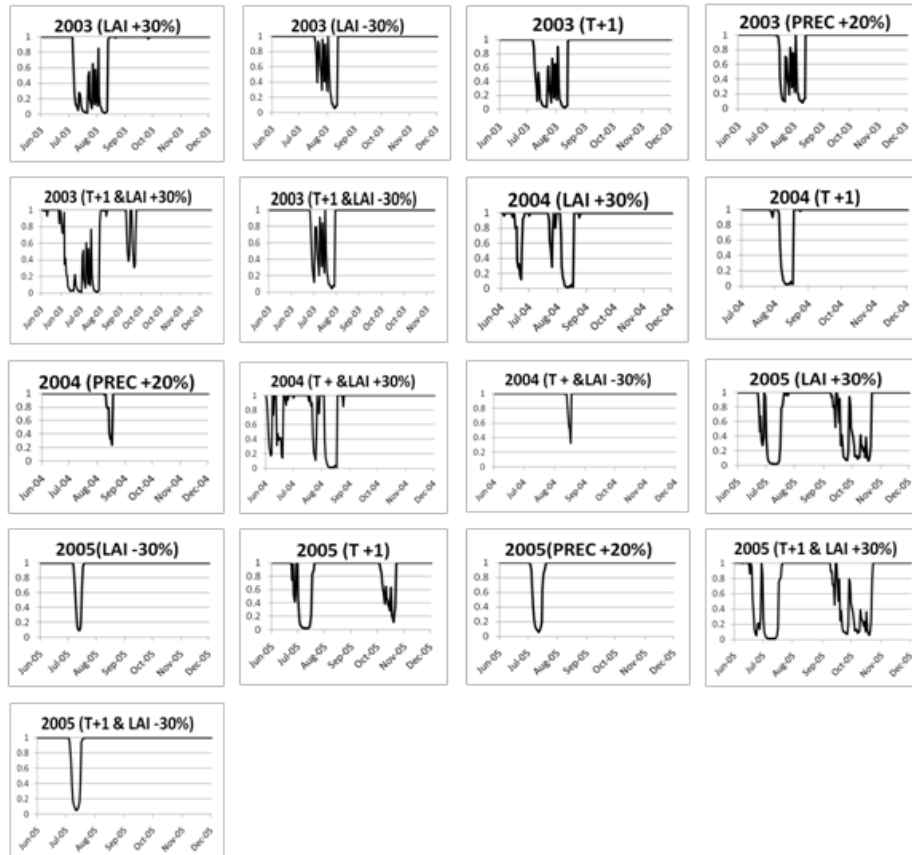
Figure 3.46: Daily values of the transpiration index T_{act}/T_{pot} at Norunda forest under all different scenarios for the period: (2003-2005)

Table 3.4: Total annual values of EVAP for original simulation (E_{mod}), actual measurement (E_{act}) and EVAP for the all different scenarios plus the mean annual incoming solar irradiation (G) mean annual temperature (T) and total annual precipitation (P) at Norunda forest for the period (2003-2005).

Date	E_{mod}	E_{act}	E LAI +30%	E LAI -30%	E T+1 ˚C	E PREC+20%	E T+1 & LAI +30%	E T+1 & LAI -30%	G (Mj/m²)	P (mm)	T (˚C)
2003	421	214	457	372	445	448	484	408	9.4	662	5.4
2004	425	194	454	376	455	455	478	406	9.2	520	5.9
2005	459	152	489	411	477	489	501	437	9.9	577	6.3

4. Discussion

4.1. Introduction

This chapter comprises the discussion of the results obtained from the two forests with focusing on the issues concerned to the data used in the model and the simulated results obtained by the system with concentrating on the hydrological system and the stress of forest that caused by water deficiency and trying to connect them to the expected future climate change.

4.2. Validation

The measured data from both sites were used to evaluate the simulated model output results. The uncertainty between the simulated and the model output results could be as a result of systematic errors, model parameterization and inaccuracy in the measurement data.

