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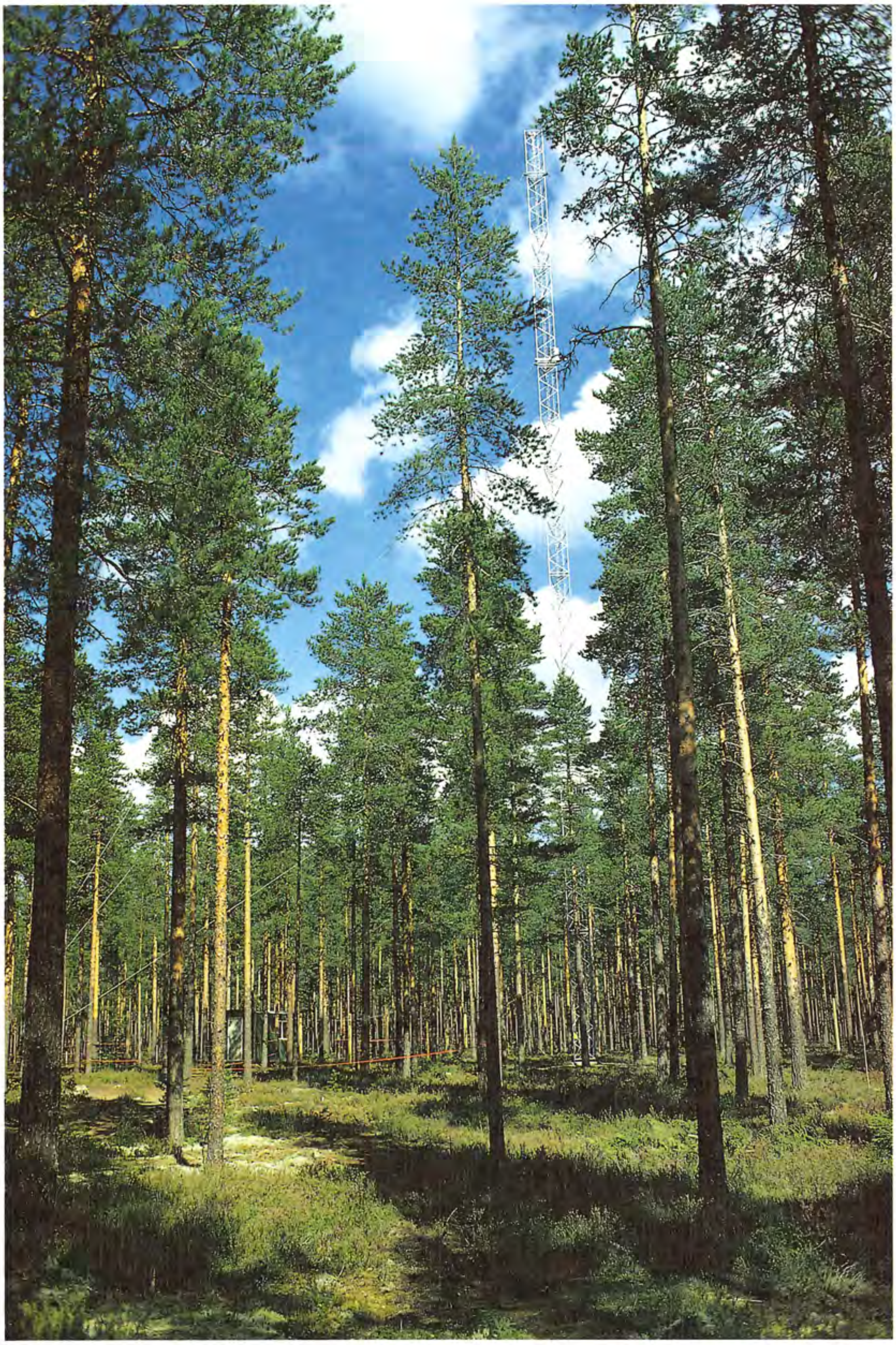

TEST OF A FOREST EVAPOTRANSPIRATION MODEL

Björn Bringfelt

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Front cover:	*The Jädraås forest and meteorological mast. Anders Lindroth, Swedish University of Agricultural Sciences (SLU), Uppsala.*
Back cover:	*Downward view of the Velen forest and vertically spaced radiation shields for air temperature sensors. Per-Olof Hårsmar, SMHI.*

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Title (and Subtitle)

TEST OF A FOREST EVAPOTRANSPIRATION MODEL

Abstract

The model computes daily forest evapotranspiration using routine weather observations. The model was developed from detailed meteorological and evapotranspiration measurements in a forest in the Velen hydrological research area in southern Sweden.
The model was tested successfully against independent monthly evapotranspiration from the Velen area obtained by the water balance method. In this report the model is improved based on this comparison and the new model is tested against water balance data from two other hydrological research areas, Kassjöån and Lappträsket in middle and north Sweden.
Model comparisons have been made for the Jädraås forest in middle Sweden where detailed meteorological and evapotranspiration measurements have also been made. The model now has a parameter set for each of the forest stands in Velen and Jädraås.
The model can interrelate various data such as routine weather data, hydrological data, rainfall interception and meteorological mast data. This may imply a better utilization of different data sets.
It has been shown that knowledge of water losses from a forest can be used to estimate dry deposition of gaseous pollutants such as sulfur dioxide. In a new study the model will be used to estimate dry deposition of sulfur dioxide to the forests of Velen and Jädraås continuously during one year.

Key words

Evapotranspiration
Forest meteorology/hydrology
Routine weather data
Rainfall interception
Surface resistance/conductance
Water balance

Supplementary notes	Number of pages	Language
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TEST OF A FOREST EVAPOTRANSPIRATION MODEL

(Test av modell för evapotranspiration från skog)

Final report

by

Björn Bringfelt

This is the final report of a project supported by the Swedish Natural Science Research Council (NFR) (G-GU-3795-105-106) with the above title. Dr Anders Lindroth, SLU, has kindly supplied measuring data from Jädraås, one of the forest areas studied. His review of the report has also been very valuable.

The report contains four sub-papers:

I A physiological expression for forest canopy resistance tested against daily transpiration data from two Swedish forests.

II Comparison between observed and estimated daily rainfall duration.

III Modelling evapotranspiration from the Jädraås forest using routine weather observations.

IV Improvement of forest evapotranspiration estimates and comparison with water balance measurements.

These sub-papers will be referred to as I, II etc. A summary of the papers will be given below and a brief description of the forest evapotranspiration model.

<u>Summary of the sub-papers I-IV</u>

(I) A physiological expression for forest canopy resistance tested against daily transpiration data from two Swedish forests.

Measured vapour concentration deficit in the air (VCD) and forest transpiration (E) in the Velen and Jädraås sites were used to calculate daily values of the canopy resistance r_s. For the Velen forest 37 daily values were obtained and for Jädraås 30 values. The complete Penman-Monteith formula was used to calculate r_s with a few alternatives for the aerodynamic resistance r_a. For these ways to get r_s from the measurements in Velen and Jädraås the fit to a physiological formula for r_s, the Lohammar equation, was tested. The r_s-data of the two sites showed the same general features, even if the fit to the Lohammar equation was better for the Jädraås data.

In the literature some small standard value for r_a has often been used when computing r_s from measurements of $\hat{E}$ and VCD. Therefore, it was tried to find out if there is a positive value or range for r_a for which the relation between measured r_s and the physiological formula for r_s was optimal. However, no relevant r_a-value was found. No improvement was found if r_a was calculated by current wind and/or stability compared to using a constant value of r_a. The use of $r_a = 0$ gave as good a result as using any other method. No improved correlation was found if r_s was calculated using the latent heat of vapourization (L), (and also Δ and γ) as functions of air temperature and pressure. Thus, it was not possible to improve the fit of the r_s-data to the physiological formula for r_s (Lohammar equation) by refining the methods to calculate r_s from the mast data. A reason why no relevant range or value for r_a was found, may be that the equations and methods used are too crude to describe the processes of the forest canopy adequately enough. Forest transpiration is known to be very insensitive to r_a, so more detailed and exact data may be required. Possibly hourly values instead of daily data could give positive result.

(II) Comparison between observed and estimated daily rainfall duration.

Rainfall duration is important as input to evapotranspiration models. The present model is based on daytime averages. The day-to-day model results would be improved if daytime rainfall duration were known better than simply calculating it from the rainfall amount. Therefore, values of daytime rainfall duration calculated from synoptic stations data, i.e. alternatively the daytime rainfall amount reported at 18 hrs GMT and the present weather (ww) reported every third hour (rainfall or no rainfall), were compared to daily rainfall durations observed manually and continuously in a study made at the airport of Sundsvall. It was found that the ww information improved the rainfall duration estimates markedly compared to using the rainfall amount.

(III) Modelling evapotranspiration from the Jädraås forest using routine weather observations.

This report is divided into two sub-reports:

(IIIi) Simulating daily interception loss using routine meteorological data from two locations.

Routine meteorological data were used to simulate daily evaporative rainfall interception losses from the Jädraås forest canopy. A large scatter was obtained between the daily calculated losses and those measured with a system of troughs in the forest. This is largely because the interception submodel uses information only on 12 hourly (day and night) rainfall amounts and not on the duration of rainfall within each 12 hourly period. Two model runs were made, one using input data (rainfall amount, air temperature and humidity) from a synoptic weather station 20 km away and the other using input data from a location within 1 km from the troughs. In both cases the scatter between measured and calculated interception amounts was large although it was smaller using data from the nearby location. In order to improve the prediciton of daily intercepted amounts, rainfall duration should be used in the interception model and it should be calculated from data on present weather (ww) in the synoptic weather code. However, as found earlier, the interception loss over one month or one week can be predicted very well with the present model.

(IIIii) Simulating interception and transpiration in Jädraås using synoptic weather data from Åmotsbruk.

Total evapotranspiration (interception loss plus transpiration) was simulated for the Jädraås forest. Then synoptic meteorological data from Åmotsbruk 20 km away was used as input driving data. Three alternative sets of parameter values were used. For interception the Jädraås parameters gave about 60% of the losses obtained with the Velen parameters due largely to the smaller canopy water storage capacity used. For transpiration the Jädraås parameters gave somewhat larger losses than the Velen ones and this reflects the different transpiration levels originally measured in the two sites. A model experiment was also made with Velen parameter values proportioned in order to hold in Jädraås according to the leaf area index values known for both forests. Then, the model transpiration in Jädraås became less than half of the original value. Therefore, factors other than differing LAI seem to be responsible for the relative magnitude in transpiration at the two sites. However, there is some uncertainty as to the correct level of transpiration in Jädraås. For more definite conclusions the results from planned eddy correlation measurements must be awaited.

(IV) Improvement of forest evapotranspiration estimates and comparison with water balance measurements.

The transpiration model was improved knowing that the biological activity of a forest is reduced in spring and autumn compared to summer. The magnitude of the transpiration reduction was deduced from monthly evapotranspiration data obtained by the water balance of the Velen area. The results from the new model version gave much better agreement with the water balance data not only from the Velen site (which had been used to improve the model) but also for two other areas with independent water balance estimates namely Kassjöån in middle Sweden and Lappträsket in the northern part.

It was not found worthwhile to refine the calculation of surface resistance r_s by putting more details in handling the meteorological resistance r_a (I). r_s in Velen could not easily be transformed to Jädraås by proportioning using the different value of leaf area index (IIIii). An improved method to compute daily rainfall duration based on routine observations of rain/no rain (ww in the synoptic code see II) was used for transpiration reduction in paper IIIii. An important improvement made is the introduction of the influence of vegetation period. This is tested successfully in IV.

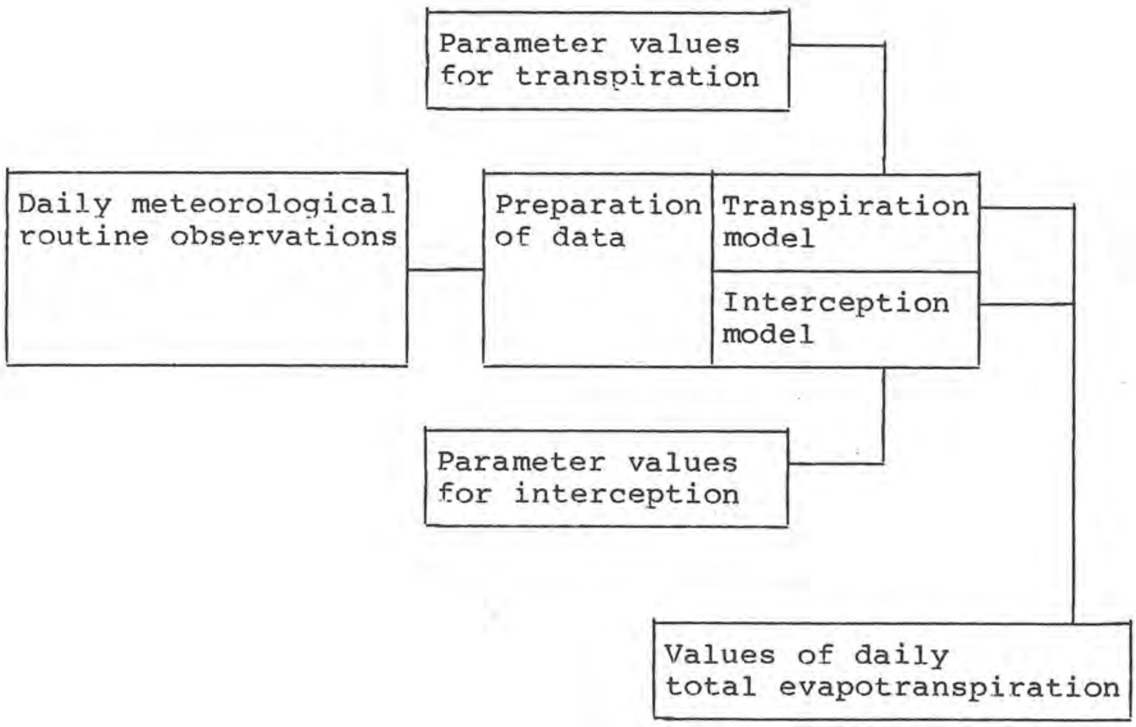
Brief description of the forest evapotranspiration model

The model has been described in detail by Bringfelt (1982b) and more briefly in the paper of 1985. The model computes daily actual forest evapotranspiration using routine weather observations as driving data. The model was developed on the basis of meteorological mast measurements over a forest in the Velen hydrological research area in southern Sweden (Bringfelt et al, 1977). The model is a computer program consisting of two sub-models:

- Model for evaporation of rain water intercepted (caught) by the forest canopy. Parameters are the free throughfall coefficient and the rain water storage capacity. For the Velen forest, parameter values were deduced by Bringfelt (1982b) from interception data taken by rain troughs below and aside the forest canopy.

- Model for transpiration from the dry forest canopy. A physiological formula is used for the surface resistance against water transpiration. The parameters are constants in this formula. Values for the Velen forest were presented in a statistical study, (Bringfelt 1982a). This study utilized daily values of transpiration from the dry forest evaluated from mast data by the Bowen ratio-energy balance method.

The calculations are made on a daily basis. As driving data are needed routine meteorological observations every third or sixth hour.



Flux diagram for the model

Originally, the model was based on detailed data on air humidity, temperature, wind, radiation, interception and evapotranspiration taken in or near a meteorological mast in the Velen area. Then, evapotranspiration values were simulated for April - October of 1967-74 (49 months). These model results were tested successfully against independent monthly values for the Velen area obtained by the water balance method. Based on this comparison the model was improved especially as regards the simulation of the spring and autumn evapotranspiration. This improved model was now tested against water balance data from two new areas in middle and north Sweden: Kassjöån and Lappträsket (IV). The model has a parameter set for each of the forest stands in Velen and Jädraås which are the two sites in Sweden where detailed forest evapotranspiration measurements have been made.

The model is considered to be well calibrated for the measuring sites and areas in question. In the Velen area, the model has been tested against three different kinds of data of actual evapotranspiration: micrometeorological mast data, interception data and water balance data. In Jädraås, the model has been tested against mast data and interception data.

As has been shown, the model can interrelate various kinds of data such as synoptic weather data, hydrological data, interception and meteorological mast data. Using monthly water loss data and synoptic weather data for a forest area, the model may separate the interception evaporation from the transpiration. Then, it may be possible to extract information about stand parameters such as water storage capacity and surface resistance. Dry deposition has been recognized as a major removal mechanism for gases from the atmosphere. According to Garland et al (1977) surface resistances to water vapour flux may be used to estimate resistances to gas fluxes to vegetation such as dry deposition of SO_2. With low SO_2 concentration in the ambient air, the concentration inside the vegetation leaf is negligible (Lorentz et al 1985). Then, daily data on resistances to water vapour flux and ambient SO_2 concentrations would make possible simulation of daily dry deposition of SO_2 if the model presented here is developed further. This may be used to evaluate harmful effects to forests due to acid deposition.

REPORT NO I

A PHYSIOLOGICAL EXPRESSION FOR FOREST CANOPY RESISTANCE TESTED AGAINST DAILY TRANSPIRATION DATA FROM TWO SWEDISH FORESTS

Abstract

A physiological expression for the forest canopy resistance r_s was adjusted to daily r_s-values calculated from hourly mast meteorological data at two Swedish forest sites. It was studied if there was a positive value of aerodynamic resistance r_a above the forest (used when calculating r_s from the data) for which the correlation to the physiological values was optimal. No such positive value could be found. The use of functions of wind speed and stability for calculating r_a neither had any effect. The data from the two sites showed similar results. Forest transpiration is known to be very insensitive to r_a and probably the physiological formula for r_s, and method of using daytime averages were too crude to reveal the dependence of r_s on r_a.

Introduction

Bringfelt (1982a) calculated 52 daily values of canopy resistance r_s from measurements above a dry forest canopy by applying a simplified Penman-Monteith formula. The vapour concentration deficit VCD and the transpiration rate E were evaluated from hourly meteorological measurements. VCD was evaluated directly and E was calculated by the Bowen ratio-energy balance method.

These daily values of r_s were fitted by a least square technique to various formal functions of incoming radiation and water vapour concentration deficit in the air. The Lohammar expression for r_s was found to give the best fit to the daily data. Such a good fit of a physiological model for r_s to field data had not been obtained earlier.

In the present study the complete Penman-Monteith (Monteith, 1965) formula was used to calculate r_s from the measurements. Then, various alternatives for the aerodynamic resistance r_a were tested. The physical parameters used in the Penman-Monteith expression (Δ, γ etc) were determined from the current values of air temperature, humidity and pressure.

These r_s-values were fitted to the physiological Lohammar expression by the above mentioned least square technique. These correlation studies were made firstly using 37 daily data sets from Velen (used also in the 1982 study) and secondly using 30 daily data sets from the forest meteorological site of Jädraås.

Lohammar-type expressions for r_s have been used in practical computer models to evaluate day-to-day evapotranspiration by the Penman-Monteith formula from routine meteorological observations. Such a model for daily evapotranspiration from a forest canopy (Bringfelt, 1985) used a simple submodel to deduce incoming radiation from date and cloudiness and vapour pressure deficit from other synoptic data.

Then, these two elements were used in the Lohammar equation to calculate r_s and then daily transpiration. The aim of this study is to see if it is possible to improve the fit of the r_s-data to the Lohammar equation by refining the methods to calculate r_s from mast measuring data.

Evaluation of canopy resistance (r_s) from measurements

The Penman-Monteith formula

$$E = \frac{\Delta \cdot A + \rho c_p \frac{\delta e}{r_a}}{\Delta + \gamma(1 + \frac{r_s}{r_a})}$$

can be rearranged to give r_s as

$$r_s = \frac{\rho c_p}{\gamma} \frac{\delta e}{E} + r_a(\frac{\Delta A}{\gamma E} - \frac{\Delta}{\gamma} - 1)$$

Using vapour concentration deficit VCD instead of vapour pressure deficit δe, r_s can be written (in s cm^{-1}) as

$$\overline{r}_s = \frac{\overline{L}}{100} \frac{\overline{VCD}}{\overline{E}} + \overline{r}_a \left(\frac{\overline{\Delta A}}{\gamma \overline{E}} - \frac{\overline{\Delta}}{\gamma} - 1\right) \qquad (1)$$

VCD (g m^{-3}) is measured at the reference level z above the vegetation. $\overline{E}$ is the mean daytime evapotranspiration (W m^{-2}) evaluated by the Bowen ratio-energy balance method, $\overline{r}_a$ (s cm^{-1}) the aerodynamic resistance between the vegetation and the level z and $\overline{A}$ the available energy equal to net radiation flux minus the flux to energy storage in soil, air and biomass below the level z. L is the latent heat of vapourization. L varies slowly with air temperature t(^{o}C) as

$$L = 4.1855\ (597.31 - 0.5655\ t)\ J\ g^{-1} \qquad (2)$$

Δ (mb K^{-1}) is the slope of the curve of saturation vapour pressure e_s as function of air temperature T(K). Given the expression for e_s (WMO, 1984a)

$$\begin{aligned} e_s = 10 \ \{ & 10,79574\ (1-\frac{T_1}{T}) - 5,028\ {}^{10}\log \frac{T}{T_1} + \\ & + 1,50475 \cdot 10^{-4}\ (1-10^{-8,2969(\frac{T}{T_1}-1)}) + \\ & + 0,42873 \cdot 10^{-3}\ (10^{4,76955(1-\frac{T_1}{T})} - 1) + \\ & + 0,78614 \} \end{aligned} \qquad (3)$$

Δ is obtained as

$$\Delta = \frac{d\ e_s}{dT} = e_s \cdot \Big(\frac{10.79574}{0.4343} \frac{T_1}{T^2} - 5.028 \frac{1}{T}$$
$$+ 1.50475 \cdot 10^{-4} \frac{8.2969}{0.4343^2} \frac{1}{T_1} \cdot 10^{8.2969(1-\frac{T}{T_1})}$$
$$+ 0.42873 \cdot 10^{-3} \frac{4.76955}{0.4343^2} \frac{T_1}{T^2} \cdot 10^{4.76955(1-\frac{T_1}{T})}\Big) \qquad (4)$$

where T_1 = 273,16 K and e_s is in mb.

γ the psychrometic 'constant' is

$$\gamma = \frac{c_p\ p}{0,622L} \qquad (\text{mb K}^{-1}) \qquad (5)$$

where the specific heat of air at constant pressure, c_p, is

$$c_p = 0,24 \cdot 4.1855\ (1 + 0,8\ \frac{0,622e}{p-e})\ \text{J g}^{-1}\ \text{K}^{-1}$$

e is the vapour pressure (mb) and

p the atmospheric pressure (mb).

