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ESTIMATION OF RIVER BASIN EVAPOTRANSPIRATION

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ABSTRACT

There is little information about actual evapotranspiration from river basins with complicated topographies and variable land usage.

In order to estimate reliable actual evapotranspiration, a modified Penman model is proposed in this study. The empirical constants of the conversion factor from potential evaporation to actual evapotranspiration in the model are decided by means of multiple regression analysis.

By combining direct solar radiation, sky diffuse radiation and ground reflected diffuse radiation, the total short-wave radiation on a sloping surface is estimated. The effective long-wave radiation is also estimated by using of air temperature and clearness index.

The estimated annual evapotranspiration is compared with the result obtained by means of the water balance method for the corresponding 6 year periods. The results show the present model provides reliable estimates of monthly and annual river basin evapotranspiration.

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LIST OF SYMBOLS

a, b, c, d, e, f	constant
A, B, C, D, E, F	constant
A	solar azimuth for a horizontal surface
A'	solar azimuth for a sloping surface
c_p	specific heat of air at constant pressure
Cr	empirical constant in the soil heat flux equation
D	discharge of river flow
Dt	possible duration of sunshine
E	evapotranspiration
Ea	actual evapotranspiration
Eac	estimated actual evapotranspiration
E_{BC}	evapotranspiration by the Brutsaert-Stricker method
Ee	equilibrium evaporation
E_0	potential evaporation by the Penman method
Ep	potential evapotranspiration by the Penman method
$Ep\alpha$	potential evapo (transpi)ration by the Priestley-Taylor method
Ev	aerodynamic term (mm day^{-1}) in Penman's Equation
e_a	vapor pressure of the air
$e_a{}^*$	saturation vapor pressure of the air
f	reduction factor in the Penman method
f_0	conversion factor to actual evapotranspiration
f(u)	wind function in Penman's equation
G	soil heat flux
h	solar altitude for a horizontal surface
h'	solar altitude for a sloping surface
k	karman's constant
$L\downarrow$	downward long-wave radiation flux
$L\uparrow$	upward long-wave radiation flux
L^*	net long-wave radiation flux
Le^*	effective long-wave radiation flux
$L\downarrow o$	downward long-wave radiation flux under a clear sky
$L\uparrow o$	upward long-wave radiation flux under a clear sky
Leo^*	effective long-wave radiation flux under the clear sky
m_c	mean fractional cloud amount
m	relative optical air mass
n	number of hours of bright sunshine
N	number of daylight hours
Nd	day number of a year
P_r	precipitation
P	atmospheric transparency coefficient
Qn	available energy
Rn	net radiation flux
Rn^*	available energy for water surface

Ro solar constant

Rs total short-wave radiation flux

Rs^* net short-wave radiation flux

Rsc total short-wave radiation flux under a clear sky (potential total short-wave radiation)

$Rscal$ calculated total short-wave radiation

Rsc' total short-wave radiation flux under the standard clear sky

$Rsdif$ sky diffuse radiation flux

$Rsdir$ direct solar radiation flux

Rse extraterrestrial radiation flux on a horizontal surface

$Rsex$ extraterrestrial radiation flux normal to the direct radiation beam

Rsn direct radiation flux at the surface normal to the direct radiation beam (direct normal radiation)

$Rsobs$ observed total short-wave radiation

$Rsref$ ground-reflected diffuse radiation flux

r correlation coefficient (single/multiple)

r sun-earth distance

r_a aerodynamic resistance

r_c canopy resistance

r_o mean sun-earth distance

t hour angle

T temperature in Celsius

Ta temperature in Kelvin

t_o, t_z temperature in Celsius at point o and z, respectively

t_r sunrise hour angle (sunset hour angle)

u, U wind speed

Z elevation (geographic altitude)

α proportional constant in the equilibrium evaporation model

α' surface azimuth angle

β slope angle of the surface, measured from the horizontal

γ phychrometric constant

Δ slope of the saturation vapor pressure curve

δ solar declination

ϵ emissivity

η lapse rate of air temperature

λ latent heat for vaporization

ρ albedo

ρ_a density of the air

σ Stefan-Boltzmann constant

τ_a atmospheric refraction

τ_s solar radius

ϕ geographic latitude

CHAPTER 1

INTRODUCTION

1-1 Problems and the purpose of the study

Water resources on the earth's surface are usually inequitable in their distribution. From the continental point of view, there exist many countries suffering from long droughts, while there also exist countries attacked by severe floods.

Even though a country may have the same conditions for a given climatic zone, modifications to the land use usually result in changes to the hydrological equilibrium of a river basin. Consequently the need may arise for water management for river control, for water use and for preservation of the hydrological environment.

In Japan, the country abounds with small scale mountains, and as a result, various complex land usages are found in the whole country. To achieve a desired water supply taking into account preservation of the hydrological environment, it is essential to know evapotranspiration from the various land uses within a water supply area.

However, quantitative knowledge of the evapotranspiration for a river basin with complex topography and land use is inadequate because of the difficulty of taking accurate observations in the field.

The purpose of the present paper is to establish an estimation method for river basin actual evapotranspiration taking into consideration topography and land use.

To achieve the above objective, the present paper tackles the following two problems.

The first is to make a convenient model for radiation estimates on a sloping surface.

The second is to analyze topography (elevation, orientation and angles of the land surface) and land use by using digitized square-grid map data for estimation of river basin actual evapotranspiration.

1-2 Review of the recent research

Many methods are proposed to estimate evapotranspiration (for example, Spittlehouse and Black, 1981; Kotoda, 1982a; and Hattori, 1985). However it seems no single method has clear advantages in all contexts, accuracy, convenience, cost for the measurement of necessary data, and suitable spatial and time scales.

Morton (1976, 1978) proposed an approach applying Bouchet's complementary relationship (Bouchet, 1963), to estimate river basin evapotranspiration by using the climatological data of 80 river basins in the temperate continental part of Canada, 3 river basins in Ireland, and 35 river basins in the southern United States.

Comparing the results with water budget evaporation for river basins, the method gave good agreement with the observed data on actual basins.

Brutsaert and Stricker (1979) presented another approach for estimating actual evapotranspiration by combining Bouchet's complementary relationship with Penman's potential evapotranspiration equation (Penman, 1948) and Priestley and Taylor's potential evaporation (Priestley and Taylor, 1972). The equation was tested by comparing the calculated daily means with correspond ing values obtained by means of an energy budget method for a dry summer period and they found good agreement.

A similar attempt was made by Otsuki et al. (1984 a, b, c) to estimate actual evapotranspiration using the climatological data obtained at 143 stations in Japan, and they found the complementary relationship equation provided reliable estimates of monthly and annual average catchment evapotranspiration.

The advantage of the above approaches based on Bouchet's complementary relationship is that they only require meteorological data, no soil moisture data, and no stomatal resistance properties of the vegetation (Brutsaert, 1982). However, all the above methods use Priestley and Tailor's equation in their evapotranspiration formulae. Therefore it will be necessary to consider the value of Priestley and Taylor's parameter α, because the magnitude of α varies with the location and period (De Bruin and Keijman, 1979; Nakagawa, 1984 a; Kondo, 1984).

Aston and Dunin (1980), Dunin and Aston (1984) estimated areal evapotranspiration from an experimental catchment and a river basin by a model which was initially developed for point values measured by a weighing lysimeter. To estimate evapotranspiration, they used the Penman-Monteith equation. They found the model performance was assessed with satisfactory agreement values between computed and measured evapotranspiration of the experimented catchment for monthly values.

However this model needs to incorporate atmospheric and biological influences in deriving an adequate characterization of the transpiration response to soil water supply.

In order to estimate the annual and monthly evapotranspiration from the land surface of Shiga Prefecture (area 3,153 m^2), in Japan, Suzuki and Fukushima (1985) used digitized square-grid (1 km x 1 km) map data of several kinds of natural factors (elevation, topography) provided by the Geographical Survey Institute, vegetation data and necessary meteorological data. They showed that the estimated evapotranspiration rate agrees fairly well with the observed rate in the grid squares where the experimental sites exist. However they used only direct short-wave radiation obtained by means of the Okanoue's formula (Okanoue, 1957) instead of solar radiation.

Recently, Seino and Uchijima (1985) calculated the total short-wave radiation and the net radiation on sloping surfaces in Japan, by means of the Yoshida and Shinoki's (1978) formula and Chang's (1970) formula. Since pyrheliometer measurements are usually not available, they used empirical relationship between sky diffuse and total short-wave radiation to separate direct radiation from total short-wave radiation.

This study will firstly concentrate on the subject of solar radiation on sloping surfaces with regard to complex topography and variable land use, and secondly on the subject of its application for estimating river basin evapotranspiration by using the digitized square-grid method.

CHAPTER 2

ESTIMATING METHOD OF ACTUAL EVAPOTRANSPIRATION

2-1 Determination of actual evapotranspiration formula

There are many methods to estimate evapotranspiration such as the water balance method, heat balance method, aerodynamic method and combination method.

However, they are not always applicable for estimating the river basin evapotranspiration, which can be precisely estimated by point evapotranspiration.

Penman (1948) proposed the combination of a heat balance equation and an aerodynamic equation to estimate evaporation from shallow open-water or a well-saturated bare soil surface. The equation is given as follows;

$$E_0 = \frac{\Delta}{\Delta + \gamma} R_n{}^* + \frac{\gamma}{\Delta + \gamma} f(\mathrm{u}) \left(e_a{}^* - e_a \right) \tag{2-1}$$

$$f(\mathrm{u}) = 0.26 \left(1 + 0.54\mathrm{u}_2 \right) \tag{2-2}$$

where

- E_0 : the rate of the potential evaporation (mm day^{-1}),
- Rn^* : the available energy for water surface (mm day^{-1}),
- Δ : the slope of the saturation water vapor pressure curve at the air temperature ($\mathrm{mb}^\circ\mathrm{C}^{-1}$),
- γ : the psychrometric constant ($\mathrm{mb}^\circ\mathrm{C}^{-1}$) ,
- e_a : the vapor pressure of the air (mb),
- $e_a{}^*$: the saturated vapor pressure at the temperature of the air (mb),
- $f(\mathrm{u})$: the wind function,
- u_2 : the mean wind speed at 2 m above the surface (ms^{-1}).

Later, Penman (1956) modified the wind function as follows;

$$f(\mathrm{u}) = 0.26 \left(0.5 + 0.54u_2 \right) \tag{2-3}$$

The above constant was derived from the data of Lake Hefner studies. E_0 in Eq. (2-1) assumes that evaporation occurs from hypothetical shallow open water. Therefore, it needs a suitable conversion of E_0 to the evapotranspiration in the localities concerned. Penman (1963) proposed the following equation using an empirical factor f.

$$E' = f \cdot E_0 \tag{2-4}$$

where E' is referred to as potential evapotranspiration. Penman obtained $f = 0.6 \sim 0.8$ from the data of Western Europe for potential evapotranspiration. Under conditions of limited water, E' is not the same as actual evapotranspiration and the magnitude of f and its seasonal behavior are still unclear.

For a well-saturated land surface covered by vegetation, the following equation is usually used;

$$Ep = \frac{\Delta}{\Delta + \gamma} Qn + \frac{\gamma}{\Delta + \gamma} f(u)(e_a^* - e_a) \qquad (2\text{-}1')$$

where Ep is the potential evaporation (mm day^{-1}), and Qn the available energy for vegetative land surface (mm day^{-1}).

In this paper, we use Ep calculated by means of Eq. (2-1') and Eq. (2-2) as "potential evapotranspiration".

Slatyer and McIlroy (1961) derived the following equation;

$$Ee = \frac{\Delta}{\Delta + \gamma} Qn \qquad (2\text{-}5)$$

where Ee given by the above equation is referred to as "equilibrium evaporation". Denmead and McIlroy (1970), McIlroy (1984) considered that Ee represents the minimum possible rate of evaporation from a large effectively wet surface. Therefore Ee can be used for minimum water requirements of an irrigated area.

Priestley and Taylor (1972) found the following empirical relationship giving evaporation from a wet surface under conditions of minimal advection.

$$Ep\alpha = \alpha \frac{\Delta}{\Delta + \gamma} Qn \qquad (2\text{-}6)$$

where $Ep\alpha$ is Priestley-Taylor's potential evaporation and α is an empirical constant. They found an overall mean value of $\alpha = 1.26$ after analyzing the data obtained over several ocean and saturated land surfaces.

Bouche (1963) proposed the following complementary relationship between potential evaporation Ep and the actual regional evapotranspiration E;

$$Ep + E = \text{constant} = 2Epo \qquad (2\text{-}7)$$

It is denoted by Epo under conditions when E equal Ep.

Using the above hypothetical relationship, Brutsaert and Stricker (1979) proposed the following equation;

$$E_{BS} = (2\alpha + 1)Ee - \frac{\gamma}{\Delta + \gamma} f(u)(e_a^* - e_a) \qquad (2\text{-}8)$$

Where E_{BS} is Brutsaert-Stricke's actual evapotranspiration.

Equation (2-8) is obtained by substituting Eq. (2-1') of Penman for Ep and Eq. (2-6) of Priestley and Taylor for Epo in Eq. (2-7). The above approach is referred to as "advection-aridity" approach.

A similar approach has been used by Morton (1976, 1978) to estimate the areal evapotranspiration in Canada and in the U.S. by using climatological data. Otsuki et al. (1984a, b, c) applied the complementary relationship to estimate actual areal evapotranspiration using the 143 points of climatological data in Japan.

The complementary relationship approach may be useful to estimate actual evapotranspiration from a large-scale area. However, all the above approaches used the Priestley and Taylor's equation written by Eq. (2-6) as E_{po} in Eq. (2-7). This means that it is necessary to check and determine suitable values of α for each place, because α changes remarkably with time of day, with season and from place to place (De Bruin and Keijman, 1979; Nakagawa, 1984; Kondo, 1984). Therefore, more research will be needed before it is used for individual practical purposes.

Monteith (1973) proposed another type of combination equation which is referred to as "Penman-Monteith" equation.

$$\lambda E = \frac{\Delta (Rn - G) + \gamma \rho_a c_p (e_a{*} - e_a)/r_a}{\Delta + \gamma (1 + r_c / r_a)} \tag{2-9}$$

where r_a is the aerodynamic resistance, r_c the canopy resistance (surface resistance), ρ_a the density of air, c_p the specific heat of air at constant pressure, λ the latent heat for vaporization, G is soil heat flux and the other symbols are already explained.

In Eq. (2-9), a new parameter r_c which characterizes the transfer between leaf stomatal cavities and the atmosphere is introduced. The concept of canopy resistance has been found to be quite useful in some simulation models and some other special purposes (Brutsaert, 1982). However, the nature of canopy resistance has been found to differ not only between different species, but also between different genetic strains of the same species (Shimshi and Ephrat, 1975) and the stages of crop development (Nkemdirim, 1976). It was also found that the movement of stomata depended on light, temperature, humidity and wind speed. Taguchi (1970) suggested that plant may close its stomata under strong wind conditions because it decreased the rate of transpiration in such a condition. Accordingly, it is practically difficult to quantify the parameter r_c for complex vegetative land from season to season.

As stated above, there are many difficulties in determining the actual evapotranspiration rate from the basin-scale area.

The present paper, therefore, considers the following issues in estimating the actual evaporation rate from a complex vegetative cover basin.

1) Computation of the actual rate of monthly and annual evapotranspiration is based on the combination formula.
2) Necessary data are limited to those easily obtainable from meteorological observations.
3) To estimate more accurate radiation terms, a new approach is introduced.
4) The distribution of topography (latitude, angle and orientation of slope) is considered.
5) The distribution of land use is considered.
6) Input data and the results are given as digitized square-grid maps.
7) 500 m x 500 m grid is used, as a standard square-grid, and 250 m x 250 m grid as land use classification (8 to 11 categoreis) by considering the complicated land use with small scale in Japan.

To estimate actual evapotranspiration from the river basin, the present paper used a similar type of Equation to that shown in Eq. (2-4). However, the values of the conversion factor are uncertain both under wet and dry conditions in Japan. Therefore, it is necessary to parameterize the factor.

Using the actual evapotranspiration data obtained by a weighing lysimeter 2 m in diameter with a length of 2 m, at the University of Tsukuba (Kotoda et al., 1978) and other meteorological data, the following empirical relationship was determined.

$$f_0 = \mathrm{a} + \mathrm{b}Pr + \mathrm{c}T + \mathrm{d}U \qquad (2\text{-}10)$$

where, f_0 is the conversion factor from potential to actual evapotranspiration, P_r the precipitation (mm·month^{-1}), T and U the air temperature (°C) and the wind speed (ms^{-1}) at a height of 1.6 m from the ground surface, respectively, a, b, c, d are empirical constants, respectively.

The results of the multiple regression analyses show the following values.

$$\mathrm{a} = 0.468 \quad ; \quad \mathrm{b} = 0.5 \times 10^{-3}$$
$$\mathrm{c} = 21.9 \times 10^{-3} \quad ; \quad \mathrm{d} = -23.6 \times 10^{-3} \qquad (2\text{-}11)$$

In order to estimate the monthly actual evapotranspiration rate from the complicated land used basin, the present paper used the following equations.

$$Eac = f_0\,(Ee + Ev) \qquad (2\text{-}12)$$

$$Ev = \frac{\gamma}{\Delta + \gamma} f(u)\,(e_a{}^* - e_a) \qquad (2\text{-}13)$$

$$f_0 = 0.468 + (0.5Pr + 21.9T - 23.6U) \times 10^{-3} \qquad (2\text{-}14)$$

where

Eac : the actual evapotranspiration rate (mm day^{-1}),
Ee : the equilibrium evaporation (mm day^{-1}) defined by Eq. (2-5),
Ev : the aerodynamic term (mm day^{-1}) in Penman's Equation (2-1),
f_0 : the conversion factor from potential to actual evapotranspiration.

Here, the available energy Qn in Eq. (2-5) is obtained as follows;

$$Qn = \frac{Rn - G}{a\lambda} \qquad (2\text{-}15)$$

where Rn is the net radiation (Jm^{-2}), G the soil heat flux (Jm^{-2}), λ the latent heat for vaporization and, a the conversion coefficient from energy units in Jm^{-2} to equivalent rates of evaporation in mm day^{-1}.

The relationship between the observed and the calculated factor f_0 is shown in Fig. 2-1. The multiple correlation coefficient r = 0.805 was obtained.

Figure 2-2 (a) shows the comparison of Ep for grass land calculated by means of Eq. (2-1') with Eq. (2-2) and the actual evapotranspiration Ea obtained by a weighing lysimeter. As seen in the Figure, there exists good agreement between the calculated and actual evapotranspiration for summer and autumn seasons, but Ep is overrestimated compared to Ea for winter and spring seasons.

Figure 2-2 (b) shows the comparison of E_{BS} obtained by Brutsaert and Stricker's equation (2-8) with $\alpha = 1.26$, and actual evapotranspiration Ea. It seems that there exists closer agreement between E_{BS} and Ea than with the Penman's method but E_{BS} is underestimated compared to Ea during the winter season.

Figure 2-2 (c) shows a comparison between the estimated actual evapotranspiration Eac calculated by means of Eq. (2-12) with Eq. (2-13) and Eq. (2-14), and the actual evapotranspiration Ea by using the weighing lysimeter. It is clear from the figure, Eac has the best agreement with Ea from among the three approaches.

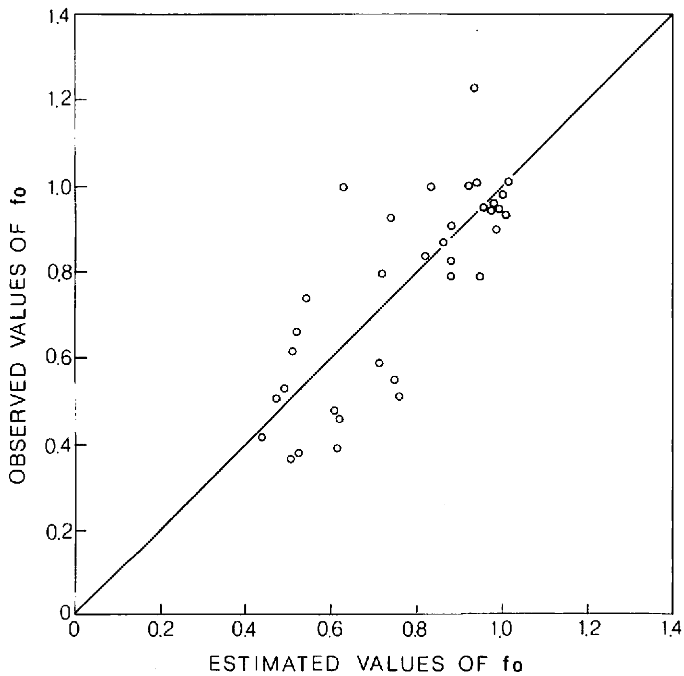

Fig. 2-1 Comparison of the values of conversion factor f_0 estimated by means of Eq. (2-14) with the corresponding values of f_0 obtained by using the weighing lysimeter at Tsukuba University (from 1980 to 1982).