4.3. BROOK90 Model

Input data: To achieve results more accurate, the input data should be with high quality. Sometimes, uncertainty of the output results is as a consequence of the imprecise input data. Therefore, to attain perfect results and more reliable, it is better to take the measurements directly from the site.

In our investigation study, the two forests show difference in their output results depending on the input data, which one site has more accurate results than the other. For Hartheim site, all the measured data and program parameterization have been taken directly from the Meteorological institute, University of Freiburg in Germany. While in the other site, for Norunda case, most of them have taken from Lund University and the remaining parameters, for instance the field capacity and wilting point of the soil, and some other information about the location, canopy cover, and soil structure have been taken different published literature. Also the precipitation data has been taken from a meteorological station belongs to Swedish Meteorological and Hydrological Institute (SMHI) called "Films Kyrkby A" which is far from Norunda forest by 45km (North-East). Depending on the international standards for taking measurements from the nearest station which is 600-900 km^2 for the flat area (Garg, 1996); this station relies outside the standards.

4.4. Simulation scenarios

This part describes the comparison between the different scenarios and the scenario of control and displays their results to investigate the future climate change effects on the hydrological cycle and the water balance of the forests.

4.4.1. Scenario 1: Model verification

This scenario aims to compare results from the simulated BROOK90 model with actual measurement achieved from the both sites and to compare our results with some other publications to see how reliable the results are.

Starting from Hartheim site, the model showed a consistency between the simulation model outputs and the measurement values. Most of the values of the simulated modeled

evapotranspiration under current conditions were ranged between 0mm to 4mm with small values relying below or above this range. Compared to the other study of evapotranspiration by (Wellpott et al, 2005), it indicates that our results were very good and reliable.

The annual values for the simulated evapotranspiration under the scenario of control were 441mm, 400mm and 487mm for 2005, 2006 and 2007 respectively. A study of evapotranspiration on the same site by (Wellpott et al, 2005) and using the same model confirms our results and showed coincidence with annual rate of eddy covariance evapotranspiration for Hartheim forest with 388mm, 344mm and 413mm for the years 2005, 2006 and 2007 respectively.

The decrease in soil water content during summer is due to the high evapotranspiration. Transpiration is increasing due to increases in solar radiation during summer. Even with no clear decrease in rainfall during summer, the soil water content is decreasing; see Figure 3.7 and 3.29 and also A.1. and A.2 in Appendix

Later on, the amount of water in the soil increased and became in a steady state roughly until the end of the year. Many reasons combined behind this steady amount of water in that period, low transpiration, the limited amount of evaporation due to the restricted availability of the incoming solar irradiation during winter, low air temperature and high air humidity have also a great effect in declining the process of evapotranspiration and maintaining a stable amount of water in the soil

The number of the days where the Hartheim forest suffered from water shortage ranged between 0 days in 2004 for the whole scenarios to 85 days for the scenario of increasing maximum daily air temperature by 1°C together with increasing LAI by 30% in 2006. In comparing to a study by Wellpott et al in 2005 that simulated drought for 24 years, he found that the numbers were ranged 0 days to 105 days; our results showed less number of the days were drought more frequent to occur. This could be due to the shorter time period in our study.

In the other site, at Norunda forest, the results showed a clear discrepancy between the simulated model and eddy-flux values. Most of the daily values of evapotranspiration of the modeled EVAP were ranged between (-1mm to 4mm) with small numbers below or above this range. In a study of evapotranspiration in the same area by (Jansson et al, 1999) who used a different model than used in our study, most of the values of evapotranspiration were between (0mm – 4mm). The corresponding number indicates that on totals the BROOK-90 model is not so wrong, but the low R^2 is not confirming the variability in evaporation.

