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Methods of Evapotranspiration Assessment and Outcomes from Forest Stands and a Small Watershed

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1. Introduction

The authors have used ET terms related to evapotranspiration terms which outcome from common equation of water budget. The components of water budget equation have been employed by the author prof. Kantor since 1970s. The terms are in compliance with terms of Encyclopedia of Forest Sciences (Burley et al., 2004) and with Committee of Hydrologic Impacts of Forest Management (National Academy of Sciences of the United States of America 2008).

All study and understanding begins with good definitions (Hewlett, 1982); therefore at first we present fundamental terms of forest hydrologic cycle taken into consideration for evapotranspiration of forest stands and small forested catchments (Bruijnzeel, 2004):

Precipitation (P) – rain, snow, and fog (occult precipitation)

Throughfall (Tf) – sum of direct throughfall reaching the forest floor without touching the canopy plus crown drip, once the storage capacity of the canopy has been filled

Stemflow (Sf) – part of precipitation travelling along the branches and trunks into the forest floor

Net precipitation (Pn) – sum of throuhgfall and stemflow [Pn = Tf + Sf]

Interception losses (Ei) – portion of the precipitation intercepted by the canopy and evaporated back to atmosphere – evaporation from a wet canopy [Ei = P – (Tf + Sf)]

Transpiration – water taken up by the roots and returned to the atmosphere via the process of transpiration (Et) – evaporation from dry canopy

Evaporation from the litter and soil surface (Es)

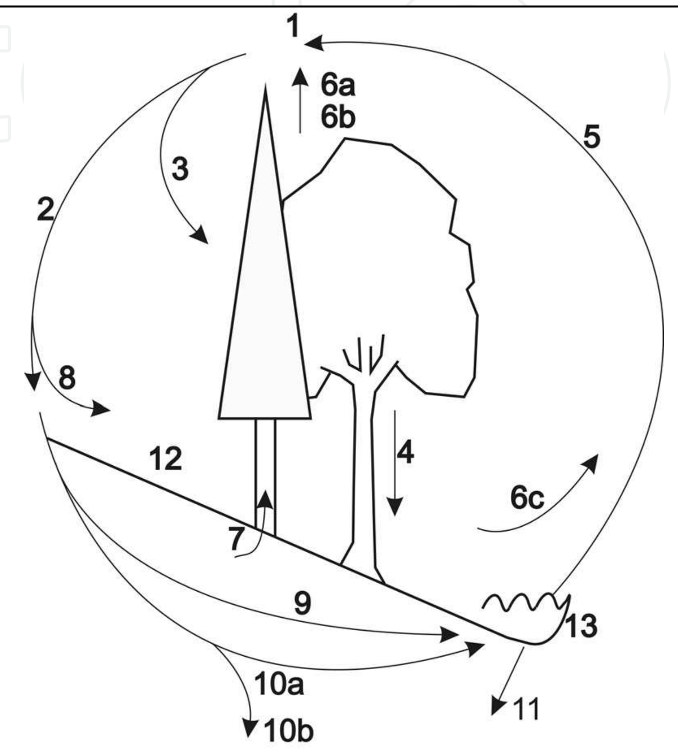
Evapotranspiration (ET) – total evapotranspiration equals to sum of Ei + Et + Es (in millimetres of water per time unit)

The interlocked character of the chief components of the hydrological cycle is summarized by the site or catchment water budget equation:

$$P = ET + Q + \Delta S + \Delta G \text{ (mm)} \quad (1)$$

where

Q is amount of drainage to deeper layers or streamflow,
ΔS change in soil water storage,
ΔG change in groundwater storage.
In forested catchments the hydrologic cycle thus in short involves precipitation, interception, evapotranspiration, overland flow, subsurface flow, groundwater flow and stream flow (**Fig. 1**).

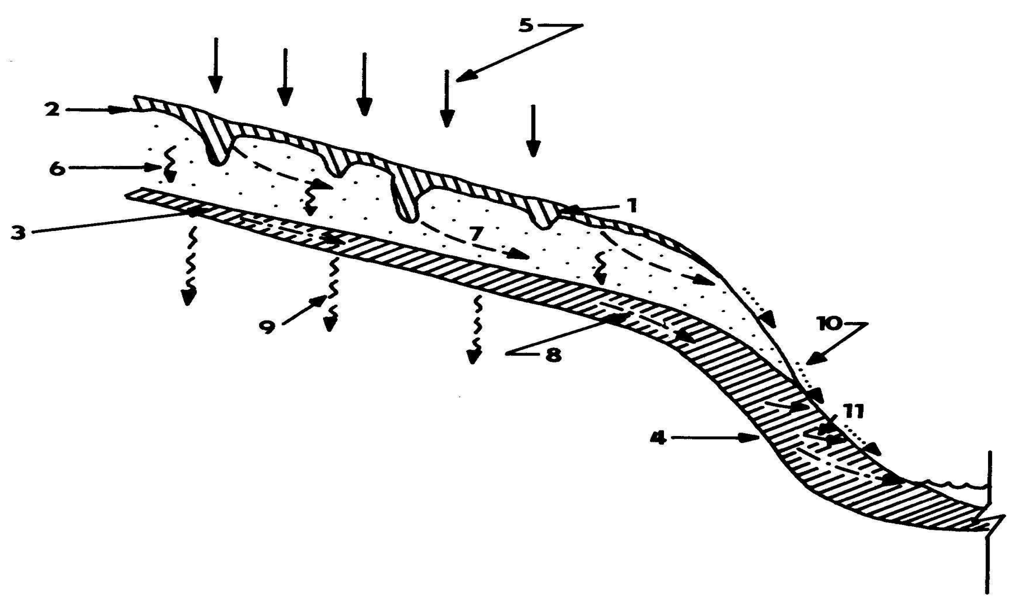


1	Atmosphere
2	Precipitation
3	Throughfall (direct throughfall and drip)
4	Stemflow
5	Evaporation
6a	Interception loss
6b	Transpiration of crown, canopy
6c	Evaporation from slope surface, forest floor and ground vegetation
7	Water uptake
8	Overland flow
9	Subsurface flow
10a	Groundwater flow
10b	Vertical percolation into the underlying bedrock and recharging deep groundwater
11	Stream flow
12	Slope
13	Stream

Fig. 1. Forest hydrologic cycle

On steeper hillslopes, which represent most of the topographical conditions of our hydrologic research areas in the Orlické hory Mts. and their piedmont, water infiltrating into soil is either stored in the soil or continues moving vertically to recharge local groundwater or flows as lateral subsurface flow; likewise comprised recent knowledge

Weiler & Mac Donnell (2004). In areas with a steep relief, the lateral subsurface flow (sometimes called interflow, throughflow, pipeflow, and subsurface stormflow) are very common in forest soils since the lateral hydraulic conductivity and the gravitational gradients are often high. Thus additional preferential flow pathways are present to enhance the downslope flow. A hypothetic hydrologic system for forest soil on a hillslope is presented in **Fig. 2** (by Thomas & Beasley, 1984).



1– organic layer
2 – mineral soil surface
3 – saturated zone
4 – impeding layer
5 – net precipitation
6 – infiltration
7 – pipe flow
8 – seepage
9 – deep percolation
10 – overland flow
11 – return flow
(Thomas & Beasley, 1984)

Fig. 2. Hypothetic hydrologic system for forest soils on a hillslope

The system of research areas in piedmont and mountain region of the Orlické hory Mts., where the water regime of montane forest ecosystems and silvicultural methods are continuously investigated, is composed of three long-term experimental silviculture-hydrologic stations: Deštenská stráň – experimental balance areas on moderate WSW slope (alt. 890 m) to complex study water budget of Norway spruce and European beech stands during progress of forest reproduction, Česká Čermná – experimental runoff areas on steep south hillside of Dubovice (alt. 500 m) to study effect of regeneration felling (clear and shelterwood) on hillslope runoff and soil erosion, U Dvou louček – experimental watershed on SW slope with moderate gradient (alt. 880-950 m) to study effect of hydroameliorative treatment and conversion of forest ecosystem after salvage felling due to air pollution on water regime of the catchment.

For the main aims of various projects, which have involved optimization of tree species composition to ensure hydrologic services of forestry, technical and biological treatments to minimize overland flow and erosion from forest lands, reproduction methods decreasing risk of floods from rainstorms and snowmelt and water regime amendment of waterlogged forest soils to provide maximum retention and detention capability in mountain forests in protected region of natural water accumulation, the evapotranspiration studies play an important role. For the chapter of this book the ET has been described and assessed only in a growing period (May – October).

1.1 General characteristics of the area under study

The research areas are situated in the natural forest region of the Orlické hory Mts (24,000 ha) with their tops reaching 1,000–1,100 m alt. and in the natural forest area of the Foothills of the Orlické hory Mts (18,500 ha) with their tops between 500 and 800 m alt. From the geological point of view, the Orlické hory Mts belong to a crystalline complex with prevailing orthogneiss, while the fringe is formed by mica schist and paragneiss, the transition to the foothills is then formed by phyllites and amphibolites. Forest soils are moist and poor in minerals. Mountain brown soils (Cambisols) and humus podzols predominate (62% and 30% respectively). Soils affected by water occur less frequently (7%). The climate of the Orlické hory Mts ranges from cold in the uppermost part of the mountains to the temperate climate in their foothills. Mean annual air temperature ranges in the whole area from 4° to 7°C, in the growing season from 10° do 13°C. Precipitation is rather copious, with the frequent occurrence of fog (occult precipitation), in winter accompanied by frost deposit and glazed frost. Mean annual total precipitation ranges between 1,300 (mountains) and 800 mm (foothills), in the growing season from 750 to 410 mm. The number of days with snowfall is related to the altitude and ranges from 80 (mountains) to 40 (foothills). Duration of the growing season is also related to the altitude and ranges between 83 and 141 days. Western air flow predominates, NE destructive wind being dangerous for forest ecosystems. In general, the climate of the region is harsh with low temperatures, rich precipitation, frequent fogs and occasional destructive winds. Stream system is dense being characterized by a considerable slope and erosion activity. The greater part of the Orlické hory Mts and their foothills belongs to the basin of the Orlice River, the smaller one to the basin of the Metuje River. In 1956, a Protected Landscape Area occupying about 60% of the Orlické hory Mts natural forest region was proclaimed in the northern and central parts of the mountains. The Protected Region of the Natural Accumulation of Water of the same area was set up in the Orlické hory Mts in 1978.