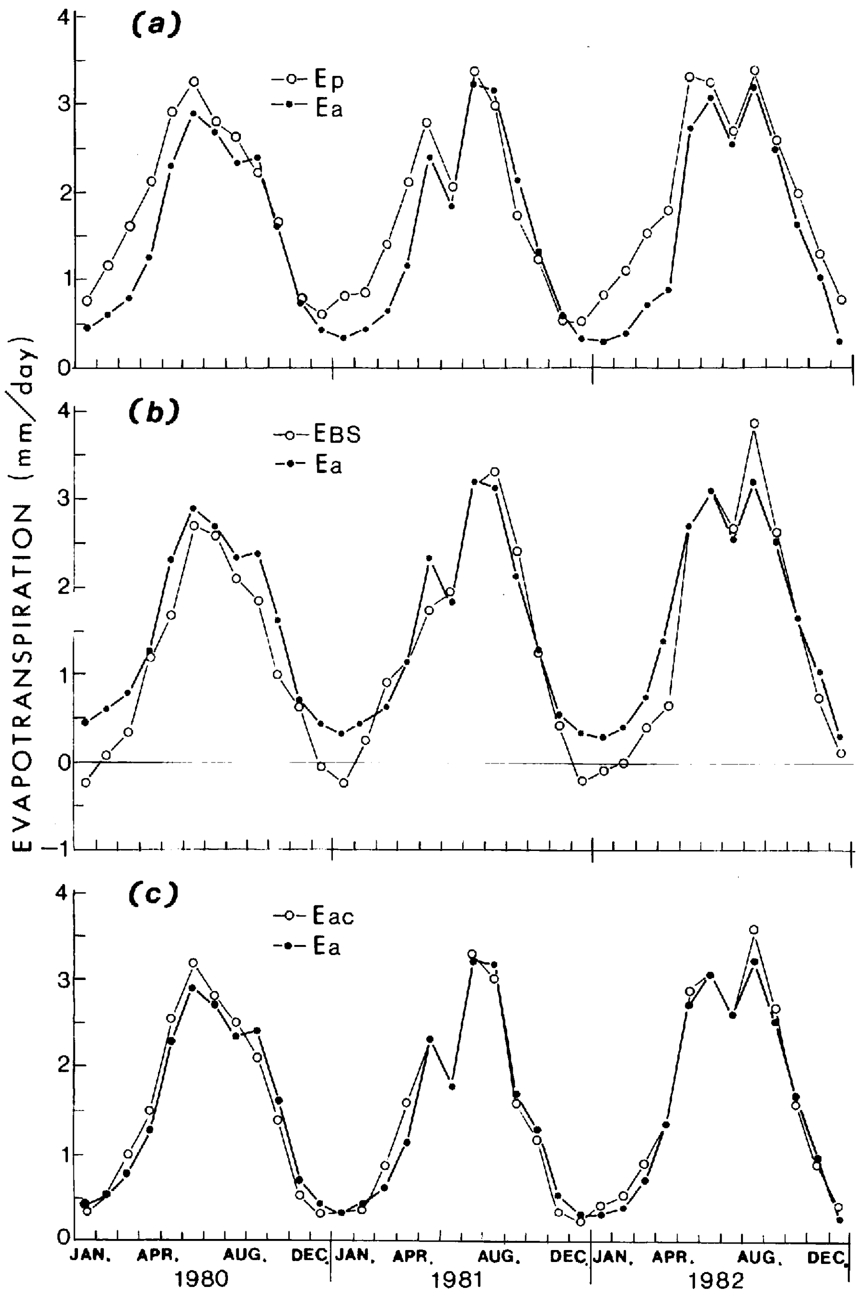

Fig. 2-2 Comparison of Penman's potential evapotranspiration for grass land (*Ep*), Brutsaert and Stricker's evapotranspiration (E_{BS}), estimated actual evapotranspiration (*Eac*) by means of Eq. (2-12) with the lysimeter's evapotranspiration (*Ea*).

2-2 Calculation of the total short-wave radiation

2-2-1 Basic equation

The observation points of the total short-wave radiation reached on a horizontal plane (solar radiation) are often limited and usually few records of the radiation in the localities concerned are available. Therefore, it is useful to develop a more convenient radiation formula in order to clarify the characteristics of the water balance and heat balance terms in time and space distribution.

Many estimating equations for total short-wave radiation have been proposed in the literature. Among them, the following three types of equations are well known.

$$Rs = Rsc\,[\mathrm{a} + (1 - \mathrm{a})\,(n/N)] \tag{2-16}$$

$$Rs = Rse\,[\mathrm{a} + \mathrm{b}\,(n/N)] \tag{2-17}$$

$$Rs = Rsc\,[1 - \mathrm{a}\cdot m_c] \tag{2-18}$$

where

Rs : the total short-wave radiation,
Rsc : the total short-wave radiation under a clear sky,
Rse : the extraterrestrial radiation (the solar radiation which would reach a horizontal surface in the absence of the atmosphere),
n/N : the relative duration of sunshine,
n : the actual number of hours of bright sunshine,
N : the number of daylight hours,
m_c : the mean fractional cloud amount,
a, b : empirical constants.

The first type, Eq. (2-16), was proposed by Ångström (1924), Kimball (1928) and Savinov (1933). Ångström found a = 0.235 using the data at Stockholm.

The second type, Eq. (2-17), proposed by Prescott (1940) used the extraterrestrial radiation Rse instead of Rsc. The values of a and b in Eq. (2-17) depend on the location, on the season and on the atmospheric conditions. Table 2-1 shows some examples of the values obtained in Japan.

Table 2-1 The constants in Prescott's Equation obtained in Japan.

Reference	a	b	Location
Sekihara and Suzuki (1967)	0.22	0.52	6 stations
Kondo (1967)	0.25	0.54	Tateno
Murai and Yamauchi (1975)	0.21	0.54	14 stations
Yoshida and Shinoki (1978)	0.18	0.53	39 stations
Otsuki et al. (1984c)	0.19	0.51	65 stations

The third type, Eq. (2-18), proposed by Kimball (1928) used the mean fractional cloud amount m_c instead of (n/N). He found a = 0.17 using the data observed in the U.S.A..

Similar types of equations have been also developed by Soviet researchers (Savinov, 1933; Berlyand, 1961) as follows;

$$Rs = Rsc\,[1 - (1 - a)\,m_c] \qquad (2\text{-}19)$$

$$Rs = Rsc\,[1 - (a + b \cdot m_c)\,m_c] \qquad (2\text{-}20)$$

However, the estimation of cloud cover is not as easy as the hours of bright sunshine.

To estimate the total short-wave radiation, the present paper used the following equation which has a slightly different form from those mentioned above.

$$Rs = Rsc'\,[a + b\,(n/N)] \qquad (2\text{-}21)$$

where Rsc' is the total short-wave radiation under "standard clear sky" conditions.

In Eq. (2-21), Rsc' is used instead of Rse in Eq. (2-17). The values of Rsc' can be calculated by semi-empirical and partly theoretical methods.

2-2-2 Total short-wave radiation under standard clear sky conditions

Figure 2-3 shows the radiation transfer model used in this study. By assuming the total short-wave radiation under standard clear sky conditions, Rsc' consists of (1) direct short-wave radiation ($Rsdir$), (2) sky diffuse radiation ($Rsdif$) and (3) ground-reflected diffuse radiation ($Rsref$), then the following equation may be given.

$$Rsc' = Rsdir + Rsdif + Rsref \qquad (2\text{-}22)$$

The computation method for each component is as follows:

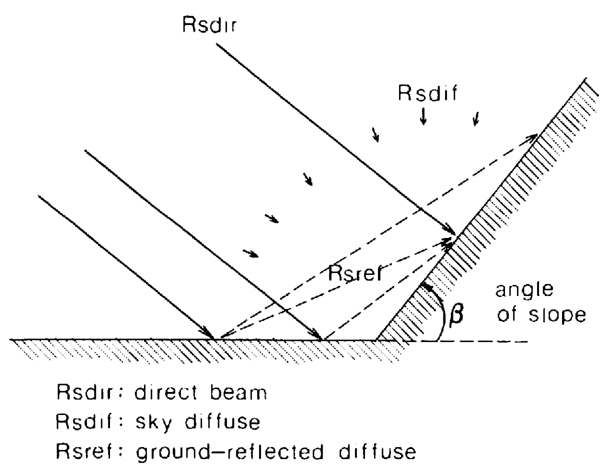

Fig. 2-3 Model of radiation transfer for a sloping surface.

(1) *Direct (short-wave) radiation (Rsdir)*

The flux of direct radiation on a surface normal to the direct radiation beam is given as

$$Rsn = Rsex \cdot P^{m} \qquad (2\text{-}23)$$

where *Rsn* is the direct normal radiation (direct normal irradiance) at the earth's surface, *Rsex* the extraterrestrial radiation on a plane normal to the direct radiation beam, *P* the transparency coefficient (atmospheric transmission coefficient), and *m* the relative optical air mass.

In this study, the following relationship between *m* and *h* is assumed.

$$m = \text{cosec } h \qquad (2\text{-}24)$$

where *h* is the solar altitude (solar height).

If we used zenith angle (zenith distance) θ_z instead of *h* in Eq. (2-24), $m = \sec \theta_z$ is obtained.

By considering the distance between the sun and earth which continuously affects the magnitude of the solar radiation at the earth surface, *Rsex* will be given as follows;

$$Rsex = (r_o/r)^2 Ro \qquad (2\text{-}25)$$

where *Ro* is the solar constant, *r* and r_o are the earth-sun distance and its mean, respectively.

In this paper, $Ro = 1382 \text{ Wm}^{-2}$ ($= 1.98 \text{ cal cm}^{-2} \text{ min}^{-1}$) is used according to WRR. The magnitude of $(r_o/r)^2$ was calculated by Lunde's equation (Lunde, 1980) as follows;

$$(r_o/r)^2 = 1 + 0.033\ (360Nd/370) \qquad (2\text{-}26)$$

where *Nd* is the day number in the year.

Direct radiation on a sloping surface may be given as follows;

$$Rsdir = Rsn \sin h' \qquad (2\text{-}27)$$

where *h'* is the altitude of the sun for a sloping surface, and it can be calculated from spherical trigonometric relationships as follows;

$$\sin h = \sin \phi \sin \delta + \cos \phi \cos \delta \cos t \qquad (2\text{-}28)$$

$$\sin A = \cos \delta \sin t / \cos h \qquad (2\text{-}29)$$

$$\cos A = (\sin h \cdot \sin \phi - \sin \delta)/(\cos h \cdot \cos \phi) \qquad (2\text{-}30)$$

$$\sin h' = \sin h \cdot \cos \beta + \cos h \cdot \sin \beta \cdot \cos (A - \alpha') \qquad (2\text{-}31)$$

$$\cos A' = (\cos \beta \cdot \sin h' - \sin h) / (\sin \beta \cdot \cos h') \qquad (2\text{-}32)$$

where *A* is the solar azimuth for a horizontal surface and it is measured clockwise from south. ϕ is the geographic latitude, north positive, δ the solar declination, *t* the time in radians (hour angle) which is negative before noon, zero at solar noon and positive after noon. β is the slope angle of the surface, measured from the horizontal and α' the surface azimuth angle, h' and A' are the altitude and azimuth of the sun for a sloping surface, respectively.

The theory of direct solar radiation for a surface oriented in any direction with respect to the local meridian has been given in detail by Kondratyev (1969, 1977), and the calculation method by Kurata and Okada (1984).

For a given geographical position, the trigonometric relations between the sun (the center of the solar disk) and a horizontal surface can be written from Eq. (2-27) as follows;

$$Rsdir(0) = Rsn\,(\sin\phi\ \sin\delta + \cos\phi\ \cos\delta\ \cos t) \qquad (2\text{-}33)$$

where $Rsdir(0)$ is the direct short-wave radiation (irradiance) at the horizontal land surface ($\beta = 0$).

(2) *Sky diffuse radiation (Rsdif)*

Sky diffuse radiation is generated by the scattering effects of air molecules and aerosols. It depends on solar altitude, distribution of diffuse irradiant components from the sky dome and transparency of the atmosphere or the atmospheric turbidity. It has been known that the maximum intensity of sky diffuse radiation occurs near the sun, the minimum at an angle of 90 degrees to the solar zenith and the second maximum at near the horizon (Kondratyev, 1977). Therefore it may be necessary to take account of such a condition (Klutcher, 1979; Hay, 1979).

The present paper, however, assumes that the intensity of sky diffuse radiation is uniform over the sky dome, since little data is available.

By assuming an isotropic model, the sky diffuse radiation incident on a horizontal surface $Rsdif(0)$ may be given as follows (Berlage, 1928).

$$Rsdif(0) = \frac{1}{2}\,Rsex\,\sin h\,\frac{(1 - P^m)}{(1 - 1.41\ln P)} \qquad (2\text{-}34)$$

where P is the transparency coefficient, and m the relative optical air mass defined by Eq. (2-24).

For a sloping surface, it may be written as;

$$Rsdif = Rsdif(0)\,(1 + \cos\beta)/2 \qquad (2\text{-}35)$$

In this model, data for P is necessary to compute the sky diffuse radiation. The present paper used the monthly mean transparency coefficients observed at 12 o'clock at Tateno Aerological Observatory, Japan Meteorological Agency from 1971 to 1980.

The monthly mean values of P at Tateno are shown in Table 2-2 compared with the arithmetic average of P observed at 14 observatories in Japan.

Table 2-2 Monthly mean values of transparency coefficient.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Tateno	75	73	70	66	66	61	63	64	65	70	73	75
Mean*	74	71	67	65	65	65	65	66	68	70	73	74

* mean values of Sapporo, Nemuro, Akita, Miyako, Wajima, Matsumoto, Tateno, Yonago, Shionomisaki, Fukuoka, Kagoshima, Ashizuri, Ishigaki-jima and Naha.

(3) *Ground-reflected diffuse radiation (Rsref)*

Ground-reflected diffuse radiation depends on the earth's cover and atmospheric conditions. Here we assume the reflectance to direct and diffuse radiation is identical, then we can use a common albedo. Under such a condition, the ground-reflected diffuse radiation can be given as follows;

$$Rsref = \bar{\rho}\,[Rsdir(0) + Rsdif(0)]\,(1 - \cos\beta)/2 \qquad (2\text{-}36)$$

where $\bar{\rho}$ is the mean albedo of the ground surface.

The present paper used the basin average albedo as $\bar{\rho}$ for the calculation of Eq. (2-36). The monthly mean values of $\bar{\rho}$ are shown in Table (4-2).

Finally, substituting Eqs. (2-27), (2-35) and Eq. (2-36) into Eq. (2-22), we can obtain the values of *Rsc'*.

2-2-3 Evaluation of the parameters

The monthly mean values of a and b in Eq. (2-21) were evaluated by using the data observed from 1979 to 1983 at Tateno Aerological Observatory.

The results of the calculation by means of the least-square method yield a = 0.34 and b = 0.71 with the correlation coefficient r = 0.973. Substitution of these values gives the following equation.

$$Rs = Rsc'[0.34 + 0.71(n/N)] \qquad (2\text{-}37)$$

where *Rsc'* is the total short-wave radiation under the standard clear sky conditions. *Rsc'* is similar to *Rsc* obtained by Berlyand (1961) in Eq. (2-19) and Eq. (2-20) but not equal, because the former is the result of the calculation using Eq. (2-22), while on the other hand the latter is based on the result of observational data under completely clear sky conditions.

Table 2-3 shows the monthly values for *Rsc'* at Tateno (geographic latitude 36°03'N) and those for *Rsc* (35°00'N) obtained by Berlyand (1961) which have been listed elsewhere (Budyko, 1971; Tsuboi, 1977). It is found that the magnitude of *Rsc'* lies within the range of 80 to 87% of *Rsc*.

Table 2-3 Comparison of the potential total short-wave radiation (*Rsc*) obtained by Berlyand (1961) with the total short-wave radiation under standard clear sky conditions (*Rsc'*).

unit MJ m^{-2}

Month	1	2	3	4	5	6	7	8	9	10	11	12
Rsc'	11.94	15.91	20.42	24.51	27.91	27.25	27.44	25.21	20.95	16.92	12.69	10.73
Rsc	14.74	19.26	24.29	28.85	32.20	33.00	32.45	29.56	24.96	20.23	15.70	13.40
Rsc'/ *Rsc*	0.810	0.826	0.841	0.850	0.867	0.826	0.846	0.853	0.839	0.836	0.808	0.801

* The values of *Rsc'* and *Rsc* are calculated at 36°03' N, and 35°00'N, respectively.

Figure 2-4 shows an example of the relationship between the monthly mean hourly totals of the observed total short-wave radiation at Tateno (*Rsobs*) and those of the calculated radiation (*Rscal*) using Eq. (2-37) with the data from 1981. As seen in the Figure, the agreement is fairly good.

Figure 2-5 shows the monthly mean daily totals of observed *Rsobs* and those of the calculated values *Rscal.*

The Figure shows that there exists close agreement between the estimated and the observed total short-wave radiation.

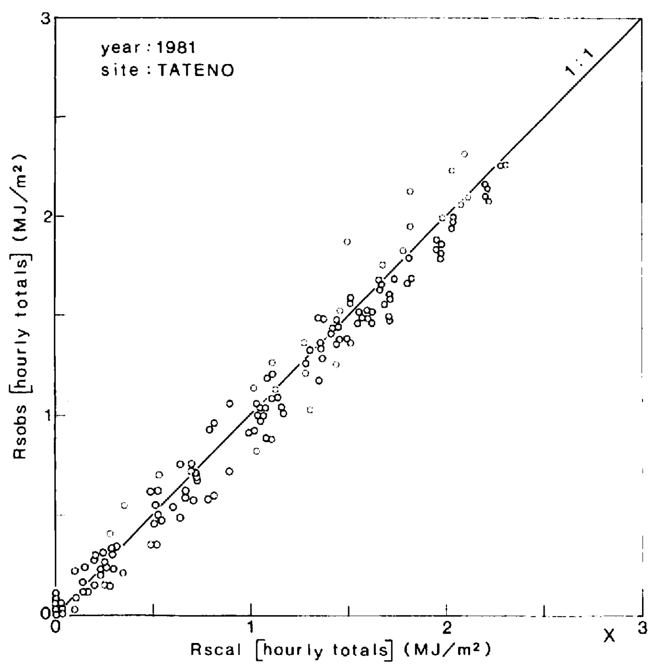

Fig. 2-4 Comparison of the hourly totals of the total short-wave radiation *Rscal* calculated by Eq. (2-37) with observed hourly totals of the total short-wave radiation *Rsobs* at Tateno.

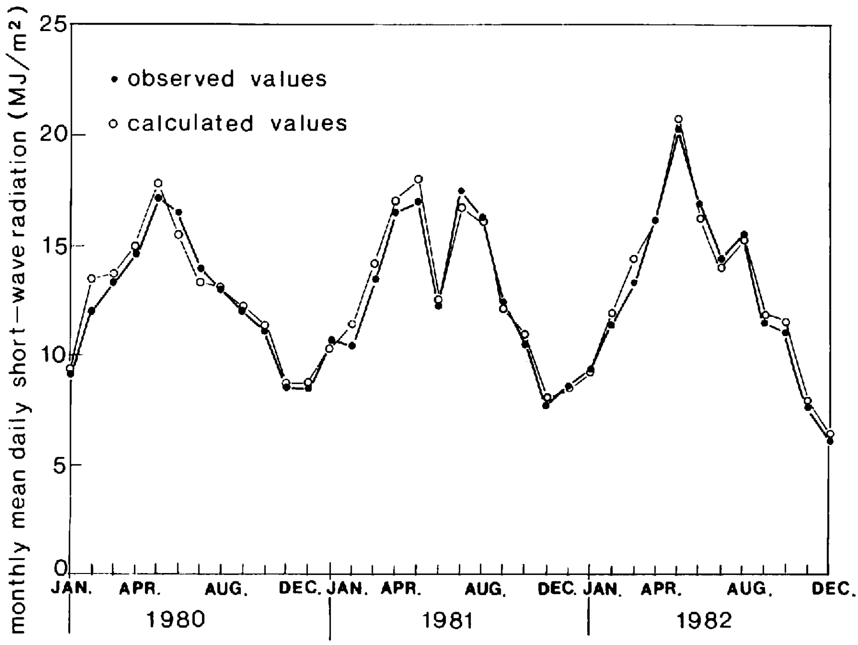

Fig. 2-5 Comparison of the monthly mean daily short-wave radiation calculated by means of Eq. (2-37) with the observed value.

2-3 Calculation of the net radiation

Net radiation consists of two components, one is net short-wave radiation and the other is net long-wave radiation.

The net short-wave radiation Rs^* is given as;

$$Rs^* = (1 - \rho) Rs \tag{2-38}$$

where ρ is the albedo of the surface and Rs is the total short-wave radiation which was discussed in Section 2-2.

The net short-wave radiation L^* is given as follows,

$$L^* = L\downarrow - L\uparrow \tag{2-39}$$

where $L\downarrow$ is downward (incoming) long-wave radiation and $L\uparrow$ is the upward (outgoing) long-wave radiation.

From the above equations, the net radiation can be written as follows;

$$Rn = (1 - \rho) Rs + L\downarrow - L\uparrow \tag{2-40}$$

$$= Rs^* + L^* \tag{2-41}$$

Generally the magnitude of $L\uparrow$ is greater than $L\downarrow$. Therefore, usually the values of L^* are negative. For convenience of calculation, effective long-wave radiation Le^* defined as follows is often used.

$$Le^* = L\uparrow - L\downarrow \tag{2-42}$$

Under clear sky conditions, Eq. (2-42) is rewritten as follows;

$$Leo^* = L\uparrow o - L\downarrow o \tag{2-43}$$

where the suffix o represents clear sky conditions.