The maximum value of monthly simulated EVAP was recorded in May 2003 with 92mm. The possible reason is the high amount of precipitation in that month with 103mm compared to the rest of the studying period with sufficient amount of incoming solar radiation with 17 (MJ/m^2 d^{-1}) sees Figure A.2 in Appendix. The minimum value was recorded in November 2003 with -1.7mm, indicating the formation of condensation. This is mainly because of the low amount of incoming irradiation in that month with mean of 0.81 (MJ/m^{2}d^{-1}) see Figure A.2 in Appendix, together with low air temperature with 2.7°C and high humidity accompanied with

stop of plant transpiration during winter. Therefore, factors affecting or increasing the rate of evapotranspiration were low and were not sufficient despite adequate amount of rainfall.

The maximum value of the simulated daily EVAP at Norunda site was recorded in 19th of June 2004 with 7.4mm. This is mainly because of the high rainfall in that specific day with 16mm which is high value compared to the closest days accompanied with high air temperature together with sufficient amount of incoming solar irradiation, see table 3.2.

Table 3.2: Simulated BROOK90 and eddy-correlation EVAP with mean daily air temperature (T), total daily precipitation(P) and solar incoming irradiation (G) at Norunda forest for the period (17th Jun 04 to 21st June 04).

Date	EVAP (BROOK90)	EVAP Measured	T (˚C)	P (mm)	G (Mj/m²)
2004-06-17	1.43	1.0	12.3	0	13.7
2004-06-18	2.3	1.0	12.4	0.5	19.5
2004-06-19	7.38	1.1	10.3	16	19.2
2004-06-20	1.43	0.9	7.8	0.1	19.0
2004-06-21	1.89	2.7	5.1	0	21.8

In winter and at the same forest, the amount of simulated EVAP reached to 4.2mm in 5th of December 2003 which was very high value compared to the other values during that period. The possible reasons were high total daily rainfall, high daily air temperature and adequate incoming irradiation in that specific day which enhance the ground to evaporate and the leaves of the plant to transpire more, see table 3.3.

Table 3.3: Simulated BROOK90 and eddy-correlation EVAP with mean daily air temperature (T), total daily precipitation (P) and solar incoming irradiation (G) at Norunda forest for the period (3rd Dec 03 to 7th Dec 03).

Date	EVAP (BROOK90)	EVAP Measured	T (˚C)	P (mm)	G (Mj/m²)
2003-12-03	-1.19	0.2	5.4	0.00	0.28
2003-12-04	-1.19	0.3	4.75	0.00	0.20
2003-12-05	4.22	0.1	7.95	9.00	0.52
2003-12-06	0.64	0.3	3.15	0.00	0.99
2003-12-07	0.64	0.1	8	0.00	0.57

The annual ratios of the simulated model EVAP at Norunda forest were 421mm, 425mm and 459mm for the years 2003, 2004 and 2005 respectively, which were more or less close to the mean annual value of evapotranspiration of Norunda forest according to Cienciala et al, 1997 and Lundin et al, 1999. In contrast, most of the measurement values at this site were ranged between 1.5mm to 3mm with very small values below or above this range. This shows that the model showed agreeable results in comparing to the published studies and indicates that the reason behind this discrepancy is mainly from the measured values.

In Norunda forest, the daily values of the simulated model transpiration during the growing season for the years 2004 and 2005 were ranged between 0.02 to 4.3mm with maximum value recorded in the beginning of June 2004. Cienciala et al. (1997) found that the values of transpiration were between 0mm to 3.6mm with maximum value in July.

Other study by Jansson et al, 1999 showed that the transpiration values were ranged between 0mm to 2.5mm. The annual values of the modeled transpiration for our study were 224mm and 266mm for the years 2004 and 2005 respectively, which were high values compared to the 181mm by Jansson et al, 1999.

One reason behind the difference between the daily values of eddy-flux and simulated model EVAP could be that precipitation values that were used in an input data for running the program has been taken from "Films Kyrkby A" meteorological station which is far from Norunda forest by 45km (North-East).s

Nevertheless, it is no wonder to have such variation, because in a certain day, it could be raining in Norunda forest, while the station recording no rainfall at all and vice verse.