The daytime average of $\overline{r}_s$ is here defined by Eq. (1).

Three alternative formulations for r_a denoted a, b and c respectively, were used:

a) r_a is independent of wind speed and the same for all days namely 0, 0.01, 0.02 ---0.10 s/cm for the eleven test runs made.

b) r_a is given as inversely proportional to wind speed u. The expression for r_a in a neutral atmosphere is (e g Bringfelt, 1975)

$$r_a = \frac{(\ln \frac{z-d}{z_o})^2}{k^2\ u_z}$$

For a given set of values on the roughness length, z_o, and displacement height, d, r_a, is only dependent on daytime average wind speed $\overline{u_k}$ as

$$r_a = \text{const}\ \frac{i}{\overline{u_k}} \qquad (6)$$

where k is the day number and i is the number of the test run.

The value of the constant has been chosen so that r_a will have the averages of a) over the days for i " 1, 2 to 10 respectively thus testing ten different levels of r_a.

c) Both wind and stability have been used. r_a is expressed in terms of flux profile relationships based on Monin-Obukhov's similarity theory (Businger, 1971):

$$r_a = \frac{R}{k^2\, u_z}\left[\ln\frac{z-d}{z_o} - \Psi_m(x) + \Psi_m(x_o)\right]$$

$$\cdot\left[\ln\frac{z-d}{z_o} - \Psi_h(y) + \Psi_h(y_o)\right] \qquad (7)$$

$$u_z = \frac{u_*}{k}\ \ln\frac{z-d}{z_o} - \Psi_m(x) + \Psi_m(x_o) \qquad (8)$$

$$\Psi_m(x) = \ln\left(\frac{1+x}{2}\right)^2 \frac{1+x^2}{2} - 2\ \mathrm{arctg}\ x + \frac{\Pi}{2}$$

$$x = \left(1-15\,\frac{z-d}{L}\right)^{1/4}$$

$$x_o = \left(1-15\,\frac{z_o}{L}\right)^{1/4}$$

$$\Psi_h(y) = 2\ \ln\frac{1+y}{2}$$

$$y = \left(1-9\,\frac{z-d}{L}\right)^{1/2}$$

$$y_o = \left(1-9\,\frac{z_o}{L}\right)^{1/2}$$

$$L = -\frac{T\,u_*^3}{g\,k\,H}\,\rho\,c_p \qquad (9)$$

where R is a constant (=0,74), k von Karmans constant (=0,35), u_z the mean daytime wind speed at level z, z the height of the reference level, Ψ_m the stability function for momentum, Ψ_h the stability function for heat, u_* the friction velocity, L the Monin-Obukhov stability length, g acceleration due to gravity and H the mean daytime sensible heat flux. The values of z_o, d and z are site dependent and will be given in Tables 2c and 4c.

Given u_z and H the friction velocity is estimated iteratively using Eqs. (8) and (9). The initial value of u_* is estimated by assuming $L = \infty$ (neutral stability). When L is obtained with good enough precision, r_a is calculated by Eq. (7). Similarly to b) above values of R have been chosen so that r_a will have the ten levels of a).

Estimation of parameters in the Lohammar form for canopy resistance r_s.

The Lohammar form for canopy resistance

$$\overline{r_s} = \frac{1}{\alpha}\left(\beta + \frac{1}{RIS}\right)\left(1 + \gamma\ \overline{VCD}\right) \qquad (10)$$

is identical with that at the bottom of Table II of Bringfelt (1982a). This relation was deduced on the basis of data from cuvette and porometer measurements on shoots of Scots pine (Lohammar et al 1980). The measuring data of Tables 1 and 3

TABLE 1. Velen forest stand.
Meteorological parameters measured above the forest (daytime averages) used to calculate the surface resistance r_s by Eq. (1).

E transpiration flux obtained by the Bowen ratio-energy balance method.

A = R_n - G where

R_n net radiation flux measured above the canopy

G flux to heat storage in soil, air and biomass

VCD measured water vapour concentration deficit in the air

u wind speed at 54 m above ground level or 34 m above mean tree height

T air temperature

P atmospheric pressure at 1300 hrs (mb) measured at Fägre (the nearest synoptic station about 20 km from the site)

RIS global radiation above the canopy

The values of E, R_n, RIS and VCD have been taken from Bringfelt (1982 a).

To the right are given values of r_s calculated from the measurements by Eq. (1) with r_a = 0 and r_a = 0.05 s cm^{-1}.

DATE	E	R_n	G	A	VCD	u	T	p	RIS	r_s (r_a=0)	r_s (r_a=0,05)
	Wm^{-2}	Wm^{-2}	Wm^{-2}	Wm^{-2}	gm^{-3}	ms^{-1}	^0C	mb	Wm^{-2}	scm^{-1}	scm^{-1}
1974-05-08	118	308	29	279	6,39	1,50	11	1006,4	444	1,34	1,38
1974-05-09	136	306	28	278	6,24	1,43	13	1005,4	441	1,13	1,16
1974-05-10	143	291	26	265	7,26	1,22	14	1003,3	420	1,25	1,27
1974-05-11	134	310	28	282	5,04	1,76	12	1006,1	417	0,93	0,96
1974-05-12	112	263	23	240	4,72	1,72	11	1014,4	367	1,04	1,07
1974-05-13	103	314	30	284	5,66	1,83	11	1020,1	453	1,36	1,42
1974-05-16	84	135	11	124	4,17	1,16	11	1012,9	166	1,23	1,21
1974-05-17	149	292	28	264	6,15	0,95	16	1017,0	412	1,02	1,03
1974-05-18	152	291	28	263	8,48	1,53	19	1017,4	410	1,37	1,39
1974-05-19	154	292	27	265	8,87	1,24	20	1011,1	389	1,41	1,44
1974-05-20	143	271	26	245	6,97	1,47	16	1006,4	364	1,20	1,21
1974-05-23	139	285	28	257	6,14	1,16	14	998,3	395	1,09	1,11
1974-05-24	115	253	25	228	6,04	1,54	15	999,8	339	1,29	1,33
1974-05-25	100	256	21	235	4,83	1,29	13	998,8	335	1,19	1,24
1974-06-02	86	179	22	157	5,29	3,13	15	1009,9	239	1,52	1,53
1974-07-11	80	177	11	166	3,74	2,00	18	985,7	262	1,15	1,21
1974-07-21	101	267	21	246	5,28	5,71	17	995,0	393	1,29	1,37
1974-07-22	50	66	9	57	2,73	5,40	15	994,7	82	1,35	1,31
1974-07-30	108	300	23	277	4,54	6,11	16	991,4	447	1,04	1,12
1974-08-01	140	279	22	257	5,87	2,90	17	995,0	434	1,03	1,06
1974-08-04	140	268	19	249	5,57	3,74	17	1004,5	444	0,98	1,00
1974-08-05	123	247	22	225	6,56	3,07	18	999,8	432	1,31	1,34
1974-08-06	111	273	22	251	6,25	5,06	16	1006,6	422	1,39	1,45
1974-08-07	122	281	22	259	6,13	3,09	16	1002,7	415	1,24	1,29
1974-08-08	101	275	23	252	6,93	3,17	17	997,2	423	1,69	1,78
1974-08-09	118	148	18	130	5,89	1,49	19	992,3	213	1,23	1,19
1974-08-20	157	253	19	234	6,78	2,16	18	1017,3	370	1,06	1,06
1974-08-21	108	197	16	181	6,28	3,39	17	1014,0	263	1,43	1,44
1974-08-22	106	174	15	159	4,72	2,88	17	1008,1	220	1,10	1,09
1974-08-23	103	168	17	151	3,44	3,27	17	1004,5	242	0,82	0,82
1974-08-24	93	124	10	114	3,40	4,24	17	1002,5	162	0,90	0,87
1974-08-25	87	130	9	121	3,37	3,19	18	1005,3	166	0,95	0,94
1974-08-26	130	187	14	173	6,27	3,14	21	1005,3	252	1,18	1,17
1974-09-01	137	218	18	200	5,54	5,06	21	1001,0	311	0,99	0,99
1974-09-14	55	92	10	82	2,67	4,75	14	1011,0	124	1,20	1,19
1974-09-15	29	37	4	33	1,72	3,70	13	1014,9	49	1,47	1,43
1974-09-17	97	142	12	130	3,39	4,37	17	1002,3	195	0,86	0,84

TABLE 2 a. Velen measurements 1974. Aerodynamic resistance $\overline{r}_a$ is kept constant at 0, 0.01 0.02 -- 0.10 s cm^{-1} (formulation a) for all days tested in the various cases.
The framed line refers to a constant value of $\overline{L}$ (= 2500 Jg^{-1}) for all the days and there the second term in Eq. (1) (containing the resistance $\overline{r}_a$) is left out thus using $\overline{r}_s$ = 25 $\overline{VCD}/\overline{E}$ exactly as in Bringfelt (1982 a).
The three columns to the right give correlation coefficients between $\overline{r}_s$ estimated from measurements by Eq. (1) and (i) calcualted $\overline{r}_s$ by the best fit of Eq. 10, (ii) $\overline{RIS}$, (iii) $\overline{VCD}$.

$\overline{r_a}$ kept constant:	α /	β	γ	RMS	$\overline{r_s}$	$\frac{RMS}{\overline{r_s}}$	$R_{MEAS\ CALC}$	$R_{MEAS\ RIS}$	$R_{MEAS\ VCD}$
0	0,0329	0,0152	0,2031	0,1520	1,207	0,126	0,640	0,058	0,347
0	0,0333	0,0154	0,1990	0,1507	1,189	0,127	0,635	0,058	0,341
0,01	0,0343	0,0163	0,1934	0,1544	1,193	0,129	0,621	0,084	0,352
0,02	0,0354	0,0173	0,1883	0,1582	0,197	0,132	0,608	0,109	0,362
0,03	0,0365	0,0183	0,1835	0,1621	1,201	0,135	0,596	0,134	0,371
0,04	0,0378	0,0194	0,1792	0,1661	1,204	0,138	0,584	0,157	0,380
0,05	0,0392	0,0206	0,1751	0,1701	1,208	0,141	0,573	0,180	0,389
0,06	0,0407	0,0219	0,1714	0,1741	1,212	0,144	0,562	0,202	0,397
0,07	0,0423	0,0233	0,1679	0,1782	1,216	0,147	0,552	0,224	0,404
0,08	0,441	0,0247	0,1647	0,1824	1,219	0,150	0,342	0,244	0,410
0,09	0,0461	0,0264	0,1617	0,1866	1,223	0,153	0,534	0,264	0,417
0,10	0,0482	0,0281	0,1589	0,1908	1,227	0,155	0,526	0,282	0,422

TABLE 2 b. $\overline{r_a}$ is calculated as a function of mean daytime wind speed according to formulation b (Eq. 6).

Mean values of r_a	α	β	γ	RMS	$\overline{r_s}$	$\frac{RMS}{\overline{r_s}}$	$R_{MEAS\ CALC}$	$R_{MEAS\ RIS}$	$R_{MEAS\ VCD}$
0	0,0333	0,154	0,1990	0,1507	1,189	0,127	0,635	0,058	0,341
DEPENDENT ON WIND SPEED:									
0,01	0,0341	0,0161	0,1954	0,1532	1,193	0,128	0,627	0,080	0,352
0,02	0,0349	0,0618	0,1921	0,1559	1,197	0,130	0,619	0,101	0,361
0,03	0,0357	0,0175	0,1890	0,1587	1,201	0,132	0,611	0,121	0,371
0,04	0,0366	0,0183	0,1862	0,1616	1,204	0,134	0,603	0,141	0,380
0,05	0,0375	0,0191	0,1836	0,1646	1,208	0,136	0,595	0,160	0,388
0,06	0,0385	0,0199	0,1812	0,1676	1.212	0,138	0,588	0,179	0,396
0,07	0,0396	0,0208	0,1790	0,1708	1,216	0,140	0,581	0,197	0,404
0,08	0,0407	0,0217	0,1769	0,1740	1,220	0,143	0,574	0,215	0,411
0,09	0,0419	0,0227	0,1750	0,1773	1,223	0,145	0,568	0,232	0,417
0,10	0,0432	0,0237	0,1732	0,1807	1.227	0,147	0,562	0,248	0,423

TABLE 2c. $\overline{r_a}$ is calculated as a function of wind speed and sensible heat flux according to formulation c (Eq. 7). The values used of z_0, d and z for the Velen site are 2 m, 15 m and 54 m respectively.

	Mean values of $\overline{r_a}$	α	β	γ	RMS	$\overline{r_s}$	$\frac{RMS}{\overline{r_s}}$	R_{MEAS} CALC	R_{MEAS} RIS	R_{MEAS} VCD
	0	0,033	0,0154	0,1990	0,1507	1,189	0,127	0,635	0,058	0,341
1	0,010	0,0344	0,0163	0,1936	0,1541	1,192	0,129	0,622	0,084	0,353
2	0,021	0,0355	0,0173	0,1888	0,1577	1,195	0,132	0,610	0,110	0,364
3	0,031	0,0368	0,0184	0,1843	0,1613	1,198	0,135	0,598	0,134	0,375
4	0,042	0,0381	0,0195	0,1801	0,1650	1,201	0,137	0,586	0,158	0,385
5	0,052	0,0396	0,0207	0,1762	0,1687	1,204	0,140	0,576	0,182	0,394
6	0,063	0,0412	0,0220	0,1727	0,1725	1,207	0,143	0,565	0,204	0,403
7	0,073	0,0430	0,0234	0,1694	0,1764	1,209	0,146	0,556	0,226	0,411
8	0,084	0,0449	0,0250	0,1663	0,1803	1,212	0,149	0,547	0,247	0,419
9	0,094	0,0471	0,0267	0,1634	0,1842	1,215	0,152	0,539	0,267	0,426
10	0,104	0,0495	0,0284	0,1608	0,1882	1,218	0,155	0,532	0,286	0,433
15	0,157	0,0663	0,0415	0,1500	0,2089	1,232	0,170	0,505	0,370	0,459

TABLE 3. Jädraås forest canopy. Explanations are given in Table 1. VPD is the water vapour pressure deficit in the air. The data (except p) have been supplied by Dr Anders Lindroth. p is atmospheric pressure at Edsbyn (70 km from the Jädraås site) at 1300 hrs.

DATE	R_n Wm^{-2}	G Wm^{-2}	A Wm^{-2}	E Wm^{-2}	VPD mb	u m/s	T °C	p mb	RIS Wm^{-2}
770519	430,12	26,897	403,22	125,07	8,498	2,299	10,711	1012,3	499,70
770525 /	417,12	14,341	492,78	104,37	5,890	3,065	7,350	1007,6	488,14
770601	276,11	22,599	253,51	107,97	6,122	2,618	11,332	999,6	305,93
770602	389,44	30,238	359,20	126,84	9,360	1,663	13,722	1003,5	440,95
770621	396,21	19,964	376,25	182,29	11,043	3,078	14,730	996,5	486,54
770622	353,21	15,978	337,23	125,13	8,368	3,853	11,189	1000,0	463,01
770706	297,48	8,836	288,64	140,39	7,682	4,272	15,999	1003,2	327,59
770707	340,57	15,022	325,55	146,84	8,915	2,794	17,482	1003,6	400,67
770713	113,21	3,076	110,13	76,96	3,671	1,621	8,866	994,0	154,07
770810	252,04	17,219	234,82	146,85	6,309	2,485	16,418	1002,0	324,37
770817	273,82	27,296	246,52	133,11	8,713	2,279	17,017	1001,2	403,77
770818	123,53	13,549	109,98	102,21	2,295	2,323	11,993	1001,1	188,55
770921	229,25	32,389	196,86	111,03	6,375	2,144	13,732	1000,3	313,20
770928	148,00	15,664	132,34	113,79	4,124	4,166	8,252	1001,0	193,51
780523	442,23	30,673	411,56	151,64	10,471	3,353	15,736	999,9	520,10
780524	428,93	23,423	405,51	151,71	11,051	2,761	14,661	1006,6	510,70
780525	266,57	27,648	238,92	135,29	10,507	1,996	14,252	1004,0	301,57
780530	367,29	27,754	339,54	183,73	15,455	2,276	20,220	1004,5	450,02
780531	349,41	29,310	320,10	184,50	15,585	1,907	20,444	1004,2	445,00
780601	391,48	27,406	364,07	184,81	13,884	2,278	20,093	1002,7	462,75
780616	396,93	0,033	396,90	148,04	5,691	4,215	11,311	992,8	471,44
780620	338,73	17,029	321,70	155,11	8,084	2,405	17,053	989,8	406,07
780621	380,67	25,774	354,90	171,12	11,853	2,831	17,722	986,4	461,74
780802	231,24	20,450	210,79	204,06	10,044	1,917	22.526	996,0	286,86
780808	261,95	11,924	250,03	191,59	5,942	2,177	14,973	988,8	335,30
780810	317,67	19,953	297,72	179,78	7,957	3,552	15,855	988,8	393,38
780811	292,89	15,350	277,54	173,14	6,333	3,328	14,773	994,7	360,31
780829	343,43	18,429	325,00	180,96	7,131	2,257	11,070	986,4	404,43
780830	290,96	22,662	268,30	120,37	3,667	1,430	10,857	987,4	321,97
780908	299,56	33,551	266,01	161,32	4,629	1,501	11,779	997,0	367,98

TABLE 4a. Jädraås measurements 1977-78 (see text of Table 2a).

	$\overline{r_a}$ kept constant	α	β	γ	RMS	$\overline{r_s}$	$\frac{RMS}{\overline{r_s}}$	R_{MEAS} CALC	R_{MEAS} RIS	R_{MEAS} VCD
0		0,2198	0,0715	0,3296	0,1655	1,023	0,162	0,845	0,562	0,844
1	0,01	0,6253	0,2138	0,3205	0,1700	1,029	0,165	0,841	0,574	0,841
2	0,02	3.0982	1,0757	0,3208	0,1746	1,035	0,169	0,838	0,586	0,838
3	0,03	7,4162	2,5616	0,3270	0,1794	1,042	0,172	0,835	0,598	0,835
4	0,04	8,1975	2,8067	0,3343	0,1844	1,048	0,176	0,831	0,609	0,831
5	0,05	13,8976	4,7221	0,3413	0,1895	1,054	0,180	0,827	0,619	0,827
6	0,06	16,1095	5,4258	0,3489	0,1949	1,060	0,184	0,824	0,629	0,824
7	0,07	22,9347	7,6570	0,3565	0,2003	1,067	0,188	0,820	0,638	0,820
8	0,08	19,9937	6,6117	0,3645	0,2060	1,073	0,192	0,816	0,647	0,816
9	0,09	15,9496	5,2257	0,3725	0,2117	1,079	0,196	0,811	0,655	0,811
10	0,10	12,3514	4,0085	0,3807	0,2176	1,086	0,200	0,807	0,663	0,807

TABLE 4b. (See text of Table 2b).

Mean values of r_a	α	β	γ	RMS	$\overline{r_s}$	$\frac{RMS}{\overline{r_s}}$	R_{MEAS} CALC	R_{MEAS} RIS	R_{MEAS} VCD
0	0,2198	0,0715	0,3296	0,1655	1,023	0,162	0,845	0,562	0,844
0,01	0,5269	0,1788	0,3226	0,1701	1,028	0,165	0,841	0,572	0,841
0,02	3,3262	1,1506	0,3221	0,1747	1,034	0,169	0,838	0,582	0,838
0,03	9,9493	3,4185	0,3289	0,1795	1,040	0,173	0,835	0,592	0,835
0,04	7,6207	2,5890	0,3370	0,1845	1,045	0,177	0,831	0,601	0,831
0,05	13,8141	4,6474	0,3449	0,1897	1,051	0,180	0,827	0,610	0,827
0,06	11,7166	3,8956	0,3537	0,1950	1,057	0,184	0,824	0,618	0,824
0,07	15,2330	5,0143	0,3618	0,2005	1,063	0,189	0,820	0,625	0,820
0,08	14,8021	4,8142	0,3709	0,2061	1,068	0,193	0,816	0,632	0,816
0,09	13,1785	4,2370	0,3799	0,2119	1,074	0,197	0,811	0,639	0,811
0,10	16,0017	5,0860	0,3892	0,2178	1,080	0,202	0,807	0,645	0,807

TABLE 4c. (See text of Table 2c).
The values of z_0, d and z for the Jädraås site are 1.3 m, 13 m and 24 m respectively.

	Mean values of $\overline{r_a}$	α	β	γ	RMS	$\overline{r_s}$	$\frac{\overline{RMS}}{\overline{r_s}}$	$R_{\frac{CALC}{MEAS}}$	$R_{\frac{RIS}{MEAS}}$	$R_{\frac{VCD}{MEAS}}$
-60	-0,4798	0,0193	-0,0009	1,2720	0,1427	0,787	0,181	0,888	-0,484	0,264
-50	-0,4000	0,0190	-0,0005	1,0261	0,1129	0,826	0,137	0,910	-0,352	0,411
-40	-0,3199	0,0192	+0,0001	0,8082	0,0936	0,865	0,108	0,925	-0,189	0,576
-30	-0,2400	0,0208	0,0012	0,6299	0,0910	0,805	0,101	0,923	0,052	0,724
-20	-0,1600	0,0255	0,0033	0,4944	0,1061	0,944	0,112	0,902	0,269	0,819
-10	-0,0810	0,0406	0,0089	0,3971	0,1328	0,983	0,135	0,872	0,442	0,852
0	0	0,2198	0,0715	0,3296	0,1655	0,023	0,162	0,845	0,562	0,844
1	0,0080	0,4560	0,1538	0,3235	0,1690	1,027	0,165	0,842	0,571	0,842
2	0,0160	2,4941	0,8600	0,3217	0,1725	1,031	0,167	0,840	0,580	0,840
3	0,0240	38,8956	13,3804	0,3260	0,1761	1,034	0,170	0,838	0,589	0,838
4	0,0320	5,9388	2,0151	0,3342	0,1798	1,038	0,173	0,835	0,597	0,835
5	0,0400	7,0631	2,3723	0,3412	0,1836	1,042	0,176	0,833	0,605	0,833
6	0,0480	8,8793	2,9512	0,3486	0,1876	1,046	0,179	0,830	0,613	0,830
7	0,0559	10,7904	3,5489	0,3563	0,1916	1,050	0,182	0,827	0,620	0,827
8	0,0640	17,1430	5,5744	0,3640	0,1957	1,054	0,186	0,824	0,627	0,824
9	0,0720	30,7130	2,8786	0,3719	0,1999	1,058	0,189	0,821	0,633	0,822
10	0,0800	21,3030	6,7725	0,3801	0,2042	1,062	0,192	0,819	0,640	0,819

FIGURE 1. Velen data.
Plot of the root-mean-square error in r_s as function of the mean value in r_a. The curves are based on Tables 2a, 2b and 2c with corresponding notations used. For c (r_a dependent on both wind and stability) the diagram has been extended to negative r_a with a compressed scale. For c Eq. (7) for r_a has been used giving r_a = 0.104 (encircled square).