There are many methods for estimating the values of Leo^* from climatological data. Among them, Brunt's equation (Brunt, 1932) is one of the well known equations which is written as follows;

$$Leo^* = \epsilon\sigma Ta^4 (1 - \mathrm{a} - \mathrm{b}\sqrt{e}) \tag{2-44}$$

where ϵ is the emissivity, σ is the Stefan-Boltzmann constant, Ta the air temperature, e the vapor pressure of air, a and b are empirical constants, respectively.

The values of a and b obtained in Japan and other countries are listed in Table 2-4. These values of a and b are used for Leo^* in Wm^{-2}, Ta in K and e in mb with $\sigma = 5.67 \times 10^{-8}\mathrm{Wm}^{-2}\mathrm{K}^{-4}$.

Table 2-4 The constants in Brunt's Equation.

Reference	a	b	Location
Yamamoto (1950)	0.51	0.066	Japan
Sellers (1965)	0.605	0.048	
Budyko (1971)	0.61	0.050	
Nakagawa (1977)	0.634	0.036	Tateno

$Leo^* = \mathrm{Wm}^{-2}$ $\quad Ta = \mathrm{K}$
$\sigma = 5.67 \times 10^{-8}\mathrm{Wm}^{-2}\mathrm{K}^{-4}$ $\quad e = \mathrm{mb}$

Taking account of relative duration of sunshine (n/N), Penman (1948) proposed the following equation.

$$Le^* = Leo^* \left[\mathrm{a} + (1 - \mathrm{a})(n/N)\right] \tag{2-45}$$

where a is an empirical constant; he derived a = 0.1. Linacre (1968) used a = 0.2 and recently, Brutsaert (1982) suggested that a = 0.2 should be taken as an average value for practical calculation.

Generally, the long-wave radiation is highly correlated with the temperature and the vapor pressure of the air near the surface. Therefore an effective long-wave radiation equation based on both temperature and vapor pressure is preferable. However, data on vapor pressure are rarely available in this field.

Several empirical equations based on temperature were proposed by Swinbank (1963), Linacre (1968) and Idso and Jackson (1969).

Linacre (1968) proposed the following equations to estimate $L\uparrow o$ and $L\downarrow o$ under clear sky conditions.

$$L\uparrow o = b\, Ta^4 \tag{2-46}$$

$$L\downarrow o = c\, Ta^4 - d \tag{2-47}$$

where Ta is the air temperature in K and b, c, d are constants. He obtained $b = 0.813 \times 10^{-3}$ in Eq. (2-46) and used the constants $c = 0.971 \times 10^{-10}$ and $d = -0.245$ derived by Swinbank (1963) for the calculation of Eq. (2-47).

Using the relationship between clearness index Rs/Rse and n/N, Sekine (1979) proposed the following formula,

$$(Rs/Rse) = e + f\,(n/N) \tag{2-48}$$

where e and f are empirical constants.

Equation (2-45) with Eqs (2-43), (2-46), (2-47) and Eq. (2-48) can be rewritten as follows;

$$Le^* = (A - B Ta^4)\,[C\,(Rs/Rse) - D] \tag{2-49}$$

where the new constants are replaced by $A = d$, $B = (b - c)$, $C = (1 - a)/f$ and $D = [a - e\,(1 - a)/f]$.

Combining Eq. (2-38) with Eq. (2-49), Nakayama et al. (1983) proposed the following equation,

$$Rn = (1 - \rho)\, Rs - (A - B Ta^4)\,[C\,(Rs/Rse) - D] \tag{2-50}$$

They found the following values for constants using the values of $e = 0.21$ and $f = 0.53$ obtained by Sekine (1979) at Mt. Tsukuba.

$$\begin{aligned} A &= 0.245 \quad ; \quad B = 0.158 \times 10^{-10} \\ C &= 1.509 \quad ; \quad D = -0.117 \end{aligned} \tag{2-51}$$

Similar relationships were proposed by Chang (1970), Kondo (1967) and Brutsaert (1975).

Using the climatological data observed at the Environmental Research Center, the University of Tsukuba and Tateno Aerological Observatory, Japan Meteorological Agency, Zhu and Kotoda (1985) found the following relationship which has better correlation between the observed data and the calculated values.

$$\begin{aligned} Le^* = {} & 198.834 - 287.593\,(Rs/Rse) - 312.946\,(Ta^4/10^{10}) \\ & + 698.026\,(Rs/Rse)\,(Ta^4/10^{10}) \end{aligned} \tag{2-52}$$

From Eq. (2-40), Eq. (2-42) and Eq. (2-52), we can write the following equation;

$$Rn = (1 - \rho) Rs - Le^* \qquad (2\text{-}53)$$

in which Rs can be obtained by means of Eq. (2-37).

The present paper used the above equation to estimate the net radiation.

2-4 Calculation of the other terms

2-4-1 Air temperature

The areal distribution of monthly mean air temperature is estimated by the following approach.

The monthly mean air temperature decreases with the elevation of the topography in the lower atmosphere and its lapse rate has been known as about 0.6°C/100 m in Japan. However this lapse rate is slightly different from place to place and also for different periods (Yoshino, 1978).

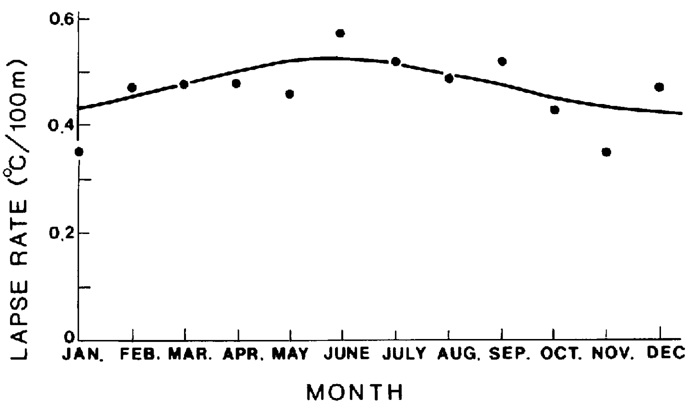

Fig. 2-6 Annual trend of lapse rate (°C/100 m) of air temperature around Mt. Tsukuba.

Figure 2-6 shows the monthly mean lapse rate calculated by using the data observed at around the Koise river basin (Tateno, Mt. Tsukuba, Tsuchiura and Kasama) from 1979 to 1983. It seems, as shown in the Figure, that the lapse rate changes seasonally rather than being constant throughout the year. Analyzing these data by means of Fourier approximation, we obtained a first approximation for the lapse rate as listed in Table 2-5 which is also shown with the solid line in Fig. 2-6.

Table 2-5 Monthly mean air temperature (1970–1975) at Tateno and the temperature lapse rate around Mt. Tsukuba.

Month	1	2	3	4	5	6	7	8	9	10	11	12
T	2.40	3.28	5.43	12.47	16.82	20.30	24.52	26.25	22.02	15.55	9.60	3.80
η	0.43	0.45	0.48	0.50	0.52	0.53	0.52	0.50	0.48	0.45	0.43	0.43

T : mean air temperature (°C) at Tateno (1970–1975)
η : mean lapse rate (°C/100 m)

By assuming the areal distribution of monthly mean temperature is mainly affected by elevation, because no significant heat sources or heat sinks such as a large city or a large lake exist, the air temperature near the surface in the river basin may be given by the following formula;

$$t_z = t_o - 0.01\eta(z - z_o) \tag{2-54}$$

where η is the lapse rate of the air temperature ($^\circ$C/100 m). t_z, t_o are the temperatures at the elevation of z and at z_o (base point) in m from the mean sea level, respectively. The base point was selected at Tateno ($z_o = 25$ m) for estimating t_z.

2-4-2 Albedo

The ratio of the reflected short-wave radiation to the corresponding incoming short-wave radiation, that is short-wave reflectivity of a surface, is referred to as its albedo. The surface albedo depends on the natures of the surface, the soil-water contents, the solar altitude and the atmospheric conditions (Kayane, 1980). However the present study aims to clarify the monthly mean river basin evapotranspiration. So, we consider the daily mean values of surface albedo.

Table 2-6 The values of albedo used for the calculation.

	month	1	2	3	4	5	6	7	8	9	10	11	12
1	WATER:W:	10	9	8	7	6	6	6	6	7	8	10	11
2	CITY :C:	32	32	30	30	28	27	28	30	30	30	30	32
3	SETL :S:	26	26	25	25	24	23	25	25	25	25	25	25
4	FORES:F:	9	10	10	10	11	12	12	12	12	11	11	10
5	DECID:D:	10	10	10	10	13	15	15	15	15	14	13	10
6	ORCHR:O:	15	15	15	15	16	17	17	17	17	16	15	15
7	MULB :M:	16	16	16	17	17	18	18	18	18	17	17	16
8	GRAS :G:	20	20	19	18	17	17	17	17	17	17	19	20
9	RICE :R:	16	15	10	8	8	10	13	22	18	15	15	15
10	VEGE :V:	25	25	25	25	24	23	25	25	24	24	25	25
11	BARE :B:	32	32	30	30	28	26	28	30	30	30	30	32

W : OPEN WATER　C : CITY　S : SETTLEMENT
F : FOREST 1 (EVER GREEN)　D : FOREST 2 (DECIDUOUS)
O : ORCHARD　M : MULBERRY FIELD ETC.　G : GRASS LAND ETC.
R : RICE FIELD　V : VEGETABLE FIELD　B : BARE SOIL

Table 2-6 shows the monthly values of albedo for various surfaces obtained from the literature (Kondratyev, 1969, 1972; Budyko, 1971; Monteith, 1976; Oke, 1978; Research group of evapotranspiration, 1967; Iqbal, 1983; Kotoda and Sugita, 1984; Hattori, 1984; Nakagawa, 1984b etc.).

The monthly areal distribution of the river basin albedo is estimated by the following procedure:

1) Digitizing on a square-grid map the data of land use from the land use map provided by the Geographical Survey Institute. The grid system of the land use map covers an area of 250 m x 250 m per square, because the study area has complicated land use. The land use is classified into 11 categories as shown in Table 3-4.
2) Calculation of the albedo (500 m x 500 m square-grid map data) by using the above land use square-grid data (250 m x 250 m square-grid) according to values for the reference surfaces shown in Table 2-6.

The albedo data calculated for the digitized square-grid system are stored on a floppy disk of a personal computer to use for the farther calculations.

2-4-3 Relative duration of sunshine

The monthly mean relative duration of sunshine (n/N) was calculated by the following procedure;

$$\frac{n}{N} = \frac{\text{monthly total of } n}{(N \text{ on 15th each month}) \times \text{days}} \tag{2-55}$$

By taking into account the effects of the solar radius τ_s = 16'1" and the atmospheric refraction τ_a =35'8" which are used by Tokyo Astronomical Institute, the hour angles of sunrise and sunset can be calculated. For a horizontal surface in the Kanto district, the sunrise or the sunset hour angle may be given as ;

$$\cos\, t_r = -(0.0148 \sec\phi \sec\delta + \tan\phi \tan\delta) \tag{2-56}$$

where t_r is negative for sunrise and positive for sunset (in radian).

The first term of the right hand side of Eq. (2-56) is referred to as the corrective term for the solar radius and the atmospheric refraction; the value of the solar parameter is given as sin(-0.0149) ≒ 0.0148. If we ignore both τ_s and τ_a, then the first term becomes zero.

The solution of Eq. (2-56) will be given as;

$$t_r = \tan^{-1} \frac{(1 - \cos^2 t_r)^{1/2}}{\cos t_r} \tag{2-57}$$

Then, the possible duration of sunshine Dt is given as follows ;

$$Dt = 2\, t_r \tag{2-58}$$

The solar declination in Eq. (2-56) was obtained by means of Lunde's equation (Lunde, 1980).

$$\delta = 0.4093 \sin\,[0.01698\,(Nd - 80)] \tag{2-59}$$

where Nd is the day number and δ is the solar declination in radian.

2-4-4 Soil heat flux

The present study used the following empirical relationship between net radiation Rn and soil heat flux G.

$$G = \mathrm{Cr} \cdot Rn \qquad (2\text{-}60)$$

where Cr is an empirical constant.

Fuchs and Hardas (1972) found, on average, Cr = 0.3 for a bare soil and Narita et al. (1984) found Cr=0.3~0.4 for an asphalt pavement in the city during day time. For surfaces well covered by vegetation, the values of G lie below 10% of the net radiation above the vegetation canopy. Tajchman (1971) obtained Cr=0.015 for a spruce forest, Kotoda (1982b) found Cr=0.03~0.06 for a Japanese oak forest in the summer season and Sugita (1984) obtained Cr=0.02~0.06 for a pine forest in the daytime of the summer season. For short grass, Kotoda (1984) found Cr = 0.03 ~ 0.10 and also Nakagawa (1984a) Cr=0.05 ~ 0.10.

The monthly approximated values of Cr are listed in Table 2-7.

Table 2-7 The values of constants Cr in Equation (2-60). Notations are the same as those in Table 2-6.

	month	1	2	3	4	5	6	7	8	9	10	11	12
1	WATER:W:	20	20	20	20	20	20	20	20	20	20	20	20
2	CITY :C:	40	40	40	40	40	40	40	40	40	40	40	40
3	SETL :S:	30	30	30	30	30	30	30	30	30	30	30	30
4	FORES:F:	4	4	4	4	4	4	4	4	4	4	4	4
5	DECID:D:	15	15	15	10	6	5	5	5	5	10	12	15
6	ORCHR:O:	18	18	18	15	12	10	10	10	10	12	15	18
7	MULB :M:	18	18	18	16	16	15	15	15	15	16	16	18
8	GRAS :G:	12	12	12	12	10	10	10	10	10	10	12	12
9	RICE :R:	15	15	15	15	15	8	8	8	8	15	15	15
10	VEGE :V:	20	20	20	20	20	20	20	20	20	20	20	20
11	BARE :B:	30	30	30	30	30	30	30	30	30	30	30	30

2-4-5 Evapotranspiration parameter

Evapotranspiration parameters f_0 in Eq. (2-14) for the river basin are calculated with the monthly mean digitized square-grid air temperature data, the monthly mean wind speed and the monthly mean vapor pressure of the air which were observed at Kakioka in the koise river basin (see Fig. 3-1).

2-4-6 Flow chart for calculation procedure

The calculation procedure for the river basin evapotranspiration is shown as a flow chart in Fig. 2-7. The computations in the present research were performed with use of the NEC PC-9801 Vm2 personal computer by BASIC language.

Data concerned with radiation are relatively easily measured, however the factors of wind speed and precipitation distribution are as yet uncertain. Therefore, more research will be needed to obtain suitable information on wind speed and precipitation for our estimates.

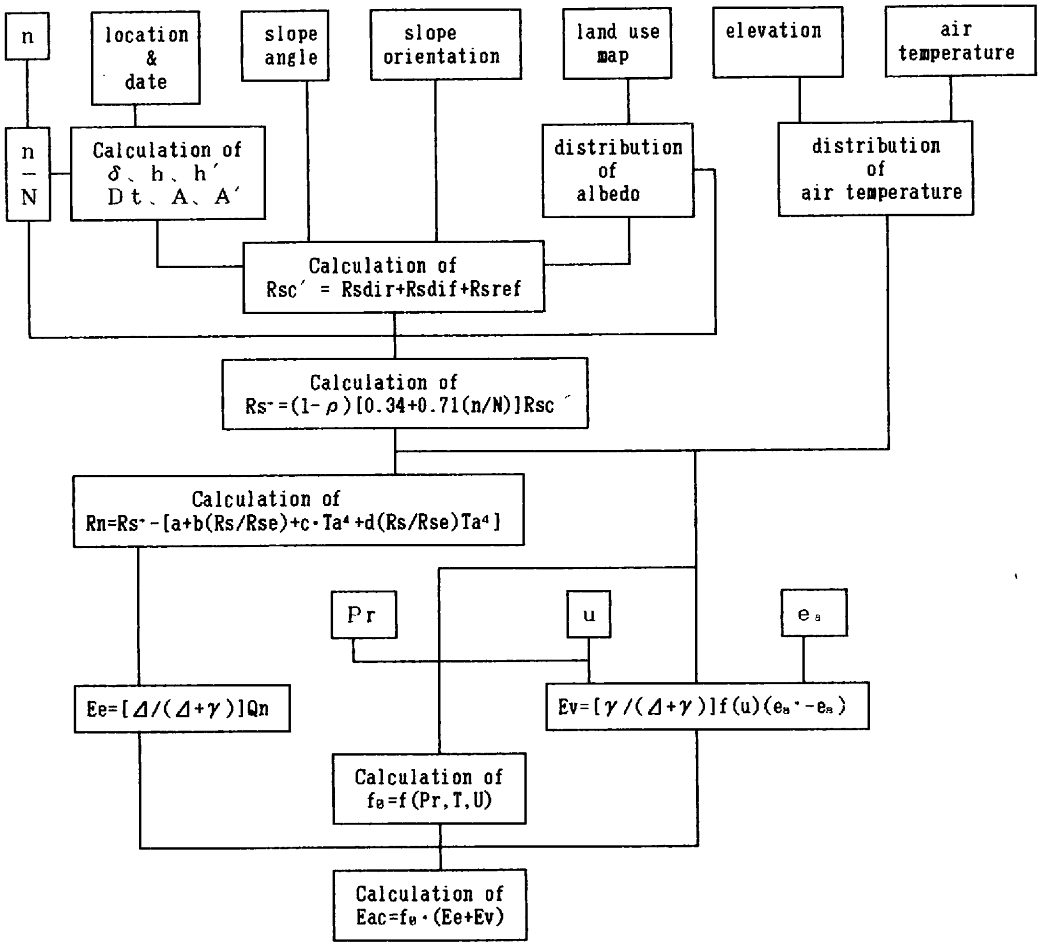

Fig. 2-7 A flow chart for calculating the river basin evapotranspiration

CHAPTER 3

TOPOGRAPHY AND LAND USE

3-1 Site description

Location of the study area and the map of the Koise river basin on the 500 m x 500 m square-grid are shown in Fig. 3-1 (a) and Fig. 3-1b, respectively. There are two meteorological stations in and near the basin. One is Kakioka(K) and the other is Mt. Tsukuba(NA).

Kakioka (36°14'N, 140°12'E, Alt. 27 m) is located in the center of the Koise river basin about 72 km northeast of Tokyo. Mt. Tsukuba (36°13'N, 140°06'E, Alt. 869 m) is located near the south-west corner of the basin.

The University of Tsukuba (36°05'N, 140°06'E, Alt. 25m) and Tateno Aerological Observatory (36°03'N, 140°08'E, Alt. 25 m) are situated about 12 km south of Kakioka.

The Koise river has an area of about 135 km^2 at the point of Gorindo(GO). The highest mountain in the basin is Mt. Nyotai of Tsukuba(NY). The altitude is about 875.9 m above mean sea level. The lowest is the outlet of the river basin, which is about 10 m above msl.

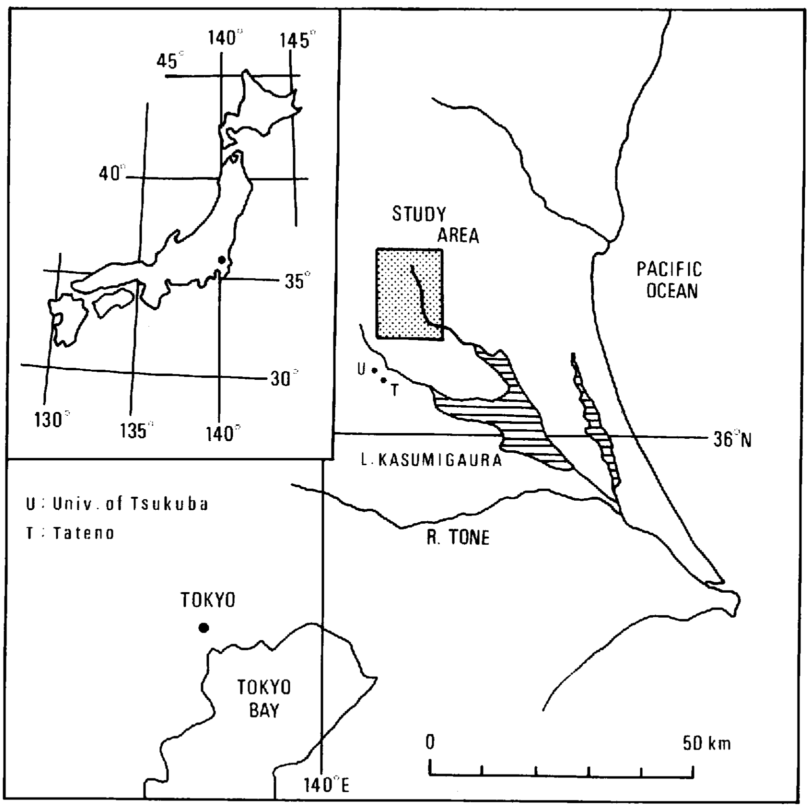

Fig. 3-1a Location of the study area.