The Orlické hory Mts and their foothills are situated between the 8th and 5th forest vegetation zones (FVZ). The 6th spruce/beech FVZ predominates (49% of the area) being followed by the 5th fir/beech FVZ (33%) and the 7th beech/spruce FVZ (16%). Acid edaphic categories (57% of the area) are mostly distributed while rich categories occupy only 24% of the area. Acid spruce/beech and acid fir/beech stands occupy the largest area, viz. 30 and 13%, respectively. Spruce management of higher altitudes (management sets of Nos. 51–57) occupies 80% of the area.

The Orlické hory Mts, particularly their uppermost parts, were in the last 15 to 20 years affected by air pollution disasters when extensive areas of damaged stands of all age categories were felled (thousands of hectares, today clear-cut areas and regenerated stands up to 20 years of age occupying about 3,200 ha). The nearly monotonous species composition (Norway spruce percentage about 90%) of the stands participated to a great extent in the extremely severe impacts of air pollution (particularly SO_2) on the local mountain ecosystems. Decrease in the biodiversity of forest ecosystems in the past period resulted in the marked reduction of their ecological and static stability. Subsequent enforced felling measures reduced their wood-producing as well as non-wood-producing functions/effectiveness. From the hydrological point of view it is important that extensive air pollution clear-cut areas have been created associated with the marked extension of the forest road network. The density of forest roads reaches about 51 m/ha, 1/3 of the figure being represented by logging roads with frequently unsatisfactory slope conditions and drainage. Regeneration of forest stands after the disasters is aggravated by difficult air pollution and ecotope conditions. It is particularly difficult to ensure forest ecosystem biodiversity. It is expected that richer tree species composition will be applied particularly through the increase in the percentage of broadleaved species (European beech, sycamore maple, Scotch elm, and soil-improving species) as well as silver fir.

1.2 Characteristics of experimental areas and watershed

1.2.1 The Deštenská stráň Hillside experimental area

The Deštenská stráň Hillside experimental area in the Orlické hory Mts serves for studying the water balance of spruce and beech ecosystems as representatives of two most important tree species of middle-altitude mountain locations in the Czech Republic. A couple of balance plots forms the research area. Both balance plots (40x30 m each) are 50 m apart being situated on a slope with WSW aspect and mean gradient 16° at an altitude of 890 m; their latitude and longitude determines 50°19´20´´ N and 16°21′45′ E respectively. Mean annual temperature is 4.9°C and mean annual precipitation 1200 mm.
From the forest site classification point of view, the spruce and beech stands belong to the most widespread forest type of the spruce/beech FVZ, to the forest type of an acid spruce/beech stand with Deschampsia (6K1). From the pedological point of view, both stands can be ranked among typical acid Cambisols of higher altitudes, sandy loam to loamy sand with the 50% mean admixture of skeleton, the proportion of which reaches 90 – 98% at a depth of 0.7–1.0 m (weathered parent rock being mica schist).
The study was started in autumn 1976. During the first five hydrological years (1 November 1976 to 31 October 1981), hydrological effectiveness of mature stands was studied. In winter 1981/1982, both stands were felled at a time and immediately (in spring 1982) the research plots were reforested again with Norway spruce and beech so that since 1 November 1982, the study of the water regime of both species could be continued under changed unfavourable air pollution/ecotope conditions.
In the course of the experiment, the following components of the water regime have been continuously studied by the same procedures and using the same measuring devices on both plots, both in mature stands and in newly established plantations/present young growths (Kantor, 1992, 1995): interception and transpiration of trees (in mature stands being determined numerically as the only unknown quantity in the equation of water balance), evaporation from the soil surface, interception and transpiration of ground vegetation, changes in soil moisture, overland flow, lateral water flow through the soil, water seepage to the subsoil (with the following subsurface flow), snowpack depth, density and water equivalent value, air temperature and humidity.

1.2.2 The U Dvou louček experimental watershed

The U dvou louček experimental watershed was established for the purpose of studying the problems of draining a waterlogged forested watershed situated on a mountain slope. The small forested watershed U Dvou louček occurs in the uppermost part of the Orlické hory Mts. The position of the watershed is determined by geographical coordinates l6º 30' 56'' E and 50º l3' 16'' N. The watershed is situated at 880–950 m altitude, mean altitude according to a hypsographic curve being 922 m.

The watershed is fan-shaped (substitute figure being a parabola with the side B length 820 m), form coefficient is 1.16, watershed divide length is 2,290 m (coefficient of the watershed divide division 1.13) and talweg length is 530 m. The area of the watershed amounts to 32.6 ha. The area exhibits variable slope, viz. in the lower part 7.5°, in the middle part 8.5° and in the upper part 4.3°. Mean slope calculated from the course of contours is 6.4°. The talweg inclination is 5.4°. The SW watershed aspect changes in border parts to the SE and W aspects. A watercourse draining the watershed is formed by two branches. The right branch exhibiting 5.9° inclination is 340 m long while the left branch having 5.3° inclination is 300 m long. One quarter of the watershed area is affected by high groundwater table (flowing water and spring area). Permanent waterlogging occurs on 5.5 ha, temporary waterlogging in the summer half-year does not exceed the area of 5 ha. Out of the period of soil profile waterlogging, volume soil moisture ranges from 30 to 60%. In the winter half-year, soil profile is saturated by water to the field moisture capacity in the whole watershed. The area of the full-grown European beech/Norway spruce stand (mean age 80 years) was 6.8 ha in 1991 (21% of the area) and till the year 1995 decreased to 5.7 ha (17%) due to the further disintegration of spruce ecosystems. The remaining area of the watershed is a clear-cut area resulted from air pollution salvage felling with a Norway spruce young plantation of various age (max. 15 years old). Road density in the watershed amounts to 62 m.ha^{-1} being formed by skidding and hauling roads.

In terms of hydrogeology the watershed belongs to the crystalline complex of the Eagle Mts. with a low even medium crevice permeability of the rock and unstable penetration of the quaternary mantle. The rock consists namely of honeycombed muscovite gneiss of the Proterozoic Era and mica schist of the strontian series. Results of hydrodynamic tests in boreholes carried out in the watershed showed that gneiss in the hydrogeology structure of the watershed plays the role of a collector and the mica schist acts as a hydrogeology insulator. In the upper part of the watershed where gneiss appears the supply of ground water is dependent exclusively on atmospheric precipitation. Due to the good permeability of gneiss and gradient of the terrain the water continually flows off via the underground. In contrast, the area of the mica schist in the lower and middle parts of the watershed prevents the water to flow via the underground and it swells to the surface. Since the supply of water from the gneiss area is virtually non-stop, the area is continually waterlogged.

On the gneiss cambisol (brown forest soil) developed and partly also humus podzols; on the mica schist humus podzols, gleyey peat podzol and peat soils. The soil is loamy-sand, in some horizons clayey, extremely stony (20 to 50%) and non-homogeneous. From the point of view of the dynamics of soil water the soils are permeable, with a high infiltration capacity. The soil areas with gleyey podzolic soil and peat are oversupplied with water and have a high water level caused by a high inflow of water from the higher areas.

In the U Dvou louček watershed, hydrological and silvicultural research programmes are conducted. The hydrological programme includes watershed calibration in hydrological years 1991/92–1995/96 including recording hydropedological characteristics, manual implementation of the ecological draining measure in summer 1996 and the study of the effects of draining on further hydrology and hydropedology of the watershed. Draining measures aimed at the restoration of functions of the existing drainage system and the interception of runoff from spring areas and areas with insufficient drainage were carried out on the area greater than 2 ha. The length of drainage ditches reached about 500 m. The silvicultural research programme follows up the implemented drainage. It deals with the improvement of the survival and growth of established spruce young plantations and increasing their biodiversity and ecological stability. In part of the drained area protected by fencing of an area of about 1 ha with three degrees of the soil profile moisture (moist, moister, moistest), European beech, sycamore maple and silver fir are interplanted into the spruce plantation and on unforested places since 1997. Various types of mound and ridge planting and amelioration using natural materials (basic rock meals) are applied.

To obtain input data, precipitation in the watershed is measured by 8 station rain gauges and 2 ombrographs connected with the automatic meteorological station. Other characteristics of the soil and air sphere are also determined as well as the dynamics of air pollution flow by a summation method. Vertical flow onto the bedrock using ten buried open lysimeters (deep infiltrometers) placed at a depth of 0.75 m with a total area of 1 m^2 and lateral subsurface flow from the interface of organic and mineral horizons and from the interface of more loose and more compacted mineral layers was also measured. Groundwater table is monitored by 52 water table measuring perforated pipes placed in two transects (perpendicularly to the contour and across ditches) and on four microplots differing in vegetation cover (peat moss, reed, hairgrass and mixed growth). Suction pressure of soil is measured by 288 tensiometers at a depth of 0.15–0.60 m in two elementary runoff-balance plots (10 x 10 m each) differing in moisture. On the elementary runoff-balance plots (ERBP) groundwater table is measured by 42 soil water level measuring perforated pipes built-in depth of 0.7 m. The flow (discharge) in the closing profile of watercourse was monitored by mechanical float water level recorder. Since 1996, the flow is recorded by manometric water level recorder with automatic data collection.