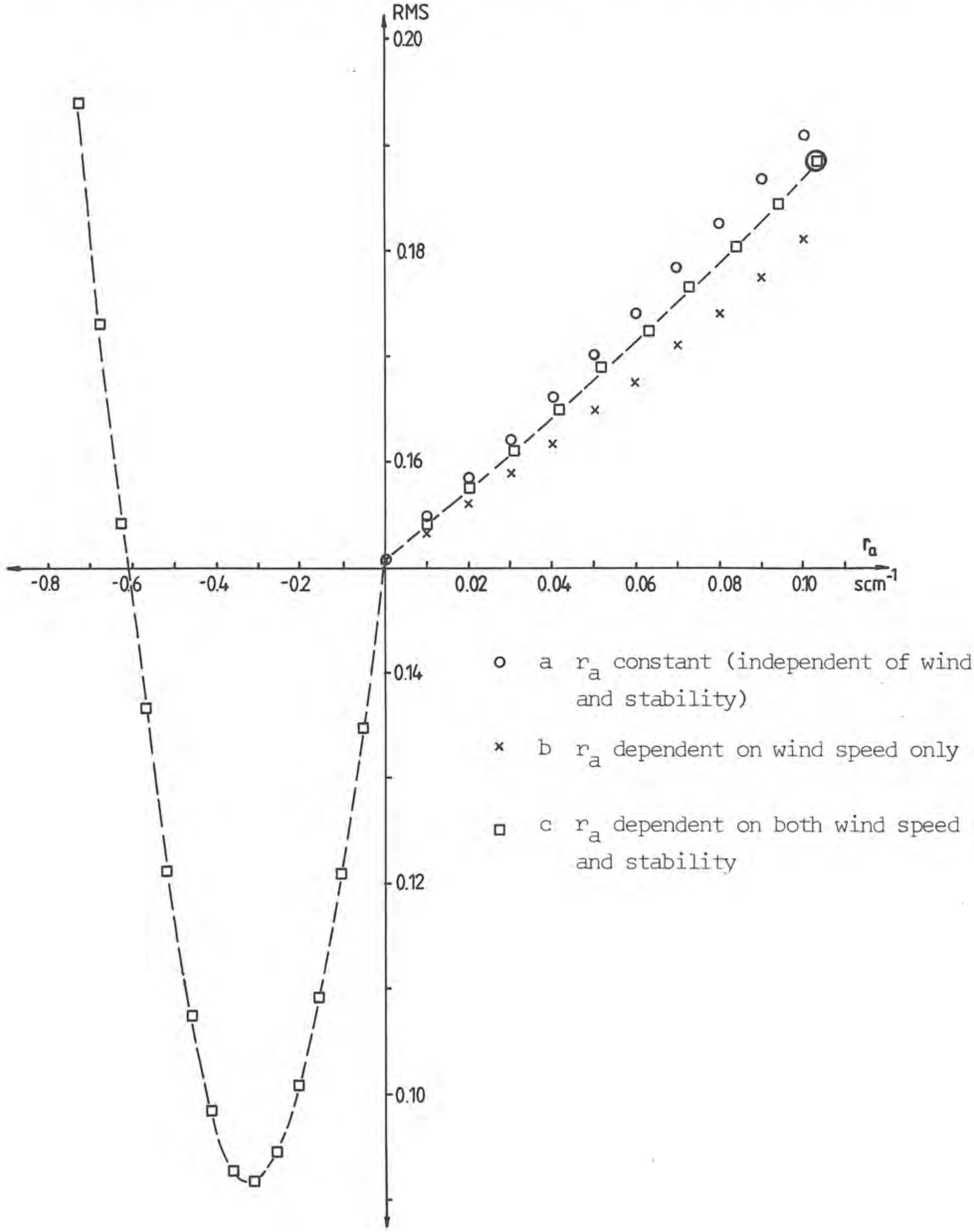
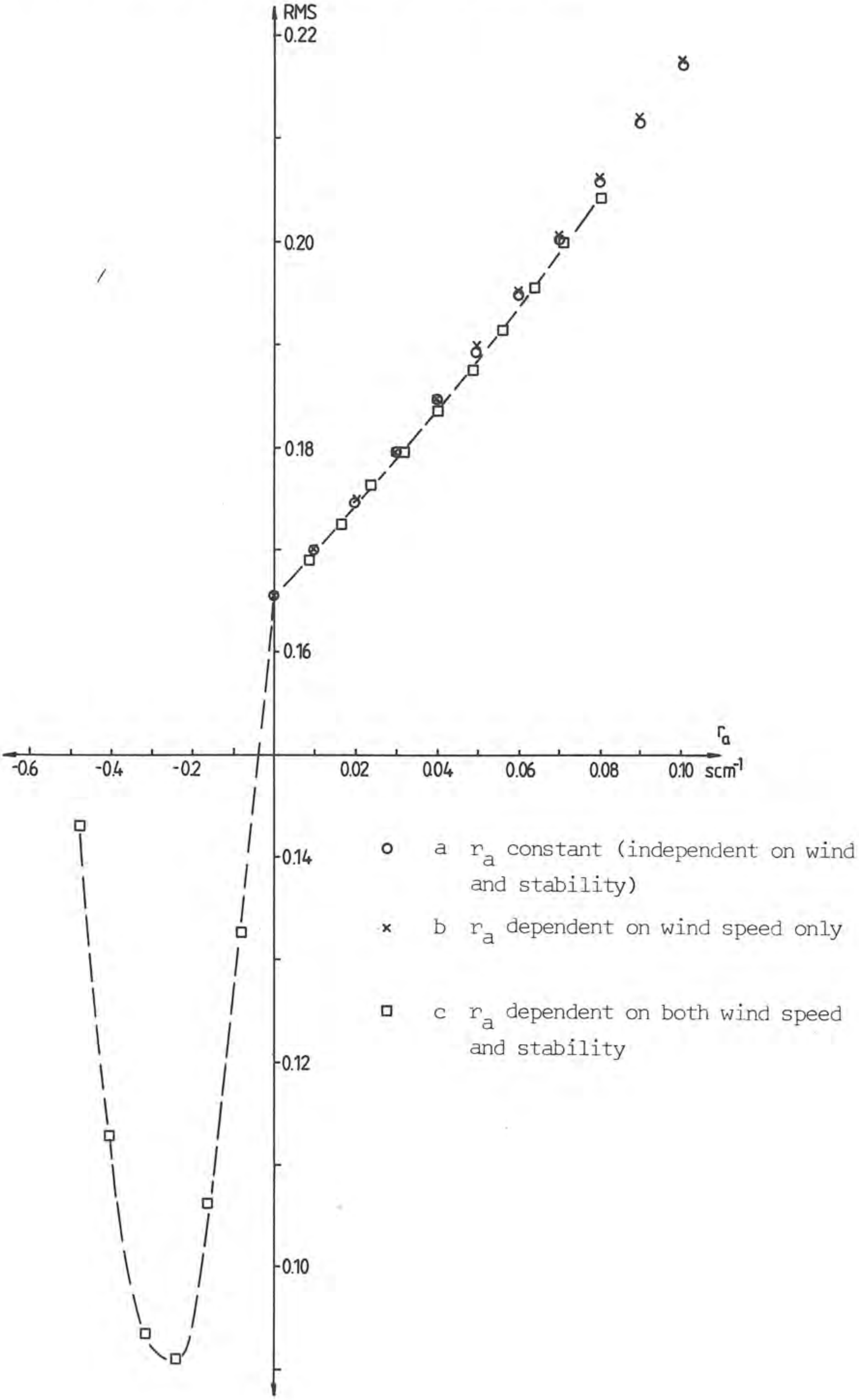


*FIGURE 2. Jädraås data. See text of Figure 1.
The curves are based on Tables 4a, 4b and 4c.*



were used in Eq (1), with the three formulations for r_a given above, to estimate daily $\overline{r_s}$ values. These will be fitted to Eq (10) by a least square method and the results are presented in tables 2a-c and 4a-c and Figs 1 and 2.

The Velen data (Table 1) comprise 37 daily sets from 1974 which also were used by Bringfelt (1982a). The correlation results are given in Tables 2a-c and a plot of the root mean square error (RMS) in r_s as function of r_a is given in Figure 1. From the Jädraås site (Table 3) 30 daily data sets from 1977 and 1978 were used (A Lindroth, pers.com.). The correlation results are given in Tables 4a-c. The RMS error is plotted in Figure 2.

For each test case the coeficients α, β and γ in eq. 10 were adjusted so that the root mean square

$$\sqrt{\frac{1}{N}\sum_{1}^{N}(\bar{r}_{s/meas} - \bar{r}_{s/calc})^2}$$

is minimum = RMS. N is the number of daily data sets. Subscripts meas and calc refer to measured and calculated values of $\bar{r}_s$. The daytime averages $\bar{L}$, $\bar{\Delta}$ and $\bar{\gamma}$ are calculated by Eqs. 2, 3 and 5 respectively.

The values of z_o, d and z are needed only in c) above and are given in Tables 2c and 4c for the two sites.

Discussion

Eq. (1) was used to estimate r_s from the mast measurements. As can be seen in Tables 2a-c and 4a-c the mean values of the $\overline{r_s}$ are of the order of 1 s cm^{-1}. From literature one would expect the most correct value of r_s to be obtained when r_a is about 0,05 s cm^{-1}. r_a -values of that magnitude have been used as a crude average in many forest studies using the Penman-Monteith equation. However, as can be seen in Figures 1 and 2 the root-mean square error of r_s increases monotonously with positive $\bar{r}_a$ no matter if $\overline{r_a}$ is formulated as constant (a), as dependent on wind speed (b) or as dependent on both wind speed and stability (c).

Figures 1 and 2 also show that the difference in RMS between a, b and c are not very large. It could be expected that RMS would be smallest for case c, where both wind speed and stability are used to calculate r_a, but this is not the case.

For c parameter estimations were made also for negative r_a. Such r_a -values were formed by multiplying r_a of equation (7) by a negative number. This case is not physically realistic but was tested here in order to find out where RMS had its minimum.

The expression with which $\overline{r_a}$ is multiplied in Eq. (1) is mostly positive but is negative for some days. For the Velen data it ranges between -0,8 and +1,6 with an average of +0,4.

If $\overline{r_a}$ is small the second term in Eq. (1) is usually also small in absolute value. For both sites the best adjustment of the $\overline{r_s}$-data to the Lohammar equation is found when $\overline{r_a}$ is around -0,3, i. e. the second term in Eq. (1) is of the order of -0,15 compared to the first term which is about 1. The main conclusion is that there is no minimum in RMS (and no maximum in correlation coefficient R) for positive $\overline{r_a}$ which would be expected from a physical point of view.

The minimum in RMS found for negative $\overline{r_a}$ is a numerical effect and has nothing to do with any physical significance of $\overline{r_a}$. It can be seen from Table 4c that the minimum in RMS (for r_a around -0,3) occurs when β is so small that it is negligible compared to $1/\overline{RIS}$ in the Lohammar form Eq. (10). Thus, using α and γ according to the smallest RMS in Table 4c, Eq. (10) can be approximated by

$$\overline{r_s} \approx \frac{31,5\ \overline{VCD}}{\overline{RIS}} + \frac{50}{\overline{RIS}}$$

For typical $\overline{VCD}$ (around 5 g m^{-3}) the first term is dominant. Since $\overline{RIS}$ and E are well correlated this results in an expression similar to the first term in Eq. (1). Thus, the reason that the minimum in RMS is found for negative r_a (around -0,3) is that the Lohammar form then becomes formally similar to Eq. (1) which was used to compute the basic $\overline{r_s}$-values.

Possible reasons for the non-existence of a positive $\overline{r}_a$ giving optimal adjustment of the r_s-data to the Lohammar form will be discussed below:

1. The use of daytime averages. The averaging of the hourly data to form daytime values may have masked some features of the data. It would have been possible to make a similar correlation study for hourly values. However, this could have required a larger data set due to the larger scatter of hourly values.

2. Eq. (1) may not be relevant to compute canopy resistance. However, it was derived directly from the well-known Penman-Monteith formula, which is generally considered to be relevant for a homogeneous vegetation cover. However, in its derivation, it is assumed that the aerodynamic resistances to both sensible and latent heat fluxes are the same. When relating r_a to wind speed, as made above, similarity is also assumed to momentum transfer. It has been questioned by Thom et al. (1975) if these assumptions are justified for forests. It is also assumed that the site is uniform so that the energy balance equation holds (R_N - G = H + L E).

3. For forests, the second term in Eq. (1) is only of the order of 10% of the first, see discussion above. Thus, errors in the first term arising from errors in the measurement of $\overline{VCD}$ and E may enhance the scatter and thus mask any dependence on $\overline{r_a}$. Errors in $\overline{E}$ may in turn be caused by errors in profiles of humidity and temperature, net radiation and non-uniformity of the site. Earlier work in Velen does not point

to a systematic error in $\bar{E}$ but, as mentioned above, a scatter in E (standard deviation estimated as about ± 20-25 %) may mask the dependence.

4. The Lohammar form may be too simple and crude to reveal the features looked for. In the form used here the influence of soil water potential has been left out. However, some independent indications (Bringfelt 1982a) support the assumption made here that soil water influence is not essential at least in the Velen material (The soil did never become dry enough to reduce transpiration).

Table 4c gives tests for the Jädraås data using the values d = 13 m and z_o = 1,3 m (Lindroth A., personal communication). For comparison another run was made using the values d = 14,5 m and z_o = 0,9 m. The resulting RMS behaved very similarly to the values in Table 4c and Figure 2 but the RMS-values were a little larger. Thus, changes of d and z_o within reasonable limits will not alter the overall results of the tests. It should be pointed out that evaluation of both d and z_o from wind speed profile data are extremely difficult for forests. In Jädraås, d was estimated from mean tree height by a crude standard method and then z_o was estimated from traditional wind profile analysis.

The fit of the data of r_s to the Lohammar form is better for Jädraås than for Velen (compare the correlation coefficients in table 4 with those of table 2). No definite reason can be given for this.

In table 1 are given daily r_s-values calculated for Velen by Eq. 1 using r_a = 0 and r_a = 0,05 s cm^{-1}. For Jädraås no such data will be given here, since there is greater uncertainty as to the general magnitade of r_s. This will be discussed in paper (IIIii).

Conclusions

The study, performed on daytime averages, was made in order to find out if there is a positive value or range of values of r_a for which the relation between measured r_s and a physiologically based formula for r_s is optimal. No such relevant r_a -value was found. No improvement was found when r_a was calculated by wind and/or stability compared to using a constant value of r_a. In fact the use of r_a = 0 (only the first term in Eq. 1) gave as good a result as using any other value of r_a. In the study of Bringfelt (1982) a constant value of the latent heat of vaporization, L was used in calculating r_s from the measurements. No improved correlation was found if r_s was calculated using L (and also Δ and γ) as functions of air temperature and pressure.

The results for Velen and Jädraås both show the same general features. This confirms the generality of the conclusions.

A reason why no relevant r_a-value was found, may be that the equations and methods used are too crude to describe the processes of the forest canopy adequately enough. Thus, transpiration from forest is known to be very insensitive to r_a. This is so while the second term in Eq. (1) is small. In deriving the Penman-Monteith formula (and Eq. (1)) it is assumed that r_a is the aerodynamic resistance to both heat and water vapour transfer. In relating r_a to wind speed, similarity to momentum transfer is also supposed. These assumptions need not be justified for forest.

To conclude, it was not possible to improve the fit of the r_s-data to the physiological formula for r_s (Lohammar equation) by refining the methods to calculate r_s from the mast data.

REPORT NO II

COMPARISON BETWEEN OBSERVED AND ESTIMATED DAILY RAINFALL DURATION.

Abstract

Values of daytime rainfall duration calculated from synoptic stations data using alternatively

(i) the daytime rainfall amount reported at 18 hrs GMT

(ii) the type of present weather reported every third hour (rainfall or no rainfall)

were compared to daily rainfall durations observed manually and continuously. It was found that the use of (ii) considerably improved the estimates of rainfall duration.

This result may be used in models for calculating evapotranspiration from routine synoptic observations.

INTRODUCTION

In the forest evapotranspiration model, (Bringfelt, 1985), an effective daylength is used in rainy days to reduce the daytime transpiration amount from the forest canopy. This effective daylength is calculated by subtracting the time the canopy is wet from the astronomical daylength. The time when the canopy is wet is calculated as 1,5 times the actual rainfall duration and the daily rainfall duration is calculated by an empirical function of the amount of rainfall, see Bringfelt (1982b). This method is very crude, however, and in this paper another, more refined, method is suggested.

Improvements when calculating the time when the canopy is wet can be made in two steps: The first step is to improve the method to calculate daytime rainfall duration. The second step could be to improve the calculation of the time when the forest canopy is wet using the rainfall duration and other data. In this report the method for daytime rainfall duration (first step) will be tested against real data.

MATERIAL AND METHODS

Two methods of calculating rainfall duration from synoptic weather observations ((a) using the rainfall amount and (b) using the ww-information) will be compared by relating the results to (c) continuously observed rainfall duration at the Airport of Sundsvall.

(a) Using the rainfall amount. In the model, the duration of daytime rainfall VR (hours) is calculated as

$$VR = 7 \cdot {}^{10}\log (1 + AR) \qquad (1)$$

were AR (mm) is the amount of rainfall between 06 and 18 GMT reported at 18 GMT. This empirial relation is derived from data on Vr and AR from the Velen site consisting of durations evaluated from a raingauge record and daytime amounts respectively. See further Bringfelt (1982b).

(b) Using the ww-information. The data on ww in the synoptic code (weather at the time of the observation, see WMO 1984) are also used to calculate daytime rainfall duration. This is made for daytime synoptic observations every third hour. For the observations at 09, 12, 15 GMT rainfall was stated to occur during 3 hours if $50 \leq ww \leq 75$ or $80 \leq ww \leq 99$. For each of the observations at 06 and 18 GMT only 1,5 hours of rainfall were ascribed. By summing the rainfall duration hours in a daytime period the total daytime rainfall duration was obtained. The interval $50 \leq ww \leq 99$ means that there was precipitation at the synoptic station when the observation was made. Exclusion is made here for the interval 76-79 meaning special forms of snow. The relevant part of the ww-code is explained in table 1.

(c) Continuously observed rainfall duration at the airport of Sundsvall. These observations were made manually by watching continuously if it was raining or not. The data were supplied by Mr Bernt-Ove Bergsten. The duration of rainfall was given in hours and minutes for each 12-hourly period 18-06 GMT and 06-18 GMT.

RESULTS

Figure 1 shows the continuously observed daytime rainfall durations (c) compared with durations calculated from the empirical relation to the daytime rainfall amount (a). As can be seen, the scatter is very large and no systematic relation can be seen.

Figure 2 shows the same continuously observed durations compared with durations obtained from the synoptic data of ww every third hour (b). The scatter is seen to be reduced substantially. Thus, the synoptic ww-data are systematically related to the continuously observed rainfall duration.

Table 2 shows monthly sums of these rainfall durations deduced by (a), (b) and (c) and the total sums over the period April - October 1979.

DISCUSSION

The large scatter of daily values in Figure 1 is partly due to the occurrence of rain regimes with different rainfall intensity such as convective and frontal. Thus, two days may have the same rainfall amount but different durations. Figure 2, however, where the ww-information is used for the same period, shows remarkably smaller scatter although only crude three-hourly observations were used.

Even for the monthly sums in table 2, the ww-information gives the best agreement with the continuously observed durations. Utilizing the rainfall amounts gives smaller total durations due to deficiencies in the raingauge record used when originally deriving the empirical relation (1). Standard rain gauges are known to underestimate rainfall duration especially for small intensities (Eriksson 1982). In many ww CODE TABLES

(Code table 4677 continued)

Code figure		
44	Fog or ice fog, sky visible	no appreciable change during the preceding hour
45	Fog or ice fog, sky invisible	
46	Fog or ice fog, sky visible	has begun or has become thicker during the preceding hour
47	Fog or ice fog, sky invisible	
48	Fog, depositing rime, sky visible	
49	Fog, depositing rime, sky invisible	

ww = 50–99 *Precipitation at the station at the time of observation*

ww = 50–59 Drizzle

ww		
50	Drizzle, not freezing, intermittent	slight at time of observation
51	Drizzle, not freezing, continuous	
52	Drizzle, not freezing, intermittent	moderate at time of observation
53	Drizzle, not freezing, continuous	
54	Drizzle, not freezing, intermittent	heavy (dense) at time of observation
55	Drizzle, not freezing, continuous	
56	Drizzle, freezing, slight	
57	Drizzle, freezing, moderate or heavy (dense)	
58	Drizzle and rain, slight	
59	Drizzle and rain, moderate or heavy	

ww = 60–69 Rain

ww		
60	Rain, not freezing, intermittent	slight at time of observation
61	Rain, not freezing, continuous	
62	Rain, not freezing, intermittent	moderate at time of observation
63	Rain, not freezing, continuous	
64	Rain, not freezing, intermittent	heavy at time of observation
65	Rain, not freezing, continuous	
66	Rain, freezing, slight	
67	Rain, freezing, moderate or heavy	
68	Rain or drizzle and snow, slight	
69	Rain or drizzle and snow, moderate or heavy	

ww = 70–79 Solid precipitation not in showers

ww		
70	Intermittent fall of snowflakes	slight at time of observation
71	Continuous fall of snowflakes	
72	Intermittent fall of snowflakes	moderate at time of observation
73	Continuous fall of snowflakes	

CODE TABLES ww

(Code table 4677 continued)

Code figure		
74	Intermittent fall of snowflakes	heavy at time of observation
75	Continuous fall of snowflakes	
76	Diamond dust (with or without fog)	
77	Snow grains (with or without fog)	
78	Isolated star-like snow crystals (with or without fog)	
79	Ice pellets	

ww = 80–99 Showery precipitation, or precipitation with current or recent thunderstorm

ww		
80	Rain shower(s), slight	
81	Rain shower(s), moderate or heavy	
82	Rain shower(s), violent	
83	Shower(s) of rain and snow mixed, slight	
84	Shower(s) of rain and snow mixed, moderate or heavy	
85	Snow shower(s), slight	
86	Snow shower(s), moderate or heavy	
87	Shower(s) of snow pellets or small hail, with or without rain or rain and snow mixed	– slight
88		– moderate or heavy
89	Shower(s) of hail*, with or without rain or rain and snow mixed, not associated with thunder	– slight
90		– moderate or heavy
91	Slight rain at time of observation	thunderstorm during the preceding hour but not at time of observation
92	Moderate or heavy rain at time of observation	
93	Slight snow, or rain and snow mixed or hail** at time of observation	
94	Moderate or heavy snow, or rain and snow mixed or hail** at time of observation	
95	Thunderstorm, slight or moderate, without hail**, but with rain and/or snow at time of observation	thunderstorm at time of observation
96	Thunderstorm, slight or moderate, with hail** at time of observation	
97	Thunderstorm, heavy, without hail**, but with rain and/or snow at time of observation	
98	Thunderstorm combined with duststorm or sandstorm at time of observation	
99	Thunderstorm, heavy, with hail** at time of observation	

* French: grêle.
** Hail, small hail, snow pellets. French: grêle, grésil ou neige roulée.