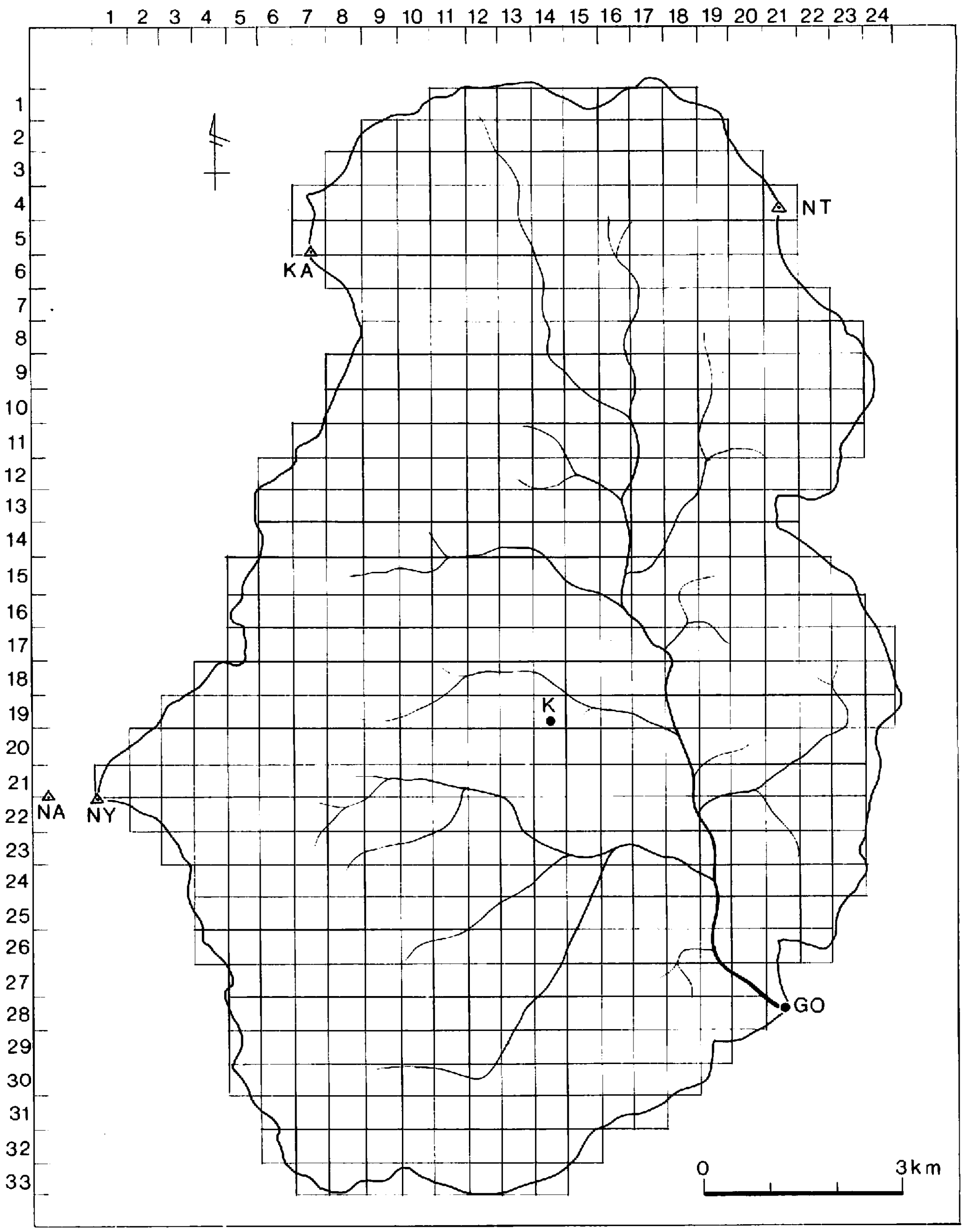

Fig. 3-1b Square-grid map of the Koise river basin and the location of some important points. K: Kakioka, GO: Gorindo, NA: Mt. Tsukuba (Nantai-san), NY: Mt. Nyotai, KA: Mt. Kaba, NT: Mt. Nantai

3-2 The results of the morphological analysis

(1) *Distribution of mean elevation*

The mean elevation (geographic altitude) *Zmean* of each grid-square is calculated by using the following formula

$$Zmean = (Zmax + Zmin)/2 \qquad (3\text{-}1)$$

where *Zmax, Zmin* are the highest and the lowest elevation in a grid-square. The data of elevation is obtained from the topographic map (scale 1 : 25000) prepared by the Geographical Survey Institute, Ministry of Construction.

Table 3-1 shows the distribution of the mean elevation for the Koise river basin. These data are used for the calculation of air temperature.

Figure 3-2 shows the frequency of the mean elevation by histogram. It is found that about 60% of the total area is situated below 100 m.

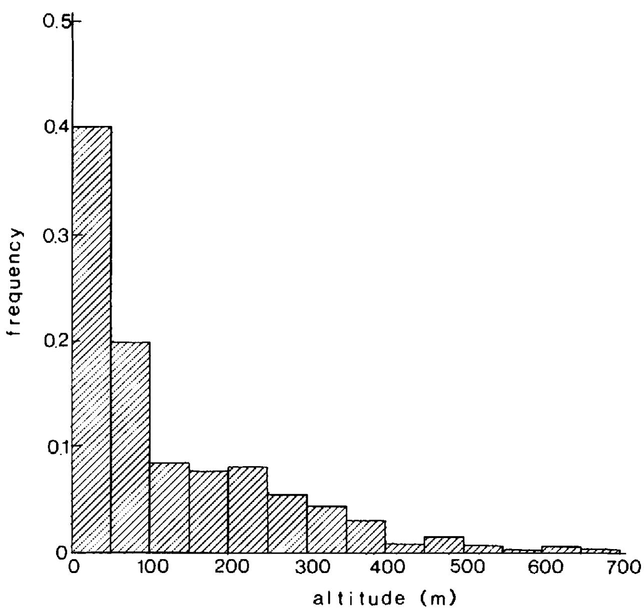

Fig. 3-2 Frequency of the geographic altitudes of the Koise river basin.

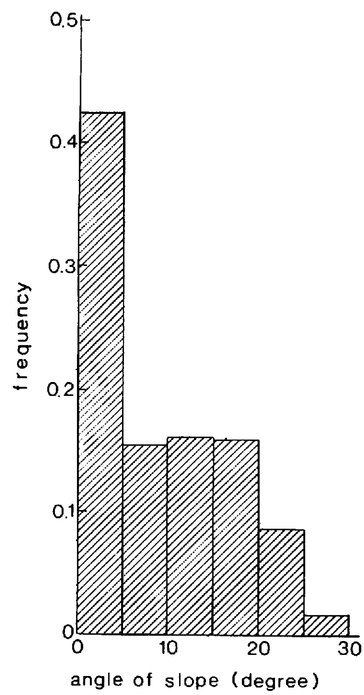

Fig. 3-3 Frequency of the slope angles of the Koise river basin.

Table 3-1 Distribution of the geographic altitudes in the Koise river basin (unit: m above msl).

0	0	0	0	0	0	0	0	0	0	110	95	175	220	275	210	375	365	0	0	0	0	0	0
0	0	0	0	0	0	0	0	295	220	125	90	85	115	205	265	229	245	330	0	0	0	0	0
0	0	0	0	0	0	0	435	360	215	115	70	50	95	155	125	180	175	295	375	0	0	0	0
0	0	0	0	0	0	620	490	370	235	133	85	55	95	155	103	105	120	210	310	462	0	0	0
0	0	0	0	0	0	605	465	335	235	160	95	50	70	100	63	70	95	170	270	435	0	0	0
0	0	0	0	0	0	0	535	360	235	140	78	51	48	45	43	48	75	115	225	340	0	0	0
0	0	0	0	0	0	0	0	400	220	98	68	48	33	38	35	35	43	89	170	265	305	0	0
0	0	0	0	0	0	0	0	350	220	125	70	43	32	33	30	40	45	75	125	180	170	275	0
0	0	0	0	0	0	0	525	360	250	140	78	48	38	29	33	38	43	48	72	93	130	230	0
0	0	0	0	0	0	0	494	390	280	140	76	50	43	30	28	43	48	40	43	78	90	160	0
0	0	0	0	0	0	472	385	300	205	161	65	58	38	33	29	43	45	35	40	87	115	153	0
0	0	0	0	0	450	420	380	260	140	115	65	48	36	32	29	38	42	30	53	57	83	0	0
0	0	0	0	0	380	325	240	220	105	63	43	43	44	28	23	35	30	38	50	55	0	0	0
0	0	0	0	0	345	202	165	115	63	40	30	38	38	35	25	25	37	45	50	53	0	0	0
0	0	0	0	380	330	200	120	90	50	34	30	30	25	28	31	35	39	39	50	53	53	0	0
0	0	0	0	340	290	260	220	155	65	46	45	43	33	25	30	41	25	38	47	53	50	58	0
0	0	0	0	355	305	270	290	185	90	43	45	43	40	30	20	20	24	35	35	43	43	45	61
0	0	0	305	342	275	135	160	113	68	38	30	25	28	25	25	20	25	41	43	38	43	41	48
0	0	340	245	235	190	105	70	84	38	35	40	40	30	23	23	21	20	35	35	38	54	35	38
0	505	350	275	205	165	100	58	40	38	43	43	40	33	28	26	20	15	23	28	38	34	35	0
675	555	375	270	180	120	90	55	28	28	43	30	32	48	65	70	43	17	20	23	28	35	48	0
0	605	455	325	205	80	43	42	33	33	28	25	45	102	93	68	23	14	18	20	23	65	110	0
0	0	485	335	200	93	65	48	33	28	38	25	25	43	58	33	18	15	16	27	27	40	110	0
0	0	0	300	185	100	70	68	73	50	55	45	27	20	20	20	20	17	36	38	30	35	90	0
0	0	0	320	235	150	135	95	90	81	65	63	26	25	25	28	28	20	41	80	73	48	0	0
0	0	0	345	290	280	220	190	70	45	45	75	63	22	28	28	34	23	30	75	85	60	0	0
0	0	0	0	295	286	255	200	115	65	100	80	48	25	63	60	23	25	13	25	0	0	0	0
0	0	0	0	275	210	165	175	154	130	148	90	29	33	100	105	70	45	58	30	0	0	0	0
0	0	0	0	340	265	185	125	105	95	105	68	28	50	160	200	150	75	95	0	0	0	0	0
0	0	0	0	335	230	165	95	85	90	55	40	45	85	165	236	185	160	0	0	0	0	0	0
0	0	0	0	0	245	150	115	170	165	70	75	110	160	170	240	263	0	0	0	0	0	0	0
0	0	0	0	0	310	210	185	215	205	120	160	180	225	225	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	285	295	285	235	227	240	305	280	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)= 216	F(6)= 29	F(11)= 3	F(16)= 0
F(2)= 107	F(7)= 23	F(12)= 1	F(17)= 0
F(3)= 45	F(8)= 16	F(13)= 3	F(18)= 0
F(4)= 41	F(9)= 4	F(14)= 1	F(19)= 0
F(5)= 43	F(10)= 8	F(15)= 0	F(20)= 0

MAX = 1000	MIN = 0	DLT = 50
TOTAL= 540	MEAN = 125.1	DIV = 126.4

(2) *Distribution of the slope angles*

The problem of determining the incoming radiation on sloping surfaces with various orientations is important not only for agricultural meteorology but also for hydrology. Because the incoming radiation depends on the slope angle and its orientation, information about their distributions provides basic data to estimate evapotranspiration.

The slope angles are calculated by using the following simple equation ;

$$\beta = \tan^{-1} [(Zmax - Zmin)/L] \tag{3-2}$$

where β is the angle of the slope in each square-grid, *Zmax* and *Zmin* are the maximum and minimum elevations in the square-grid, respectively. *L* is the distance between *Zmax* and *Zmin*.

Table 3-2 Distribution of the slope angles in the Koise river basin (unit: degree).

```
999999999999999999999999999999  9  8 23 20 21 13 25 17999999999999999999
999999999999999999999999 15 16 12  7  8 12 19 25 15 17 20999999999999999
999999999999999999999 21 24 15 10  5  0  8 15  8 18 12 27 21999999999999
999999999999999999 16 26 26 21 13  8  3 10 15  9 10  9 16 20 20999999999
999999999999999999 23 27 21 15 11  8  2  7 11  4  5  8 13 20 23999999999
999999999999999999999 21 24 19  9  7  4  3  1  1  3  8 15 21 26999999999
999999999999999999999999 27 18 10  5  3  1  1  1  1  2  9 16 23 23999999
999999999999999999999999 22 22 12  7  2  0  1  1  2  1  8 10 20 16 15999
999999999999999999999 19 22 20 11  7  3  2  1  1  3  2  3  7 11 16 24999
999999999999999999999 28 24 20 16  8  3  2  1  1  2  4  2  1  7  7 11999
999999999999999999 14 21 24 15 18  6  5  1  1  0  2  3  1  1 11 12 14999
999999999999999 16 24 20 24  9 12  6  3  1  0  1  3  3  1  4  4  9999999
999999999999999 20 21 18 26 10  6  2  2  2  1  1  1  1  3  2  3999999999
999999999999999 21  7 15 12  6  2  1  3  3  2  1  1  3  3  2  4999999999
999999999999 13 20 18  9  7  2  1  1  1  1  2  3  3  3  3  5  4  3999999
999999999999 11 16 18 20 21  6  2  2  3  2  1  2  5  1  3  4  2  2  3999
999999999999  8 21 20 20 21 11  3  3  3  2  1  0  0  1  2  2  3  3  3  2
999999999 12 16 25 15 20 15  7  2  1  1  2  1  1  1  1  5  4  3  3  3  4
999999 18  8 12 22 10  7 10  1  1  2  2  2  1  1  1  0  3  3  3  2  2  2
999 19 16 10 10 15 11  5  2  3  4  3  3  3  2  1  1  0  2  2  3  3  2999
 27 15 15 18 16 13  7  6  1  1  4  2  3  5  8 11  3  0  1  2  3  3  5999
999 23 21 17 21  7  2  3  1  1  1  1  6 12 10 10  2  0  1  1  2 10 13999
999999 15 21 22  7  6  3  1  1  3  1  1  6 10  4  1  0  1  3  2  5 16999
999999999 16 17  9  7  7  9  5  6  6  2  1  1  1  1  1  5  5  2  3 13999
999999999 16 19 16 19 10  9 12  8 10  1  1  1  2  2  1  6  9 11  5999999
999999999 12 20 18 20 22  7  3  3 11  9  1  2  2  1  2  5 12 10  7999999
999999999999 17 17 19 22 17  6 11 11  5  1  9  9  2  2  1  1999999999999
999999999999 17 11 10 15 14 16 11 13  1  2 16 17 11  6 10  4999999999999
999999999999 13 12 17 12 12 12 15 10  1  5 24 20 18  8 10999999999999999
999999999999 17 16 12  8  8 11  6  2  3 10 21 17 21 16999999999999999999
999999999999999 15 13 10 16 19  7 10 13 20 18 16 18999999999999999999999
999999999999999 22 20 15 19 19 11 22 20 19 23999999999999999999999999
999999999999999999 17 17 17 12 17 20 19 18999999999999999999999999999
```

FREQUENCY

F(1)=	220	F(6)=	25	F(11)=	0	F(16)=	0
F(2)=	76	F(7)=	2	F(12)=	0	F(17)=	0
F(3)=	82	F(8)=	0	F(13)=	0	F(18)=	0
F(4)=	73	F(9)=	0	F(14)=	0	F(19)=	0
F(5)=	62	F(10)=	0	F(15)=	0	F(20)=	0

MAX	=	90.0	MIN	=	0.0	DLT	=	4.5
TOTAL=		540	MEAN	=	9.3	DIV	=	7.3

The distribution of the slope angle is shown in Table 3-2 and its frequency histogram is also shown in Fig. 3-3. It is found that about 42% of the total area is occupied by land below 5 degrees slope angle.

(3) *Orientation of the slope surface*

The incoming radiation on the inclined surface also depends on its orientation which is expressed as surface azimuth in relation to the local meridian. The surface azimuth angle, that is the projection of the normal to the slope on a horizontal surface, can be determined using the data obtained from the topographic map (scale 1 : 25000) provided by the G.S.I.

Figure 3-4 shows the distribution of the surface orientations classified in 16 convenient directions. The frequency of the orientations is shown in Table 3-3. It can be seen from the Table that the surfaces are predominantly inclined eastward rather than westward.

```
 0   0   0   0   0   0   0   0   0   0  ESSWSSWSSWSSW NW  SSSE  0   0   0   0   0   0
 0   0   0   0   0   0   0   0 SWSEE  E  E SW SW SWSSE SWSSE  W   0   0   0   0   0
 0   0   0   0   0   0   0 NENEE  E  ESEESSE  W NW SW SW  S SW SW  0   0   0   0
 0   0   0   0   0  ONEE SE  E  ENEENEE  SSWW SESEE  SSWWSWW SWNWW  0   0   0
 0   0   0   0   0  ONEE  E  E  E  E  ENEE SW  S  S  SSWW  WSWW  W   0   0   0
 0   0   0   0   0   0   0  ENEE  ESEESEE SESSE SWSEESSW SW SW SWSWW  0   0   0
 0   0   0   0   0   0   0   0  E  E  ESEESEESSE SW  S SW  W SW SW SWSSW  0   0
 0   0   0   0   0   0   0   0  ENEENNENEENNESEE  SSEE  W NWSWW  S SW SW SW  0
 0   0   0   0   0   0  ONNENEENEE  ESEE  E NE SW SESWWSWW SW  S SW SWSWW  0
 0   0   0   0   0   0   0 SE SE  E  ENEE  SSSE NENNE  W NWSEESWW NW  W  W  0
 0   0   0   0   0   0 SE  ESSE SE  ESEESEENNESWWSEE  WSEE SW SW SWSSW SE  0
 0   0   0   0  OSEE SE SESEE SESEE SE NESEE SE  S NW  E  W NW NE  W   0   0
 0   0   0   0  OSSESSE SE SESSE SESWW  N  N NESSE  S SENWW  WSWW  0   0   0
 0   0   0   0   0  ESEESEESEE SE SESEE  S SW  E  E  WNWW NWNNWSSE  0   0   0
 0   0   0  ONNESEESEE  E  E  E  E  N NE NE SW  E NW SESSENNW  N SE  0   0
 0   0   0   0 NE NENNENNENNENEE  N  N  N  E  ESSW  S  S  S  S  SSEE SW  0
 0   0   0   0  ESEE  S SW  ENEE SW  SSEE SE SE  ESSE SW NE SWNWW  WSWWSSE
 0   0   0 SW  S SE SESSW SE SE  E  NNNESSWSWW NE  ESWW  W  NSSW  SNWW SW
 0  ONEE SE SE SESEE SESSESEE  N  W  N NESEESEE SESSE  SSSENWW SE  S  W
 0  ENEE NE  E SE NE NESSE  W  S  S  S NE  NNNE  NSSE SWSSWNWW  SNWW  0
NEENEENEE  E  ESEESEE  ENEE  ESWW  ENNWNNW NW NE  ESSE SW SESWW NW NW  0
 0  ENEE  ENEE  ESEESEENNW  NNNENNE  W  WNNW  E  E  E  W  NSWW SW  N  0
 0  OSEE  ESEE NE NW  ENEE  ENNW NE  NSSW  SNNWSEESEE  S  SNNE NWNWW  0
 0   0   0 SENEE NE  N NW  NNEE  NNNESSE  N  E  NNEE  E NW NWNEE SWNWW  0
 0   0  ONEE NE  NNNENNWSWWNEESWW  ENNW SESSWNNE  N NE  W  N NE NW  0   0
 0   0  OSWWNNENNE NENEE  E  E  NNWWNNE  ENWW  S  W  ESWWSWW SE SW  0   0
 0   0   0  OSEE  S  SNEE NE  NNNW SE SE  S NWNEE  SNNWNNESWW  0   0   0   0
 0   0   0  ONNE NESEE SW  N  N  N  ENEE NWNWW NENNENNW  NNNE  0   0   0   0
 0   0   0   0  ENEE  E  S  S  SSSE  ENNW NWNWW  NNNENNENEE  0   0   0   0   0
 0   0   0  OSEE SESEE  E  N  NNNE  N  NNNW  W SW NE  N   0   0   0   0   0   0
 0   0   0   0   0 NENEE  NNNW NE  N  NNNW NW  NNWWSEE  0   0   0   0   0   0   0
 0   0   0   0   0 NE NE  N NW  E  NNNW  N NW SE  0   0   0   0   0   0   0   0   0
 0   0   0   0   0  ONNENNWSEE NENNE NWNNW  N   0   0   0   0   0   0   0   0   0   0
```

Fig. 3-4 Distribution of the orientations of the land surfaces.

Table 3-3 Frequency of the orientations of the slope surfaces.

FREQUENCY											
N	=	45	E	=	70	S	=	41	W	=	25
NNE	=	29	SEE	=	47	SSW	=	14	NWW	=	15
NE	=	34	SE	=	43	SW	=	46	NW	=	25
NEE	=	36	SSE	=	24	SWW	=	26	NNW	=	20

3-3 Distribution of the land use

The distribution of the radiation flux is influenced considerably by the nature of the earth's surface, for instance the surface albedo. The determination of the albedo, as stated by Kondratyev, is exceptionally important in the study of the radiation balance of underlying surfaces. Therefore, information on the land use provides important data for the heat and the water balance studies.

The land use classification data can be obtained from an analysis of remotely sensed satellite data (for example; Kotoda et al., 1984; Kondoh and Kotoda, 1985) where there is no land use classification map. For the present study area, however, land use classification maps have been published by the Geographical Survey Institute (1976). We converted those maps into the form of a digitized square-grid map.