4.4.2. Scenario 2

This scenario shows the comparison between the two forests regarding their sensitivity to the drought occurrence and the water balance through adding and removing 30% to LAI of the forests.

Increasing MAXLAI by30%

Starting with evapotranspiration, by adding more trees to the forest through increasing MAXLAI by 30%, Hartheim site showed an increase in the annual evapotranspiration by 40mm, 33mm and 57mm for the years 2005, 2005 and 2007 respectively which is equal to 10% raise as an average value from the original conditions, while at Norunda forest, the annual EVAP rate increased by 37mm, 28mm and 30mm for the years 2003, 2004 and 2005 respectively which is equal to 7% increase from the scenario of control. The maximum value of the annual EVAP at Norunda site that recorded in 2005 with 489mm was mainly because 2005 has higher amount of mean annual air temperature and incoming solar irradiation and sufficient amount of precipitation with 6.3˚C, 10 Mj/m^2 and 577mm respectively, see table 3.4 which of course are among the main factors enhancing evapotranspiration and increasing its rate.

By comparison, Hartheim forest will evaporate more water than Norunda forest. This indicates that Hartheim will be more stressed than Norunda if the forests had been well developed and this can be clearly seen in the next paragraph.

The model showed a reduction in the soil water at Hartheim forest under increasing LAI 30% by 12%, 4% and 9% for the years 2005, 2006 and 2007 respectively, while at Norunda site, the rate in 2004, the amount of water content diminished by 7%. The reduction of the water is due the increasing demand for water by plants leaf area index LAI increased. This indicates that the amount of the rainfall will not compensate the amount of water lost by evapotranspiration from increasing the canopy cover. As mentioned above and by comparison, Hartheim forest will be more stressed under this scenario than Norunda. Despite that 1.3% difference between the two forests is not high, but could be for the long-term this rate will increase.

In our investigation period, the rate of transpiration raised only about 2.7% in 2004 while it decreased by 1.5% in 2005 at Norunda forest despite increasing LAI by 30%. Possible reason is high number of trees will increase the competition for water in the deeper layer where most of the roots of coniferous trees rely. Despite the clay content in the soil at Norunda forest, some water could drain into the groundwater since the soil of Norunda forest is boulder-rich soil in which the water could infiltrate easily.

Decreasing MAXLAI by30%

Thinning forest by 30% in both forests will have a considerable effect on the rate of evapotranspiration and the water balance of the forest. Annual ratios of evapotranspiration diminished by 62mm, 36mm and 67mm for the years 2005, 2006 and 2007 respectively, which is equal to 12% decrease as an average value for Hartheim forest compared to 49mm, 50mm and 58mm decreasing at Norunda forest for the years 2003, 2004 and 2005 respectively, which is equal to 10% decrease from the original conditions. This indicates that thinning of the forest by 30% will approximately has the same effect on both forests.

Reduction of the rate of EVAP by 12% will affect the water balance of the forest and the climate change of the region. Once LAI decreased by 30%, it will lead to save more water in the soil by decreasing the competition from roots. Hence, the demand of water and nutrient will decrease.

The soil water content under thinning scenario increased by 9% at Hartheim forest as a mean value for the whole studying, while in Norunda site in 2004, the amount raised by 13%. Thus, more water will gain at Norunda forest compared to Hartheim forest if thinning occurred.

4.4.3. Scenario 3

In this scenario, we will try to evaluate the output results for both sites regarding the increase in daily maximum air temperature by 1˚C and adding rainfall to the system by 20%.

Increasing daily maximum air temperature by 1˚C

Increasing in the daily maximum air temperature by 1˚C results in 27mm increase to annual EVAP as an average values for the entire investigation period at Hartheim forest which equals to 6% increase compared to control. On the other site, it increased by 22mm as a mean value for the years 2003, 2004 and 2005 at Norunda forest, which is equal to 5.5% increase in comparing to the scenario of original conditions.