TABLE 1. Explanation of the ww code for synoptic weather stations (ww = 50-99). From WMO (1984b).

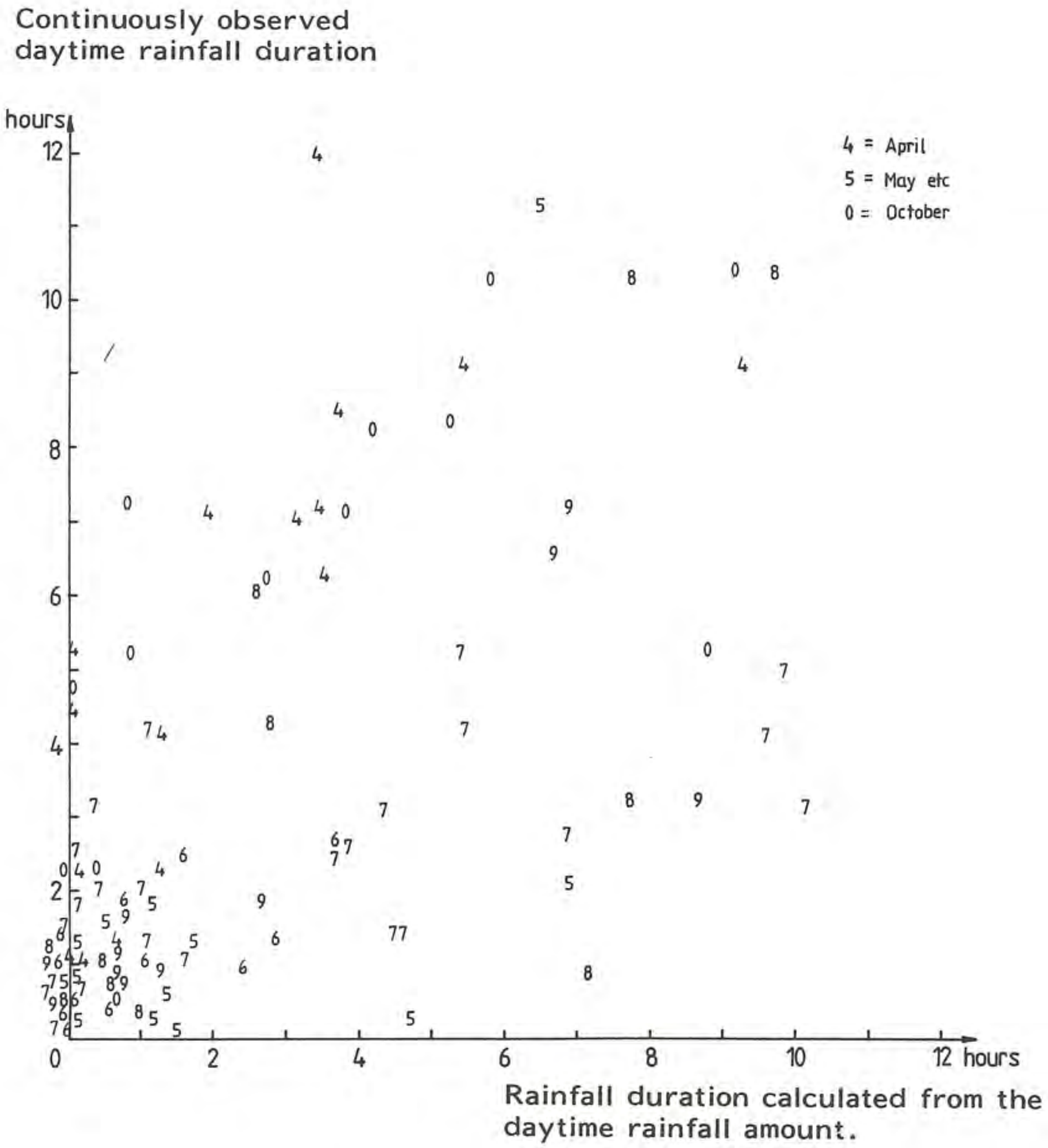


FIGURE 1. Continuously observed daytime rainfall durations at Sundsvall airport during 06-18 GMT compared with durations calculated from empirical relation with daytime rainfall amount at 18h GMT at the same location. The daily data are taken from April-October 1979.

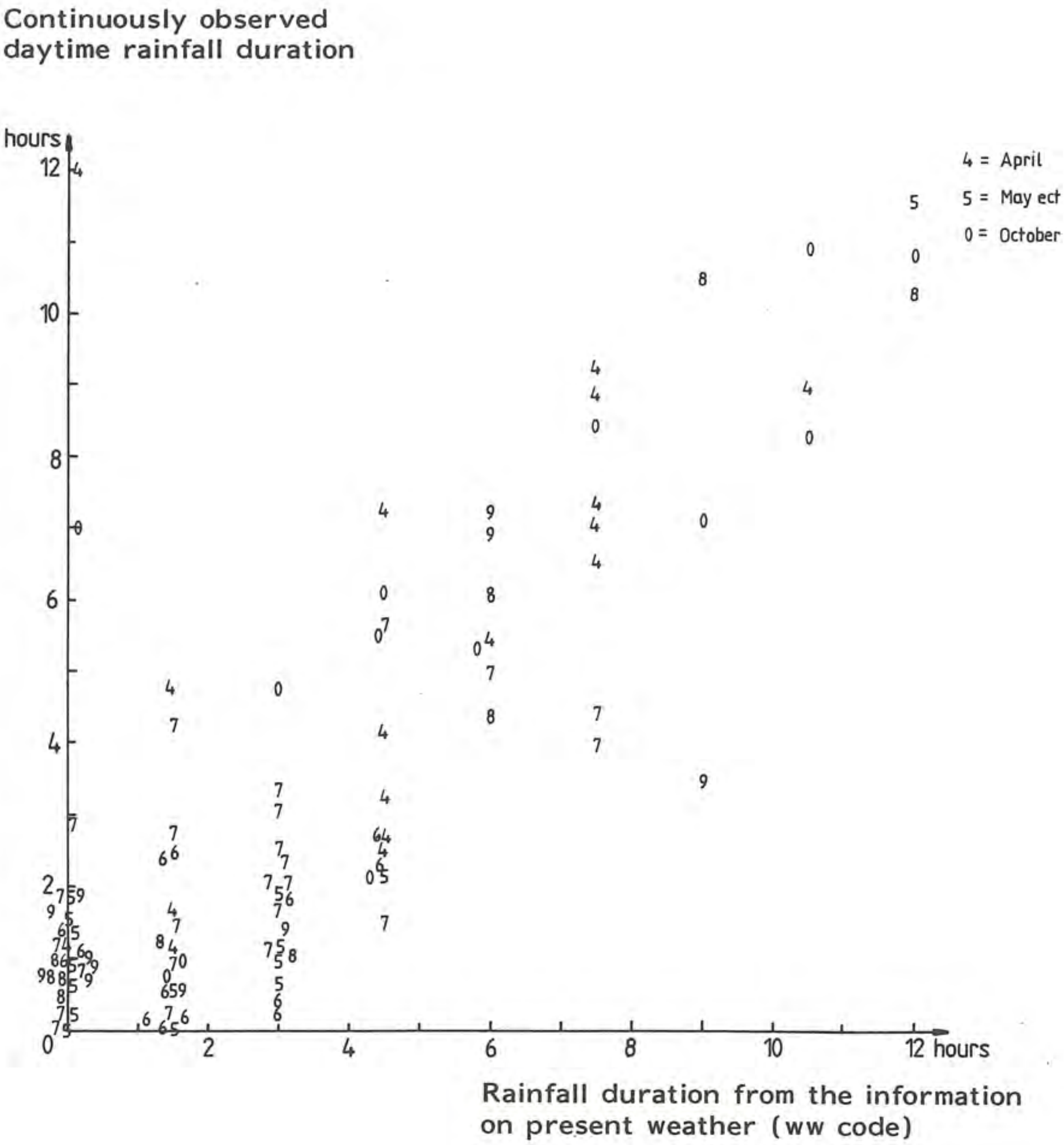


FIGURE 2. Continuously observed daytime rainfall durations at Sundsvall airport 06-18 GMT compared with durations from the information on present weather (ww) in the three hourly synoptic observations during 06-18 GMT at the same location. The data are from April-October 1979.

cases, the ww-code should be preferred before duration records from automatic standard rain gauges. Eriksson found that the long-term duration formed from continuous manual observations was twice as long as found from a rain gauge record.

In the model the rainfall duration is used in calculating the time the canopy is wet. In the studies with this model the resulting daily reduced transpiration (see introduction) has been used to calculate the total evapotranspiration. This has been compared successfully with measurements. Although the duration has been underestimated in using the amount method (a) this has been compensated for when calculating the time the canopy is wet. In a model improvement to come these effects should be studied together using better measuring data.

CONCLUSION

The use of the information on present weather (ww) in the synoptic weather code instead of the daytime rainfall amount will very much improve the daily and monthly estimates of rainfall duration and related variables such as evapotranspiration.

TABLE 2. Monthly sums of duration of daytime rainfall at the Airport of Sundsvall (hours) deduced by using

(a) the rainfall amount reported and the empirical relation (1)

(b) the ww-information reported

(c) directly the continuously observed rainfall duration

1979	(a)	(b)	(c)
April	37.2	76.5	91.0
May	24.2	31.5	25.4
June	12.7	24.0	14.9
July	74.0	66.0	59.6
August	38.8	37.5	40.1
September	29.4	25.5	26.7
October	41.6	76.5	80.9
Apr-Oct	257.9	337.5	338.6

REPORT NO III

MODELLING EVAPOTRANSPIRATION FROM THE JÄDRAÅS FOREST USING ROUTINE WEATHER OBSERVATIONS

This report is divided into two parts i and ii. Part i deals only with the evaporative interception loss. In part ii also the transpiration loss is treated.

i SIMULATING DAILY INTERCEPTION LOSS USING ROUTINE METEOROLOGICAL DATA FROM TWO LOCATIONS

The forest evapotranspiration model (Bringfelt, 1985) has a routine for calculating the daily interception loss of rainwater on the tree canopy. This routine has not been tested earlier against daily measurements of interception. For the Jädraås forest site the following data for testing the model are available for the period July 18 to Oct 25 during 1979:

- Daily measured evaporative loss of rainwater intercepted on the forest canopy. The loss was obtained by subtracting the measured troughfall below the canopy from measured rainfall in a clearing. The former meaurements were made by four precipitation troughs, each ten metres long, located below the forest canopy close to the main mast in Jädraås.

Two alternative sets of daily input driving data to the model are also available:

- Routine meteorological observations from the synoptic station Åmotsbruk located 20 km from Jädraås, see map of Figure 1.

- Routine meteorological observations made in clearings (mostly IhI) within 1 km from the interception troughs, see Lindroth (1982).

The meteorological observations used are

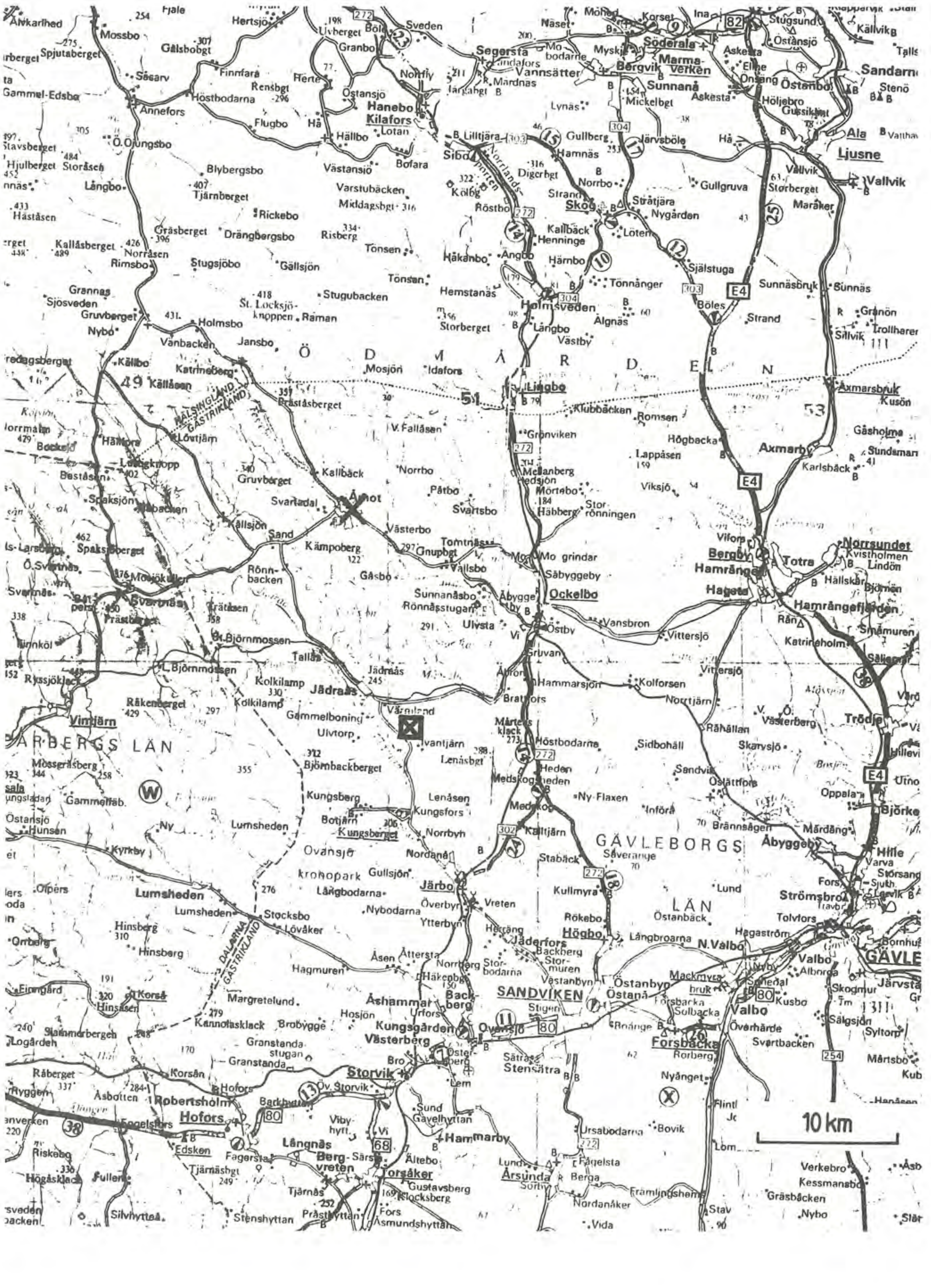
- air temperature and relative humidity at 07, 13 and 19 hrs

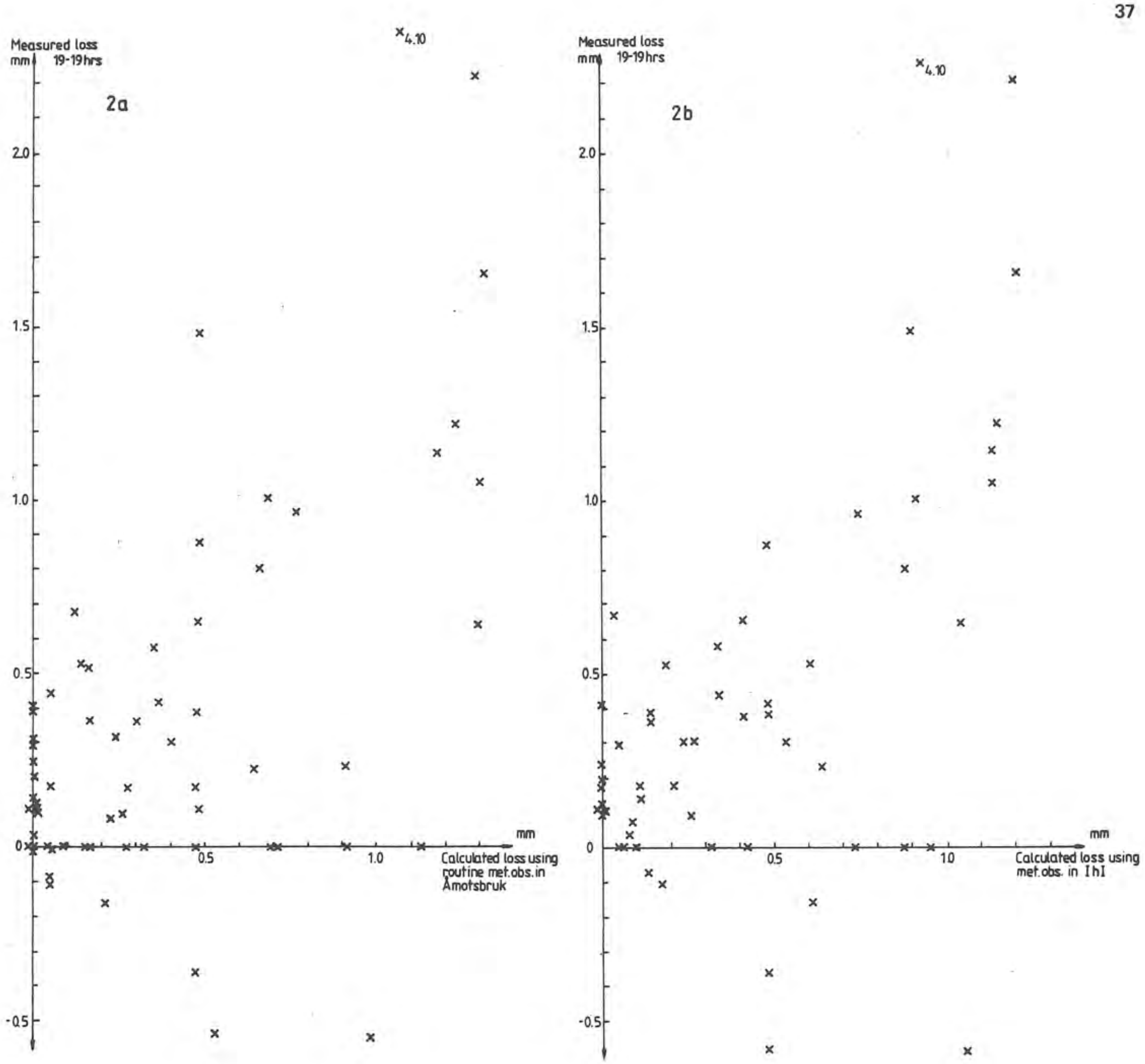
- rainfall amount at 07 hrs (caught 19 hrs the preceding day - 07 hrs) and 19 hrs (caught 07-19 hrs)

The interception routine was run for each of the two alternative sets given above. The period was the one given above with available daily measured interception data. The obtained daily values of evaporative loss of intercepted rain water is compared with the measured values in Figures 2a and b.

As shown in the figure text the correlation coefficient turned out to be r = 0.59 and 0.65 using data from Åmotsbruk and IhI respectively. In calculating these r-values one extreme measured loss of 4.1 mm and six negative losses have been excluded.

FIGURE 1. Detailed map showing the Jädraås site ⊠ and the synoptic station of Åmotsbruk x.





FIGURES 2a and 2b. Daily evaporative losses of rain water intercepted on the Jädraås forest for July 18 – October 25, 1979. Each point refers to one night and day, 19–19 hrs. The ordinates give measured loss on the forest canopy. The abscissae give calculated loss using meteorological observations

Figure 2a from Åmotsbruk 20 km away. Correlation coefficient r = 0.59.

Figure 2b from Ihl close to the Jädraås forest. r = 0.65.

Discussion

As can be seen in Figures 2a and b the scatter between measured and calculated losses is large in both cases, but both values of r are large enough to be significant. In Figure 2b, where the driving meteorological data were taken from the nearby location, the scatter is smaller (and r larger) than in Figure 2a with data taken 20 km away. This is what was expected, but the question remains why the scatter is so large (r as small as 0.65) even in Figure 2b. The answer is largely that in the interception routine only the amount of rainfall is used not the duration. The use of rainfall duration would require rather drastic changes of the routine (for example a better time resolution).

Other reasons for the large scatter are, of course, errors in the meteorological input data (rainfall, temperature and humidity) and in the interception measurements. These latter are sometimes in error because they are differences between two quantities measured several hundreds of metres from each other. It should be observed that the slope in Figures 2a and b is close to 45^{o} (1:1 - relationship). Therefore it seems that the model and parameter values used (Jädraås values, see Table 1 in part ii) are largely in agreement with data. Such agreement of the model with data has been found earlier to be the case for monthly data, see e g Bringfelt (1982b). The Jädraås parameter values used have been derived earlier using interception measurements in the same location.

Summary and conclusions

Measured values of daily evaporative interception loss from the Jädraås forest canopy have been compared with values simulated by the interception model. Input meteorological data have been used from two locations, one 20 km and one within 1 km from the interception measuring site.