The color printed land use classification map with 250 m × 250 m square-grid is shown in Fig. 3-5.

Table 3-4 shows the statistical values of the land use classification. Evergreen forest (forest 1) which consists of mainly Japanese cypress, Cryptomeria and Pine prevails in the river basin. It has about 51% of the total area. Second are the rice fields which have about 21% of the total area.

Table 3-4 The areas classified by land use in the Koise river basin and their ratio to total area. Notations are the same as those in Table 2-6.

No.	LAND USE	AREA(Sq.Km)	RATIO(%)
1	OPEN WATER	0.00	0.00
2	CITY	0.06	0.05
3	SETTLEMENT	8.88	6.57
4	FOREST 1	69.38	51.39
5	FOREST 2	5.81	4.31
6	ORCHARD	4.25	3.15
7	MULBERRY	1.25	0.93
8	GRASS LAND	0.75	0.56
9	RICE FIELD	27.88	20.65
10	VEGITABLE	15.75	11.67
11	BARE SOIL	1.00	0.74
	TOTAL	135.00	100.00

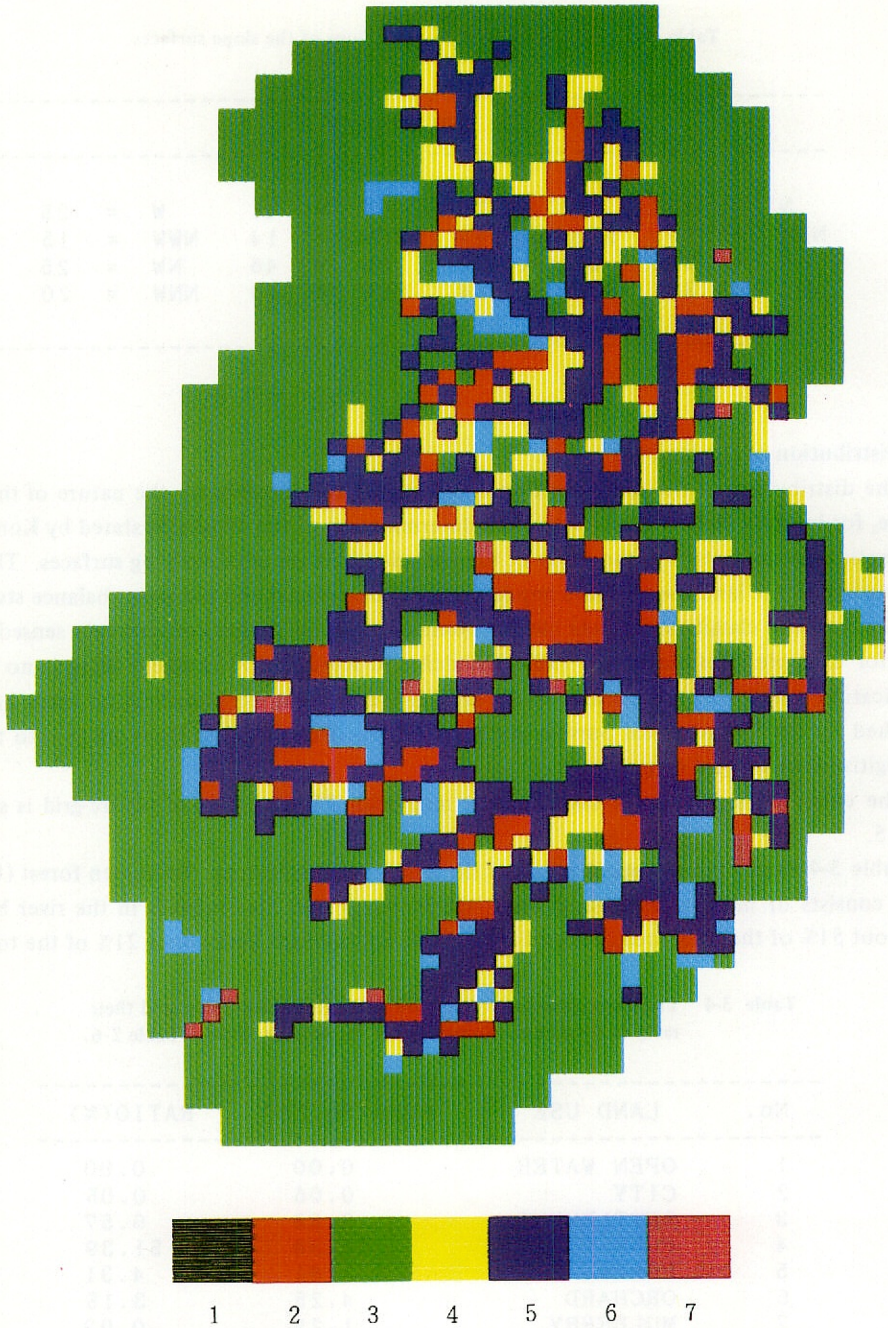

Fig. 3-5 Distribution of the land use.
1. open water
2. city, town and settlement
3. forest
4. vegetable field, grass land
5. rice field
6. orchard, mulberry field
7. bare soil

CHAPTER 4

RIVER BASIN EVAPOTRANSPIRATION

Monthly, seasonal and annual values of air temperature, and radiation fluxes are calculated using the data observed from 1970 to 1975 at Tateno Aerological Observatory and Kakioka Observatory Station, Japan Meteorological Agency. Then, the monthly, seasonal and annual mean values of equilibrium evaporation, Penman's potential evapotranspiration and actual evapotranspiration for complex ground surfaces are estimated. The results are as follows:

4-1 Distribution of air temperature

The values of monthly mean air temperature at Tateno (1970–1975), Mt. Tsukaba (1970–1975), Kakioka (1941–1970) and the areal average of the monthly mean temperatures covering the whole catchment are shown in Table 4-1.

As seen in the Table, the minimum temperature of areal average occurs in January (2.08°C) and the maximum in August (25.87°C).

The areal distribution of the air temperature in January shows that the greater part of the river basin bottom is about 2°C. On the other hand, the air temperatures around the peak of Mt. Tsukuba and Mt. Kaba are below freezing point.

In July, most of the river basin bottom is occupied by 24°C to 25°C air temperatures, while the air temperatures around the high mountains remained about 21°C. The distribution of the estimated annual mean temperature is shown in Table A-1 of the Appendix.

Table 4-1 Monthly mean air temperature at Tateno, Mt. Tsukuba, Kakioka and areal averages of air temperature in the Koise river basin. (unit °C)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Tateno*	2.40	3.28	5.43	12.47	16.82	20.30	24.52	26.25	22.02	15.55	9.60	3.80
Mt. Tsukuba*	0.45	0.50	2.23	9.00	13.52	16.02	20.28	21.98	17.77	12.25	7.62	2.77
Kakioka**	2.8	3.4	6.3	12.2	16.7	20.4	24.5	25.9	22.0	16.0	10.4	5.2
Basin***	2.08	2.95	5.03	12.04	16.19	19.87	24.06	25.87	21.43	15.12	9.17	3.25

* monthly mean from 1970 to 1975
** monthly mean from 1941 to 1970
*** areal average of the Koise river basin from 1970 to 1975

4-2 Distribution of surface albedo

Figure 4-1 and Table 4-2 show the areal averages of the surface albedo. It is found that the minimum value occurs in April (13.0%) and the maximum in August (17.2%). It seems that the areal variation of the albedo is greater in the winter season (standard deviation μ is 4.7% in January and 4.2% in December) than that in the summer season (μ = 2.7% in June and μ = 3.3% in July) as shown in Table 4-2. The distribution of the annual mean surface albedo is shown in Table A-2 of the Appendix.

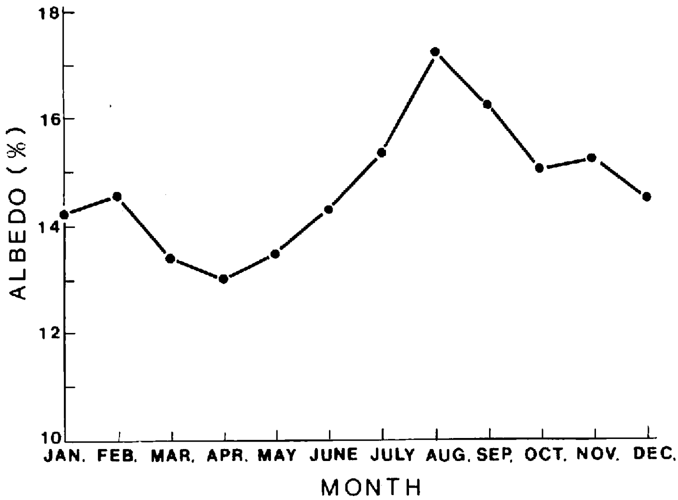

Fig. 4-1 Areal average of the surface albedo.

Table 4-2 Areal averages of surface albedo in the Koise river basin.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Albedo* (%)	14.19	14.54	13.40	13.00	13.48	14.28	15.33	17.16	16.23	15.03	15.16	14.49
μ	4.70	4.30	3.80	3.70	3.30	2.70	3.30	4.40	3.60	3.60	3.80	4.20

* areal average of the Koise river basin
μ : standard deviation

4-3 Distribution of radiation

1) *The total short-wave radiation*

The areal average of the monthly total short-wave radiation Rs obtained by means of Eq. (2-37) is shown in Table 4-3.

The minimum value of Rs is found in December (7.8 MJm^{-2} day^{-1}). The primary maximum is found in May (18.0 MJm^{-2} day^{-1}) and the secondary in August (16.7 MJm^{-2} day^{-1}). The depression of Rs between the two maxima in May and in August mainly depends on the weather conditions of the rainy season which is called "bai-u" in Japan, usually occuring in the period from June to July. The distribution of the annual mean total short-wave radiation is shown in Table A-3 (Appendix).

(2) *The net total short-wave radiation*

The areal average of the monthly net total short-wave radiation Rs^* is also shown in Table 4-3. It can be seen that Rs^* has a minimum in December (6.7 MJm^{-2} day^{-1}), a primary maximum in May (15.5 MJm^{-2} day^{-1}) and a secondary in August (13.9 MJm^{-2} day^{-1}).

(3) *The effective long wave radiation*

The effective long-wave radiation Le^* has a tendency to be a minimum in June (3.5 MJm^{-2}

day^{-1}) and a maximum in January (6.5 MJm^{-2} day^{-1}) as shown in Table 4-3.

This tendency is, in general, opposed to that of *Rs or Rs**.

(4) *The net radiation*

The areal average of the monthly net radiation *Rn* has a minimum in December (0.4 MJm^{-2} day^{-1}), a primary maximum in May (11.0 MJm^{-2} day^{-1}) and a secondary in July of 8.5 MJm^{-2} day^{-1}.

The distribution of the annual mean totals of net radiation is shown in Table A-4 (Appendix).

Table 4-3 Areal averages of total short-wave radiation (*Rs*), net short-wave radiation (*Rs**), effective long-wave radiation (*Le**) and net radiation (*Rn*). (MJ m^{-2} day^{-1}) (1970–1975)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Rs	8.92	10.92	14.14	15.13	18.03	13.40	15.09	16.73	12.22	9.68	8.61	7.78
μ	1.52	1.40	1.17	0.76	0.66	0.30	0.55	0.71	0.85	1.07	1.33	1.43
*Rs**	7.67	9.36	12.30	13.15	15.54	11.54	12.66	13.93	10.18	8.28	7.38	6.71
μ	1.38	1.27	1.18	0.84	0.73	0.44	0.56	0.80	0.82	0.99	1.21	1.29
*Le**	6.50	6.36	6.39	5.46	4.50	3.50	4.29	5.96	4.53	5.00	6.11	6.41
μ	0.83	0.67	0.47	0.32	0.00	0.00	0.41	0.58	0.53	0.78	0.97	0.89
Rn	1.10	3.07	5.87	7.60	11.01	8.13	8.53	7.96	5.62	3.35	1.34	0.35
μ	0.73	0.82	0.88	0.68	0.67	0.51	0.51	0.73	0.53	0.50	0.52	0.61

Rs : total short-wave radiation
*Rs** : net short-wave radiation
*Le** : effective long-wave radiation
Rn : net radiation
μ : standard deviation

4-4 Distribution and monthly changes of the evapotranspiration

4-4-1 The comparison of *Ee* and *Ep* with *Eac*

Figure 4-2 shows the monthly changes of the areal mean equilibrium evaporation *Ee*, Penman's potential evapotranspiration *Ep* and estimated actual evapotranspiration *Eac*. All of *Ee*, *Ep* and *Eac* are characterized by a seasonal trend with two peaks in May and August. These trends are similar to that of the net radiation, but the primary peak of *Eac* appears in August (94.3 mm) and the secondary in May (92.9 mm).

The annual values of *Ee, Ep* and *Eac* are estimated as 624, 735 and 583 mm, respectively.

From July to September, the values of *Eac*/*Ee* are indicated as being between 1.01 and 1.09. This means that the estimated actual evapotranspiration is slightly greater than the equilibrium evaporation in the period from late summer to early autumn. On the contrary, from February to May, the values of *Eac*/*Ee* range between 0.70 and 0.84. But, the value of *Eac*/*Ee* in January and December are extremely high as shown in Table 4-4. The annual mean of *Eac*/*Ee* is 0.93.

The ratio *Eac*/*Ep*, namely f_0 in Eq. (2-12), takes a value around 1.0 in the summer season, however, in the winter season the value drops to around 0.5. The mean value of f_0 = 0.79 is obtained.

The distribution of *Ee* is shown in Table 4-5. It is found that the smallest *Ee* rate area exists at the urban district in Kakioka (38 cm/year).

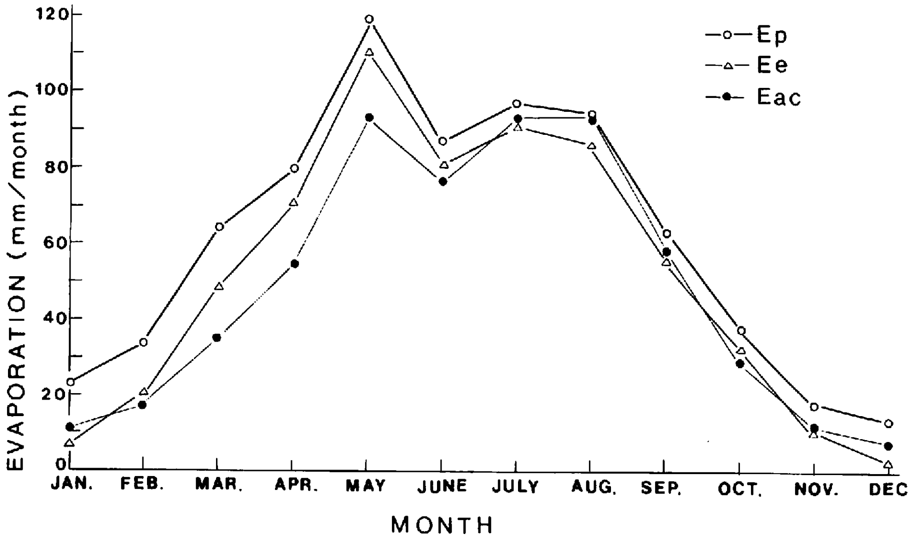

Fig. 4-2 Comparison of equilibrium evaporation (*Ee*), Penman's potential evapotranspiration (*Ep*) with estimated actual evapotranspiration (*Eac*).

Table 4-4 Areal averages of equilibrium evaporation (*Ee*), Penman's potential evapotranspiration (*Ep*) and estimated actual evapotranspiration (*Eac*).

(unit mm)

Month	*Ee*	*Ep*	*Eac*	*Eac/Ee*	*Eac/Ep*
1	7.6	23.7	11.6	1.53	0.49
2	20.4	33.9	16.9	0.82	0.50
3	48.8	63.8	34.3	0.70	0.54
4	70.9	79.6	54.8	0.77	0.69
5	111.2	119.0	92.9	0.84	0.78
6	81.8	87.2	76.3	0.93	0.88
7	91.7	97.5	93.7	1.02	0.96
8	86.5	94.2	94.3	1.09	1.00
9	57.5	63.4	58.1	1.01	0.92
10	33.1	38.1	29.8	0.90	0.78
11	11.7	19.3	12.4	1.06	0.65
12	2.6	14.8	7.7	3.00	0.53
	623.8	734.5	582.8	0.93	0.79

Table 4-5 Distribution of equilibrium evaporation (cm/year).

0	0	0	0	0	0	0	0	0	0	70	65	77	75	75	66	77	76	0	0	0	0	0	0
0	0	0	0	0	0	0	0	74	73	71	62	56	70	74	77	73	76	68	0	0	0	0	0
0	0	0	0	0	0	0	61	63	70	64	47	57	55	65	54	67	76	74	74	0	0	0	0
0	0	0	0	0	0	64	73	67	69	69	61	58	58	75	47	69	71	73	75	60	0	0	0
0	0	0	0	0	0	57	64	68	70	71	57	48	56	68	46	56	54	71	71	62	0	0	0
0	0	0	0	0	0	0	67	63	69	63	70	67	61	47	52	54	62	75	75	69	0	0	0
0	0	0	0	0	0	0	0	66	70	72	61	41	57	59	45	53	45	64	75	75	77	0	0
0	0	0	0	0	0	0	0	68	65	66	56	61	64	61	61	55	51	61	64	75	75	74	0
0	0	0	0	0	0	0	60	64	66	71	47	54	55	66	60	59	65	47	55	61	75	72	0
0	0	0	0	0	0	0	73	74	69	71	69	69	64	63	58	57	69	52	52	58	70	71	0
0	0	0	0	0	0	73	68	77	75	70	69	60	50	41	48	50	72	50	57	73	76	74	0
0	0	0	0	0	70	74	74	72	66	73	61	45	52	58	59	70	49	53	51	54	60	0	0
0	0	0	0	0	76	76	75	75	55	62	47	48	58	59	58	62	59	46	65	58	0	0	0
0	0	0	0	0	68	71	70	71	64	59	52	67	56	57	57	57	53	72	70	71	0	0	0
0	0	0	0	64	72	69	72	60	45	57	53	48	58	56	59	67	63	54	69	67	64	0	0
0	0	0	0	67	65	62	61	61	60	48	50	56	54	61	59	57	61	72	58	73	69	70	0
0	0	0	0	66	69	73	73	69	68	61	74	73	45	39	52	58	57	55	54	62	73	69	51
0	0	0	73	76	75	75	77	75	60	53	68	56	59	44	38	52	57	58	57	51	69	60	62
0	0	66	74	74	75	73	60	63	64	62	50	43	59	52	50	57	64	57	63	54	50	69	64
0	67	67	66	63	75	61	59	57	55	66	48	53	57	60	47	61	64	54	65	47	54	60	0
58	65	67	69	70	71	47	41	63	62	61	61	53	59	70	59	49	60	59	53	69	62	61	0
0	65	64	69	66	63	64	57	44	48	62	50	66	72	68	64	48	44	57	51	69	75	65	0
0	0	71	68	72	53	64	52	58	51	48	55	53	70	74	65	64	50	57	58	60	69	68	0
0	0	0	74	67	67	67	64	63	56	61	54	53	56	57	48	41	57	61	66	53	60	69	0
0	0	0	67	64	64	62	65	69	66	65	65	49	49	54	52	52	53	68	68	42	69	0	0
0	0	0	72	61	62	63	61	59	58	57	58	52	53	65	68	60	58	65	71	75	74	0	0
0	0	0	0	69	77	76	64	63	62	67	75	52	57	61	68	52	51	63	62	0	0	0	0
0	0	0	0	60	64	72	74	65	64	67	64	64	58	61	66	58	53	56	64	0	0	0	0
0	0	0	0	70	64	57	74	77	68	64	67	58	51	63	61	63	64	70	0	0	0	0	0
0	0	0	0	72	52	70	59	59	63	57	56	48	50	68	73	63	64	0	0	0	0	0	0
0	0	0	0	0	66	67	65	63	63	59	61	64	62	62	66	72	0	0	0	0	0	0	0
0	0	0	0	0	61	62	63	64	70	64	60	61	64	75	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	63	63	72	67	62	63	60	59	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	5	F(11)=	26	F(16)=	47	F(21)=	35
F(2)=	0	F(7)=	4	F(12)=	26	F(17)=	60	F(22)=	28
F(3)=	0	F(8)=	6	F(13)=	16	F(18)=	39	F(23)=	34
F(4)=	1	F(9)=	15	F(14)=	42	F(19)=	38	F(24)=	13
F(5)=	1	F(10)=	14	F(15)=	44	F(20)=	46	F(25)=	0

MAX =	80.0	MIN =	30.0	DLT =	2.0
TOTAL=	540	MEAN =	62.4	DIV =	8.4

The large *Ee* areas are found mainly at the southward facing slopes in the north-west part of the basin (77 cm/year) .

The distribution of Penman's annual *Ep* is shown in Table 4-6. The results show that a minimum of *Ep* = 50 cm/year is found at the urban district. The large *Ep* rate areas (85∼88 cm/year) are rather scattered and are found at the southward facing slopes in the river basin.

Table 4-6 Distribution of Penman's potential evapotranspiration (cm/year.)