2. Method of ET calculation from water balance equation

2.1 ET calculated from complex of measured water balance components in a forest stand with only single unknown Et

2.1.1 Outline of method procedure

The method of ET assessment is performed on the Deštenská stráň Hillside experimental area. Investigations, from which the ET components for mature Norway spruce and European beech stands were obtained, we have done in a continuous sequence of five water years (from 1 Nov. 1976 to 31 Oct. 1981). Two components of vaporization process, i.e. interception losses (Ei) and evaporation from the litter and soil surface (Es) were ascertained directly; the tree canopy transpiration (Et) was estimated by calculation from water budget equation as the only unknown:

$$Et = P - Tf - Sf - Es - OlF - SslF - VF - \Delta S \text{ (mm)} \quad (2)$$

where

P is precipitation, **Tf** throughfall, **Sf** stemflow, **Es** evaporation from forest floor and ground vegetation, **OlF** overland flow, **SslF** subsurface lateral flow, **VF** vertical flow (infiltration) to bedrock, and **ΔS** change in soil water storage.

From these components of water budget, the total evapotranspiration (ET) was possible to calculate as the sum of Ei + Et + Es (in millimetres of water per time unit).

Interception losses were calculated as the difference of open area precipitation P and net precipitation Pn = Tf + Sf. In both stands, throughfall (Tf) were measured by a series of 10 station ombrometers each of them with an orifice of 500 cm^2, located in spacing 4 m along a contour line. Stemflow (Sf) was collected from spiral collar attached to a tree trunk and conveyed by hose into gauge barrels; Sf was recorded from 3 trunks in the spruce stand and 11 trunks in the beech stand of all diameter classes.
Evaporation from forest floor and ground vegetation (Es) were found out using modified Popov's evaporimeter. It is a double cylinder container; the inner cylinder, its bottom is covered by wire mesh, is filled by an undisturbed soil monolith. Its circular cross section is 160 square centimetres and depth 0.2 m. The evaporimeter is inserted in the soil so that its upper edge may be levelled with surrounding soil surface. Evaporimeters were weighted in regular time intervals usually once a day. After precipitation, water infiltrated through evaporimeter was measured. From weight difference of the soil monolith the evaporation was calculated. In each of both balance plots 20 evaporimeters were installed. In the spruce stand, 6 evaporimeters were planted by bilberry (Vaccinium myrtillus) and six ones by hair-grass (Deschampsia flexuosa), two main dominant plants of ground vegetation. Evaporation from soil surface was estimated from weighing eight evaporimeters. In the beech stand, all twenty evaporimeters were used to determination of evaporation from soil surface.
The further necessary components of water balance were obtained by following procedures.
Precipitation (P) of open area was measured by 5 station rain gauges (ombrometers) with an orifice of 500 cm^2 on a clearcutting area of 150 x 90 m and in the middle of a gap 40 x 40 m in the immediate vicinity of the water balance plots.
Overland and subsurface lateral flow was measured on elementary runoff plots (ERP) each of 3.5 x 5 m in size. The lower edge of the runoff plot is presented by the timbering pit. Into the front wall, three gutters each with entering section are inserted and tamped beneath the undisturbed soil profile. The overland flow from a depth 0.05 m (horizon interface of LFH and A horizon) and subsurface lateral flow from depths of 0.25 and 0.7 m was collected.
Vertical flow (infiltration) through soil profile onto the subsoil at a depth of 0.7 m was measured in 3 lysimetric pits in a spruce stand and 3 lysimetric pits in a beech stand. The lysimetric pit of 4 m in length was equipped with 10 buried open lysimeters (deep infitrometers) with orifice of 0.3 x 0.3 m each.
Soil moisture was surveyed using a gravimetric method. Disturbed soil samples were taken from 4 soil horizons (characterizing a soil profile) on three places both in a spruce and in a beech stand. Sampling was done usually once a week during growing season in rainless days.
Measurements of water budget components during growing season were done in all days with measurable precipitation, i.e. usually 2 to 3 times in a week.

2.1.2 Results containing ET components

Interception losses (Ei) represent the most different component between spruce and beech stand. During five growing seasons (May – October) spruce canopy intercepted and later evaporated 150.1 mm, i.e. 20.6% of open area precipitation; beech canopy interception losses represented only 56.5 mm, i.e. 7.8% precipitation of open area. Significant lower Ei of beech stand was caused mainly by different values of stemflow. The spruce stand showed negligible stemflow 1.4% of growing period precipitation, while the beech one showed 18.8%, which presented substantial decrease of interception losses.

Interception losses of both stands were further decreased by occurrence of occult precipitation which increased near equally value of net precipitation in observed growing seasons by 40 to 70 mm, i.e. by 5 to 10% of summer precipitation. Practically the same ability of both stands to obtain occult precipitation is explainable on one hand by greater intercepting area of needle biomass, on the other hand by better conditions for precipitation travelling along the branches and trunks and lower storage capacity of the broadleaved tree.
Evaporation from forest floor and ground vegetation (Es) did not present any important difference between both stands during investigated growing seasons. They equal to 75.6 mm, i.e. 10.4% and 72.0 mm, i.e. 9.9% in the spruce and beech stand, respectively.
Transpiration (Et) represented the most important component of water cycle in the spruce and beech forest stands during observed growing seasons. Et of the spruce stand equalled to 182.4 mm, i.e. 25.1%, Et of the beech stand equalled to 176.3 mm, i.e. 24.3% of summer precipitation in average. Somewhat lower Et in the beech stand can be ascribed to shorter only five months lasted growing period of that tree species.
The values of further measured components necessary for calculation of transpiration from water budget equation of spruce and beech stand are presented in **Table 1** and **2**.
Total ET reached in the mature, fully-stocked Norway spruce stand during five investigated growing seasons 1977-1981 (summer water half-years, i.e. May – October) 408.1 mm, i.e. 56.1% of summer precipitation in average. Similarly characterized European beech stand vaporized 304.8 mm, i.e. 42.0%.
Both mature stands were clear-cut during winter 1981/1982 and both clearcuttings were reforested by the same tree species, i.e. by outplants of Norway spruce and European beech. The plantations influenced the water budget in years after reforestation only insubstantially. Both interception (Ei) and transpiration (Et) was negligible due to small needle and foliage biomass. Water regime in both established plantations was being successively influenced by evaporation from ground vegetation. In 5 years after logging weeds had been infesting near the whole surface of both balance plots. In vegetation cover the following species dominated: Rubus idaeus L., Carex sp., Avenella flexuosa (L.) Drejer, Calamagrostis arundinacea (L.) Roth, Deschampsia caespitosa (L.) Beauv., and Calamagrostis epigeios (L.) Roth. In summer mean dry matter of weed above ground biomass exceeded 3 metric tons per hectare.
Evaporation of ground vegetation (Es), i.e. its interception and transpiration ranged from 268 to 332 mm (i.e. from 40.8% to 67.7% of summer precipitation) during 5 growing seasons after clearcutting.

2.2 ET obtained from complex of partially measured water balance components and partially derived from tensiometric measurements in a small watershed with only single unknown E(t, s)

2.2.1 Outline of method procedure

The method of ET assessment is performed on the U Dvou louček experimental watershed (UDL). Two constructed elementary runoff-balance plots – ERBP (each of size 10 x 10 m and slope 6°) were used for ET determination by above mentioned method (viz heading). The first plot (named Nad cestou) is covered by 15 year-old Norway spruce, pole-stage stand of 6 m high; the second plot (named Pod cestou) is covered by a similar fully stocked spruce stand with 5% admixture of European beech. The soil type is Cambisol in the plot No. 1 and the humus podzol in the plot No. 2. Detail soil characteristics are shown in **Table 3**.

Table 1. Water balance of the mature Norway spruce stand over the growing periods from 1977 to 1981 (average values in particular months)

Month	Air temper-ature	Air humidity	Precipi-tation P	Interception Ei		Evaporation Es		Transpiration Et		Overland flow OlF		Subsu latera Ss
	°C	%	mm	mm	%	mm	%	mm	%	mm	%	mm
May	8.2	76.5	67.5	21.6	32.0	13.9	20.6	35.4	52.4	0.1	0.1	0.2
June	12.3	79.2	115.3	33.2	28.8	17.8	15.5	31.9	27.7	0.6	0.5	1.2
July	11.4	84.6	212.0	36.5	17.2	13.5	6.4	34.9	16.5	1.3	0.6	3.2
Aug	12.4	84.1	133.8	28.1	21.0	15.3	11.4	31.5	23.6	0.9	0.7	2.6
Sept	9.2	87.1	100.3	13.0	13.0	8.8	8.8	30.5	30.4	0.1	0.1	0.7
Oct	5.8	85.9	98.2	17.7	18.0	6.3	6.4	18.2	18.6	0.4	0.4	0.7
Average Total	9.9	82.9	727.1	150.1	20.6	75.6	10.4	182.4	25.1	3.4	0.5	8.6

Table 2. Water balance of the mature European beech stand over the growing periods from 1977 to 1981 (average values in particular months)

Month	Air temper-ature	Air humidity	Precipi-tation P	Interception Ei		Evaporation Es		Transpiration Et		Overland flow OlF		Subsu lateral Ssl
	°C	%	mm	mm	%	mm	%	mm	%	mm	%	mm
May	8.1	75.9	67.5	10.5	15.6	12.6	18.7	29.9	44.3	0.5	0.7	0.4
June	12.3	78.7	115.3	13.6	11.8	16.4	14.2	38.1	33.1	1.0	0.9	0.8
July	11.9	84.3	212.0	9.5	4.5	13.1	6.2	36.3	17.1	3.6	1.7	3.5
Aug	12.7	83.2	133.8	11.6	8.7	15.5	11.6	36.1	27.0	2.1	1.6	1.8
Sept	9.6	86.3	100.3	2.0	2.0	8.7	8.7	28.3	28.2	0.9	0.9	0.6
Oct	6.0	85.2	98.2	9.3	9.5	5.7	5.8	7.6	7.8	0.7	0.7	0.4
Avera ge Total	10.1	82.3	727.1	56.5	7.8	72.0	9.9	176.3	24.3	8.8	1.2	7.5