Significant correlation between measured and calculated values was obtained in both cases but the scatter was large even when meteorological data from the nearby location was used. Measured and calculated values were in the average nearly equally large. The scatter is largely due to the crude time resolution in the model: only 12-hourly values of rainfall amount are used. In order to improve the prediction of daily intercepted amounts, rainfall duration should be used in the interception model and it should be calculated from the data on present weather (ww) in the synoptic weather code. However, as found by Bringfelt (1982a) the interception loss over one month or one week can be predicted very well with the present model.

ii SIMULATING INTERCEPTION AND TRANSPIRATION IN JÄDRAÅS USING SYNOPTIC WEATHER DATA FROM ÅMOTSBRUK

Detailed micrometeorological measurements have been performed at the forest site in Jädraås 40 km NW of Gävle in middle Sweden. Transpiration was measured by the Bowen ratio-energy balance method (EBBR) and interception by a system of rainfall troughs. See Lindroth (1984a) and Fig 1 of part i above. Data for both the Velen and Jädraås forests will be used below and some characteristics are shown in Table 1.

TABLE 1. Site characteristics. Stand data refer to 1974 for the Velen forest and 1973 for the Jädraås forest.

	Velen	Jädraås
Latitude	58°48'N	60°49'N
Longitude	14°19'E	16°30'E
Altitude (m)	130	185
Tree species distribution (%):		
Pinus silvestris	27	100
Picea abies	64	0
Betula verrucosa	9	0
Stand age (years)	60	120
Tree density (no. ha^{-1})	1500	393
Max. tree height (m)	25	21
Proj. needle area index	5.0	2.6 (max) 2.0 (min)

TABLE 2. Parameters for simulation of Jädraås forest evapotranspiration (using SYNOP-data from Åmotsbruk).

	Alternative: A		B		C	
Transp param						
a	0.9860	From regression	0.5400	See the text	5.495	From regression
b	0.0191	of Velen	0.0191	As for A	0.0715	of Jädraås
c	0.1942	canopy	0.1942	- " -	0.3296	canopy
Intercep param						
k(=1-p)	0.633	Velen	0.41	Jädraås	0.41	Jädraås
S	1.5	canopy	0.48	canopy	0.48	canopy
A	0.45	values	0.45	values	0.45	values
TU	0.16		0.24	(estimated)	0.24	(estimated)

a, b and c are used in Eq. 1.

p free throughfall coefficient

S rain water storage capacity of canopy (mm)

A time decay constant of water on canopy

TU storage capacity of low vegetation and ground vegetation (mm)

In (I) regression coefficients for daily transpiration were derived for the Jädraås forest site. The equation used for the daily transpiration rate (W m^{-2}) is (Bringfelt 1982a):

$$E = \frac{a}{(b + \frac{1}{RIS})(c + \frac{1}{VCD})} \qquad (1)$$

where RIS (W m^{-2}) and VCD (g m^{-3}) are daytime average global radiation and saturation deficit.

In using the forest evapotranspiration model routine three-hourly synoptic weather data from Åmotsbruk 20 km from Jädraås have been used. Rainfall duration data are needed for estimating the time when the canopy is wet, since the total transpiration then is reduced. To get rainfall duration, the improved method of using ww-information in the synoptic code (rain/no rain, see II) has been used. Parameter values have to be given to the transpiration and interception routines. In simulating the combined evapotranspiration for the Jädraås site, three alternative sets of parameters (A, B and C) have been used, see Table 2.

Alternative A
The same parameter values as for the Velen site have been used. The values for the Velen site have been derived using the Velen measuring data. The transpiration parameters were derived in Bringfelt (1982a) and the interception parameters in Bringfelt (1982b).

Alternative B
For the transpiration part the parameter values have been estimated starting from the values for the Velen site. The values of b and c in Eq. (1) have been left unchanged but the value of a has been reduced regarding the different tree species and the smaller leaf area index in Jädraås.

The conductance of the Velen canopy is related to the Jädraås canopy by

$$k_{VEL} = \frac{5}{2.2} \left(\frac{64}{100}\, 0.7 + \frac{36}{100}\right) k_{JÄ} \qquad (2)$$

using the LAI estimates of 2.2 and 5 for the Jädraås and Velen stands respectively. In Velen approximately 64% are spruce and 36% are pine while in Jädraås there is 100% pine. Regarding that spruce has 30% lower conductance than pine (Lindroth, personal communication) Eq. (2) is obtained.

Then it turns out that

$$a_{JÄ} = \frac{2.2}{5} \frac{1}{\frac{64}{100}\, 0.7 + \frac{36}{100}} a_{VE} = 0.544\ a_{VE}$$

In alternative B this gives a = 0.986 • 0.544 = 0.54 as shown in Table 2.

For the interception parameters the values deduced for Jädraås (Lindroth, personal communication) have been used. Alternative B may be considered the best possible estimate of the parameters for the Jädraås stand knowing only data for the Velen stand and some rough data such as tree species and LAI for the Jädraås stand.

Alternative C
Here the parameter values have been deduced using the interception and EBBR measurements at the Jädraås stand itself, Lindroth (1984a). The results of the model calculations therefore may be regarded as the 'correct' values with which the results from A and B could be compared.

Discussion

Interception

In alternatives B and C of Fig. 1 the Jädraås parameter values are used. Since the water storage capacity of the canopy is smaller than in Velen the amounts intercepted (shaded) are seen to be about 60% of those in alternative A.

Transpiration

The white areas of Fig. 1 show that taking the model parameters directly from the Velen Study (alt A) gives the best agreement with the results from the Jädraås site (alt C). In alt B, where the parameter a from the Velen study was reduced to hold for Jädraås with regard to the different tree species and the smaller LAI, the transpiration became less than half of alt C. Thus it seems that the magnitude of the transpiration cannot be proportioned from one site to another by regarding the species and density (LAI) of the stand. One could expect smaller transpiration in Jädraås due to the smaller LAI. Instead, the transpiration from the Jädraås canopy is somewhat larger than in Velen which is illustrated by alternatives C and A in Fig. 1.

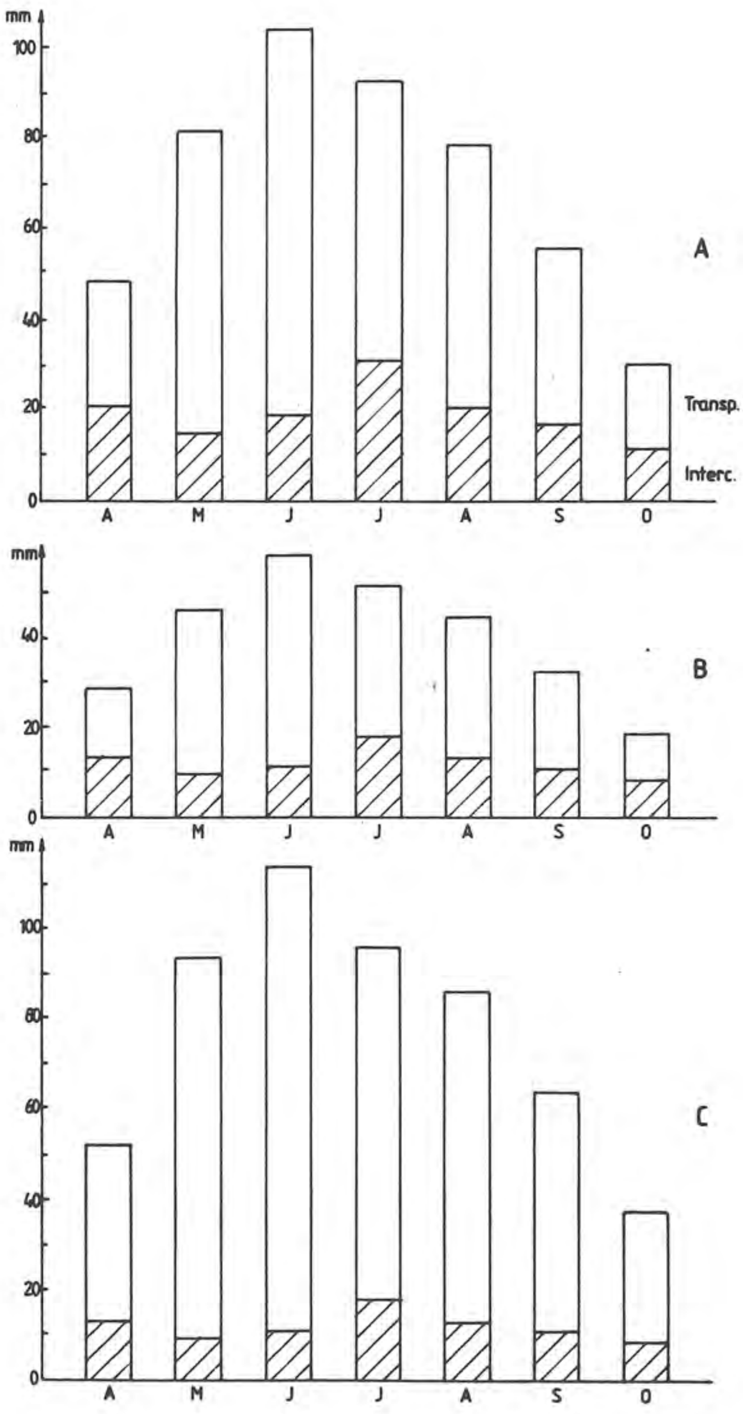
In Jädraås, Grip et al (1979) estimated summer evapotranspiration in 1977 by the EBBR and water balance methods as 350 and 150 mm respectively. Later, Lindroth (1984b) made a detailed analysis of the EBBR measurements and his results suggested that 300 mm was a more resonable result for the EBBR method. One possible explanation to the large discrepancy was assumed to arise from lack of similarity between diffusion coefficients for fluxes of heat and water vapour from the forest. That is, the ratio K_H/K_E of exchange coefficients for these fluxes may differ from 1.0, the value assumed and used in the EBBR method. There is reason to believe that K_H/K_E might differ from 1 over the Jädraås stand which is very sparse with less than 400 trees per ha in comparison to the Velen stand with 1500 trees per ha. To solve this problem, eddy correlation measurments are now planned in and above the Jädraås forest. From a limited set of preliminary correlation data, Smedman et al (1986) found K_H/K_E 1,47. If this value is used instead of 1.0, the earlier EBBR estimates will be futher reduced by 20-30% (Lindroth, personal communication). Then, the white areas in Fig. 1 alt C would be reduced similarly. This is a rather small reduction

FIGURE 1. Jädraås forest stand. Model calculated mean monthly transpiration (white areas) and interception evaporation (shaded areas) over 1977, 1978 and 1979. For these years, synoptic weather data from Åmotsbruk 20 km N of Jädraås have been used. Parameter values are used according to Table 2, i.e. for transpiration:

A *parameters for the Velen forest*

B *parameters based on Velen forest and corrected to hold for the Jädraås forest*

C *parameters for Jädraås forest*



and the above reasoning will still hold essentially. However, the magnitude of K_H/K_E in Jädraås remains uncertain and only the planned eddy correlation measurements can make definitive conclusions possible.

Conclusions

Factors other than LAI seem to be responsible for the relative magnitude in transpiration from the two forest stands investigated. Based on the results obtained sofar, it seems that the transpiration at a new forest site cannot be calculated using detailed transpiration data from an earlier site plus proportioning using simple stand parameter values from both sites such as LAI. For more definite conclusions, the results from planned eddy correlation measurements in Jädraås must be awaited.

REPORT NO IV

IMPROVEMENT OF FOREST EVAPOTRANSPIRATION ESTIMATES AND COMPARISON WITH WATER BALANCE MEASUREMENTS.

1. Introduction

The forest evapotranspiration model (FM) (Bringfelt 1982b, 1985) originally was based on meteorological data from the forest station in Velen. Comparisons were made with independent evapotranspiration values obtained by the water balance method (WB) in the Velen area. In this study these WB-data will be used to improve the model. Evapotranspiration will be calculated by the original and improved models for other areas in order to compare with estimates made there by the water balance method.

2. Discussion of the original forest model

For each day the forest model modifies the synoptic meteorological observations into a form which can be used to calculate transpiration and evaporation of intercepted rain water. This calculation is made using the values of some canopy-related parameters.

The model computes daytime rainfall duration using the rainfall amount caught between 07 and 19 hrs. As shown, better agreement with continuously observed daily durations is obtained when using instead the information on present weather (ww in the synoptic code) given every third hour. Therefore, it was intended that the new model version would calculate daytime rainfall duration by increasing the duration with three hours for every three-hourly observation (ww) reporting precipitation. However, it was found that the necessary three-hourly data was not stored in the computer material to be used. Therefore the old model version will be retained in this respect, that is the daily rainfall duration will still be calculated from the amount reported.

As pointed out for the Velen area (Bringfelt 1985) there was a difference between the original FM and WB estimates in spring and in autumn. A reason suggested was that the model all the time assumes full stomatal activity (as deduced for summer) but that the real transpiration rate should be lower in spring and autumn due to reduced activity. This effect was quite clear in the Velen estimates, see Fig. 1. Especially for the drier months with larger share of transpiration (hatched curve) there is clear tendency for smaller WB-values in spring and autumn. This aspect of the model has been revised and will be discussed below.

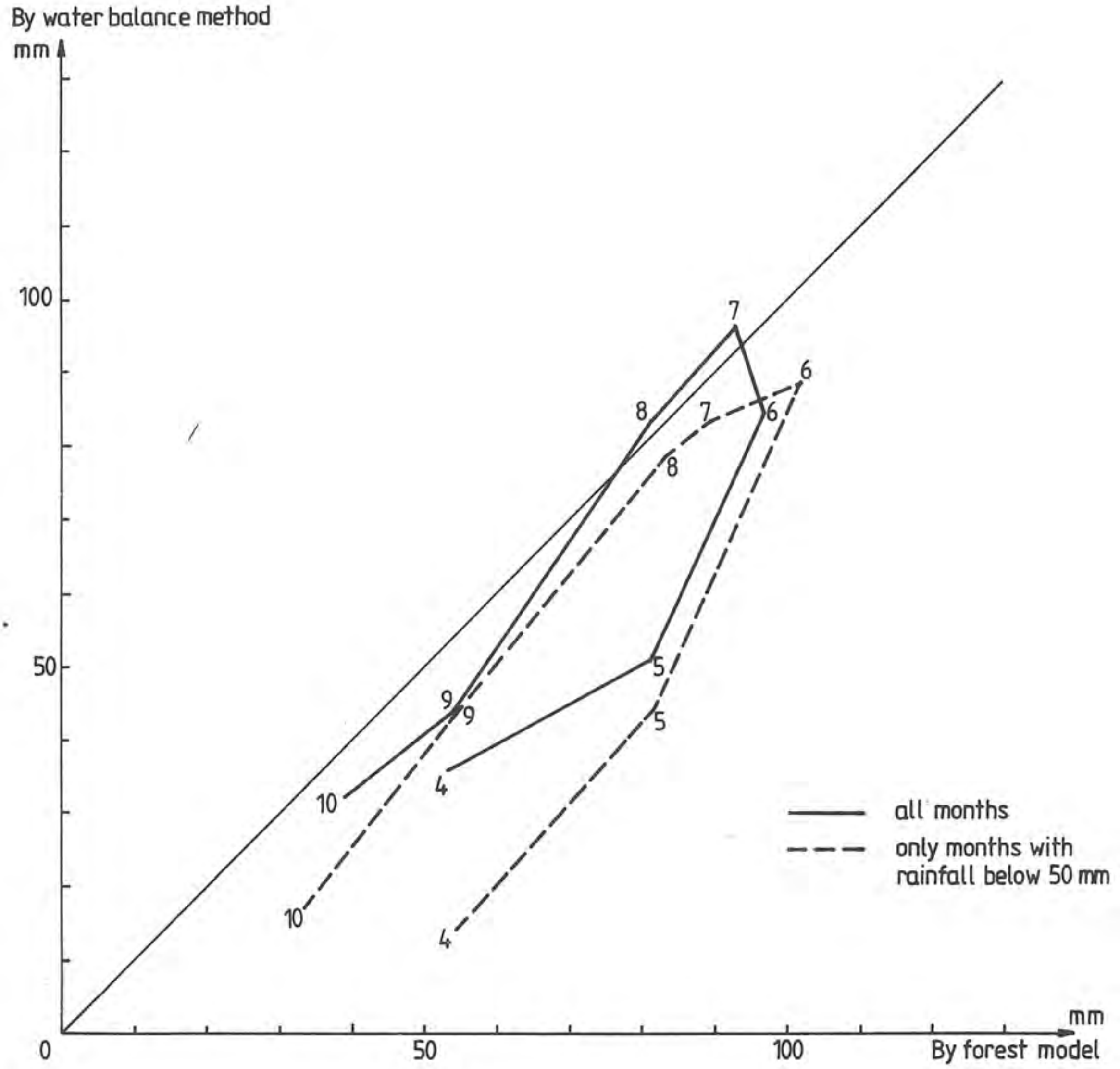


FIGURE 1. Averages over 1967-74 of monthly evapotranspiration values in the Velen area. Data taken from Bringfelt (1982b). 4 means April, 5 May etc.

3. Revision of the forest model considering water balance estimates of evapotranspiration in the Velen area

The monthly WB data will now be used to make a simple correction of the model. The factor to be treated is the seasonal effect on stomatal activity. As can be seen in Fig. 1 this effect is - as expected - greater in dry months. Therefore, the correction factor WB/FM (with which to multiply the monthly transpiration value from the original forest model) was deduced studying the limiting values as rainfall becomes small, see Fig. 2. The scatter is large but the average limiting values obtained are shown in Table 1. For months with no observed increase of WB/FM with larger rainfall all values in Fig. 2 have been averaged. For the remaining months only the values below some 50 mm have been used.

TABLE 1. Velen area 1967-74.
Limiting values of WB/FM when rainfall becomes small.

Month	WB/FM
04	0.26
05	0.54
06	0.86
07	0.93
08	0.94
09	0.80
10	0.52

TABLE 2. Velen forest. Values (mm) of evaporation of rain water intercepted on the forest canopy and floor (I), transpiration (T) and evapotranspiration (E = I + T) calculated by the forest model improved to regard the time variation of transpiration within the vegetation period. The latter is assumed centered on August 1. Synoptic data from Fägre (20 km away) and parameter values for the Velen forest have been used. The E values are those plotted for the FM in diagram 2. The monthly values have been summed from calculated daily values.

Year	Apr	May	Jun	Jul	Aug	Sep	Oct
1970							
I	33	13	7	37	17	22	32
T	1	30	81	50	56	30	6
E	34	43	88	87	73	52	38
1971							
I	11	13	21	28	27	15	20
T	1	36	56	65	48	29	12
E	12	49	77	93	75	44	32
1972							
I	24	29	22	21	21	16	12
T	1	26	56	71	49	31	11
E	25	55	78	92	70	47	23
1973							
I	17	22	12	21	18	19	9
T	2	30	72	70	65	31	8
E	19	52	84	91	83	50	17
1974							
I	2	10	20	17	17	26	28
T	2	38	56	63	56	23	5
E	4	48	76	80	73	49	33

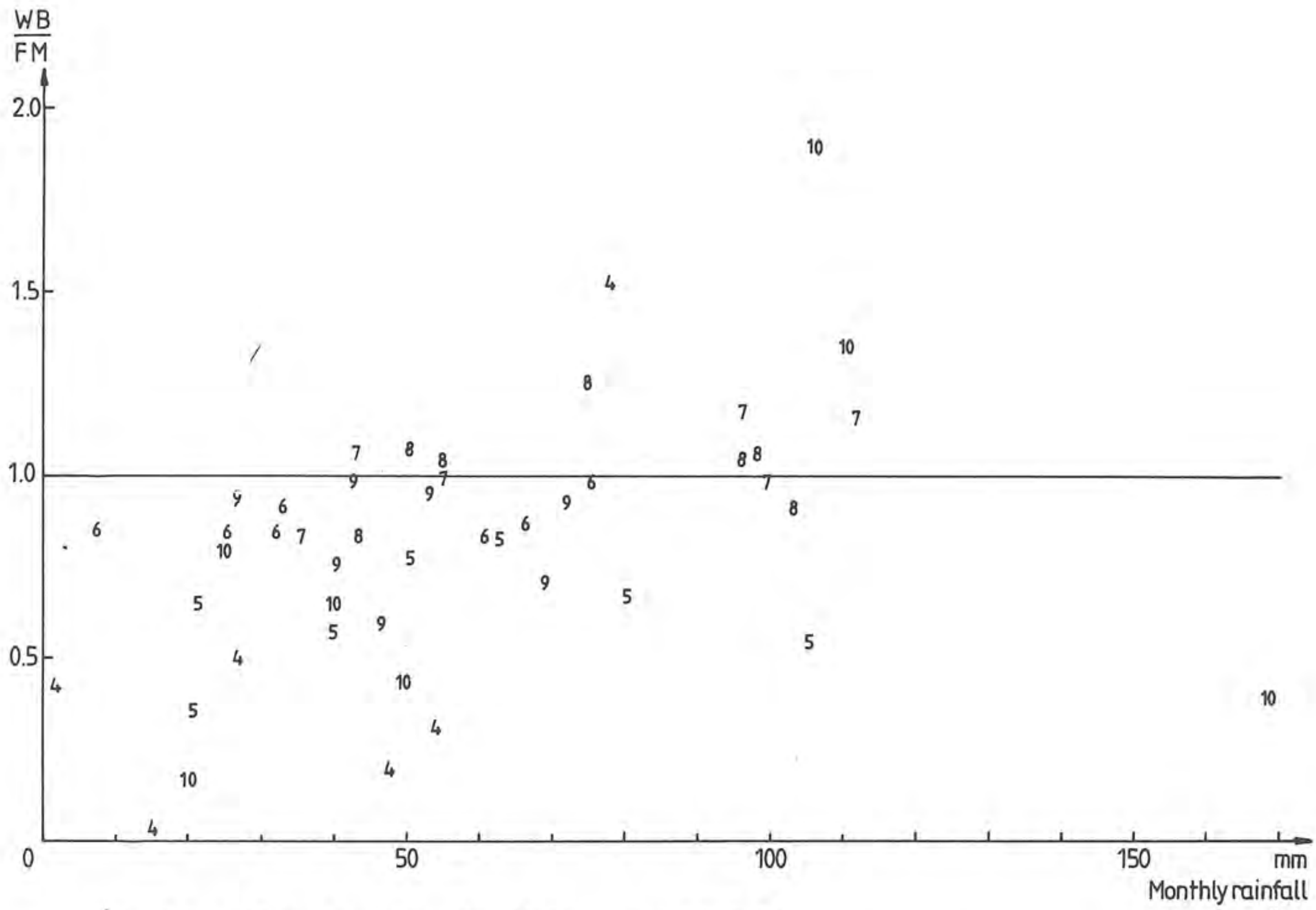


FIGURE 2. Results from the Velen area 1967-74.
Monthly ratios between total evapotranspiration from water balance method and from the forest model are plotted against total rainfall at synoptic station Fägre. 4 stands for April, 5 for May etc.