0	0	0	0	0	0	0	0	0	0	81	76	88	86	85	77	85	84	0	0	0	0	0	0
0	0	0	0	0	0	0	0	84	83	82	74	68	81	84	87	83	86	77	0	0	0	0	0
0	0	0	0	0	0	0	69	72	81	75	59	68	66	76	65	77	87	84	83	0	0	0	0
0	0	0	0	0	0	70	80	75	79	80	73	69	69	86	59	80	82	83	84	68	0	0	0
0	0	0	0	0	0	63	72	77	80	82	68	60	68	79	58	68	65	82	80	70	0	0	0
0	0	0	0	0	0	0	73	72	79	74	82	79	73	59	64	66	74	87	85	78	0	0	0
0	0	0	0	0	0	0	0	74	80	83	73	53	69	71	57	65	57	76	86	85	86	0	0
0	0	0	0	0	0	0	0	77	75	77	68	73	76	73	73	67	63	73	75	86	86	84	0
0	0	0	0	0	0	0	66	73	76	82	59	66	67	78	72	71	77	59	67	73	86	82	0
0	0	0	0	0	0	0	80	82	78	82	80	81	76	75	70	69	81	64	64	70	81	82	0
0	0	0	0	0	0	80	76	86	85	81	80	72	62	53	60	62	84	62	69	84	87	84	0
0	0	0	0	0	77	82	82	81	77	85	72	57	64	71	71	82	60	65	63	66	72	0	0
0	0	0	0	0	84	85	85	85	67	73	59	60	70	72	70	74	71	58	77	69	0	0	0
0	0	0	0	0	77	82	80	82	76	71	64	79	68	69	69	69	65	84	81	83	0	0	0
0	0	0	0	72	81	79	83	71	57	69	65	60	70	68	71	79	75	66	80	79	76	0	0
0	0	0	0	75	74	72	71	72	71	60	61	68	66	73	71	69	73	84	70	85	81	82	0
0	0	0	0	75	78	82	83	80	79	73	86	85	57	51	64	71	69	67	66	74	85	81	62
0	0	0	82	85	84	86	88	87	72	65	80	68	71	56	50	64	69	70	69	63	81	72	73
0	0	75	84	84	86	85	72	75	76	74	62	55	71	64	62	69	76	69	75	66	62	81	76
0	74	75	76	74	86	72	71	69	67	78	60	65	69	72	59	73	76	66	77	59	66	72	0
64	72	75	79	81	82	58	53	75	74	73	73	65	71	82	71	60	72	71	65	81	74	73	0
0	71	72	78	76	75	76	69	56	60	74	62	78	83	79	76	60	56	69	64	81	87	77	0
0	0	78	77	83	64	76	63	70	63	60	68	65	82	86	77	76	62	69	70	72	81	79	0
0	0	0	84	78	78	79	75	75	68	72	66	65	69	69	60	53	69	73	78	65	72	81	0
0	0	0	76	74	75	73	77	81	78	77	77	61	61	66	64	64	66	80	80	54	81	0	0
0	0	0	81	70	72	73	71	71	70	69	69	63	65	77	80	72	71	77	83	86	86	0	0
0	0	0	0	78	86	85	75	75	74	78	87	64	69	73	80	64	63	75	74	0	0	0	0
0	0	0	0	70	75	82	84	75	75	78	76	76	70	72	77	70	64	68	76	0	0	0	0
0	0	0	0	79	74	67	85	88	80	76	79	70	63	74	71	74	75	82	0	0	0	0	0
0	0	0	0	81	62	81	70	71	74	69	68	60	62	79	83	73	74	0	0	0	0	0	0
0	0	0	0	0	76	78	76	74	74	71	73	75	73	73	76	82	0	0	0	0	0	0	0
0	0	0	0	0	71	72	74	74	80	75	71	71	74	85	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	72	72	82	77	72	73	69	69	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	1	F(11)=	16	F(16)=	56	F(21)=	46
F(2)=	0	F(7)=	5	F(12)=	26	F(17)=	57	F(22)=	34
F(3)=	0	F(8)=	4	F(13)=	26	F(18)=	57	F(23)=	34
F(4)=	0	F(9)=	6	F(14)=	23	F(19)=	35	F(24)=	15
F(5)=	1	F(10)=	15	F(15)=	43	F(20)=	37	F(25)=	3

MAX =	90.0	MIN =	40.0	DLT =	2.0
TOTAL=	540	MEAN =	73.5	DIV =	8.0

4-4-2 Distribution of the estimated actual evapotranspiration

The estimated monthly actual evapotranspiration rates *Eac* for the Koise river basin are shown in Table A-5 (Appendix).

The monthly *Eac* rates in the summer season vary from 56~66 mm/month to 86~109 mm/month in the basin. In the winter season, they vary from 5~10 mm/month to 13~24 mm/month. Besides climatological conditions, data for orientation, slope angle, elevation of the land surface and land use are reflected in the total results for the above regional variations of *Eac* rates.

The distribution of the estimated seasonal actual evapotranspiration is shown in Tables 4-7-1 to 4-7-4. The areal averages of *Eac* give 182 mm in spring, 264 mm in summer, 101 mm in autumn and 36 mm in winter. Therefore, it can be seen that about 76.5% of the annual evapotranspiration occurs in the period from the spring to the summer (irrigated) season.

Table 4-8 shows the distribution of the estimated annual actual evapotranspiration in the basin.

Generally, the north-east part of the basin has a high rate of evapotranspiration (maximum 69 cm/year).

The areas with a low rate of evapotranspiration are found at urbanized, residential or bare soil (stone quarry) locations (minimum 40 cm/year). These low evapotranspiration rate areas are scattered in the basin.

4-5 Comparison of the other results with estimated actual evapotranspiration

(1) *Comparison of results of the water budget method with Eac*

The measurement of discharge at Gorindo in the Koise river was started in December, 1984.

Therefore, we used the data of Yamaguchi-gawa Watershed (Ura-Tsukuba Experimental Site) adjacent to the Koise river. The measurements of discharge and precipitation have been carried out by the Public Works Research Institute (1978). The Experimental Site has an area of 3.12 km^2 with a double quadrangle weir. Precipitation is recorded at Kamihonsha (Alt. 170 m) in the Experimental Site.

Table 4-9 shows the monthly mean and annual total of the precipitation *Pr*, the discharge *D*, the difference ($Pr - D$), the estimated actual evapotranspiration *Eac* and the residual S ($= Pr - D - Eac$). They are calculated by using the data obtained from 1970 to 1975.

The annual totals of the each term are Pr = 1396 mm/y, D = 778 mm/y and ($Pr - D$) = 618 mm/y.

This means that if there is neither deep percolation nor change of storage in the Experimental Site, ($Pr - D$) can be assumed to be the evapotranspiration. However, 35 mm/year of discrepancy is found between ($Pr - D$) and *Eac*. One of the reasons for this discrepancy may arise from disparity of the river basin. Therefore more investigation will be required, but a rough comparison is possible.

If we assume that there exists deep percolation, it's flow rate will be equivalent to the order of 0.097 mm/day.

The ratios of the hydrological elements to the annual precipitation are given as, (D/Pr) = 0.56, (E/Pr) = 0.42 and (S/Pr) = 0.02, respectively.

(2) *Comparison of other results with Eac*

Using the data observed at 1991 stations in Japan, Shinobe (1984) calculated monthly point evapotranspiration by means of the Thornthwaite (1948), Blaney and Criddle (1950) and Hamon (1963) formulae.

Table 4-7-1 Distribution of estimated actual evapotranspiration (cm/spring).

0	0	0	0	0	0	0	0	0	0	20	19	21	20	20	19	20	20	0	0	0	0	0	0
0	0	0	0	0	0	0	0	20	20	20	18	17	20	20	20	20	21	18	0	0	0	0	0
0	0	0	0	0	0	0	16	17	19	19	15	18	17	19	17	19	21	20	19	0	0	0	0
0	0	0	0	0	0	16	18	18	19	20	18	18	17	21	15	20	20	20	20	16	0	0	0
0	0	0	0	0	0	15	17	18	19	20	17	15	17	20	15	17	16	20	19	16	0	0	0
0	0	0	0	0	0	0	17	17	19	18	20	20	19	15	16	17	18	21	20	18	0	0	0
0	0	0	0	0	0	0	0	17	19	21	18	13	18	18	15	17	15	19	21	20	20	0	0
0	0	0	0	0	0	0	0	18	18	19	17	18	20	18	19	17	16	18	18	21	21	20	0
0	0	0	0	0	0	0	16	17	18	20	15	17	17	20	18	18	19	15	17	18	21	20	0
0	0	0	0	0	0	0	18	19	19	20	20	21	19	19	18	18	20	16	16	18	20	20	0
0	0	0	0	0	0	19	18	20	21	20	20	18	16	13	15	16	21	16	18	21	21	21	0
0	0	0	0	0	18	19	19	19	19	21	18	14	16	18	18	21	15	17	16	17	18	0	0
0	0	0	0	0	20	20	20	20	17	19	15	15	17	18	18	18	18	15	19	17	0	0	0
0	0	0	0	0	18	20	19	20	19	18	16	20	17	17	18	18	17	21	20	20	0	0	0
0	0	0	0	17	19	19	20	18	14	18	17	15	18	17	18	20	19	17	20	20	19	0	0
0	0	0	0	18	18	17	17	18	18	15	15	17	17	19	18	17	19	21	18	21	20	20	0
0	0	0	0	18	19	20	20	19	20	19	21	21	14	13	16	18	18	17	17	19	21	20	16
0	0	0	19	20	20	21	21	21	18	17	20	18	18	14	13	16	18	17	17	16	21	18	18
0	0	18	20	20	21	21	18	19	20	19	16	14	18	16	16	18	20	17	19	16	16	21	19
0	17	18	18	18	21	18	18	18	17	19	15	16	18	18	15	19	20	17	20	15	17	18	0
14	17	18	19	20	20	15	13	19	19	19	19	16	18	20	18	15	18	18	17	20	19	18	0
0	16	17	19	18	19	20	18	14	15	19	16	20	20	20	19	15	14	18	16	20	21	19	0
0	0	18	18	20	16	19	16	18	16	15	17	17	21	21	20	20	16	18	18	18	20	20	0
0	0	0	20	19	20	20	19	19	17	18	16	16	18	18	15	13	18	19	19	17	18	20	0
0	0	0	18	18	18	18	19	20	19	19	20	15	15	17	16	16	17	20	20	13	20	0	0
0	0	0	19	17	17	18	17	18	18	17	17	16	17	19	20	18	18	20	21	21	21	0	0
0	0	0	0	19	20	20	18	19	18	19	21	16	18	18	20	16	16	19	19	0	0	0	0
0	0	0	0	17	18	20	20	19	18	19	19	20	18	18	19	17	16	17	19	0	0	0	0
0	0	0	0	19	18	16	21	22	20	19	20	18	16	18	17	18	19	20	0	0	0	0	0
0	0	0	0	19	15	20	18	18	19	17	17	15	15	19	20	18	18	0	0	0	0	0	0
0	0	0	0	0	18	19	19	18	18	18	18	19	18	18	18	20	0	0	0	0	0	0	0
0	0	0	0	0	17	18	18	18	19	19	17	17	18	20	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	17	17	19	19	18	18	17	17	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	0	F(11)=	35	F(16)=	81	F(21)=	0
F(2)=	0	F(7)=	0	F(12)=	64	F(17)=	17	F(22)=	0
F(3)=	0	F(8)=	2	F(13)=	95	F(18)=	0	F(23)=	0
F(4)=	0	F(9)=	6	F(14)=	132	F(19)=	0	F(24)=	0
F(5)=	0	F(10)=	22	F(15)=	86	F(20)=	0	F(25)=	0

MAX =	30.0	MIN =	5.0	DLT =	1.0
TOTAL=	540	MEAN =	18.2	DIV =	1.8

Table 4-7-2 Distribution of estimated actual evapotranspiration (cm/summer).

0	0	0	0	0	0	0	0	0	0	29	27	29	28	28	28	27	28	0	0	0	0	0	0
0	0	0	0	0	0	0	0	28	29	29	27	24	28	28	28	28	29	27	0	0	0	0	0
0	0	0	0	0	0	0	26	26	29	27	21	25	24	28	23	27	29	28	27	0	0	0	0
0	0	0	0	0	0	25	26	27	28	29	26	25	25	29	21	28	29	29	28	25	0	0	0
0	0	0	0	0	0	23	25	27	28	29	25	22	24	27	21	24	23	29	28	25	0	0	0
0	0	0	0	0	0	0	26	26	28	27	29	28	26	22	23	24	26	30	29	27	0	0	0
0	0	0	0	0	0	0	0	26	28	30	26	19	25	26	21	24	21	27	29	28	28	0	0
0	0	0	0	0	0	0	0	27	28	29	25	27	28	26	26	25	23	26	26	29	29	28	0
0	0	0	0	0	0	0	25	27	28	29	21	24	25	28	26	26	28	22	24	26	30	28	0
0	0	0	0	0	0	0	26	27	28	29	29	29	27	27	26	25	29	23	23	26	29	29	0
0	0	0	0	0	0	27	27	28	29	29	29	26	23	19	22	23	30	23	25	29	30	29	0
0	0	0	0	0	26	27	27	28	27	30	26	21	23	26	26	30	22	24	23	24	26	0	0
0	0	0	0	0	28	28	29	28	24	26	22	22	26	26	25	27	26	22	28	25	0	0	0
0	0	0	0	0	27	29	28	29	27	26	23	28	25	25	25	25	24	30	29	29	0	0	0
0	0	0	0	27	28	27	30	26	21	25	24	22	26	25	26	29	27	24	29	29	27	0	0
0	0	0	0	27	27	27	27	28	26	22	23	25	24	26	26	25	26	30	25	30	29	29	0
0	0	0	0	26	27	27	28	28	29	26	30	30	21	19	23	26	25	25	24	27	30	29	23
0	0	0	28	28	28	30	29	30	26	24	29	25	26	20	18	23	25	26	26	23	29	26	26
0	0	27	29	29	29	30	25	26	27	27	23	21	26	23	23	25	28	25	27	24	23	29	27
0	26	27	28	26	29	27	26	25	25	28	22	24	25	26	22	27	28	24	28	22	24	26	0
23	26	27	28	29	29	21	20	27	27	26	26	24	26	30	26	22	26	26	24	29	27	27	0
0	25	26	28	28	27	27	25	20	22	27	23	28	30	29	27	22	21	25	23	29	30	29	0
0	0	27	27	29	24	28	23	26	23	22	25	24	29	30	28	28	23	25	25	26	29	29	0
0	0	0	28	28	29	29	28	28	25	27	25	24	25	25	22	20	25	27	28	24	26	29	0
0	0	0	27	28	28	28	29	29	28	28	28	22	22	24	24	24	24	29	30	20	29	0	0
0	0	0	28	27	27	28	26	26	26	25	25	24	24	28	29	26	26	28	29	30	30	0	0
0	0	0	0	27	28	28	27	28	27	29	30	23	25	27	29	23	23	27	27	0	0	0	0
0	0	0	0	26	27	29	29	29	29	29	27	28	26	27	29	26	24	26	28	0	0	0	0
0	0	0	0	28	27	24	29	30	27	26	29	26	23	28	28	28	28	30	0	0	0	0	0
0	0	0	0	28	22	28	25	26	28	25	25	22	23	28	28	28	28	0	0	0	0	0	0
0	0	0	0	0	28	29	28	28	28	26	27	28	28	28	28	28	0	0	0	0	0	0	0
0	0	0	0	0	27	27	28	28	28	28	28	28	28	29	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	27	27	28	28	27	27	27	26	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	0	F(11)=	10	F(16)=	66	F(21)=	10
F(2)=	0	F(7)=	0	F(12)=	14	F(17)=	76	F(22)=	0
F(3)=	0	F(8)=	0	F(13)=	24	F(18)=	106	F(23)=	0
F(4)=	0	F(9)=	2	F(14)=	42	F(19)=	93	F(24)=	0
F(5)=	0	F(10)=	4	F(15)=	38	F(20)=	55	F(25)=	0

MAX =	35.0	MIN =	10.0	DLT =	1.0
TOTAL=	540	MEAN =	26.4	DIV =	2.4

Table 4-7-3 Distribution of estimated actual evapotranspiration (cm/autumn).

0	0	0	0	0	0	0	0	0	0	11	10	13	12	12	10	12	12	0	0	0	0	0	0
0	0	0	0	0	0	0	0	12	12	12	10	9	11	12	12	12	12	11	0	0	0	0	0
0	0	0	0	0	0	0	9	10	11	10	8	9	9	10	9	11	12	12	11	0	0	0	0
0	0	0	0	0	0	9	11	10	11	11	10	9	10	12	8	11	11	12	12	9	0	0	0
0	0	0	0	0	0	8	10	10	11	11	9	8	9	11	8	9	9	11	11	9	0	0	0
0	0	0	0	0	0	0	10	10	11	10	11	11	10	8	8	9	10	12	12	11	0	0	0
0	0	0	0	0	0	0	0	10	11	12	10	7	9	10	8	9	8	10	12	12	12	0	0
0	0	0	0	0	0	0	0	10	10	11	9	10	10	10	10	9	9	10	10	12	12	12	0
0	0	0	0	0	0	0	8	10	10	11	8	9	9	11	10	10	11	8	9	10	12	11	0
0	0	0	0	0	0	0	11	11	11	11	11	11	11	10	9	9	11	8	8	9	11	11	0
0	0	0	0	0	0	11	10	12	12	11	11	10	8	7	8	8	12	8	9	12	12	12	0
0	0	0	0	0	10	11	11	11	11	12	10	8	8	9	9	11	8	9	8	9	10	0	0
0	0	0	0	0	12	12	12	12	9	10	8	8	10	10	9	10	10	8	11	10	0	0	0
0	0	0	0	0	10	11	11	11	10	9	9	11	9	10	9	9	9	12	11	12	0	0	0
0	0	0	0	10	11	11	12	10	8	9	9	8	9	9	10	11	10	9	11	11	11	0	0
0	0	0	0	10	10	10	10	10	10	8	8	9	9	10	9	10	10	12	10	12	11	11	0
0	0	0	0	10	11	11	11	11	11	10	12	12	8	7	9	9	9	9	9	10	12	11	8
0	0	0	11	12	12	12	13	12	10	9	11	9	9	7	7	9	9	10	10	9	11	10	10
0	0	10	12	12	12	12	10	10	10	10	8	7	10	9	8	9	10	9	11	9	8	11	11
0	10	10	10	10	12	10	10	9	9	11	8	9	9	10	8	10	10	9	11	8	9	10	0
8	9	10	11	11	11	8	7	10	10	10	10	9	10	11	10	8	10	10	9	11	10	10	0
0	9	9	11	10	10	10	9	7	8	10	8	10	12	11	11	8	8	9	8	11	12	11	0
0	0	10	10	12	9	10	8	9	9	8	9	9	11	12	10	10	8	9	10	10	11	11	0
0	0	0	12	11	11	11	10	10	9	10	9	9	9	9	8	7	9	10	11	9	10	11	0
0	0	0	10	10	10	10	11	11	11	11	10	8	8	9	9	9	9	11	11	7	11	0	0
0	0	0	11	9	10	10	10	10	9	9	10	9	9	11	11	10	9	11	12	12	12	0	0
0	0	0	0	11	12	12	10	10	10	11	12	9	9	10	11	9	8	10	10	0	0	0	0
0	0	0	0	9	10	11	12	10	10	11	10	10	9	10	11	10	9	9	10	0	0	0	0
0	0	0	0	11	10	9	12	12	11	10	11	9	9	10	10	10	10	11	0	0	0	0	0
0	0	0	0	11	8	11	9	10	10	9	9	8	8	11	12	10	10	0	0	0	0	0	0
0	0	0	0	0	10	11	10	10	10	10	10	10	10	10	10	11	0	0	0	0	0	0	0
0	0	0	0	0	9	10	10	10	11	10	10	10	10	12	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	10	10	11	10	10	10	9	9	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	0	F(11)=	0	F(16)=	140	F(21)=	0
F(2)=	0	F(7)=	0	F(12)=	3	F(17)=	110	F(22)=	0
F(3)=	0	F(8)=	0	F(13)=	27	F(18)=	30	F(23)=	0
F(4)=	0	F(9)=	0	F(14)=	76	F(19)=	0	F(24)=	0
F(5)=	0	F(10)=	0	F(15)=	154	F(20)=	0	F(25)=	0

MAX =	20.0	MIN =	-5.0	DLT =	1.0
TOTAL=	540	MEAN =	10.1	DIV =	1.3

Table 4-7-4 Distribution of estimated actual evapotranspiration (cm/winter).