Soil type	Depth (cm)	Soil porosity	Maximum capillary water capacity	Lento-capillary point	Retention capacity		
					Dynamic	Static	Total
Cambisol	4 – 15 15 – 26 26 – 42	87.53 47.05 25.33	75.87 43.72 21.72	40.26 25.79 14.98	11.66 3.33 3.61	35.61 17.93 6.74	47.27 21.26 10.35
	Average	45.78	40.07	23.64	5.71	16.43	22.14
Humus podzol	5 – 17 17 – 25 25 – 50	80.47 50.52 32.05	74.47 44.10 29.85	43.00 36.16 21.73	6.00 6.42 2.20	31.47 7.94 8.12	37.47 14.36 10.32
	Average	48.24	44.28	29.97	3.96	14.31	18.27

Table 3. The soil parameters of elementary runoff plots in the "U Dvou louček" watershed (volume percentage)

Notes: Maximum capillary water capacity by Novák (1954)

Lento-capillary point – soil water constant representing point of decreased availability for plants, i.e. soil moisture at pF 2.8

Retention capacity dynamic or static – volume of pores gravitational or capillary

Maximum capillary water capacity and total retention capacity of 0.6 m deep soil profile amounts to 236 mm and 129 mm for Cambisol and 266 and 111 mm for humus podzol.

Each of both ERBP was equipped by following instruments:

- 144 tensiometers in depths of 0.15, 0.3, 0.45, and 0.6 m with 36 repetitions in each depth
- 21 auger holes equipped by soil water level measuring perforated pipes with diameter of 22 mm built-in depth of 0.7 m.

Data coming from both ERBP were further completed by data from:

- 10 buried open lysimeters (deep infiltrometers) each of them with orifice 0.1 m^2 placed at the depth of 0.75 m below undisturbed forest soil layer
- 3 gutters for measurement of overland flow and 3 gutters for measurement of lateral shallow subsurface flow in common pit with whole catchment area of 3 x 2 m
- an automatic meteorological station and 8 additional ombrometers
- water level recorder with automatic data collection at closing profile of experimental watershed with automatic data recording

2.2.2 Description of ET model design

The scheme of the measurement assessment for the ET estimation is shown on the **Figure 3**. The ET is calculated as the single unknown from the following water budget equation:

$$P - \overbrace{Ei - Et - Es}^{ET} - Q(c,\ sc) - \Delta\ SW(a) - \Delta SW(g) - Q(g) = 0 \text{ (mm)} \quad (3)$$

where

P = Pn + Ei	precipitation of open area
Pn = P – Ei	net precipitation
Ei	interception losses of spruce pole-stage stand derived from relation of open area precipitation and net precipitation on the bases long-term measurements

Et + Es = E(t, s)	transpiration of forest stand and evaporation from forest floor and ground vegetation
Q(c, sc)	vertical flow (outflow or inflow) of capillary and semicapillary soil water
Δ SW(a)	change in content of capillary and semicapillary soil water in aeration (unsaturated) zone
Δ SW(g)	change in content of gravitation water in soil layer with depth of 0.6 m
Q(g)	discharge of gravitation water
E(t, s) = Et + Es	transpiration of spruce pole-stage stand and evaporation from forest floor and ground vegetation

The model (design, pattern) given by Figure 3 and Equation (3) takes in consideration two interlinking forest soil zones, i.e. zone gravitational and zone capillary including semicapillary. Soil moistures are derived from suction-pressure measurements using retention curves created by a laboratory. Vertical capillary and semicapillary outflow (or inflow) is determined on the basis of Darcy equation for an aeration (unsaturated) zone using measurement of suction pressures and responding coefficients of unsaturated hydraulic conductivity. These coefficients have been found out by treatment of volume soil samples using the vaporization method by Schindler with the instrument Ku-pFUGT Muenchebeck applying approximation of measured data by Van Genuchten equations in the programme RETC, version G.

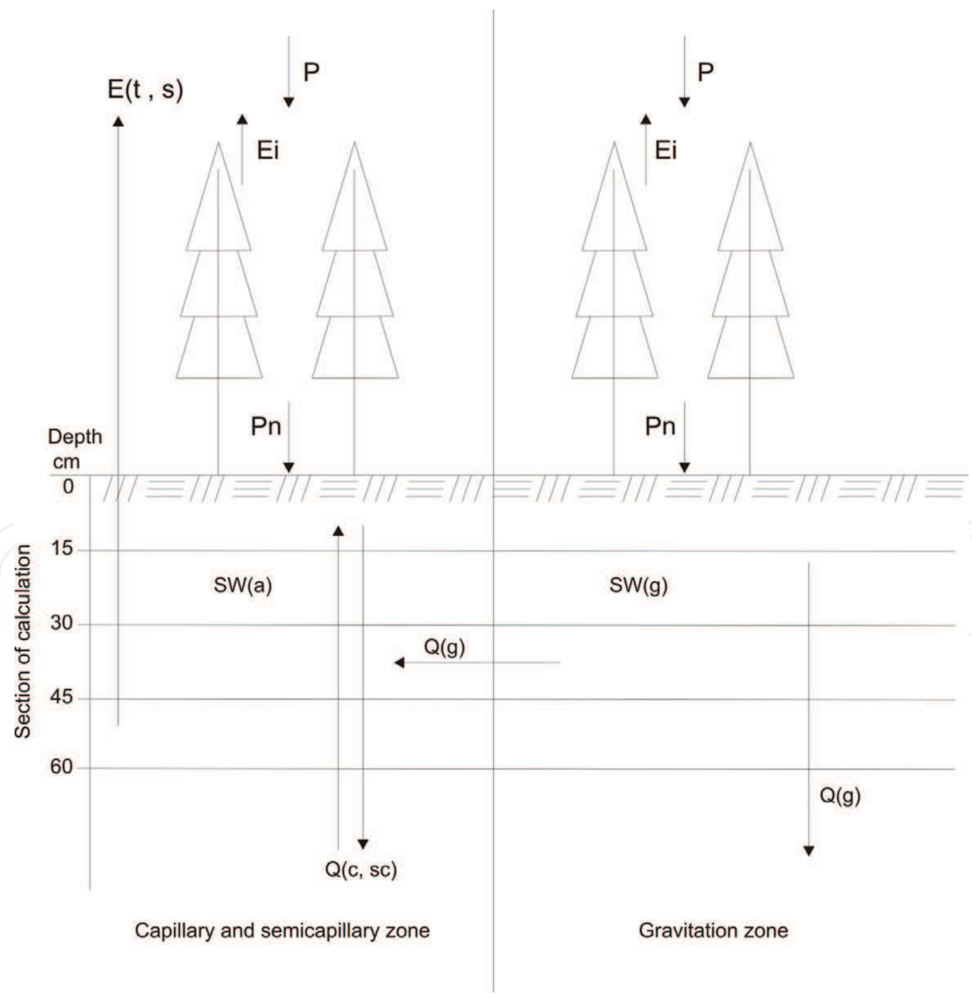


Fig. 3. Scheme of the measurement assessment for the E(t, s) estimation

Suction pressures for calculation of capillary, semicapillary soil water including its flow in partially saturated soil and hydraulic depths of gravitational water in auger holes are measured by tensiometers and perforated water-level pipes, respectively. These data are collected in 6 – 10 day intervals.

2.2.3 Results of model

Results of the model are presented for the growing period of moderately dry year 2008 (precipitation equalled to 77% of long-term mean) in **Tables 4** and **5**.
Overland flow (OlF) attains only negligible values. Therefore, these values are not taken in consideration at computing the model outcomes by the Equation (1).
Interception losses (Ei) of forest stand in common with E(t, s) results in estimating total evapotranspiration (ET) equal to 303 – 309 mm per evaluated time period of 148 days in the growing season. Interception equal to 22.9% of precipitation (P) is consistent with data from other research areas mentioned in the Orlické hory Mts.
Q(c, sc) represents ascending or descending vertical flow of capillary and semicapillary soil water in the aeration zone. The soil of both ERBP has not been during the whole growing period 2008 saturated. The soil moisture has not descended under lentocapillary point at pF 2.8 (point of decreased availability).
Gravitational water of auger holes and buried open lysimeters (subsoil infiltrometers) is located in irregular space network of gravitational pores. These devices serve for observing level of gravitational water and bring information on its dynamics. During dry period the instruments present vertical fluctuation of gravitational water; during stormflow they give level of gravitational water in gravitational pores in combination with its lateral and vertical movement. Volume portion of gravitational pores ranges between 3.3 – 11.7% in ERBP "Nad cestou" and 2.2 – 6.4% in ERBP "Pod cestou" in dependence on soil depth (cf. **table 3**). Gravitational pores create in forest soil irregular network spatially restricted. Flow in gravitational pores is evident and its proportion ranges between 28 – 30% of total discharge from the ERBP.
The total runoff of gravitational water during observed growing period amounted to depth of 30.7 mm (cf. **tables 4** and **5**). The value was estimated using similarity with hydrological balance model of the Divoká Orlice River basin (Horský 1970), where the experimental watershed is located. The time behaviour of gravitational water discharge was then derived in relation to time behaviour of runoff obtained from the closing profile of the "U Dvou louček" watershed. The procedure is substantiated by knowledge of hydrogeological survey that the portion of gravitational water vertically percolates into the underlying bedrock and recharges deep groundwater. At computing procedure the measurements from open subsoil infitrometers and auger holes were taken into account.
Transpiration of tree canopy and evaporation from forest floor and ground vegetation E(t, s) of depth 212 – 218 mm per evaluated time period of 148 days in the growing season, i.e. in average 1.4 – 1.5 mm per day, is consistent with measurements on other examined research areas in the Orlické hory Mts.