The results from our simulations under the scenario of increasing maximum air temperature by 1˚C indicate a small difference between the two forests. Even the difference was not high, could be for the long-term the rate increase. As Hartheim locates in the mid-Europe relying in temperate forest, it has longer growing season, high levels of incoming energy, higher mean annual air temperature and total annual precipitation. Therefore, the projected increasing in the future air temperature will help the Hartheim forest to have more EVAP than Norunda site due to changes in the forest's growing conditions and induced an earlier start and lengthening in the growing season and well development.

As a mean values for the entire investigation period, the soil water under increasing air temperature scenario were decreased by 4% at Hartheim forest with 7% reduction at Norunda site. This could be due to the soil structure of the both forests which is boulder-rich in Norunda with sandy loam in Hartheim in which the water infiltrate and drain downward to the groundwater much easier in Norunda than Hartheim.

Transpiration from the canopy covers under current scenario at Norunda forest increased by 10% and 6% for the years 2004 and 2005 respectively. Mainly because rising temperature will increase the stand productivity of the forest and lengthening the growing season through the earlier spring soil thawing and the later autumn freezing, opening the stomata and make it more activate enhancing to evaporate more. Hence, all these factors will facilitate trees to transpire more.

Increasing total daily precipitation by 20%
After adding 20% rainfall to the model, the response differs between the two sites. At Hartheim forest, the amount of EVAP increased by 23mm as an average value from the whole studying period which is equal to 5.5% increase from the original conditions, while at Norunda site, the rate increased by 29mm which equal to 6.7% increase in comparing to the scenario of control. Although 6mm difference was not observable value for comparison, but could be for the far future Norunda forest will evaporating more than Hartheim site. This is might be that Norunda is denser than Hartheim having LAI of 4-5 compared to 1.5 for Hartheim forest.

Another reason is Norunda could have quicker response to evaporation than Hartheim, because they include 33% spruce trees which characterized from pine by their shallower roots, therefore when adding more rainfall, they will activate faster as the trees will take up water and transpire, at the same time, pine tree roots will get water later due to their deep roots.

Increasing rainfall will lead to an increase in the amount of water in the soil depending on the regional climate conditions, slope of the area, vegetation cover, tree species, type structure and texture of the soil. Under the current scenario, soil water increased by 5% as an average value for the whole studying period at Hartheim forest with 6% increase at Norunda site. Therefore, the small difference in the amount of water holding by the two forests could be due the homogeneity of the soil in which both of the forests have approximately the same soil type of sandy loam, but the structure of the soil differ in both sites in which one of them has more clay content than the other that affect the rate of infiltration in both sites.

Water availability is known to be one of the limitation factors for the development and growth of the forest. Under the current scenario, transpiration rate increased by 16% at Norunda forest compared to control. Possible explanation of this case is that the quantity added rainfall to the model will make the soil wetter and act to decrease the water deficiency, in other words, declining the stress of the forest through decreasing the demand for water by tree roots.

4.4.4. Scenario 4

This scenario shows the comparison between the two forests under two different scenarios: increasing daily maximum temperature by 1˚C together with increasing LAI by 30% and the scenario of increasing daily maximum temperature by 1˚C combined with decreasing LAI by 30%.

Increasing maximum daily air temperature by 1˚C with increasing LAI by 30%

With this scenario, the rate of annual evapotranspiration tend to increase about 67mm in the annual values as an average for the whole investigating at Hartheim site period compared to control which equivalent 15% increase, while at Norunda forest, the rate of EVAP increased by 53mm as a mean value which equal to 12% increase than original conditions. As stated previously under the scenario of increasing maximum temperature by 1˚C, Hartheim forest will evaporate more than Norunda. So, increasing LAI of the forest means increasing transpiration of the plants leading to more evapotranspiration. Therefore, Hartheim will have more evapotranspiration than Norunda under the current scenario.

Both Hartheim and Norunda forest were approximately showed the same amount of the reduction in the water content of the soil by 12%. Despite this and as mentioned above, Hartheim forest will be more stresses by having higher EVAP.