Using a length of 209 days for the vegetation period in Velen (estimated from Odin et al, 1983) centered around day number 213 (Aug 1) gives that the original model transpiration for a day with number DAG should be multiplied by

$$y = -\,0.0002083\,x^4 - 0.0116667\,x^2 + 0.951875 \qquad (y \geq 0) \tag{1}$$

where

$$x = \frac{|DAG-213| \cdot 209}{15.2 \cdot VEGPER}$$

and VEGPER is the length of the vegetation period. Thus, for a location with shorter vegetation period (VEGPER < 209) the seasonal relative transpiration curve will be run through in a smaller number of days.

The model will be adjusted to the WB values from the Velen area which are smaller than the original FM values especially in spring and autumn (Table 1). These FM values were obtained from the mast meteorological measurments mainly in June-August and the agreement these months with the independent WB values to a factor about 0,9 is quite satisfactory. Thus the model is improved mainly by reducing transpiration in spring and autumn. The results are seen in diagram 2 to be compared with diagram 1 resulting from the old version. The improved agreement in diagram 2 is natural since the Velen material itself was used in constructing the correction procedure.

In diagram 2, for 7004, WB seems to give too high evapotranspiration value but in diagram 1 this month did not show that extreme due to the greater scatter. In spring, there are difficulties with the WB-estimates e. g. due to melting snow-cover. This probably has given the subsequent month 7005 too small a WB-value. Monthly estimates with the improved model are given in Table 2 for 1970-1974. The model gives very good continuous estimates for the Velen forest, since it is now based on all available kinds of evaporation measurements, i. e. mast meteorological, interception and WB.

The correction procedure for transpiration was deduced from the FM and WB results in the Velen area. In section 5 the old and corrected model versions will be tested against the WB data from Kassjöån and Lappträsket.

4. The Kassjöån and Lappträsket areas and water balance estimates

Monthly WB estimates of evapotranspiration have been made in the Kassjöån and Lappträsket areas. These data are given in Tables 3 and 4. Both areas have been described by Falkenmark (1972). They are the only hydrological research areas in Sweden (besides the Velen area) covered with coniferous forest to a large percentage. Figures 3, 4 and 5 show the location and size of the two areas.

The Kassjöån area is covered to 81% mainly with coniferous forest which has a rather high canopy density in some parts. The rest are swamps (12%), lakes (4.5%) and other areas. A rather large part of the forest is clearcut.

The basin of Lappträsket is considered representative for the forest and swamp areas of northern Sweden. The area is covered by coniferous forest to 67% (with some clearcutting), treeless peatland to 30%, lakes to 2.6% and other areas.

5. Comparison between forest model and water balance estimates.

In high latitudes, the vegetation period starts later in spring and ends earlier in autumn. The vegetation period (defined as when the mean air temperature exceeds +5^{o}C) was deduced from Odin et al (1983) as

Figure 3 Map of Sweden showing the representative areas Kassjöån (K) and Lappträsket (L). The names of the five synoptic stations used have been underlined. Letters V and J mark the meteorological measuring sites of Velen and Jädraås.

Figur 4 Detailed map showing the representative area of Kassjöån. The synoptic stations of Krångede and Fränsta are marked by crosses.

<u>Figure 5</u> Detailed map showing the representative area of Lappträsket. The synoptic stations of Pålkem (within the area), Boden and Överkalix are marked by crosses.

20 April - 15 Nov for the Velen area
2 May - 5 Oct for the Kassjöån area
15 May - 22 Sept for the Lappträsket area

Accordingly, the length VEGPER used will be

156 days for Kassjöån and
129 days for Lappträsket

Table 5 shows the model runs compared with the water balance estimates. For Kassjöån and Lappträsket most runs were made using model parameter values deduced from the Velen study. For comparison some runs were made using parameter values deduced from the Jädraås study.

For Kassjöån, diagrams 3 and 4 show the results (using synoptic weather data from Krångede) with and without correction for vegetation period. It can be seen that the correction procedure improves the monthly values markedly. Improved agreement comes out also for the Lappträsket area, compare Figures 7 and 8 where synoptic data from Överkalix was used. Thus the correction procedure, deduced from the Velen data, gave a marked improvement also for Kassjöån and Lappträsket with their independent data sets.

The Velen material (Table 1) gave similar factors for July and August (0.93 and 0.94) to correct for time within the vegetation period. This suggests the use of August 1 as date of maximum transpiration activity. The effect will be kept symmetrical about this date. In section 3 July 19 was mentioned. This date was tested because it was the middle date of the vegetation period in Lappträsket and Kassjöån. To compare, runs were made for both these dates, see diagrams 5 and 6 for Kassjöån and 9 and 10 for Lappträsket. August 1 showed better for both areas, especially Lappträsket. August 1 fitted well even for the Velen data. However, it should be pointed out that our method is crude, using a symmetrical 4th degree curve (Eq. 1). Using Aug 1 gives the best agreement for the months June, July and August.

In the forest model, the position of the synoptic station relative to the hydrological area should have some effect on the comparison between the FM and WB values. In the Velen study where data from many stations were tested, there was no better agreement between FM and WB in using Fägre, the site nearest to the hydrological area. There, all the synoptic sites used gave roughly the same general picture of monthly data. In Kassjöån, diagrams 4 and 5 give the results for Krångede and Fränsta respectively. The nearest station Fränsta (see map) gives about the same agreement as using Krångede. Pålkem situated within the Lappträsket area gives slightly better agreement than using synoptic data from Överkalix, compare diagrams 8 and 9.

The stand parameter values used are given in Table 1 of III. Most runs have been made using the Velen parameters, see values under A in this table. Some runs also have been made using the parameter values given for the Jädraås stand, see values under C. Results using the Jädraås parameters are given in diagrams 12, 13 and 14. These have to be compared with the corresponding runs with Velen parameters (diagrams 3, 7 and 11). For both Kassjöån and Lappträsket the calculated summer values (June-August) are higher using the Jädraås parameters. This is reflected by the fact that these values give higher transpiration amounts, see Figure 1 of IIIii. The Velen parameters give the best agreement with the WB-values (diagrams 3, 7 and 11). Therefore, most runs in this study were made with this set of parameters.

In diagram 11 the spring and autumn months for Lappträsket have larger FM values than WB values. Here only the September months (values underlined) can be regarded with confidence because April, May and October may have snow cover where the WB estimates are uncertain. For September the evaporation of intercepted water is a large share. Then it could be possible that the interception parameters are not suitable. In diagrams 11 and 14, where the only difference is the parameter set used, it is possible that the counteracting effects of the interception and transpiration parts may have led to unchanged model results. With the Jädraås parameters interception namely becomes smaller and transpiration becomes larger than using the Velen parameters, see III. One possible reason for the difference in spring and autumn is the uncertainty in the WB-values as mentioned above. Thus for April, May and October some of the WB-values are even negative. These WB-values of evaporation were often calculated as differences between large numbers (precipitation, runoff or storage change) and possibly also the September values may be uncertain due to that cause.

6. Summary and conclusions

The original model was constructed and parameters were adjusted using mast data and interception data at the Velen site. The present model change is based on WB data on evapotranspiration from the Velen area. Comparison with these data showed that the original model gave larger transpiration values in autumn and especially spring. The change was introduced in the way that regard was made to the influence of the point of time within the vegetation period. Then the transpiration in spring and autumn was reduced due to the known smaller activity of the forest and with an amount suggested by the WB data. With the new model better agreement was found with the WB data from the Velen site just because these data had been used, but also for Kassjöån and Lappträsket with their independent data.

Table 1 shows that the original FM transpiration in May has been reduced to 54% using the Velen WB estimates. However, the original EBBR results did not give lower transpiration in May 1974 compared to the summer months, see Fig 7 of Bringfelt (1982b). Also, for Jädraås, Fig 5(d) of Lindroth (1984a) suggests a smaller reduction (to about 80% of the summer values). Thus, it is not quite straightforward to reduce transpiration to 54% as suggested by the WB data alone, even if the May months of 1970-74 suggest this, see diagrams 1 and 2.

The position of the synoptic station used relative to the area tested plays a minor role for the general picture of the monthly data given by the model.

The results of IIIii suggest that forest transpiration cannot be calculated at a new site making changes based on the new values for simple stand parameters such as leaf area index. In this study the Velen parameter values give better agreement with the WB-data for both Kassjöån and Lappträsket than the Jädraås values. However, only the forest stand in Kassjöån is more similar to the Velen stand than to the Jädraås stand. The Lappträsket stand is more sparse and resembles that of Jädraås. However, as pointed out above, the Velen parameters gave the best agreement also for Lappträsket. This illustrates the difficulties pointed out above with estimating reasonable stand parameters.

The agreement found in the diagrams is encouraging and it seems that a crude model like this could be used for practical estimates.

TABLE 3. Monthly water balance estimates (mm) of evapotranspiration from the representative area of Kassjöån (Waldenström, 1976).

Year	June	July	August
1970	71	94	69
1971	83	100	62
1972	52	97	77
1973	88	100	68
1974	69	71	69
1975	93	98	62

TABLE 4. Monthly water balance estimates (mm) of evapotranspiration from the representative area of Lappträsket (Persson, 1976).

Year	Apr	May	Jun	Jul	Aug	Sep	Oct
1969	-	-20	92	74	55	28	-
1970	-6	-13	90	72	63	8	-
1971	2	7	54	70	82	25	3
1972	8	6	52	117	61	24	17
1973	1	6	42	94	108	19	-1
1974	-13	96	-	138	60	63	-1
1975	-18	60	70	71	60	28	11
1976	-8	36	78	80	57	26	-
1968-76	-	20	69	81	68	28	-

TABLE 5. Runs by the forest model for some areas and synoptic stations and some alternatives for parameter values. The numbers refer to diagrams.

Representative area and synoptic stations used	Duration of rainfall calculated from its amount Model parameter values deduced from the Velen site	 deduced from the Jädraås site
Velen (1970-74)		
Fägre	1 No veg. period used 2 Veg. period centered Aug 1	
Kassjöån (1970-75)		
Krångede	3 No veg. period used 4 Veg. period centered July 19	12 No veg. period used
Fränsta	5 Veg. period centered July 19 6 Veg. period centered Aug 1	
Lappträsket (1970-76)		
Överkalix	7 No veg. period used 8 Veg. period centered July 19	13 No veg. period used
Pålkem	9 Veg. period centered July 19 10 Veg. period centered Aug 1	
Boden	11 Veg. period centered July 19	14 Veg. period centered July 19

Diagram 1:

Monthly evapotranspiration values (mm)

Period: April-Oct, 1970-1974
Values by the WB-method (ordinates): Velen data
Values by the FM (abscissae):
- synoptic data: Fägre
- parameter values: Velen study
- vegetation period: not regarded

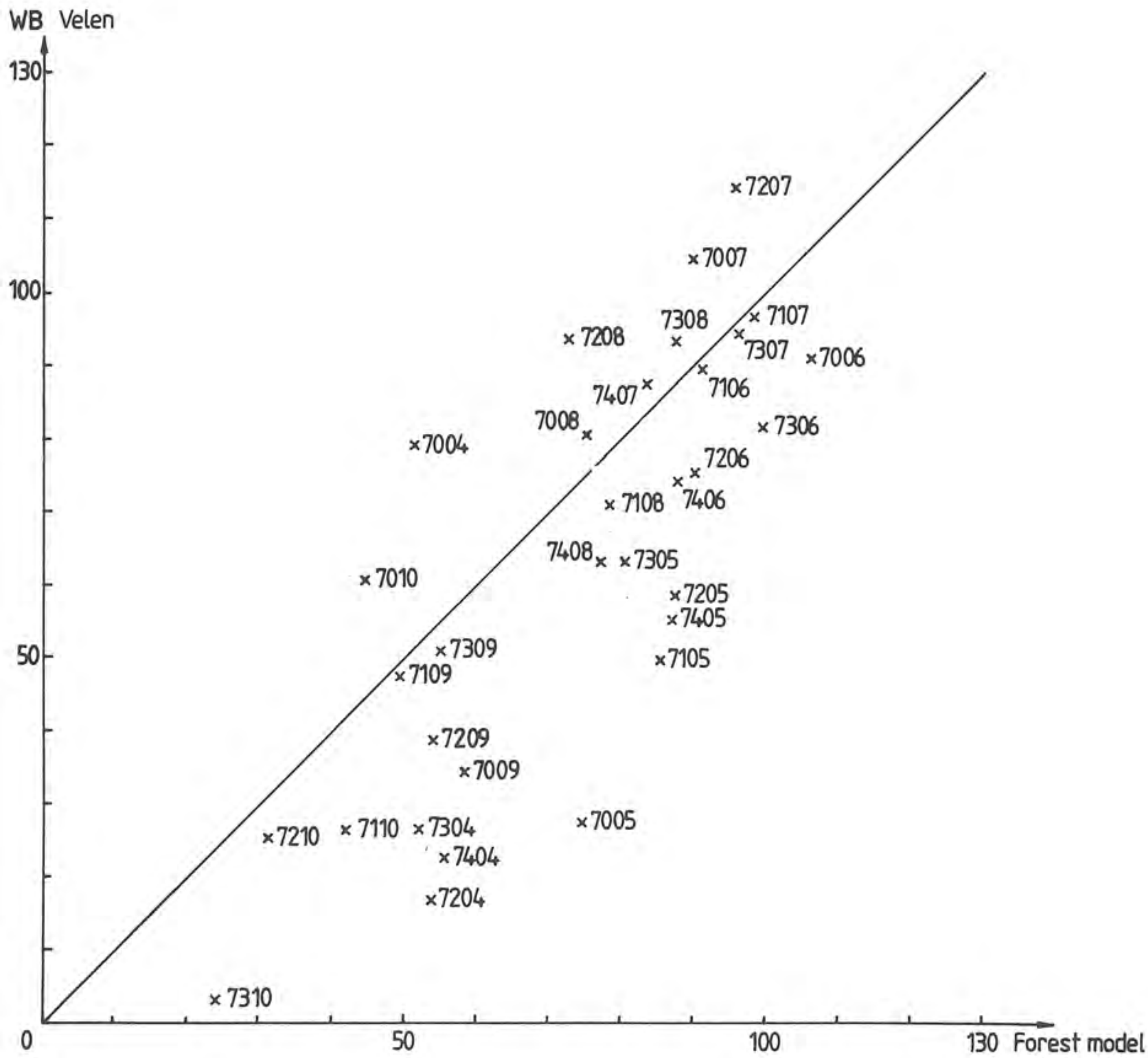


Diagram 2:

Monthly evapotranspiration values (mm)

Period: April-Oct, 1970-1974
Values by the WB-method (ordinates): Velen area
Values by the FM (abscissae):
- synoptic data: Fägre
- parameter values: Velen study
- vegetation period: regarded, centered on Aug 1

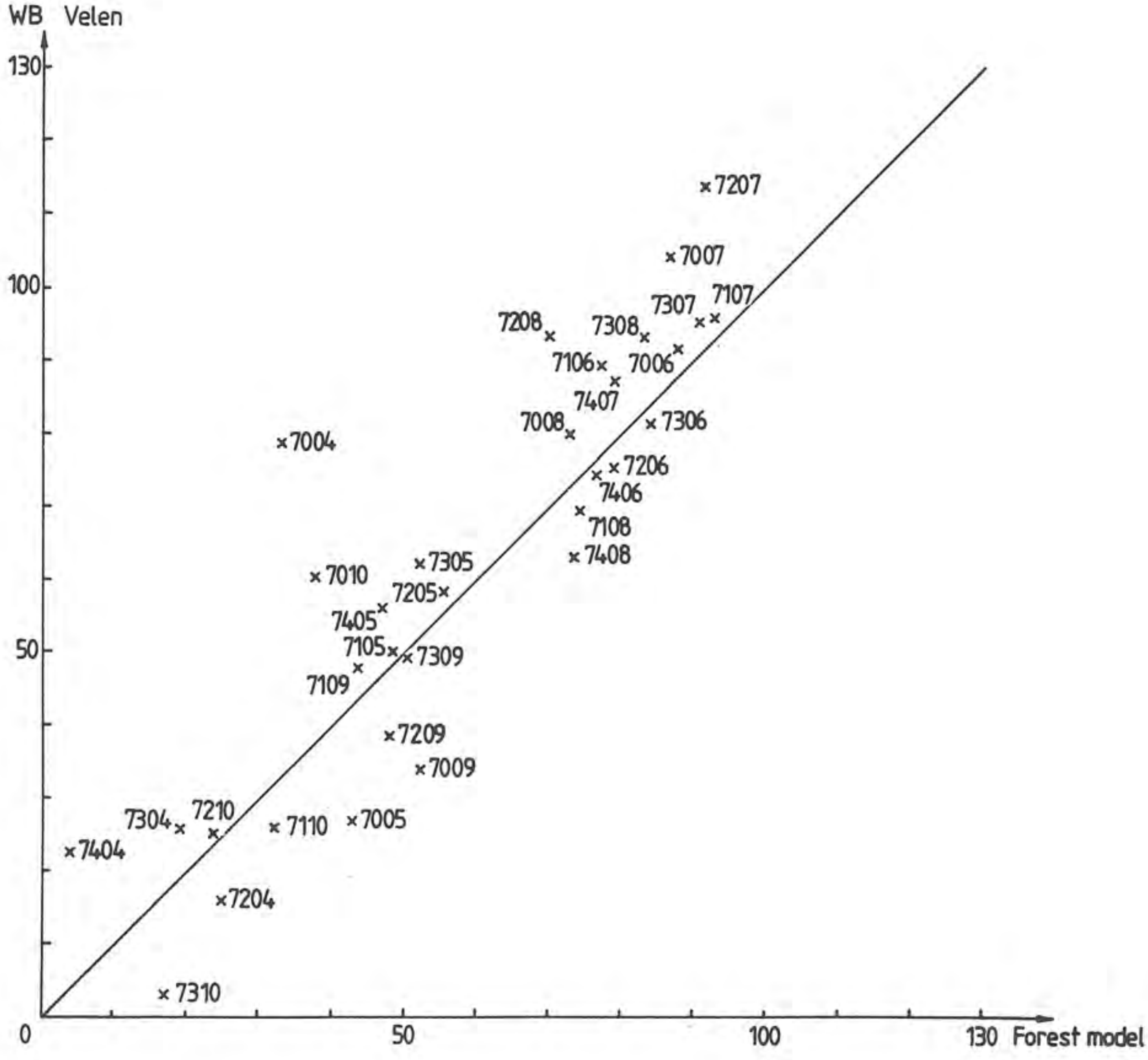


Diagram 3:

Monthly evapotranspiration values (mm)

Period: June-Aug, 1970-1975 (7306 means June 1973)
Values by the WB-method (ordinates): Kassjöån
Values by the FM (abscissae):
- synoptic data: Krångede
- parameter values: Velen study
- vegetation period: not regarded

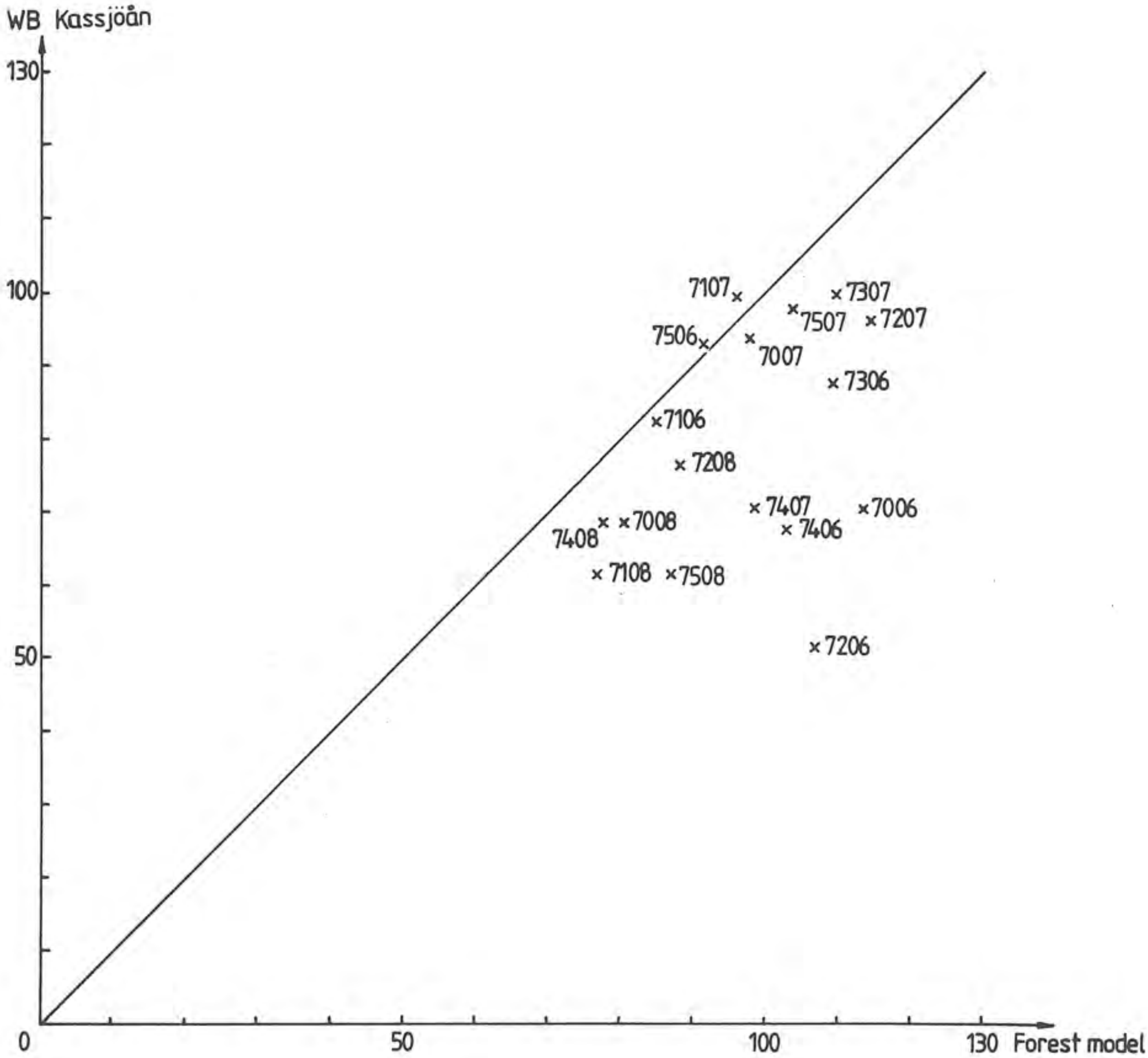


Diagram 4:

Monthly evapotranspiration values (mm)

Period: June-Aug, 1970-1975
Values by the WB-method (ordinates): Kassjöån
Values by the FM (abscissae):
- synoptic data: Krångede
- parameter values: Velen study
- vegetation period: regarded, centered on July 19

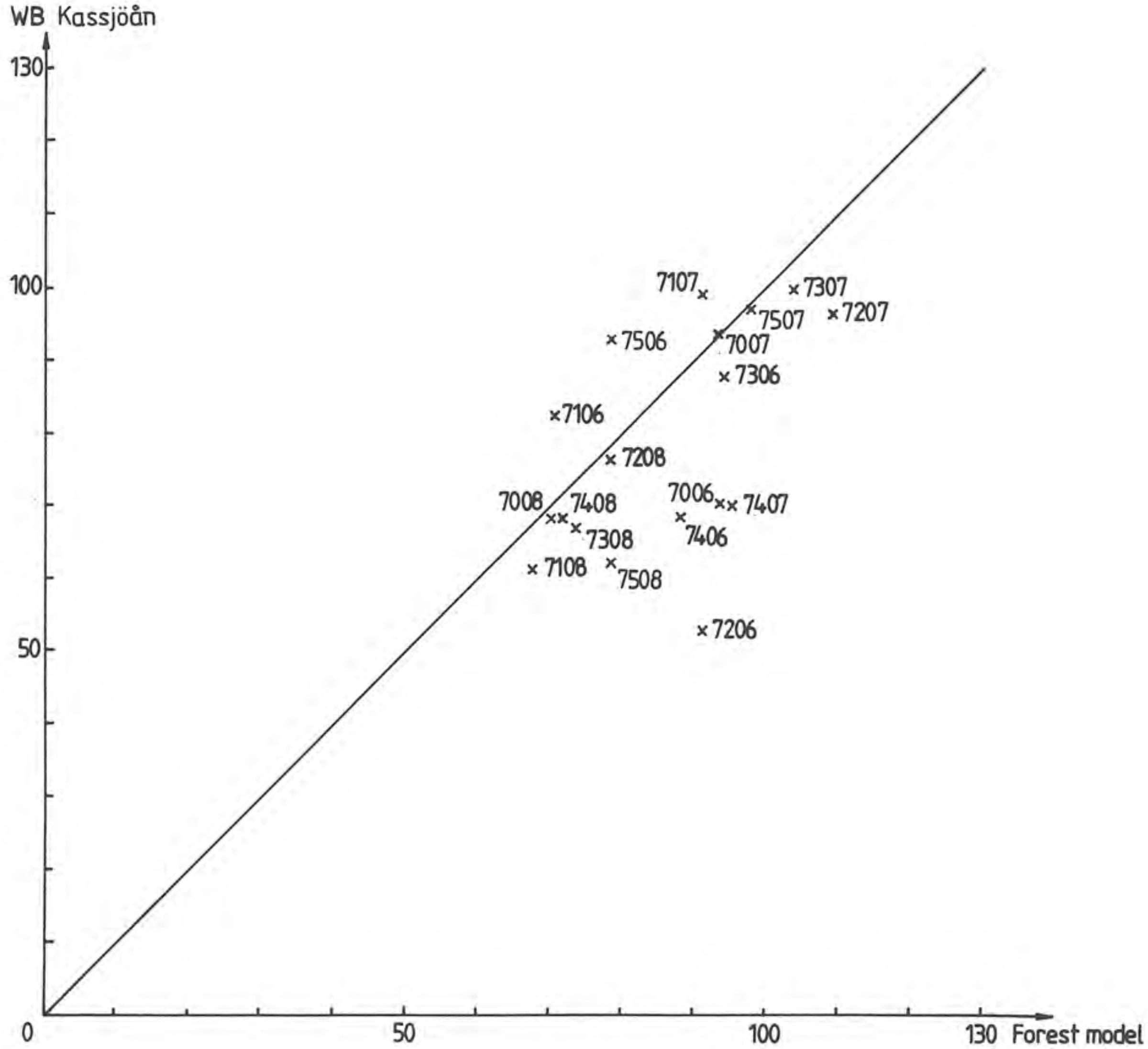


Diagram 5:

Monthly evapotranspiration values (mm)

Period: June-Aug, 1970-1975
Values by the WB-method (ordinates): Kassjöån
Values by the FM (abscissae):
- synoptic data: Fränsta
- parameter values: Velen study
- vegetation period: regarded, centered on July 19

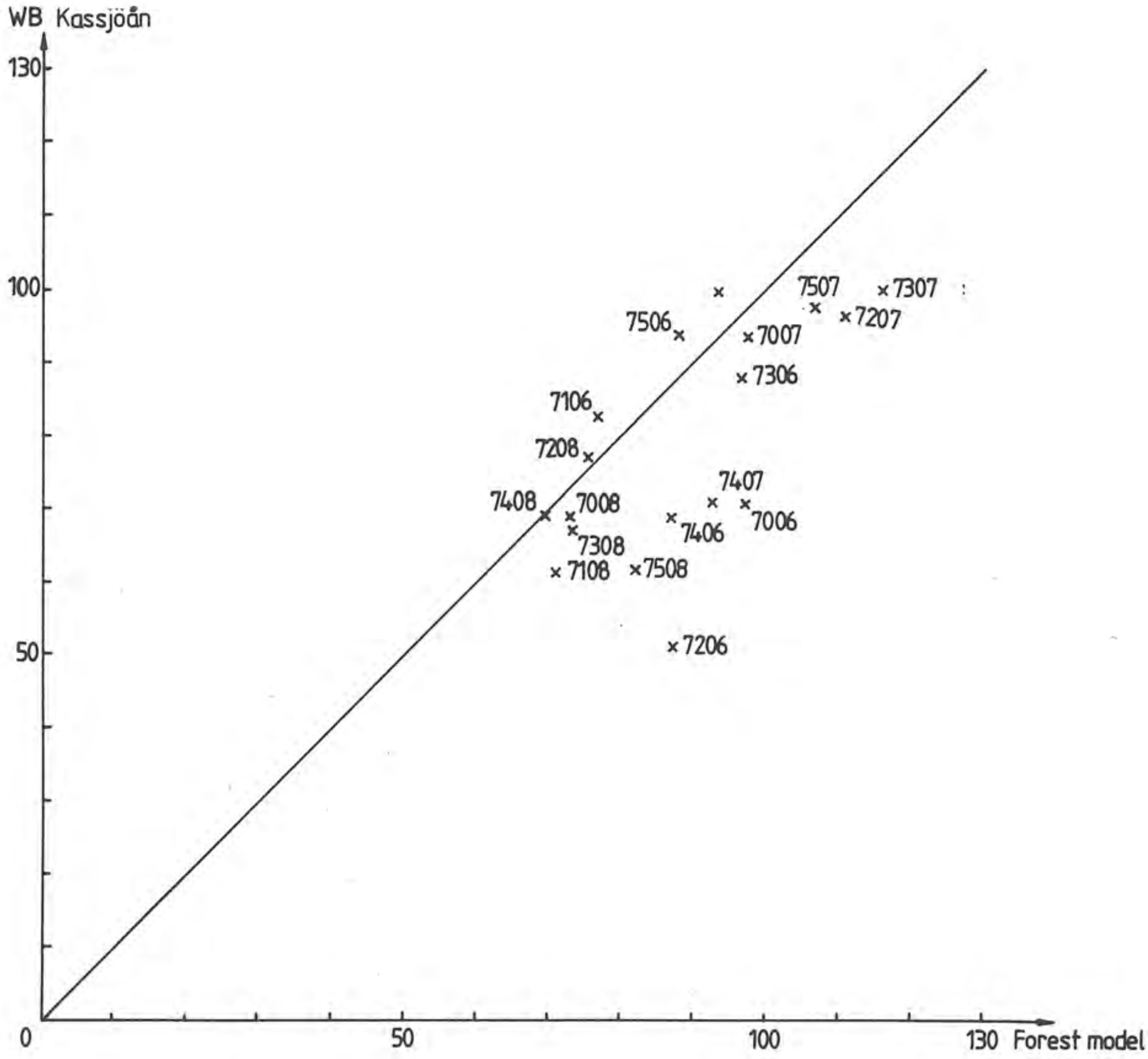


Diagram 6:

Monthly evapotranspiration values (mm)

Period: June-Aug, 1970-1975
Values by the WB-method (ordinates): Kassjöån
Values by the FM (abscissae):
- synoptic data: Fränsta
- parameter values: Velen study
- vegetation period: regarded, centered on Aug 1

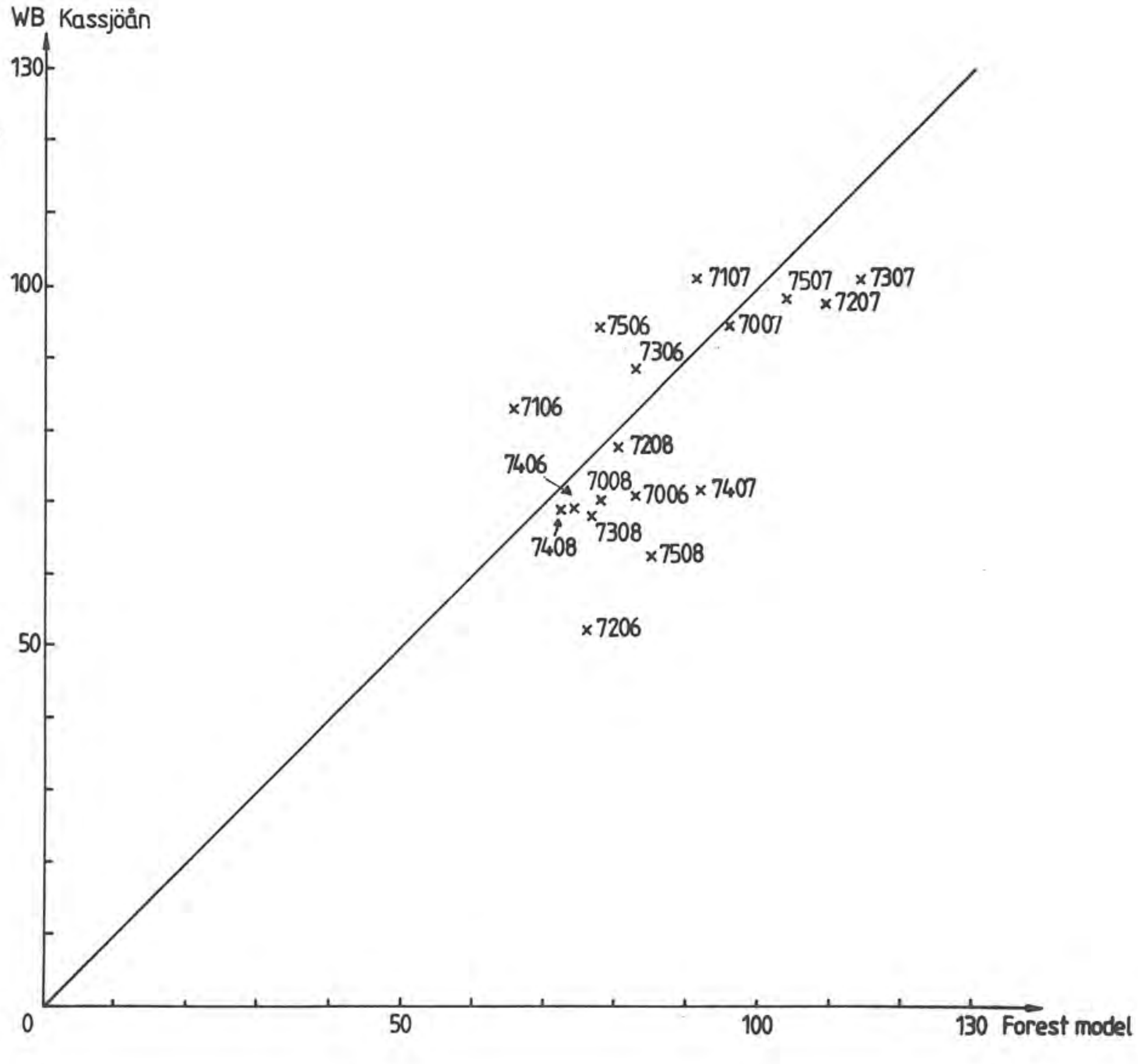


Diagram 7:

Monthly evapotranspiration values (mm)

Period: April-Oct, 1970-1976 (7207 means July 1972)
Values by the WB-method (ordinates): Lappträsket
Values by the FM (abscissae):
- synoptic data: Överkalix
- parameter values: Velen study
- vegetation period: not regarded

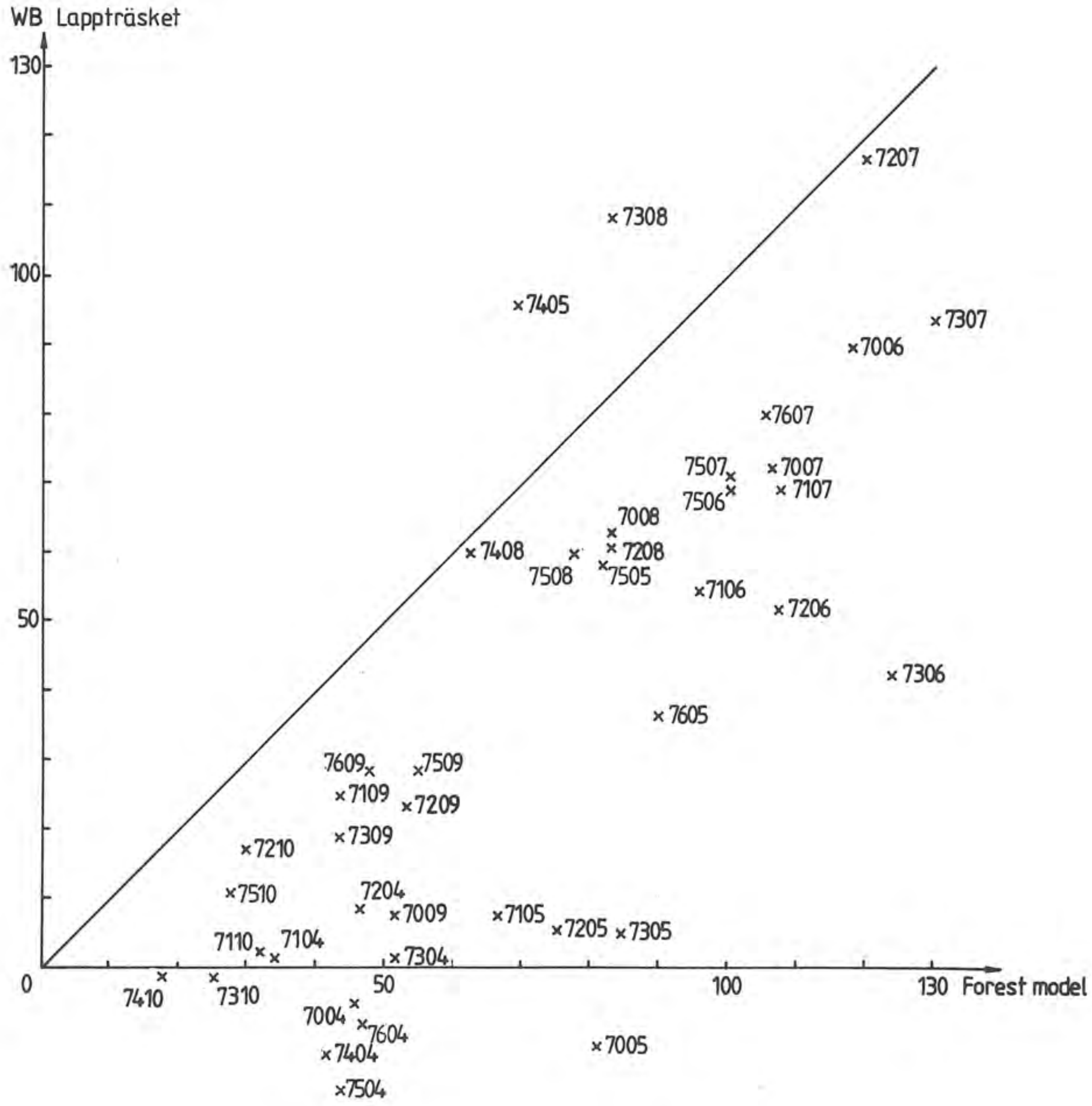


Diagram 8:

Monthly evapotranspiration values (mm)

Period: April-Oct, 1970-1976
Values by the WB-method (ordinates): Lappträsket
Values by the FM (abscissae):
- synoptic data: Överkalix
- parameter values: Velen study
- vegetation period: regarded, centered on July 19

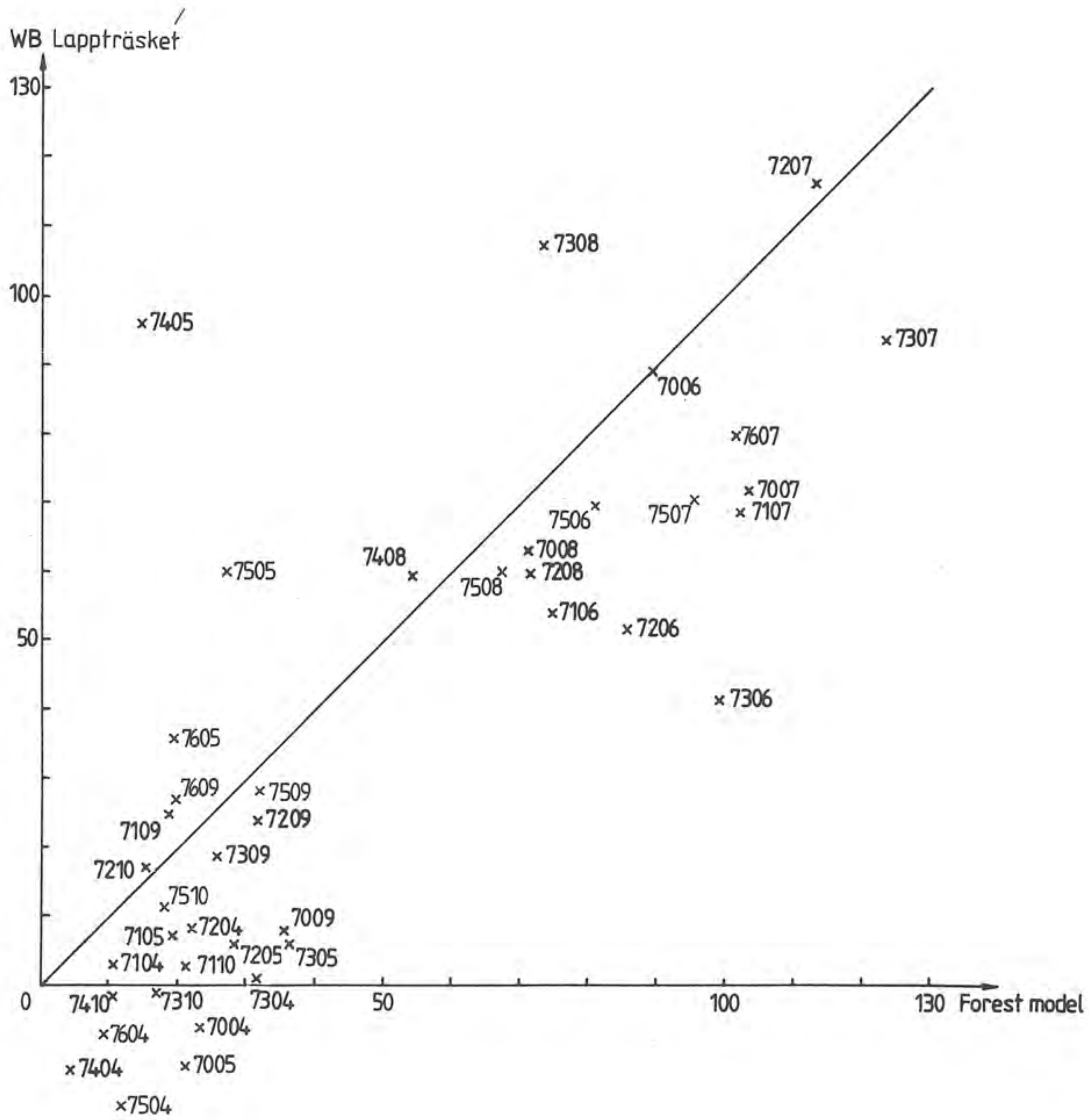


Diagram 9:

Monthly evapotranspiration values (mm)

Period: April-Oct, 1970-1976
Values by the WB-method (ordinates): Lappträsket
Values by the FM (abscissae):
- synoptic data: Pålkem
- parameter values: Velen study
- vegetation period: regarded, centered on July 19