2.2.4 Conclusions

Estimation of total evapotranspiration (ET) equalled to 303 – 309 mm per evaluated time period of 148 days in the growing season 2008.

Period	Precipitation P	Interception Ei	Net precipitation Pn	Capillary and semicapillary outflow Q(c, sc)	Soil water content variation Δ SW(a)	Gravita wat variat Δ SW
Year 2008	mm					
28. 5. – 3.6.	2.5	-1.0	1.5	-7.5	11.6	6.1
4.6. – 10.6.	9.9	-4.2	5.7	-3.0	4.3	0.0
11.6. – 17.6.	4.2	-2.9	1.3	-0.9	8.6	0.0
18.6. – 24.6.	5.4	-2.8	2.6	0.8	7.8	0.0
25.6. – 2.7.	37.7	-4.5	33.2	1.3	-5.6	0.0
3.7. – 10.7.	41.9	-10.1	31.8	-2.0	-10.7	0.0
11.7. – 17.7.	12.4	-3.5	8.9	-2.6	6.2	0.1
18.7. – 5.8.	31.0	-12.8	18.2	-0.6	7.7	-0.2
6.8. – 13.8.	3.0	-2.0	1.0	-0.3	1.3	0.6
14.8. – 19.8.	73.6	-5.8	67.8	-0.7	13.4	0.6
20.8. – 2.9.	21.5	-6.0	15.5	3.6	6.8	-0.5
3.9. – 8.9.	35.0	-4.6	30.4	-8.0	-44.6	0.0
9.9. – 16.9.	8.8	-3.6	5.2	-7.3	14.6	-0.1
17.9. – 25.9.	43.1	-11.0	32.1	-5.6	-7.0	-1.0
26.9. – 2.10.	27.1	-6.5	20.6	-5.4	4.0	4.2
3.10. – 22.10.	39.2	-9.5	29.7	-40.7	-5.9	0.0
Sum	396.3	-90.8	305.5	-78.9	12.5	9.8
Percentage	100.0	-22.9	77.1	-19.9	3.1	2.5

Table 4. The hydrologic balance of the ERBP no. 1 "Nad cestou" in the "U Dvou louček" watershed

Note: E (t, s) transpiration of forest stand and evaporation from forest floor and ground vegetation [E(t, s) + Ei = ET]

Table 5. The hydrologic balance of the ERBP no. 2 "Pod cestou" in the "U Dvou louček" watershed

Note: E (t, s) transpiration of forest stand and evaporation from forest floor and ground vegetation [E(t, s) + Ei = ET]

Period	Precipitation P	Interception Ei	Net precipitation Pn	Capillary and semicapillary outflow Q(c, sc)	Soil water content variation Δ SW(a)	Gravitat... wate... variat... Δ SW...
Year 2008	mm					
28. 5. – 3.6.	2.5	-1.0	1.5	-4.0	10.8	1.2
4.6. – 10.6.	9.9	-4.2	5.7	-3.2	12.0	2.3
11.6. – 17.6.	4.2	-2.9	1.3	-0.5	2.9	0.0
18.6. – 24.6.	5.4	-2.8	2.6	1.9	10.9	0.0
25.6. – 2.7.	37.7	-4.5	33.2	-0.1	-15.3	0.0
3.7. – 10.7.	41.9	-10.1	31.8	-3.2	-8.3	-0.8
11.7. – 17.7.	12.4	-3.5	8.9	-3.5	11.5	0.8
18.7. – 5.8.	31.0	-12.8	18.2	-7.3	15.7	0.0
6.8. – 13.8.	3.0	-2.0	1.0	5.1	12.7	0.0
14.8. – 19.8.	73.6	-5.8	67.8	0.0	-40.0	-1.5
20.8. – 2.9.	21.5	-6.0	15.5	-13.0	5.8	1.5
3.9. – 8.9.	35.0	-4.6	30.4	-4.0	-6.1	-0.6
9.9. – 16.9.	8.8	-3.6	5.2	-3.4	7.8	0.0
17.9. – 25.9.	43.1	-11.0	32.1	-6.4	-21.5	0.0
26.9. – 2.10.	27.1	-6.5	20.6	-9.5	8.5	-6.4
3.10. – 22.10.	39.2	-9.5	29.7	-19.8	0.6	3.9
Sum	396.3	-90.8	305.5	-70.9	8.0	0.4
Percentage	100.0	-22.9	77.1	-17.9	2.0	0.1

The presented model of hydrological balance brings values of ET and Q consistent with experimental results from comparable conditions and with runoff data issued for streams in upper part of the Divoká Orlice River basin by Czech Hydrometeorological Institute (Horský 1970).
The results of investigation represent conditions of mountain land covered predominantly by coniferous forest in the Czech Republic.

3. Hydropedological and hydrological methods of ET assessment

3.1 ET obtained from continuous measuring the volumetric moisture of soil profile in a forest stand and calculation of E(t, s) from soil moisture differences

3.1.1 Outline of method procedure

A long-term observation of the water balance elements during the forest regeneration of a Norway spruce stand and that of European beech on the Deštenská hillside in the Orlické hory Mts serves also for comparing evapotranspiration (ET) of both stands. ET represents interception losses from the canopy (Ei), transpiration of forest stand (Et), and evaporation from forest floor and ground vegetation (Es). The first observations were made in mature spruce- and mature beach stands (1976–1981); a clearcut harvest with hole planting of spruce and beech transplants followed in 1982. Then, the research continued during the growth, development, and thinning of both stands from the stage of young plantation up to the small pole stage (1983–2006). The transpiration of the tree species was calculated as the only unknown of the water budget equation (cf. Kantor 1985, and the first method in this ET chapter). In 1998, we started a continuous measuring of soil moisture by volume in layers of the soil segments with the aim to come up with a new procedure of direct determination of ET. In 2005, a method of E(t, s) determination in the spruce and beech stands was devised on the basis of volumetric moisture changes in the soil profile – E(t, s) by Soil Water Content Variation, in abbreviation E(t, s)-SWCV and the results obtained in the growing season of 2005 were published (Šach et al. 2006). In the winter of 2005/06, the young spruce stand (25 years old) was completely damaged by crown and stem snowbreaks.
The extreme disturbance of the forest environment in the young experimental spruce stand after the snow breakage disaster in the winter of 2005/2006 became an impulse to carry out the next study. The investigation was based on two methodical procedures:

- assessing the E(t, s) of the forest stands based on continuous measuring of the water content in the root zone of the soil profile,
- intermittent measuring of the evaporation from the soil surface including the ground vegetation separately by dominant species (Es).

A comparative investigation was simultaneously done in the young experimental beech stand. The aim of this part of the ET chapter is to present the method E(t, s)-SWCV, examples of its use, its validation, and some results obtained during recent growing seasons.

3.1.1.1 Description of forest stand development and present feature of the spruce and beech stands on experimental balance plots

1976–1981: observation of the water balance components run in the mature spruce and beech large-diameter stands (interception and transpiration of trees, soil surface evaporation, soil moisture changes, surface runoff, seepage of water, snow cover parameters, air temperature and humidity).
1982: forest regeneration by the clear felling method and hole planting of spruce and beech.

1983–2005: following the observation of the water balance components during the growth and progress, and tending both stands from plantation to small pole stage and pole stage stands (Kantor 1992, 1995) including foliage biomass.
2005–2006: 25-year-old spruce stand was severely damaged in winter by crown and stem snow breaks, the young beech stand was afflicted with snow breaks only minimally; 98% spruce trees were affected by snow breakage, the stand density decreased from 1550 to 950 trees per ha, the needle foliage of the stand was reduced to about 40%, and the stand canopy was markedly disturbed.
2006: following the observation of the water balance components in the remedying spruce and beech stands after the snow disaster.
2007: stand gaps began to get infested by forest weeds whose cover reached up to 80% in the summer and autumn.

3.1.2 E(t, s) of the young spruce and beech stands

During the growing season from May 1 to October 31 in 2005, 2006 and 2007, E(t, s) was determined by the calculation obtained through the continuous measurement of the volumetric moisture changes in the soil profile (Šach *et al.* 2006). An analogous procedure, e.g. Tesař et al. (1992) and Vilhar *et al.* (2005), was also used but with discrete data from discontinuous observations. By rooting through depth, we induced the thickness of the root zone equal to 500 mm for calculating E(t, s). The volumetric soil moisture was measured with the VIRRIB transducers belonging to sufficiently precise ones in the estimation of the changes in the volumetric soil moisture. The transducers were placed into the deductive root zone in depths of 50 mm, 200 mm, and 500 mm with 3 repetitions. The repeating followed the forest stand variability. In 3 depths with 3 repetitions the total of 9 transducers were placed into each forest stand.

3.1.3 Procedure of calculating E(t, s) of a forest stand

The calculation of E(t, s) in mm for a particular soil layer per month was done by using the formula:

$$E(t, s)_{LM} = \sum W_V \times D_{SL} \times (1 - S_{VP}) \quad \text{(mm)} \tag{4}$$

where
$E(t, s)_{LM}$ E(t,s) for a soil layer (mm/month)
$\sum W_V$ sum of volumetric soil moisture decrements as decimal number
D_{SL} soil layer thickness (mm)
S_{VP} skeleton volumetric proportion as decimal number (an especially important entry)
The sum of $E(t, s)_{LM}$ for three observed soil layers of the root zone represents the E(t, s) of the forest stand in the respective month. Using the newly devised method, we can also calculate the daily values of E(t, s) (Šach et al. 2006).