0	0	0	0	0	0	0	0	0	0	4	4	5	5	5	3	5	5	0	0	0	0	0	0
0	0	0	0	0	0	0	0	5	4	4	4	4	4	5	5	5	5	4	0	0	0	0	0
0	0	0	0	0	0	0	2	3	4	4	3	3	3	3	3	4	5	5	5	0	0	0	0
0	0	0	0	0	0	3	4	3	4	4	3	3	4	5	3	4	4	4	5	3	0	0	0
0	0	0	0	0	0	2	3	4	4	4	3	3	3	5	3	3	3	4	4	3	0	0	0
0	0	0	0	0	0	0	3	3	4	4	4	4	4	3	3	3	4	5	5	4	0	0	0
0	0	0	0	0	0	0	0	3	4	4	4	3	3	4	3	3	3	4	5	5	5	0	0
0	0	0	0	0	0	0	0	4	3	3	3	4	4	4	4	3	3	4	4	5	5	5	0
0	0	0	0	0	0	0	2	3	3	4	3	3	3	4	4	4	4	3	4	4	5	4	0
0	0	0	0	0	0	0	4	5	4	4	4	4	4	4	3	3	4	3	3	3	4	4	0
0	0	0	0	0	0	4	3	5	5	4	4	4	3	3	3	3	4	3	3	5	5	5	0
0	0	0	0	0	4	4	4	4	4	5	4	3	3	3	3	4	3	3	3	3	4	0	0
0	0	0	0	0	5	5	5	5	4	4	3	3	3	4	4	4	4	3	4	4	0	0	0
0	0	0	0	0	4	4	4	4	4	3	3	4	3	3	3	3	3	4	4	4	0	0	0
0	0	0	0	3	4	4	4	3	3	3	3	3	3	3	4	4	4	3	4	4	4	0	0
0	0	0	0	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	5	4	4	0
0	0	0	0	4	4	5	5	4	4	4	5	5	3	3	3	3	3	3	3	4	4	4	3
0	0	0	4	5	5	5	5	5	4	3	4	3	3	3	3	3	3	3	3	3	4	3	4
0	0	3	4	5	5	5	4	4	4	4	3	3	3	3	3	3	4	4	4	3	3	4	4
0	3	3	3	4	5	3	3	3	3	4	3	3	3	4	3	4	4	3	4	3	3	4	0
2	3	3	4	4	4	3	2	4	4	4	4	3	3	4	3	3	4	4	3	4	4	4	0
0	3	3	4	3	4	4	3	3	3	4	3	4	4	4	4	3	3	3	3	4	5	3	0
0	0	4	4	5	3	4	3	3	3	3	3	3	4	5	4	4	3	3	4	3	4	4	0
0	0	0	5	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	4	3	4	4	0
0	0	0	3	3	3	3	3	4	4	4	4	3	3	3	3	3	3	4	4	2	4	0	0
0	0	0	4	2	3	3	3	4	3	3	3	3	3	4	4	4	3	4	4	5	5	0	0
0	0	0	0	4	5	5	3	3	4	3	5	3	3	3	4	3	3	4	4	0	0	0	0
0	0	0	0	3	3	4	5	3	3	3	4	4	3	3	3	3	3	3	4	0	0	0	0
0	0	0	0	4	3	3	5	5	5	4	4	3	3	3	2	3	3	4	0	0	0	0	0
0	0	0	0	4	3	4	3	3	3	3	3	3	3	4	5	3	3	0	0	0	0	0	0
0	0	0	0	0	3	4	3	3	3	3	3	3	3	3	3	4	0	0	0	0	0	0	0
0	0	0	0	0	3	3	3	3	4	3	2	2	3	5	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	3	3	4	3	3	3	2	2	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	0	F(11)=	75	F(16)=	18	F(21)=	0
F(2)=	0	F(7)=	0	F(12)=	180	F(17)=	0	F(22)=	0
F(3)=	0	F(8)=	0	F(13)=	133	F(18)=	0	F(23)=	0
F(4)=	0	F(9)=	0	F(14)=	75	F(19)=	0	F(24)=	0
F(5)=	0	F(10)=	12	F(15)=	47	F(20)=	0	F(25)=	0

MAX =	10.0	MIN =	-2.5	DLT =	0.5
TOTAL=	540	MEAN =	3.6	DIV =	0.7

Table 4-8 Distribution of estimated actual evapotranspiration (cm/year).

0	0	0	0	0	0	0	0	0	0	64	60	68	66	65	61	64	64	0	0	0	0	0	0
0	0	0	0	0	0	0	0	64	65	65	59	54	64	65	66	65	66	60	0	0	0	0	0
0	0	0	0	0	0	0	53	56	63	60	47	55	53	61	52	60	68	64	63	0	0	0	0
0	0	0	0	0	0	53	60	58	62	64	58	55	55	67	47	63	65	65	64	52	0	0	0
0	0	0	0	0	0	48	55	60	63	65	54	48	54	63	46	54	52	64	62	53	0	0	0
0	0	0	0	0	0	0	55	56	62	59	65	63	59	47	51	53	59	68	66	60	0	0	0
0	0	0	0	0	0	0	0	57	63	66	58	42	55	57	46	53	46	60	67	65	65	0	0
0	0	0	0	0	0	0	0	59	60	62	54	59	61	58	58	54	51	58	59	67	67	65	0
0	0	0	0	0	0	0	51	57	60	65	47	53	54	63	58	57	62	47	53	58	68	64	0
0	0	0	0	0	0	0	60	62	61	65	64	65	61	60	57	55	65	51	51	56	65	65	0
0	0	0	0	0	0	60	59	66	66	64	64	57	50	42	49	50	67	50	55	67	69	66	0
0	0	0	0	0	59	62	63	63	61	67	58	45	51	57	57	66	49	53	51	53	57	0	0
0	0	0	0	0	64	65	66	66	53	59	47	48	56	58	56	59	57	47	61	56	0	0	0
0	0	0	0	0	59	64	63	65	60	57	51	63	54	56	55	55	52	67	65	66	0	0	0
0	0	0	0	56	62	62	66	57	46	55	52	48	57	54	57	64	60	53	65	64	61	0	0
0	0	0	0	59	58	57	57	58	57	48	50	55	53	58	57	55	59	67	56	68	65	65	0
0	0	0	0	58	60	63	63	63	63	59	69	68	45	41	51	57	55	54	53	60	68	64	50
0	0	0	63	65	65	68	68	68	57	52	64	55	57	45	40	51	55	56	56	51	65	58	59
0	0	58	65	65	67	67	57	59	61	60	50	44	57	51	50	56	61	55	60	53	50	65	61
0	56	59	59	58	67	58	57	55	54	62	48	52	55	58	48	59	61	53	62	47	53	58	0
48	54	58	62	64	65	47	42	60	59	58	58	52	57	65	57	49	58	57	52	65	59	59	0
0	53	55	61	60	60	61	55	45	48	59	50	62	66	64	61	49	45	55	51	65	69	62	0
0	0	59	60	65	51	61	51	57	51	48	54	52	65	68	62	61	50	56	56	58	65	64	0
0	0	0	64	62	63	63	60	60	55	58	53	52	55	55	49	43	55	59	62	53	58	64	0
0	0	0	59	58	60	59	62	64	62	62	62	49	49	53	52	52	53	64	64	43	65	0	0
0	0	0	62	56	57	58	56	57	56	56	56	51	53	62	64	58	57	62	66	68	69	0	0
0	0	0	0	60	66	66	59	60	60	63	69	51	56	58	64	52	51	60	59	0	0	0	0
0	0	0	0	55	59	65	66	60	60	62	61	61	56	58	62	57	52	55	61	0	0	0	0
0	0	0	0	61	58	53	66	69	63	60	63	57	51	59	57	59	61	65	0	0	0	0	0
0	0	0	0	62	48	64	56	57	60	55	55	48	50	62	65	59	60	0	0	0	0	0	0
0	0	0	0	0	60	62	61	59	59	57	59	60	59	59	60	64	0	0	0	0	0	0	0
0	0	0	0	0	56	58	59	59	63	60	57	57	59	66	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	57	57	63	61	57	58	55	55	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	2	F(11)=	30	F(16)=	59	F(21)=	0
F(2)=	0	F(7)=	5	F(12)=	36	F(17)=	51	F(22)=	0
F(3)=	0	F(8)=	8	F(13)=	54	F(18)=	73	F(23)=	0
F(4)=	0	F(9)=	15	F(14)=	72	F(19)=	23	F(24)=	0
F(5)=	0	F(10)=	21	F(15)=	78	F(20)=	13	F(25)=	0

MAX =	80.0	MIN =	30.0	DLT =	2.0
TOTAL=	540	MEAN =	58.3	DIV =	5.8

Table 4-9 WATER BALANCE (mm/month) [1970–1975]
Pr : Precipitation at Kamihonsha in Yamaguchi-gawa Watershed,
D : Discharge of Yamaguchi-gawa,
Eac : Estimated actual evapotranspiration,
S : Residual (= *Pr* – *D* – *Eac*).

month	*Pr*	*D*	*(Pr-D)*	*Eac*	*S*
1	49.2	54.2	-5.0	11.6	-16.6
2	57.9	51.4	6.5	16.9	-10.4
3	51.1	51.7	-0.6	34.3	-34.9
4	135.4	58.9	76.5	54.8	21.7
5	131.7	63.9	67.8	92.9	-25.1
6	206.0	73.2	132.8	76.3	56.5
7	136.5	78.7	57.8	93.7	-35.9
8	141.5	62.5	79.0	94.3	-15.3
9	196.9	77.5	119.4	58.1	61.3
10	130.8	75.2	55.6	29.8	25.8
11	103.0	73.1	29.9	12.4	17.5
12	56.4	58.0	-1.6	7.7	-9.3
TOTAL	1396.4	778.3	618.1	582.8	35.3

Figure 4-3 shows the annual progress of the monthly totals of evapotranspiration at Kakioka (B&C: Blaney and Criddle method, T: Thornthwaite method, H(K): Hamon method), at Mt. Tsukuba (H(T): Hamon method) and the estimated actual evapotranspiration *Eac*.

As seen in the figure, the result of the B&C method is extremely large compared to the other methods. Shinobe used K = 1 as the parameter value for the B&C method. Therefore, a suitable parameter value must be selected for the place concerned.

The evapotranspiration obtained by the T method is, as seen in Fig. 4-3, over estimated in the summer season, and underestimated in the winter season.

It is seen that the evapotranspiration calculated by means of the H method most resembles the seasonal trend of *Eac* from among the three methods.

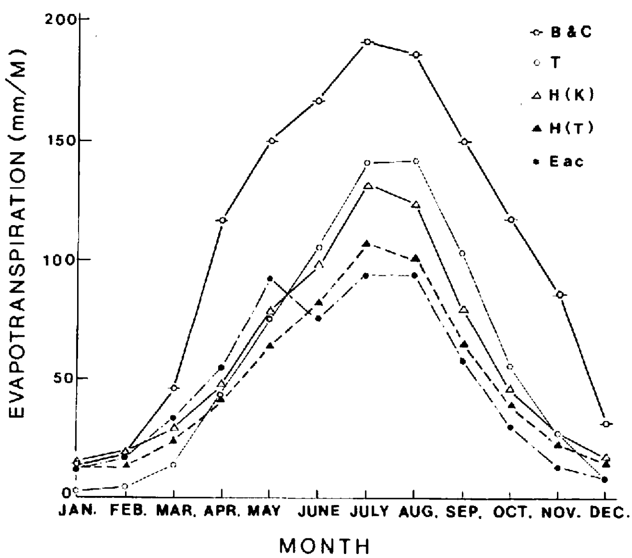

Fig. 4-3 Comparison of the results obtained by the methods of Blaney and Criddle (B&C), Thornthwaite (T) and Hamon(H) with estimated actual evapotranspiration (Eac).

CHAPTER 5

CONCLUSIONS

Evapotranspiration, that is evaporation of water in the natural environment, is one of the important elements in the water balance of the earth's surface. There has been a remarkable improvement in the understanding of the evapotranspiration process during the last two decades. However, evapotranspiration from a regional scale area, such as a river basin surface with complicated topography and variable land usage, is still among the less understood aspects of the hydrological cycle.

The present paper is intended to establish an estimation method for actual evapotranspiration from a river basin scale area taking into consideration topographic conditions and complex land use.

The results are summarized as follows:

(1) From analysis of the data obtained by a weighing lysimeter and meteorological observations, the following formula for estimating actual evapotranspiration is derived.

$$Eac = f_0 \ (Ee + Ev)$$

$$f_0 = 0.468 + (0.5Pr + 21.9T - 23.6U) \times 10^{-3}$$

where Eac is the actual evapotranspiration (mm/day), Ee the equilibrium evaporation (mm/day), Ev the aerodynamic term in the Penman method (mm/day), f_0 the conversion factor to actual evapotranspiration, Pr the precipitation (mm/month), T the monthly mean air temperature (°C) and U the monthly mean wind speed at a height of 1.6m (m/sec).

(2) In order to estimate short-wave radiation on a sloping surface, the following formula is derived;

$$Rs = Rsc' \left[0.34 + 0.71 \,(n/N)\right]$$

where Rs is the total short-wave radiation on a sloping surface, Rsc' the total short-wave radiation on a sloping surface under the standard clear sky condition, n the number of hours of bright sunshine and N the number of daylight hours.

The values of Rsc' can be calculated by means of a semiempirical formula.

(3) The magnitudes of the constants in the effective long-wave radiation formula proposed by Linacre-Nakayama et al. are determined by using the data obtained at the University of Tsukuba and Tateno Aerological Observatory.

$$Le^* = 198.834 - 287.593\,(Rs/Rse) - 312.946\,(Ta^4/10^{10}) + 698.026\,(Rs/Rse)\,(Ta^4/10^{10})$$

where Le^* is the effective long-wave radiation, Rse the extraterrestrial radiation on a horizontal surface, and Ta the air temperature (°C).

(4) Actual evapotranspiration, equilibrium evaporation and Penman's potential evapotranspiration were estimated on a monthly basis using the data from 1970 to 1975. The model was tested by comparing the estimated annual actual evapotranspiration for the Kakioka river basin with the result obtained by the water balance method (precipitation minus discharge) for the neighboring Experimental watershed. It was found that the estimated actual evapotranspiration was a little smaller than the result using the water balance residual.

This discrepancy (0.1 mm/day) is acceptable, assuming deep percolation and estimation errors.

(5) Since there are few observation points in the river basin, the values of the conversion factor f_0 were calculated by assuming wind speed, vapour pressure of the air and precipitation were uniform in the basin. Therefore, further information about wind speed, vapour pressure of the air and precipitation will be needed.

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* In Japanese with English summary.

**In Japanese.

Appendix

Table A-1 Distribution of estimated annual mean air temperature (°C).