Transpiration rate at Norunda forest increased by 17% and 13% for the years 2004 and 2005 respectively. Despite that 2005 has weather conditions more appropriate for transpiration to occur than 2004 (see table 3.4) but the model showed less value of transpiration in 2005 instead of 2004. Possible reason could be due to systematic error.

Increasing maximum daily air temperature by 1˚C with decreasing LAI by 30%

Under the current scenario, annual evapotranspiration at Hartheim forest decreased by 7% decrease as an average value compared to control, with 4% reduction at Norunda forest. By comparison, Hartheim will evaporate more than Norunda.

Soil water at Hartheim forest increased by 5% as an average value compared to the scenario of original conditions, while at Norunda forest, the amount of water in the soil increased by 6% in comparing to control. The less amount of water increasing in both forests were because of the increasing maximum daily air temperature by 1˚C at the same time of removing 30% of the forest's density which enhances the soil to evaporate more and the plant to take up more water for transpiration and other important processes like photosynthesis and growing. Hence, diminishing water reservoir in the soil and altering the forest's water balance. The small difference between Hartheim and Norunda was because both forests differ in their soil structure and having different climate conditions, therefore the amount of water in the soil varied.

Transpiration rate at Norunda forest decreased by 5% during the whole studying period compared to the scenario of control. This indicates that for the near future and under the current scenario water will loss from the soil and will affect the hydrological cycle of the area.

Conclusions

This study concludes that Norunda forest will be more sensitive to the projected future increase in the air temperature than Hartheim forest. Increasing daily maximum temperature by 1˚C made soil water at Norunda forest to decrease by 7% as a mean value for the both layers in 2004 with only 4% decrease in Hartheim site during the whole investigation period, and the number of the days with T_{act}/T_{pot} >1 in 2006 for example, in Hartheim forest, increased by only 1 day, from 51 to 52 days, whilst at Norunda and in 2005, the number of the days increased from 18 to 27 days. However, this reduction in the amount of water at Norunda more than Hartheim could be compensate by the projected future increasing in the precipitation at high latitude more than mid and low latitude.

Despite the economical benefits, thinning of the forest acts to help the soil maintaining more water through decreasing the vulnerability of drought occurrence and reducing the competition for water. For instance, soil water at Hartheim forest under thinning scenario, increased by 9% as an average value and the number of the days in 2006 were decreased from 47 in control to 26 days. On the other site, at Norunda forest, the number of the days in 2004 reduced from 18 days in control into 12 days in thinning scenario and the amount of the water in the soil increased about 13% as an average value.

Increasing precipitation by 20% at both sites has less influence than thinning of the forest by 30% for maintaining more water in the soil and the water balance of the forest. Under increasing rainfall by 20%, soil water increased by only 5% at Hartheim forest as a mean value for the whole studying period compared to 9% increase under thinning scenario. In Norunda forest, the amount of water in the soil increased by 6% under increasing precipitation by 20% as an average rate for the entire investigation period compared to 13% increase under the scenario of decreasing LAI by 30%.

Recommendations

For further studies, the following tips are recommended to take in to account in order to get better results:

1. Time period: It is better for such research to apply for longer time period than used in our study.

2. Soil structure and texture: For results to be more precise, it is further suggested to identify all the structure and texture of the soil.

3. Measurements: It's highly recommended when doing a simulation modeling to use data which are measured directly from the field rather than literature or other sources to avoid the uncertainty and obtaining results more reliable and comparable to the actual measurements.

4. Meteorological station: In case of missing data from the forest, it recommend to depend on the nearest meteorological station. As in our case, precipitation data for Norunda forest has been taken from a station which was about 45km far from the forest relied outside the cycle or the distance where to be allowed for taking data according to the global standard distance due the guidelines of World Meteorological Institution of taking data from the nearest station.