3.1.3.1 Criteria for calculating E(t, s) of a forest stand

- We included the changes of the volumetric soil moisture into the calculation (the mean of 3 repetitions in the same depth) if the volumetric soil moisture in the subsequent record was lower than that in the preceding one.
- We did not usually include into the calculation small decreases in the volumetric soil moisture at night considering six-hour intervals (0, 6, 12, 18, 0, 6... hours of Central European Time – CET = UTC + 1).

- Decreases in the volumetric soil moisture during 12 hours after rain were considered to be a vertical flow and, especially at a low air temperature and a high air humidity (usually 100%), we did not take them into calculation (similarly Cheng 1987 under comparable conditions).
- During rain, when the volumetric soil moisture usually increases, we did not take E(t, s) into consideration.

3.1.4 Evaporation from soil surface including ground vegetation in the young spruce and beech stands – Es

Es was determined by intermittent accurate weighing sets of Popov's evaporimeters in the summer hydrologic half year of 2005, 2006, and 2007. The evaporimeter with evaporative circle cross-section equal to 160 square centimetres indicated the evaporation from the soil layer 0–20 cm. The evaporimeter set (more than 10, usually 16) represented the proportional soil cover in the spruce and beech stands, and newly for comparison also on the clearcut. The observations were realised during characteristic rainless periods on the beginning, in the middle, and at the end of the growing season. They provided the results about the morning, afternoon, and night evaporation. The determination of evaporation is based on an accurate weighing of evaporative vessels at regular time intervals 3 to 4 times per day by digital scales with accuracy of ± 0.1 g. Three comparable 5-day cycles were evaluated from the 14th to the 19th June in the respective years.

3.1.5 Validation and examples of the method use

The results of devised method are consistent with those represented by Kantor (cf. with the first method in this ET chapter). Average E(t, s) during growing season 1977-1982 equalled to 258 mm for the mature spruce stand and 234 mm for the undisturbed pole stage spruce stand in growing season 2005 found by the method of E(t, s)-SWCV (Šach et al. 2006). Similarly, average E(t, s) during growing season 1977-1982 equalled to 248 mm for the mature beech stand and 221 mm for the undisturbed small pole stage beech stand in growing season 2005 found by the method of E(t, s)-SWCV (Šach et al. 2006).
Methodical procedure of ET finding based on computing changes of recorded volumetric moisture in a soil profile and obtained results are consistent with procedures and data of further authors doing research in comparable mountain conditions; these results were discussed in papers by Šach et al. (2006) and Černohous, Šach (2008). However, accuracy of the devised method E(t, s)-SWCV is increased by continuous recording volumetric moisture and computing ET from its differences, and also taking volumetric stoniness into account in particular layers of a soil profile.
The method of E(t, s) computation in the young spruce- and the young beech stands based on the volumetric moisture changes in the soil profile (soil water content variation – SWCV) as applied on the Deštenská hillside in the Orlické hory Mts, comes from similar principals as the method based on tensiometric measuring of the suction pressure in the soil profile in mature spruce and beech stands on a NE slope in the experimental object Zdíkov-Liz in the Šumava Mts. (Mráz et al. 1990). Also the observed soil profile depths (100, 200 and 500 mm) corresponded practically to those on the Deštenská hillside including the features and course of drawing water for E(t, s). In the observed growing seasons of 1986–1989, the calculated ET in the mature spruce stand were equal to 274 mm on average. ET in the mature beech stand was calculated only in the growing season of 1989 and its value exceeded 300 mm.

Table 6. Water budget of Norway spruce pole stage stand (24 years old, stocking 10) in growing season 2005 (May – October)

Month	Precipitation P	Stemflow Sf	Through fall Tf	Net Precipitaton Pn	Interception Ei	Evapo transpiration E(t, s)	Overland flow OlF	Subsurface Lateral flow SslF
	mm	mm	mm	mm	mm	mm	mm	mm
May	196.0	0.2	144.9	145.1	50.9	51.3	0.4	0.0
June	84.4	0.1	70.9	71.0	13.4	51.1	0.3	0.0
July	169.6	0.2	135.9	136.1	33.5	43.6	0.6	0.5
August	97.6	0.1	84.1	84.2	13.4	46.0	0.3	0.2
September	69.8	0.2	53.1	53.3	16.5	23.3	0.3	0.1
October	17.4	0.0	12.0	12.0	5.4	18.8	0.0	0.0
Sum	**634.8**	**0.8**	**500.9**	**501.7**	**133.1**	**234.1**	**1.9**	**0.8**
Percentage	**100**	**0.1**	**78.9**	**79.0**	**21.0**	**36.9**	**0.3**	**0.1**

Table 7. Water budget of European beech pole stage stand (24 years old, stocking 10) in growing season 2005 (May – October)

Month	Precipitation P	Stemflow Sf	Through fall Tf	Net Precipitaton Pn	Interception Ei	Evapo transpiration E(t, s)	Overland flow OlF	Sub La f S
	mm	mm	mm	mm	mm	mm	mm	
May	196.0	13.5	155.0	168.5	27.5	36.5	0.7	
June	84.4	6.9	65.9	72.8	11.6	38.3	0.3	
July	169.6	18.3	120.8	139.1	30.5	54.9	0.4	
August	97.6	9.1	76.0	85.1	12.5	52.0	0.2	
September	69.8	9.4	47.5	56.9	12.9	22.8	0.3	
October	17.4	1.2	11.8	13.0	4.4	15.7	0.0	
Sum	**634.8**	**58.4**	**477.0**	**535.4**	**99.4**	**220.2**	**1.9**	
Percentage	**100.0**	**9.2**	**75.1**	**84.3**	**15.7**	**34.7**	**0.3**	

The E(t, s)-SWCV method may be made more precise if the results obtained from Es determination are used, especially at open canopy and weed infestation, e.g. after snow breakage of a forest stand (**Fig. 4**).
The method of E(t, s) estimation by SWCV may be employed also in computation of daily E(t, s) values (**Tab. 8**).

3.2 ET calculation from daily variation of baseflow between day and night from the small forest watershed

3.2.1 Outline of method procedure

Within the soil water regime observation of the partially waterlogged mountain catchment U Dvou louček (near the village Říčky in the Orlické hory Mts, Czech Republic), we recorded diurnal streamflow variation during the precipitation free period. The fluctuation emerged after doing the drainage in support of the forest stand regeneration and forest plantation growing out. The decline of the streamflow in the daytime against that in the night time, without influence of precipitation, is caused by fluctuation of baseflow from the catchment. We suppose the cause of the streamflow fluctuation in declining total evaporation in the night time. The principal component of total evaporation in rainless period is E(t, s), i.e. transpiration of forest stand and evaporation from forest floor and ground vegetation.
The changes of baseflow during day and night time in conditions of the catchment U Dvou louček were most likely caused by loss of soil water from saturated horizons of waterlogged and drained part of the catchment and from saturated horizons of natural watercourse surroundings connected directly hydraulically with streambed. The water loss was, in all likelihood, induced by total evaporation comprising transpiration of tree species and ground vegetation, evaporation from soil, interception evaporation from vegetation cover and evaporation from water surface of streams. The interception practically did not occur in precipitation free period and evaporation from water surface of streams was negligible in relation to total evaporation from the catchment area. To express water loss from the catchment, just only transpiration of trees and ground vegetation and evaporation from soil, i.e. evapotranspiration, were substantial. The deduction resulted from known increased soil water uptake by fine roots of trees on daytime transpiration, when concurrently under the drought period the evaporation from soil and transpiration of ground vegetation raised. We submitted the hypothesis on the basis of recording of outflow decrease at daytime against night time, when at night processes of total evaporation were not running so intensively, and on the basis of stream discharge analyses performed on the catchment U Dvou louček in the Orlické hory Mts.
Constantz et al. (1994, 1998) were interested in similarly causes of diurnal variation of streamflow. He substantiated the fluctuation by increasing of water temperature in a watercourse during daytime against night time and consequently greater infiltration into a streambed. Ronan et al. (1998) contemplated the relation between streamflow decrease in daytime and associated evapotranspiration of riparian vegetation, nevertheless, as the main factor of that streamflow decrease during daytime they considered temperature changes of water infiltrating into a streambed. We believe the theory can be accepted only in arid regions with conditions similar to those in the Middle West of the United States, where

Date	1	2	3	4	5
1.6.2005	10.0	76.9	0.4	1.9	1.0
2.6.2005	12.2	71.1	0.0	2.6	1.2
3.6.2005	18.0	65.9	0.0	2.9	1.7
4.6.2005	12.3	96.3	11.8	0.0	0.0
5.6.2005	10.2	100.0	11.2	0.7	1.0
6.6.2005	8.5	100.0	3.2	0.5	0.8
7.6.2005	4.4	99.6	6.2	0.3	0.9
8.6.2005	5.3	97.3	4.8	2.2	2.5
9.6.2005	7.9	77.6	0.0	1.6	2.1
10.6.2005	11.4	75.7	0.6	2.4	1.5
11.6.2005	7.3	100.0	3.0	0.3	0.7
12.6.2005	8.6	88.1	4.2	2.4	2.7
13.6.2005	15.2	86.9	3.6	1.7	1.2
14.6.2005	20.5	72.5	0.0	3.3	4.5
15.6.2005	16.7	94.1	3.4	0.6	0.8
16.6.2005	17.9	85.6	0.2	1.6	1.9
17.6.2005	17.5	87.4	0.0	1.6	1.2
18.6.2005	15.8	70.2	2.0	2.4	1.2
19.6.2005	16.1	73.8	0.0	2.1	1.6
20.6.2005	16.8	70.7	0.0	2.6	1.4
21.6.2005	19.4	63.5	0.0	2.9	1.7
22.6.2005	18.9	74.5	0.2	2.0	1.1
23.6.2005	17.2	67.7	0.0	2.3	1.4
24.6.2005	20.5	61.6	0.0	2.2	1.6
25.6.2005	22.1	71.8	4.8	2.3	1.5
26.6.2005	14.7	100.0	1.0	0.1	0.0
27.6.2005	18.5	72.5	0.0	1.8	1.3
28.6.2005	19.5	60.5	0.0	1.8	1.5
29.6.2005	17.6	68.5	0.0	1.3	1.2
30.6.2005	14.3	94.2	23.8	0.4	0.3