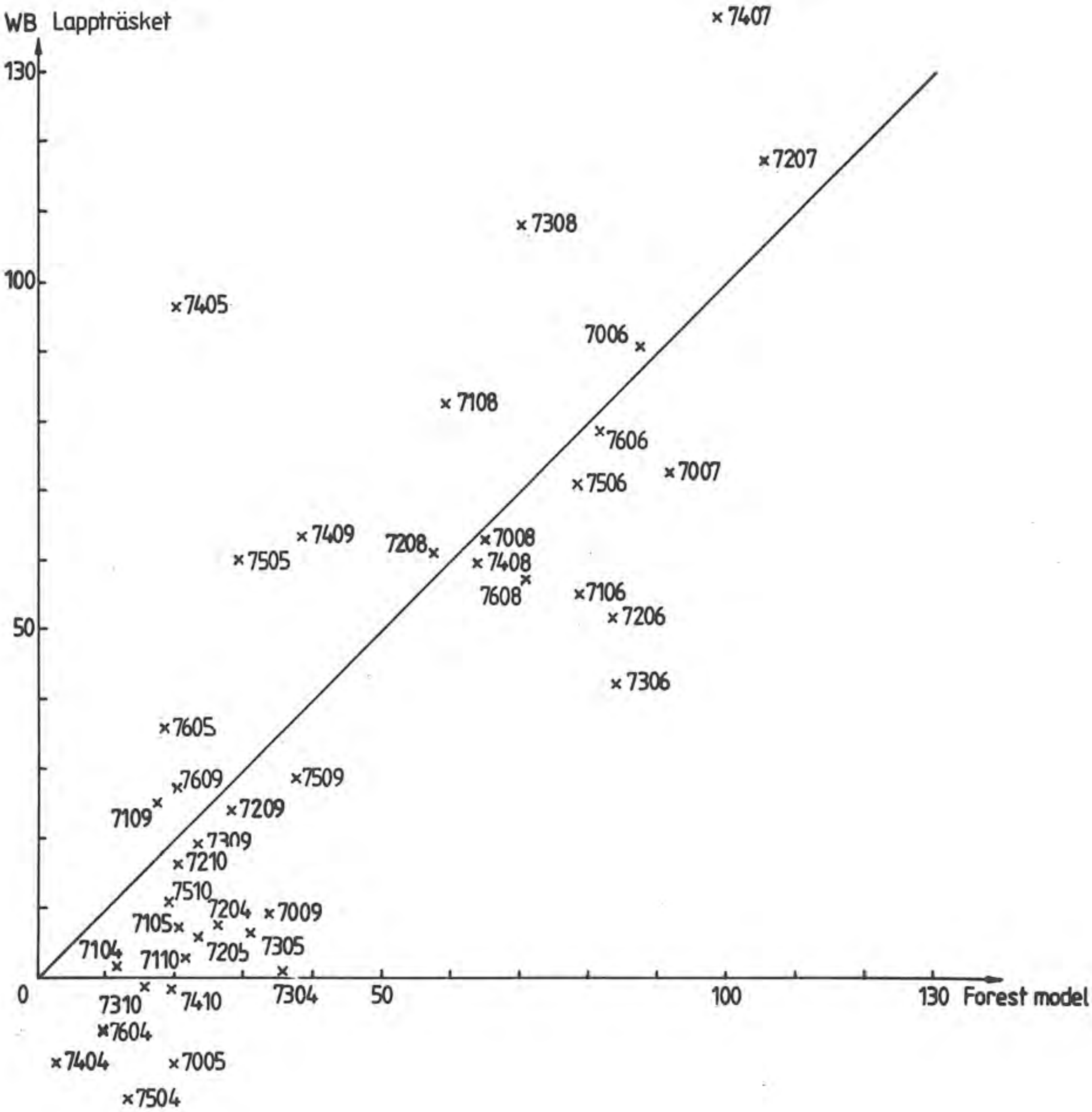


Diagram 10:

Monthly evapotranspiration values (mm)

Period: April-Oct, 1970-1976
Values by the WB-method (ordinates): Lappträsket
Values by the FM (abscissae):
- synoptic data: Pålkem
- parameter values: Velen study
- vegetation period: regarded, centered on Aug 1

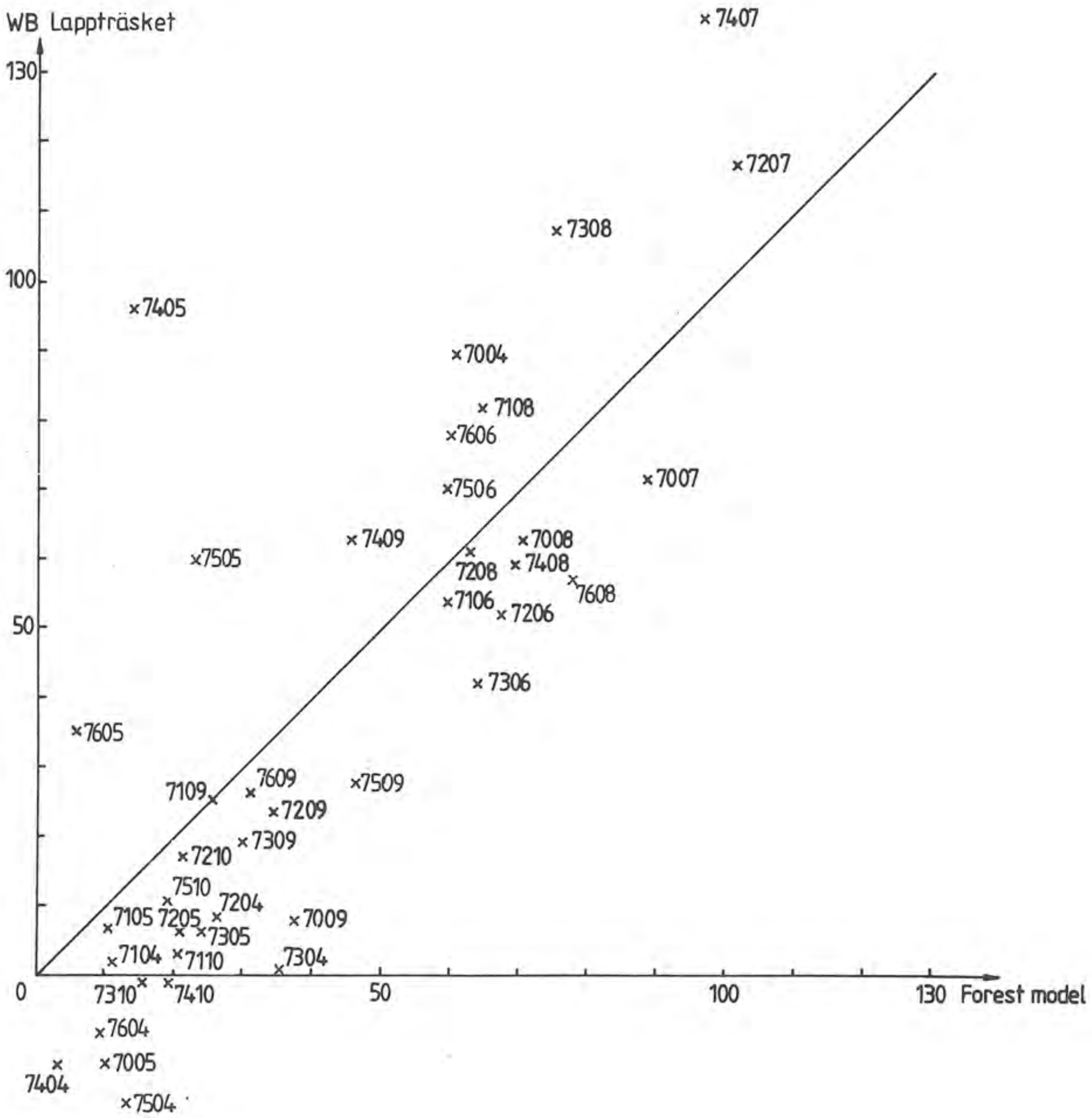


Diagram 11:

Monthly evapotranspiration values (mm)

Period: April-Oct, 1970-1976
Values by the WB-method (ordinates): Lappträsket
Values by the FM (abscissae):
- synoptic data: Boden
- parameter values: Velen study
- vegetation period: regarded, centered on July 19

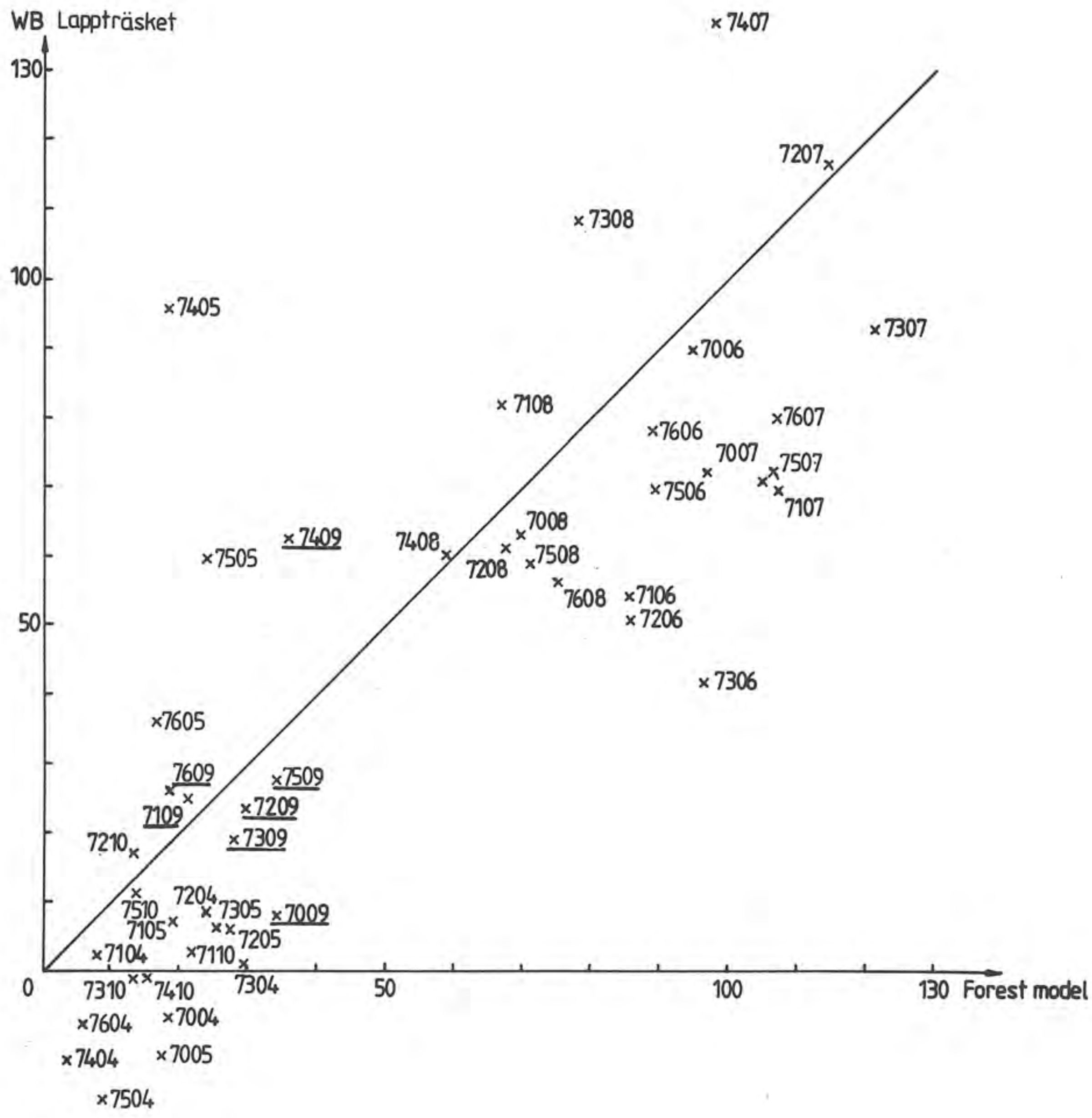


Diagram 12:

Monthly evapotranspiration values (mm)

Period: June-Aug, 1970-1975
Values by the WB-method (ordinates): Kassjöån
Values by the FM (abscissae):
- synoptic data: Krångede
- parameter values: Jädraås study
- vegetation period: not regarded

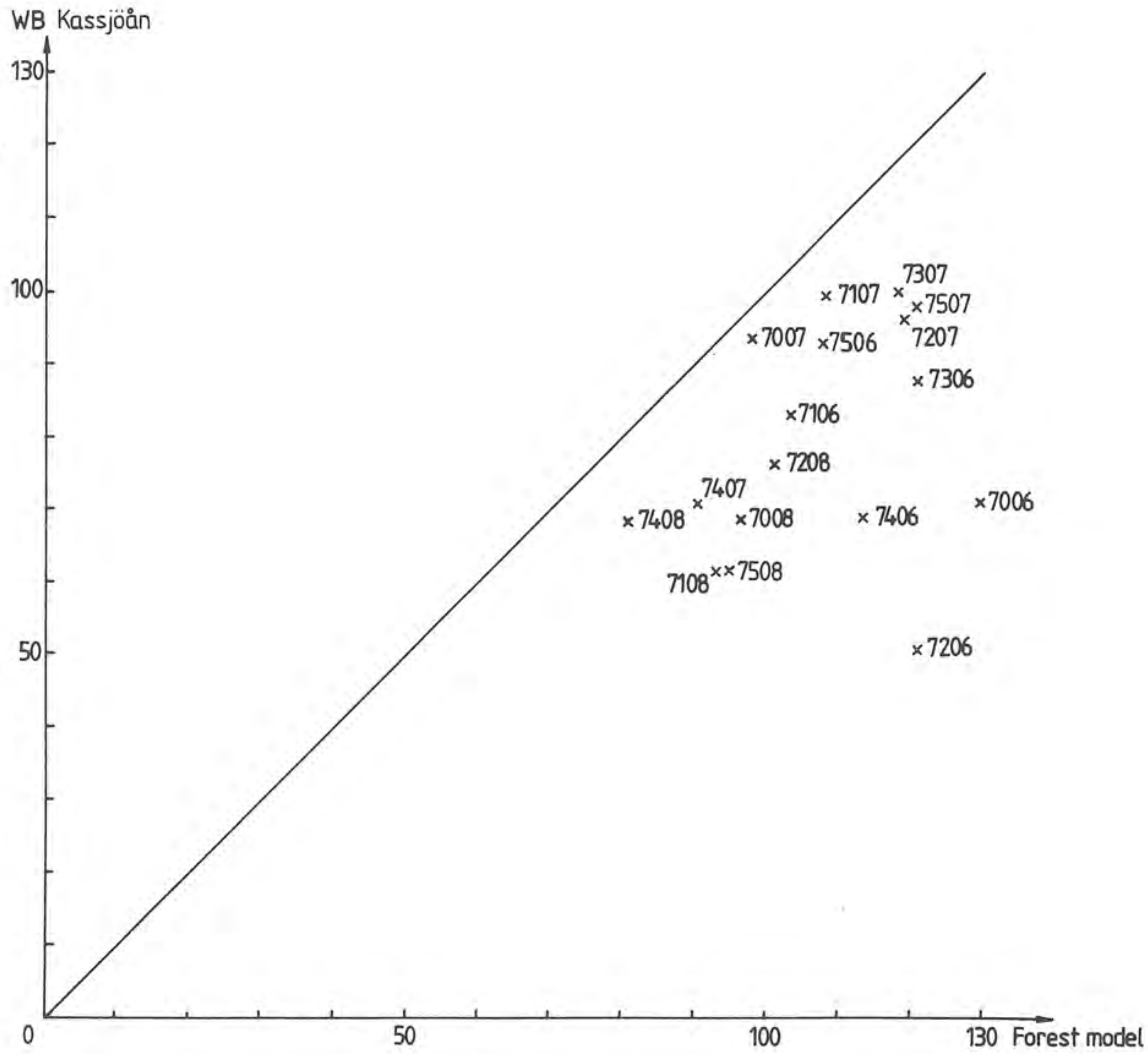


Diagram 13:

Monthly evapotranspiration values (mm)

Period: April-Oct, 1970-1976
Values by the WB-method (ordinates): Lappträsket
Values by the FM (abscissae):
- synoptic data: Överkalix
- parameter values: Jädraås study
- vegetation period: not regarded

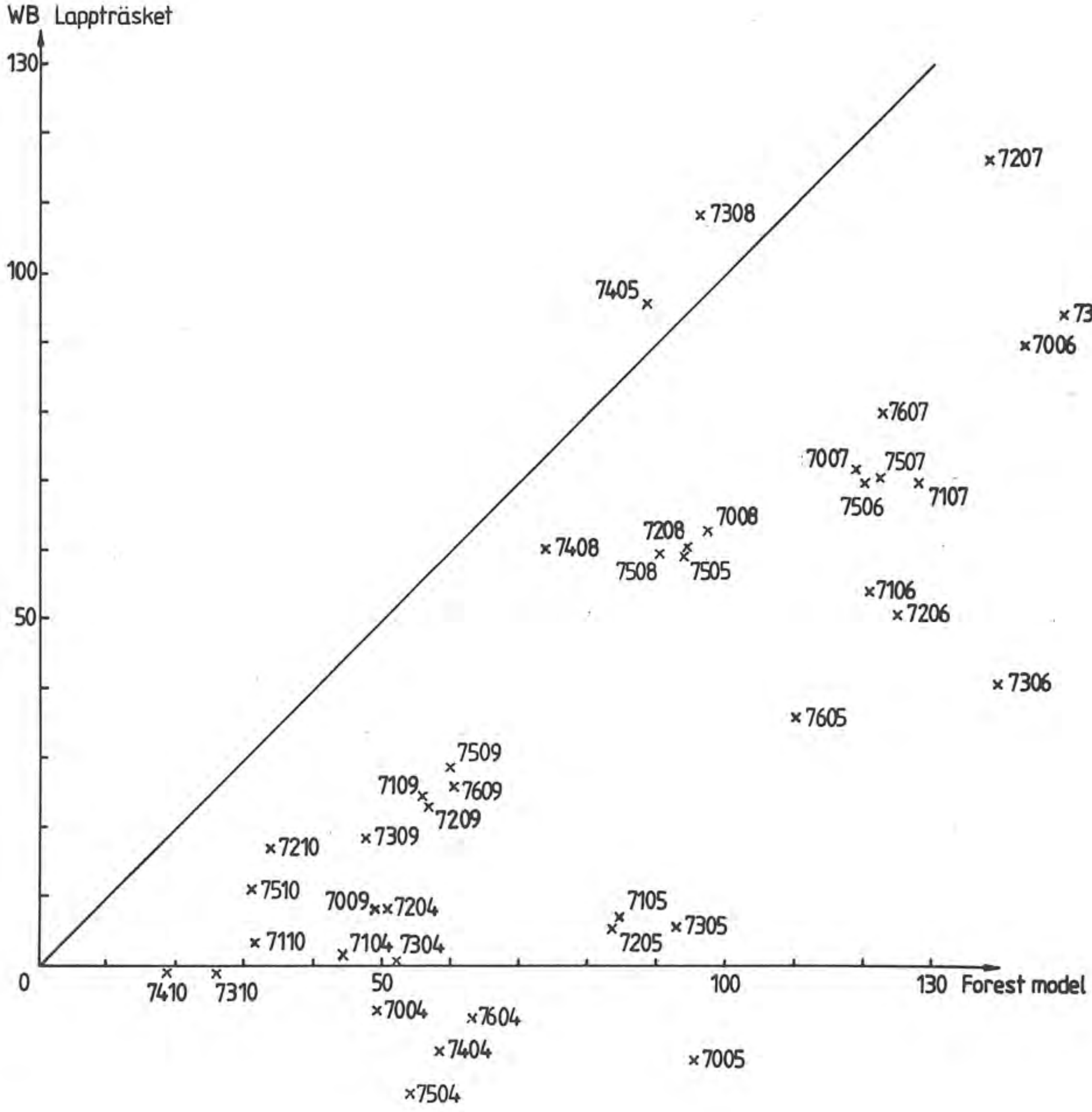
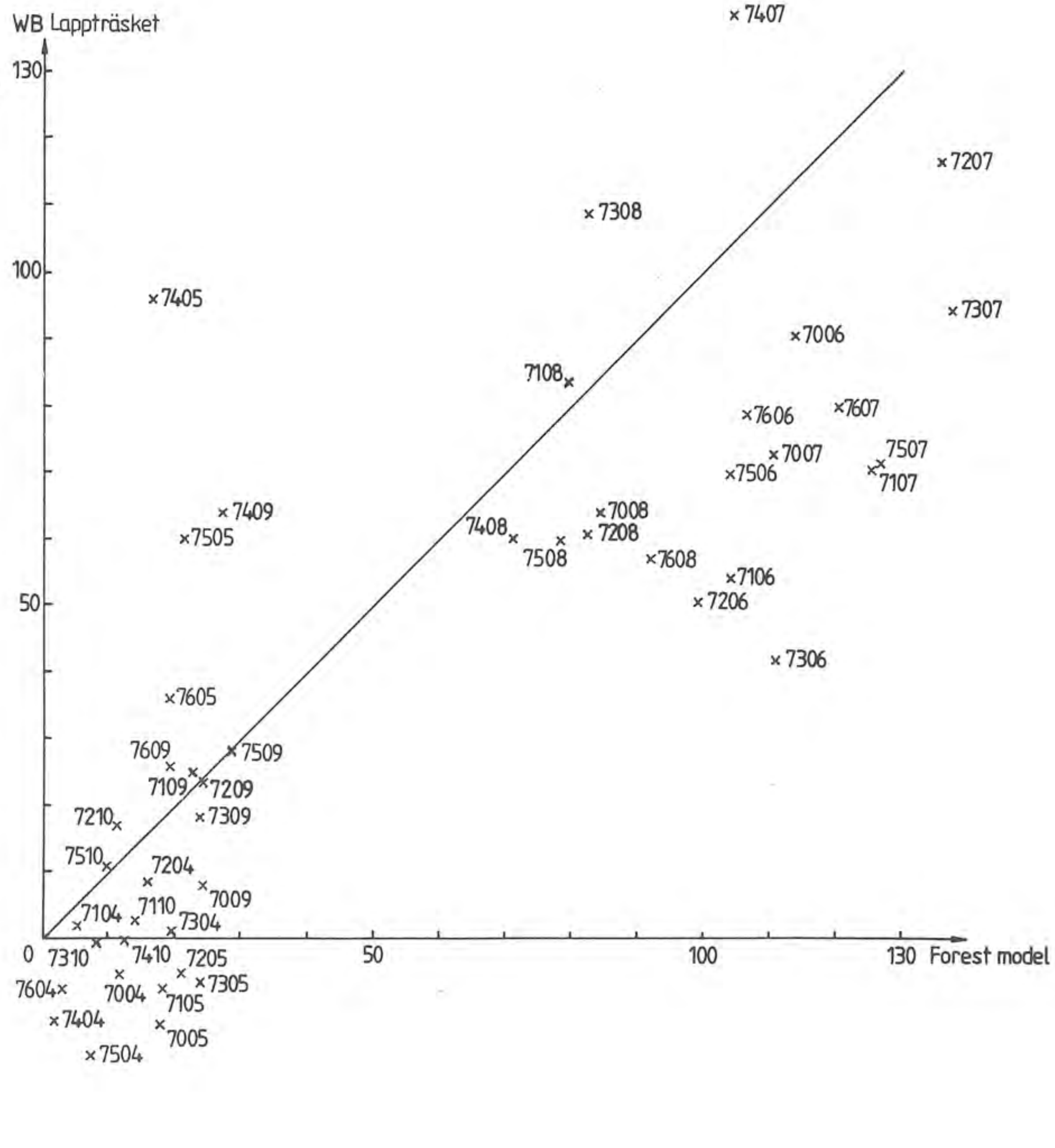


Diagram 14:

Monthly evapotranspiration values (mm)

Period: April-Oct, 1970-1976
Values by the WB-method (ordinates): Lappträsket
Values by the FM (abscissae):
- synoptic data: Boden
- parameter values: Jädraås study
- vegetation period: regarded, centered on July 19



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