5. Simulation scenarios: It's also recommended to simulate the model with some other scenarios that has relation to such studies. For example: increasing the minimum daily air temperature by 1˚C together with increasing maximum daily air temperature by 1˚C in order to have daily mean increasing by 1˚C.

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Appendix A: Evapotranspiration

A.1. Hartheim forest:

Figure A.1: Simulated monthly evapotranspiration EVAP (E) under original conditions in comparing to mean monthly global incoming radiation(G) and monthly total precipitation (P) at Hartheim Scot pine forest for the period (Jun-2004 to Oct- 2007)
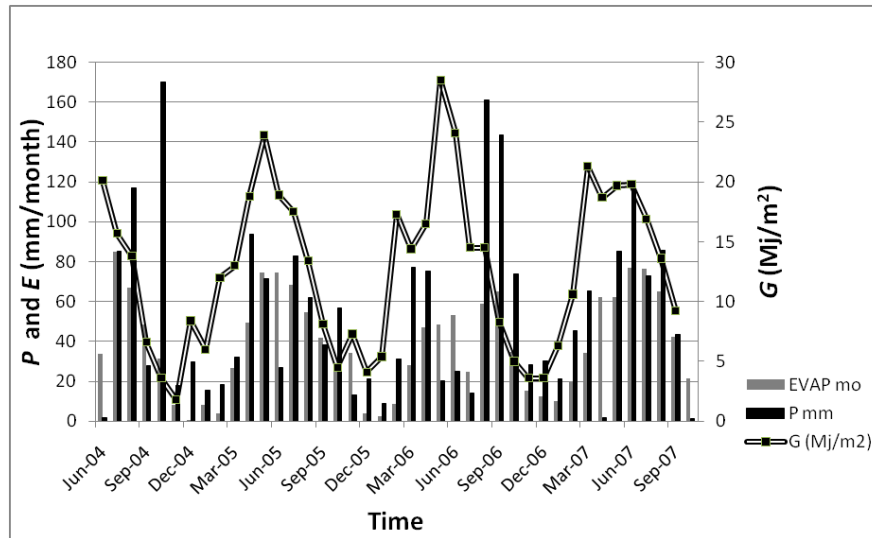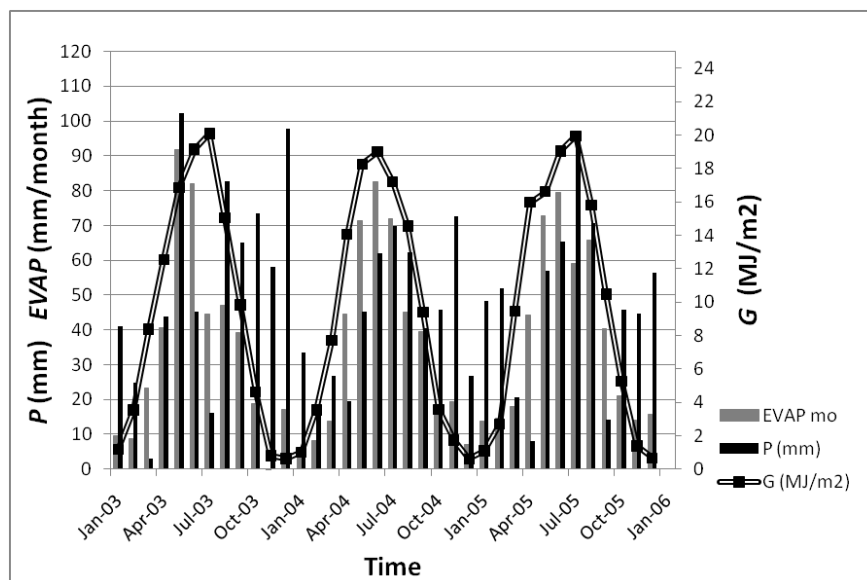
A.2. Norunda forest:

Figure A.2: Simulated monthly evapotranspiration EVAP (E) under original conditions in comparing to mean monthly global incoming radiation(G) and monthly total precipitation (P) at Norunda forest for the period (2003 to 2005)

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