Table 8. Example of daily (24 hours') values of E(t, s) in Norway spruce and European beech pole-stage stand calculated from daily decrements of volumetric soil moisture
Notes:
1 - air temperature [°C], average for 6-20 CET, open area +200 cm above ground surface;
2 - air humidity [%], average for 6-20 CET, open area +200cm above ground surface;
3 - daily precipitation in mm, open area +50 cm above ground surface;
4 - daily E(t, s) in mm, spruce pole-stage stand; 5 - daily E(t, s) in mm, beech pole-stage stand;

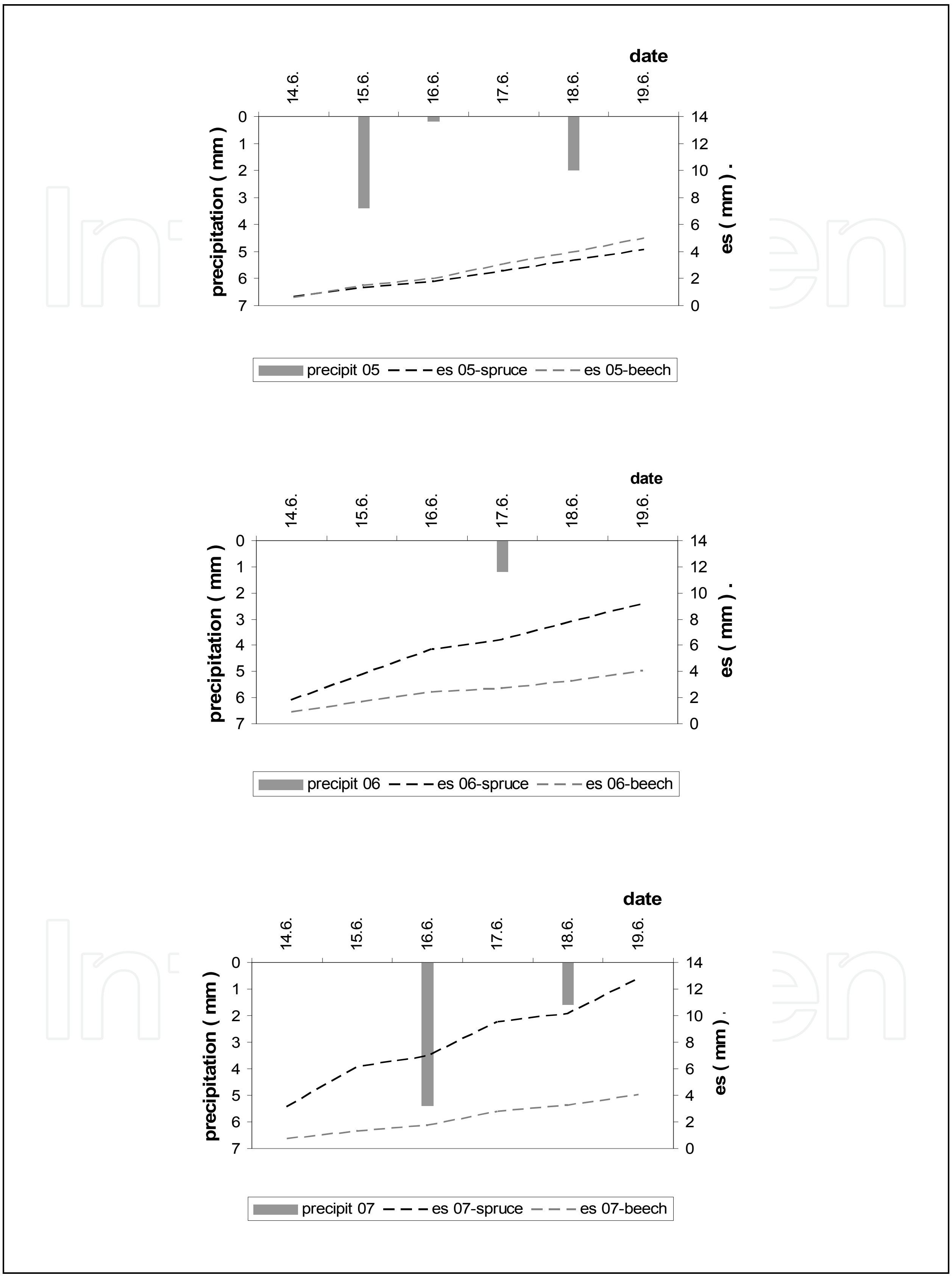


Fig. 4. Differing evaporation Es between young Norway spruce and European beech stands due to snowbreakage

Constantz et al. (1994, 1998) and Ronan et al. (1998) carried out their investigations. Under those conditions the evaporation from water surface and infiltration of water into streambeds represent the main loss factors. In humid regions, where streams predominantly drain landscape, the theory by Kobayashi et al. (1990, 1995) and Bren (1997) better corresponds with local natural conditions. They consider the evapotranspiration of riparian vegetation to be the main cause of diurnal streamflow fluctuation.
The new method of calculating evapotranspiration from decrease of day discharge in comparison with night one was developed. The procedure was demonstrated on computed example by **Fig. 5** and **Tab. 9** and it is a part of the next passage.

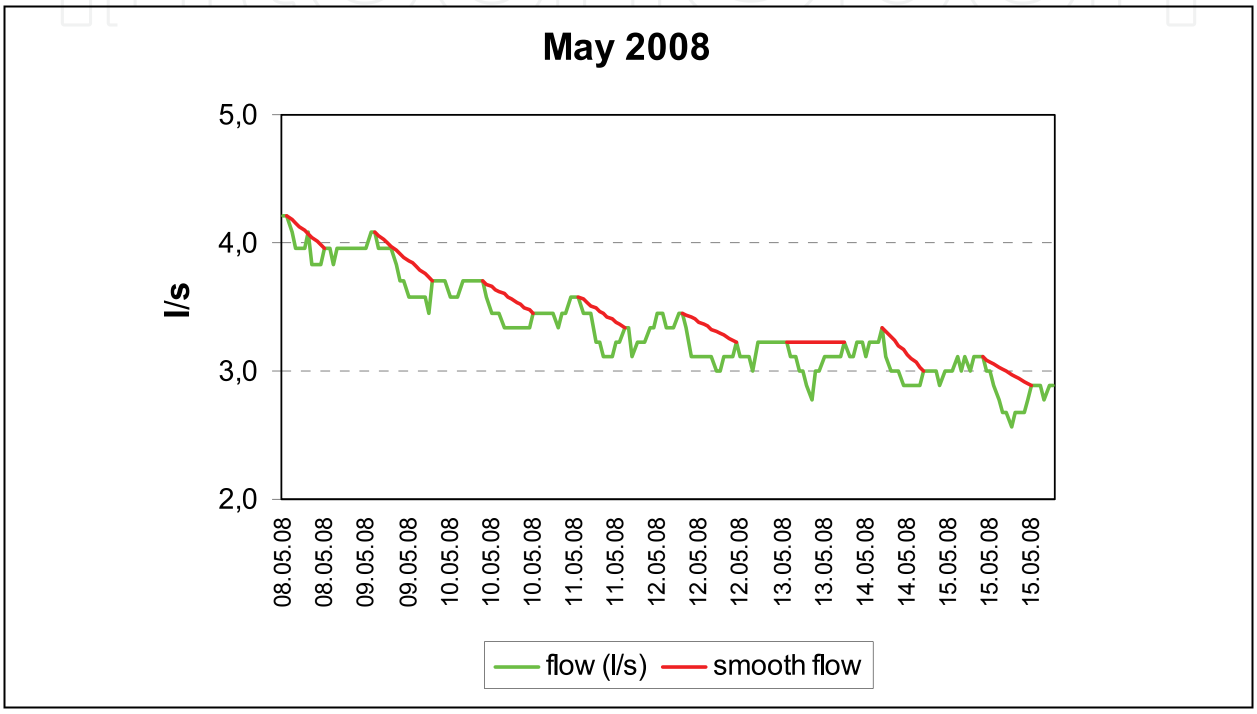


Fig. 5. Example of smoothing daily descend of streamflow

We examined the decrease of day discharge against night one from streamflows received by a manometric water-level recorder in the closing profile of the catchment. We analysed drought periods with streamflow fluctuation in revealing growing seasons 1997 – 1998, and the more recent year 2008.
In our special conditions the water loss per daytime ranged from 2,000 to 87,000 litres. By the theory of variable source areas (Hewlett & Hibbert, 1967), we determine 3 variable source areas (VSA). We derived VSA size from length of open ditches and natural streams (forming drainage network) and their possible lateral drainage reach. Hydraulic drainage reach was calculated using the Czech Government Standard No. ČSN 75 4200: "Treatment of water regime of agriculture soils by drainage". We carried out the enumeration by average weight portion of soil particles sized up to 0.01 mm and saturated hydraulic conductivity K (m per day) of the soils in our catchment. It is possible to suppose that use of agricultural procedures was not fully precise on computing values for non-homogeneous forest soils; nevertheless, its precision was sufficient for given purpose. From total length of natural streams and drainage ditches with hydraulic reach 8 m on each of both sides resulted in 3 VSA. The first VSA sized 8,000 square metres surrounds drainage open ditches

Date	Hour	Flow	Smooth flow	Difference	Litres per hour	Sum of litres	E(t, s) to 3rd VSA	E(t, s) to 2nd VSA	E(t, s) to 1st VSA
		l / s	l / s	l / s	l	l	mm	mm	mm
7.5.2008	9:00	4.63	4.63	0.000					
7.5.2008	10:00	4.35	4.59	0.244	877.22				
7.5.2008	11:00	4.35	4.56	0.212	763.84				
7.5.2008	12:00	4.35	4.53	0.181	650.45				
7.5.2008	13:00	4.35	4.50	0.149	537.07				
7.5.2008	14:00	4.22	4.47	0.252	907.08				
7.5.2008	15:00	4.08	4.44	0.353	1269.18				
7.5.2008	16:00	4.08	4.41	0.321	1155.79				
7.5.2008	17:00	4.22	4.37	0.157	566.93				
7.5.2008	18:00	3.96	4.34	0.388	1396.59				
7.5.2008	19:00	4.08	4.31	0.227	815.64				
7.5.2008	20:00	3.96	4.28	0.325	1169.82				
7.5.2008	21:00	3.96	4.25	0.293	1056.44	11,166	0.41	0.61	1.40
7.5.2008	22:00	4.22	4.22	0.000					
7.5.2008	23:00	4.08							

Table 9. Example of computing daily E(t, s)

of length equal to 500 m. The second VSA sized 18,240 square metres includes length of drainage ditches and main watercourse equal to 1,140 m in total. The third VSA sized 27,344 square metres involves strips passing along all natural and man-made watercourses on the watershed of the whole length equal to 1,709 m.

3.2.2 Results

If we recalculated the mean daytime loss of discharge equalled to 45,000 l on the probable area 27,344 square meters or 18,240 square meters influenced by drainage network, we obtained expression of runoff-depth loss in millimetres, i.e. 1.6 or 2.5 mm per day. The daily values of runoff-depth loss, computed for discharge loss interval 2,000 to 87,000 l from the VSA of 8,000 square meters, ranged between 0.25 to 2.5 mm per day. Decreases of 20,000 to 87,000 l related to the VSA of 18,240 or 27,344 square meters then response to 1.1 – 4.8 mm or 0.7 – 3.2 mm per day.

The range of values corresponded with transpiration and evapotranspiration data reported by Ladefoged (1963), Střelcová et al. (2004), Kantor (Krečmer et al., 2003), and most recently Šach et al. (2006).

Ladefoged (1963) stated maximum daily transpiration 1.9–4.9 mm per day for a mature Norway spruce stand and 2.2–4.8 mm per day for a mature European beech one under optimal climatic conditions. On the basis of his experiments in spruce stands he further specified interval of transpiration: 1.3–3.2 mm per day for the period of May to August (September). Střelcová et al. (2004) stated daily smoothed values of transpiration for a mature beech group in the Polana Mt. (the Slovak Republic) at an elevation of 850 m, calculated on the one hand from the measured sap flow and on the other hand using the SVAT model, for the period June–July 1996 in the range from 1.1 to 6.0 mm with mean value 1.6 mm per day.

Kantor (Krečmer et al., 2003) used his many years' investigation of water balance in Norway spruce stand and European beech one in the Orlické hory Mts for estimation of daily value of evapotranspiration. Young spruce or beech stand (from thicket to pole stand) gives daily evapotraspiration for cloudy spring, summer, and autumn day 1.1, 2.0, 1.0 mm respectively, for sunny spring, summer, and autumn day 2.6, 4.4, 2.5 mm respectively. Clear-cut with heavy weed infestation shows practically the same data: 1.1, 2.2, 1.0 mm respectively 2.6, 3.7, 2.4 mm. The interval of evapotraspiration 1.0–4.4 mm per day by Kantor is very close to interval 1.1–4.1 that we established for similar natural conditions on our experimental catchment U Dvou louček.

Šach et al. (2006) derived daily evapotranspiration from decrements continuously recorded volume soil moisture in young closed stands in the Orlické hory Mts. Daily evapotranspiration of spruce pole-stage stand and beech pole-stage one ranged in rainless days of June 2005 from 1.3 to 3.3 mm respectively from 1.2 to 4.5 mm. The evapotranspiration range from 1.2 to 4.5 mm again supported the range 0.7 – 4.8 mm from the examined catchment.

If we return the computing, i.e. from the known runoff loss and from E(t, s) per day, estimated by different procedure, it is possible to determine the concrete size of VSA for given streamflow per day.

3.2.3 Conclusion

The study resumes our hitherto knowledge on influence of evapotranspiration on discharge variations in conditions of the partially waterlogged catchment in growing seasons 1997, 1995, i. e. years of phenomenon revelation, and recent growing season in 2008. The daily discharge fluctuations of streamflow, which drained waterlogged pedon, were in accordance with the theory of Kobayashi et al. (1995) and Bren (1997) who also consider the evapotranspiration of riparian vegetation to be the main cause of that phenomenon in similar natural conditions. Our observations and computations in small forested watershed in the Orlické hory Mts. (Czech Republic, EU) correspond to this theory. Values of E(t, s) 0.25 to 4.8 mm per day found by us are consistent with those of other researchers.

From total length of natural streams and drainage ditches with hydraulic reach 8 m on each of both sides resulted in 3 variable source areas (VSA) different in size and area of drainage. If we return the computing procedure, i.e. from the known runoff loss and the E(t, s) per day, estimated by different procedure, it is possible to determine the concrete size of VSA for given streamflow per day.

4. General conclusion of the chapter

The evapotranspiration ET (Ei +Et + Es) plays an important role in ensuring of hydrologic and soil conservation services of forest and forestry.

Therefore knowledge of ET on sites in frame of forest stands and forest catchments is very important not only for a forest land itself but also for the landscape in lower elevations. The problem is to determine the ET promptly and accurately as much as necessary. Several methods were selected, made better or newly developed.

At the beginning, methods of ET calculation from water balance equation were used. ET was calculated from complex of measured water balance components in a forest stand with only single unknown Et. The method of ET assessment is performed on the Deštenská stráň Hillside experimental area. Investigations, from which the ET components for mature Norway spruce and European beech stands were obtained, we have done in a continuous sequence of five water years (from 1 Nov. 1976 to 31 Oct. 1981). Two components of vaporization process, i.e. interception losses (Ei) and evaporation from the litter and soil surface (Es) were ascertained directly; the tree canopy transpiration (Et) was estimated by calculation from water budget equation as the only unknown.

Measurement of water budget components during growing season, done in all days with measurable precipitation, i.e. usually 2 to 3 times in a week, resulted in very precise assessment of ET components of experimental pure Norway spruce and European beech mature stands during reproduction period. For this reason we might take it as a reference method for mountain slopes with various pure forest stands; it is corresponding to lots of research results mainly in EU.

The assessment ET values obtained from continuous measuring the volumetric moisture of soil profile in a forest stand and calculation of E(t, s) from soil moisture differences was developed as amendment and calibrated using the previous described method. It is simpler and if meeting all demands it gives the same precise results (moreover Et is directly enumerated and so the only unknown is eliminated). Of course, correct estimating volume stoniness and rooting layers is very important. Moreover, we supposed that using the method also helps to determine complicated and permanently unsolved problematic ET of mixed forest stands especially in dry periods and possible "hydraulic lift" in a soil profile (solum). The experiment was already established in the UDL experimental catchment.

The assessment of ET values obtained from complex of partially measured water balance components and partially derived from tensiometric measurements in a small watershed with only single unknown E(t, s) was performed in the UDL experimental catchment. The method taking into consideration water movement in the soil profile solves and removes the uncertainty of soil water outflow or inflow (discharge from soil mantle, eventually recharge). Up to now, the discharge from pedon (outflow from soil), measured with particular instruments (devices), greater than causal (effective) precipitation (including discharge from snowpack – so called delayed precipitation) was eliminated as outliers.

The presented model of hydrological balance brings values of ET and Q consistent with experimental results from comparable conditions, representing in the Czech Republic conditions of mountain lands covered predominantly by coniferous forest.

The method of ET calculation from daily variation of baseflow between day and night from the small forest watershed was designed. The daily discharge fluctuations of streamflow, which drained waterlogged pedon, were in accordance with the theory of Kobayashi et al. (1995) and Bren (1997) who also considered the evapotranspiration of riparian vegetation to be the main cause of that phenomenon in similar natural conditions. From total length of natural streams and drainage ditches with known hydraulic reach we determined number of variable source areas (VSA) differing in size. From concrete area of VSA and concrete runoff loss we calculated the daily ET. If we turn the computing procedure, i.e. from the known runoff loss and by other procedure estimated daily E(t, s), it is possible to determine the concrete size of VSA for given streamflow.

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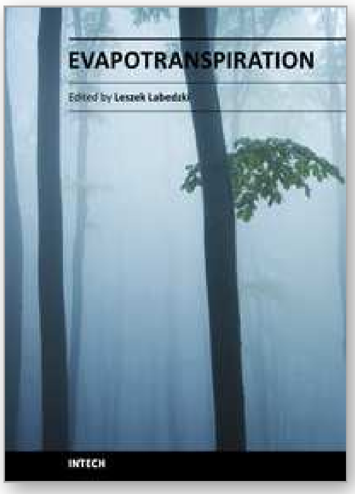

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Evapotranspiration is a very complex phenomenon, comprising different aspects and processes (hydrological, meteorological, physiological, soil, plant and others). Farmers, agriculture advisers, extension services, hydrologists, agrometeorologists, water management specialists and many others are facing the problem of evapotranspiration. This book is dedicated to further understanding of the evapotranspiration problems, presenting a broad body of experience, by reporting different views of the authors and the results of their studies. It covers aspects from understandings and concepts of evapotranspiration, through methodology of calculating and measuring, to applications in different fields, in which evapotranspiration is an important factor. The book will be of benefit to scientists, engineers and managers involved in problems related to meteorology, climatology, hydrology, geography, agronomy and agricultural water management. We hope they will find useful material in this collection of papers.