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999999999999999999999999999999 13 13 13 13 12 13 12 12999999999999999999
999999999999999999999999 12 13 13 13 13 13 13 12 13 12 12999999999999999
999999999999999999999 12 12 13 13 13 13 13 13 13 13 13 12 12999999999999
999999999999999999 11 11 12 13 13 13 13 13 13 13 13 13 13 12 11999999999
999999999999999999 11 11 12 13 13 13 13 13 13 13 13 13 13 12 12999999999
999999999999999999999 11 12 13 13 13 13 13 13 13 13 13 13 13 12999999999
999999999999999999999999 12 13 13 13 13 14 13 13 13 13 13 13 12 12999999
999999999999999999999999 12 13 13 13 13 14 14 14 13 13 13 13 13 13 12999
999999999999999999999 11 12 12 13 13 13 13 14 14 13 13 13 13 13 13 13999
999999999999999999999 11 12 12 13 13 13 13 14 14 13 13 13 13 13 13 13999
999999999999999999 11 12 12 13 13 13 13 13 13 14 13 13 13 13 13 13 13999
999999999999999 12 12 12 12 13 13 13 13 13 14 14 13 13 14 13 13 13999999
999999999999999 12 12 13 13 13 13 13 13 13 14 14 13 14 13 13 13999999999
999999999999999 12 13 13 13 13 13 14 13 13 13 14 14 13 13 13 13999999999
999999999999 12 12 13 13 13 13 13 14 14 14 14 14 13 13 13 13 13 13999999
999999999999 12 12 12 13 13 13 13 13 13 14 14 14 13 14 13 13 13 13 13999
999999999999 12 12 12 12 13 13 13 13 13 13 14 14 14 14 13 13 13 13 13 13
999999999 12 12 12 13 13 13 13 13 14 14 14 14 14 14 14 13 13 13 13 13 13
999999 12 12 13 13 13 13 13 13 13 13 13 14 14 14 14 14 13 13 13 13 13 13
999 11 12 12 13 13 13 13 13 13 13 13 13 14 14 14 14 14 14 14 13 13 13999
 10 11 12 12 13 13 13 13 14 14 13 14 14 13 13 13 13 14 14 14 14 13 13999
999 11 11 12 13 13 13 13 14 14 14 14 13 13 13 13 14 14 14 14 14 13 13999
999999 11 12 13 13 13 13 13 14 13 14 14 13 13 14 14 14 14 14 14 13 13999
999999999 12 13 13 13 13 13 13 13 13 14 14 14 14 14 14 13 13 14 13 13999
999999999 12 13 13 13 13 13 13 13 13 14 14 14 14 14 14 13 13 13 13999999
999999999 12 12 12 13 13 13 13 13 13 13 14 14 14 13 14 14 13 13 13999999
999999999999 12 12 12 13 13 13 13 13 13 14 13 13 14 14 14 14999999999999
999999999999 12 13 13 13 13 13 13 13 14 14 13 13 13 13 13 14999999999999
999999999999 12 12 13 13 13 13 13 13 14 13 13 13 13 13 13999999999999999
999999999999 12 13 13 13 13 13 13 13 13 13 13 13 13 13999999999999999999
999999999999999 12 13 13 13 13 13 13 13 13 13 13 12999999999999999999999
999999999999999 12 13 13 13 13 13 13 13 13 13999999999999999999999999999
999999999999999999 12 12 12 13 13 13 12 12999999999999999999999999999999
```

FREQUENCY

F(1)=	0	F(6)=	0	F(11)=	4	F(16)=	0	F(21)=	0
F(2)=	0	F(7)=	0	F(12)=	32	F(17)=	0	F(22)=	0
F(3)=	0	F(8)=	0	F(13)=	141	F(18)=	0	F(23)=	0
F(4)=	0	F(9)=	0	F(14)=	363	F(19)=	0	F(24)=	0
F(5)=	0	F(10)=	0	F(15)=	0	F(20)=	0	F(25)=	0

MAX = 25.0	MIN = 0.0	DL = 1.0
TOTAL NO.= 540	MEAN = 13.10	DIV = 0.64

Table A-2 Distribution of annual mean surface albedo (%).

0	0	0	0	0	0	0	0	0	0	12	15	11	11	11	11	11	11	0	0	0	0	0	0
0	0	0	0	0	0	0	0	11	11	11	15	18	12	11	11	11	11	11	0	0	0	0	0
0	0	0	0	0	0	0	11	11	11	14	22	17	18	11	19	14	11	11	11	0	0	0	0
0	0	0	0	0	0	11	11	11	11	11	15	17	18	11	21	13	12	11	11	12	0	0	0
0	0	0	0	0	0	13	11	11	11	11	18	22	18	14	22	18	19	11	11	13	0	0	0
0	0	0	0	0	0	0	11	11	11	15	12	13	16	22	19	19	15	11	11	11	0	0	0
0	0	0	0	0	0	0	0	11	11	11	15	25	17	16	22	19	22	15	11	11	11	0	0
0	0	0	0	0	0	0	0	11	11	11	18	15	14	16	16	18	19	16	16	11	11	11	0
0	0	0	0	0	0	0	11	11	11	11	22	19	18	13	16	16	14	22	19	16	11	11	0
0	0	0	0	0	0	0	11	11	11	11	12	12	14	14	16	17	12	19	19	16	12	11	0
0	0	0	0	0	0	11	11	11	11	11	12	16	19	25	22	19	11	19	17	12	11	11	0
0	0	0	0	0	11	11	11	11	14	11	16	22	19	16	16	12	21	19	20	18	15	0	0
0	0	0	0	0	11	11	11	11	19	16	22	22	17	16	16	16	16	22	14	18	0	0	0
0	0	0	0	0	11	11	12	12	14	16	19	13	18	18	17	17	19	11	12	12	0	0	0
0	0	0	0	11	11	12	11	16	22	17	19	21	16	18	16	12	15	19	12	12	15	0	0
0	0	0	0	11	11	11	11	11	16	22	21	18	19	16	16	18	16	12	18	11	12	12	0
0	0	0	0	12	12	12	11	11	12	16	11	11	23	25	19	16	17	18	19	15	11	12	21
0	0	0	11	11	11	11	11	11	16	19	12	17	16	22	25	19	17	17	18	21	12	16	15
0	0	11	11	11	11	11	16	15	14	14	21	25	16	19	19	17	14	18	16	20	21	12	15
0	11	11	11	14	11	14	16	17	18	14	22	20	17	15	22	15	14	19	14	21	19	16	0
11	11	11	11	11	12	22	25	14	15	16	16	19	15	11	15	21	15	16	18	12	15	14	0
0	11	11	11	11	14	14	17	22	20	15	19	13	11	11	14	22	25	17	19	12	11	11	0
0	0	11	11	11	18	13	19	16	20	20	17	19	12	12	13	14	19	17	18	16	12	11	0
0	0	0	11	11	12	12	13	13	17	14	18	20	17	17	22	25	17	14	13	19	16	11	0
0	0	0	11	11	11	11	12	12	12	14	13	20	21	19	19	19	19	12	11	24	12	0	0
0	0	0	11	11	11	11	13	16	16	17	16	19	19	14	13	15	16	14	12	11	11	0	0
0	0	0	0	12	11	11	11	12	14	11	11	19	17	15	12	19	19	14	15	0	0	0	0
0	0	0	0	12	12	11	11	11	11	11	13	14	16	14	11	14	19	16	14	0	0	0	0
0	0	0	0	11	13	16	12	11	14	16	12	16	20	11	11	11	13	11	0	0	0	0	0
0	0	0	0	11	20	12	16	15	12	16	17	20	19	11	11	11	11	0	0	0	0	0	0
0	0	0	0	0	11	11	12	11	11	16	13	12	11	11	11	11	0	0	0	0	0	0	0
0	0	0	0	0	11	11	11	11	11	12	11	11	11	11	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	11	11	11	11	11	11	11	12	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	224	F(11)=	26	F(16)=	0	F(21)=	0
F(2)=	0	F(7)=	55	F(12)=	11	F(17)=	0	F(22)=	0
F(3)=	0	F(8)=	85	F(13)=	8	F(18)=	0	F(23)=	0
F(4)=	0	F(9)=	62	F(14)=	0	F(19)=	0	F(24)=	0
F(5)=	0	F(10)=	69	F(15)=	0	F(20)=	0	F(25)=	0

MAX =	50.0	MIN =	0.0	DL =	2.0
TOTAL NO.=	540	MEAN =	14.48	DIV =	3.72

Table A-3 Distribution of annual totals of total short-wave radiation (× 100 MJm^{-2} $year^{-1}$).

0	0	0	0	0	0	0	0	0	0	46	49	52	52	52	41	53	51	0	0	0	0	0	0
0	0	0	0	0	0	0	0	50	48	46	46	48	49	50	52	50	51	44	0	0	0	0	0
0	0	0	0	0	0	0	38	40	45	46	47	46	46	41	48	50	51	50	50	0	0	0	0
0	0	0	0	0	0	43	50	43	44	44	45	48	47	50	47	50	47	48	50	41	0	0	0
0	0	0	0	0	0	40	43	44	45	46	46	46	48	51	48	48	47	45	47	44	0	0	0
0	0	0	0	0	0	0	44	40	45	47	47	47	48	47	47	48	48	50	50	47	0	0	0
0	0	0	0	0	0	0	0	43	45	46	47	47	47	47	47	47	46	49	50	50	52	0	0
0	0	0	0	0	0	0	0	44	41	41	45	46	47	47	47	46	46	47	50	50	50	50	0
0	0	0	0	0	0	0	37	41	41	46	47	46	46	47	47	47	47	47	49	49	50	47	0
0	0	0	0	0	0	0	50	50	44	45	45	48	47	46	46	46	45	47	47	44	46	46	0
0	0	0	0	0	0	50	44	52	50	45	47	47	46	47	47	46	47	47	47	49	50	50	0
0	0	0	0	0	48	50	50	47	49	48	48	46	47	47	47	46	46	46	45	45	46	0	0
0	0	0	0	0	52	52	50	50	50	48	47	46	46	46	47	47	47	46	46	47	0	0	0
0	0	0	0	0	44	47	48	48	48	47	47	48	47	46	46	46	46	45	46	48	0	0	0
0	0	0	0	40	48	48	46	46	46	46	46	46	46	47	46	45	47	47	45	45	47	0	0
0	0	0	0	42	40	38	37	36	45	45	45	45	46	46	47	48	47	48	48	47	47	47	0
0	0	0	0	46	48	52	50	44	44	47	48	47	47	47	46	46	47	46	47	46	46	47	47
0	0	0	49	52	50	50	52	50	48	46	46	46	47	47	46	46	47	46	45	48	48	46	48
0	0	42	48	49	50	48	48	50	47	46	46	45	46	47	47	47	46	48	48	46	47	47	46
0	45	43	43	46	50	42	45	47	46	48	48	48	46	46	46	46	46	47	47	46	48	46	0
39	43	43	45	45	48	47	46	46	46	47	46	45	44	44	42	46	47	47	47	47	45	45	0
0	44	41	45	41	46	47	47	46	46	46	46	46	46	42	46	46	46	46	46	47	49	40	0
0	0	48	44	47	44	45	46	46	46	45	46	46	49	50	45	47	46	47	48	46	45	43	0
0	0	0	50	42	43	43	44	42	46	44	44	47	46	46	46	46	46	45	45	46	47	43	0
0	0	0	43	39	39	37	42	47	44	47	46	46	47	47	46	46	46	46	42	43	45	0	0
0	0	0	48	37	38	39	41	46	46	45	44	43	46	46	47	46	46	47	48	49	48	0	0
0	0	0	0	48	52	52	41	40	44	41	49	48	47	44	45	47	45	46	47	0	0	0	0
0	0	0	0	38	42	48	50	39	39	41	45	46	46	43	40	41	44	42	45	0	0	0	0
0	0	0	0	45	44	45	51	51	51	51	46	46	45	40	36	38	43	44	0	0	0	0	0
0	0	0	0	48	50	48	46	43	41	44	45	45	42	44	50	38	39	0	0	0	0	0	0
0	0	0	0	0	41	43	42	39	39	43	42	40	39	37	43	48	0	0	0	0	0	0	0
0	0	0	0	0	38	39	39	39	45	41	36	36	39	50	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	38	38	48	42	38	39	37	37	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	0	F(11)=	75	F(16)=	0	F(21)=	0
F(2)=	0	F(7)=	0	F(12)=	334	F(17)=	0	F(22)=	0
F(3)=	0	F(8)=	0	F(13)=	85	F(18)=	0	F(23)=	0
F(4)=	0	F(9)=	1	F(14)=	8	F(19)=	0	F(24)=	0
F(5)=	0	F(10)=	37	F(15)=	0	F(20)=	0	F(25)=	0

MAX	= 100.00	MIN	= 0.00	DLT	= 4.00
TOTAL NO.=	540	MEAN	= 45.62	DIV	= 3.20

Table A-4 Distribution of annual totals of net radiation (x 100 MJm^{-2} $year^{-1}$).

0	0	0	0	0	0	0	0	0	0	21	20	23	23	23	19	24	23	0	0	0	0	0	0
0	0	0	0	0	0	0	0	22	22	21	19	18	22	22	23	22	23	20	0	0	0	0	0
0	0	0	0	0	0	0	18	19	21	20	16	19	18	19	18	21	23	23	23	0	0	0	0
0	0	0	0	0	0	20	23	20	20	20	19	19	18	22	17	22	21	22	23	19	0	0	0
0	0	0	0	0	0	18	20	20	21	21	18	16	18	21	17	18	18	21	21	19	0	0	0
0	0	0	0	0	0	0	20	19	21	20	21	21	20	16	18	18	20	22	23	21	0	0	0
0	0	0	0	0	0	0	0	20	21	21	20	15	19	19	16	18	16	20	22	23	23	0	0
0	0	0	0	0	0	0	0	20	19	19	18	19	20	19	19	18	17	19	20	23	22	22	0
0	0	0	0	0	0	0	18	19	19	21	16	18	18	21	19	19	20	16	19	20	22	21	0
0	0	0	0	0	0	0	23	23	20	21	21	21	20	20	19	19	21	18	18	18	21	21	0
0	0	0	0	0	0	22	20	23	22	21	21	19	18	15	16	18	21	18	19	22	23	22	0
0	0	0	0	0	21	23	23	22	20	22	20	16	18	19	19	21	17	18	17	18	19	0	0
0	0	0	0	0	23	23	23	23	19	20	16	16	18	19	19	19	19	16	20	18	0	0	0
0	0	0	0	0	20	21	21	21	20	19	18	21	18	18	19	19	17	21	21	21	0	0	0
0	0	0	0	19	22	21	21	19	16	19	18	17	19	18	19	20	20	18	20	20	20	0	0
0	0	0	0	20	19	18	18	18	19	16	16	18	18	19	19	19	19	21	19	22	21	21	0
0	0	0	0	21	21	23	22	20	20	19	22	22	16	15	18	19	19	18	18	19	21	21	17
0	0	0	22	23	23	22	23	22	20	18	21	19	19	16	15	18	19	18	18	17	21	19	20
0	0	20	22	22	23	22	20	20	20	20	17	15	19	18	18	19	20	19	19	17	17	21	20
0	20	20	20	20	22	18	19	19	18	20	16	18	18	19	16	20	20	18	20	16	18	19	0
18	20	20	21	21	21	16	15	20	20	19	19	18	19	20	18	17	19	19	18	21	19	19	0
0	20	19	21	19	20	20	19	16	17	20	17	20	21	20	20	16	15	19	17	21	22	19	0
0	0	22	20	22	18	20	18	19	17	17	19	18	21	22	20	20	18	19	18	19	21	20	0
0	0	0	22	20	20	20	20	19	19	19	17	17	19	19	16	15	19	19	20	18	19	20	0
0	0	0	20	19	19	18	19	21	20	20	20	17	17	18	17	17	18	21	20	15	21	0	0
0	0	0	22	18	18	18	18	19	19	18	18	17	18	20	21	19	19	20	21	22	22	0	0
0	0	0	0	21	23	23	19	19	19	20	22	18	19	19	20	18	17	20	20	0	0	0	0
0	0	0	0	18	19	21	22	19	19	19	20	20	19	19	19	18	17	18	20	0	0	0	0
0	0	0	0	21	20	18	22	23	21	20	21	19	17	19	18	18	19	21	0	0	0	0	0
0	0	0	0	22	18	21	19	18	19	18	19	17	17	20	22	18	19	0	0	0	0	0	0
0	0	0	0	0	19	20	19	18	18	18	19	19	18	18	20	22	0	0	0	0	0	0	0
0	0	0	0	0	18	18	19	19	21	19	17	18	19	23	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	18	18	22	20	18	18	18	18	0	0	0	0	0	0	0	0	0	0

FREQUENCY

F(1)=	0	F(6)=	0	F(11)=	136	F(16)=	0	F(21)=	0
F(2)=	0	F(7)=	0	F(12)=	62	F(17)=	0	F(22)=	0
F(3)=	0	F(8)=	10	F(13)=	0	F(18)=	0	F(23)=	0
F(4)=	0	F(9)=	108	F(14)=	0	F(19)=	0	F(24)=	0
F(5)=	0	F(10)=	224	F(15)=	0	F(20)=	0	F(25)=	0

MAX =	50.00	MIN =	0.00	DLT =	2.00
TOTAL NO.=	540	MEAN =	19.49	DIV =	1.93

Table A-5-01 Estimated monthly mean actual evapotranspiration (Jan. mm month^{-1})

```
999999999999999999999999999999 13 13 18 17 16 10 17 15999999999999999999999
999999999999999999999999 15 14 13 12 11 14 16 17 15 16 12999999999999999999
999999999999999999999  8 10 13 12  9 10 10 10 10 14 16 16 15999999999999999
999999999999999999  9 14 11 12 12 11 11 12 16 10 14 14 14 15  9999999999
999999999999999999  8 10 12 13 13 11  9 11 15 10 11 11 13 14 10999999999
999999999999999999999 10 10 12 12 14 12 12  9 10 10 13 16 16 13999999999
999999999999999999999999 11 13 14 12  9 11 12  9 10  9 13 16 16 17999999
999999999999999999999999 12 11 10 11 11 11 12 11 11 10 12 13 16 16 15999
999999999999999999999  7 10 11 13  9 11 10 12 11 11 13  9 11 12 16 14999
999999999999999999999 14 15 12 13 12 13 13 12 11 10 13 10 10 10 13 13999
999999999999999999 13 11 17 15 13 13 12 10  9  9 10 14 10 11 15 16 15999
999999999999999 12 14 14 14 13 15 12  9 10 11 11 13 10 10  9 10 11999999
999999999999999 15 16 16 17 12 12  9  9 11 11 11 12 11  9 13 11999999999
999999999999999 12 14 14 14 12 11 10 13 11 11 11 11 10 13 13 14999999999
999999999999  9 14 14 14 11  9 11 10 10 11 11 11 12 12 10 12 12 13999999
999999999999 10 10  8  8  8 11  9  9 11 11 11 11 12 12 14 12 15 13 14999
999999999999 11 13 16 15 13 12 12 15 14  9  9 10 11 11 10 10 12 14 13 10
999999999 14 16 16 16 17 16 12 10 12 10 11  9  8 10 11 11 10 10 13 11 13
999999 10 14 15 16 15 12 13 11 11 10  8 11 10 10 11 11 12 12 10 10 13 12
999 10 10 11 12 16 10 10 11 11 14 10 10 10 11  9 11 11 11 12  9 11 11999
  7  9 10 12 13 14  9  8 11 12 12 11 10 11 12 10 10 11 11 11 13 11 12999
999  9  9 12 11 12 11 11  9 10 11 10 12 14 11 12  9  9 11 10 13 16 10999
999999 12 12 15  9 11 10 11 10  9 10 10 14 16 11 12 10 11 12 11 13 12999
999999999 15 11 11 11 11 11 11 11 10 10 10 11  9  8 11 11 12 10 12 12999
999999999 11  9  9  9 11 14 12 13 12 10 10 10 10 10 10 13 11  8 12999999
999999999 13  8  8  9 10 11 11 11 11  9 10 12 13 12 11 12 14 16 15999999
999999999999 13 16 16 11 10 11 11 16 11 11 11 12 10 10 11 11999999999999
999999999999  8 10 14 15 10  9 11 12 11 10 11 10 10 10 10 11999999999999
999999999999 12 11 11 16 17 15 14 12 11  9 10  8  9 11 13999999999999999
999999999999 13 11 14 11 10 10 10 10  9  9 13 15  9  999999999999999999
999999999999999 10 12 11  9 10 10 10 10  9  8 11 14999999999999999999999
999999999999999  8  9  9  9 13 10  8  8  9 16999999999999999999999999999
999999999999999999  9  8 14 11  9  9  8  899999999999999999999999999999
---------------------------------------------------------------------------
 Table A-5-01 JANUARY        MEAN =  11.6     DIV  =   2.1
---------------------------------------------------------------------------
```

Table A-5-02 Estimated monthly mean actual evapotranspiration (Feb. mm month^{-1})

```
999999999999999999999999999999 19 19 24 23 22 16 22 21999999999999999999999
999999999999999999999999 20 20 19 17 17 20 21 23 21 22 17999999999999999999
999999999999999999999 12 14 18 18 14 16 15 16 15 20 22 21 20999999999999999
999999999999999999 12 19 16 18 18 16 16 17 22 14 20 20 20 21 12999999999999
999999999999999999 10 14 17 18 19 16 14 17 21 14 17 16 19 19 14999999999999
999999999999999999999 14 14 18 18 20 19 17 14 15 16 18 22 22 18999999999
999999999999999999999999 15 18 20 17 13 16 17 14 15 13 19 22 22 22999999
999999999999999999999999 16 16 16 16 17 17 17 17 16 15 17 19 22 22 20999
999999999999999999999 10 14 16 19 14 16 16 18 17 17 19 14 17 18 22 20999
999999999999999999999 19 20 17 19 18 20 19 18 16 16 19 15 15 15 19 19999
999999999999999999 18 16 23 21 19 19 17 14 13 14 14 20 15 16 21 23 21999
999999999999999 17 19 20 20 19 21 18 13 15 16 16 19 14 15 14 15 17999999
999999999999999 21 22 21 22 17 18 14 14 16 17 16 18 17 14 18 17999999999
999999999999999 16 19 19 20 18 16 15 19 16 17 16 16 15 20·19 20999999999
999999999999 13 19 19 20 16 13 16 15 14 16 16 17 18 18 16 18 18 19999999
999999999999 15 14 13 13 13 16 14 14 16 16 17 17 17 17 20 17 21 19 20999
999999999999 16 18 21 21 18 18 17 22 21 14 12 15 16 16 15 15 17 20 19 15
999999999 19 21 22 22 24 23 17 15 19 16 17 13 12 15 16 16 15 15 20 17 18
999999 15 20 21 22 21 17 19 17 17 15 13 16 15 15 16 17 17 18 15 15 19 18
999 15 15 15 17 22 16 16 16 16 20 14 16 16 17 14 17 17 16 18 14 16 17999
 10 13 15 17 19 20 14 12 17 17 17 17 15 16 18 15 14 17 17 16 19 17 17999
999 13 13 17 16 17 17 16 13 14 17 14 18 20 17 18 14 13 16 15 19 22 15999
999999 16 17 20 14 17 15 16 15 14 16 15 20 22 17 17 15 16 17 17 19 17999
999999999 20 17 17 17 16 16 16 16 15 15 16 16 14 13 16 16 18 15 17 18999
999999999 15 14 14 14 16 20 17 19 18 14 15 15 15 15 15 19 17 11 18999999
999999999 18 12 13 14 15 17 16 16 16 14 15 18 19 17 16 18 20 22 22999999
999999999999 18 22 22 15 15 17 16 22 16 16 16 18 15 14 17 17999999999999
999999999999 13 15 20 21 15 14 16 18 17 16 16 16 15 14 15 17999999999999
999999999999 17 15 15 22 23 21 20 18 16 14 15 12 14 16 19999999999999999
999999999999 19 15 20 16 15 15 15 15 14 13 18 21 14 14999999999999999999
999999999999999 15 17 16 14 14 15 15 15 14 13 16 19999999999999999999999
999999999999999 13 14 14 14 18 15 12 12 14 22999999999999999999999999
999999999999999999 13 13 19 16 13 14 12 12999999999999999999999999999
---------------------------------------------------------------------------
 Table A-5-02 FEBRUARY       MEAN =  16.9     DIV  =   2.7
---------------------------------------------------------------------------
```

Table A-5-03 Estimated monthly mean actual evapotranspiration (Mar. mm month^{-1})

```
999999999999999999999999999999 38 37 44 42 41 33 41 39999999999999999999
999999999999999999999999 39 39 38 35 33 40 40 43 39 42 34999999999999999
999999999999999999999 27 30 37 35 28 33 31 33 32 38 42 40 38999999999999
999999999999999999 27 36 32 35 36 34 34 33 42 28 40 39 39 39 27999999999
999999999999999999 23 30 34 36 38 32 28 33 39 28 33 31 38 37 29999999999
999999999999999999999 30 30 36 34 39 38 36 28 31 32 36 42 41 35999999999
999999999999999999999999 32 36 39 35 25 34 33 28 32 28 37 42 40 41999999
999999999999999999999999 33 33 34 32 34 37 34 35 32 30 35 37 42 42 39999
999999999999999999999 24 30 33 38 28 31 32 38 34 35 37 29 33 35 42 38999
999999999999999999999 36 38 35 38 38 40 37 35 34 33 38 31 31 32 39 38999
999999999999999999 35 33 42 41 37 39 34 30 25 29 30 40 30 34 41 43 41999
999999999999999 34 37 38 38 37 41 35 27 31 34 35 39 29 32 30 31 34999999
999999999999999 40 41 40 41 33 36 28 28 32 34 34 35 35 28 36 33999999999
999999999999999 34 38 38 40 37 35 31 39 33 33 34 34 31 39 39 40999999999
999999999999 29 37 36 39 34 27 33 31 28 34 33 34 38 36 32 38 37 36999999
999999999999 32 31 29 29 29 34 28 29 32 32 35 35 34 36 41 34 41 39 39999
999999999999 32 35 39 39 36 37 36 42 41 27 25 31 34 34 32 32 35 40 39 30
999999999 38 40 40 42 44 42 35 31 38 33 35 27 24 31 34 33 31 30 40 35 35
999999 32 39 40 42 41 35 37 37 36 29 26 34 31 30 34 37 33 35 31 30 40 36
999 31 32 33 34 41 32 33 34 32 38 29 32 33 35 28 36 37 32 37 28 32 35999
 23 28 32 35 37 40 28 25 36 35 35 35 31 33 38 32 29 35 35 32 39 35 34999
999 28 29 34 33 35 37 34 27 28 35 30 38 39 36 36 29 27 34 31 39 43 33999
999999 34 34 39 29 36 31 34 30 29 32 31 41 43 36 37 30 34 34 35 38 36999
999999999 39 35 36 36 35 34 32 34 29 31 33 34 29 25 34 35 36 31 35 37999
999999999 33 31 32 31 34 38 36 37 37 29 29 32 30 30 32 39 36 24 38999999
999999999 36 28 29 31 30 34 34 33 32 28 32 37 38 34 34 37 40 42 42999999
999999999999 35 41 41 32 33 34 35 42 31 34 33 38 31 30 36 36999999999999
999999999999 28 32 39 40 32 32 34 35 37 34 33 34 31 29 30 35999999999999
999999999999 35 32 30 41 44 40 38 38 34 29 32 29 31 34 38999999999999999
999999999999 37 30 38 33 32 33 32 33 28 28 36 40 31 31999999999999999999
999999999999999 32 35 33 31 31 32 32 33 31 30 33 38999999999999999999999
999999999999999 28 30 31 31 36 33 29 29 31 41999999999999999999999999999
999999999999999999 29 29 38 33 30 30 27 27999999999999999999999999999999
------------------------------------------------------------------------
 Table A-5-03 MARCH          MEAN =  34.3     DIV  =   4.2
------------------------------------------------------------------------
```

Table A-5-04 Estimated monthly mean actual evapotranspiration (Apr. mm month^{-1})

```
999999999999999999999999999999 61 57 64 62 61 56 60 60999999999999999999
999999999999999999999999 60 61 61 55 51 62 61 62 61 63 56999999999999999
999999999999999999999 49 51 59 56 44 53 50 56 49 57 64 60 59999999999999
999999999999999999 49 56 53 57 60 55 54 51 63 43 61 62 61 60 48999999999
999999999999999999 44 50 55 59 61 50 45 51 59 43 51 49 60 58 50999999999
999999999999999999999 51 51 58 54 61 61 56 44 49 50 56 64 62 56999999999
999999999999999999999999 52 58 62 55 39 53 53 43 50 43 57 63 61 61999999
999999999999999999999999 55 55 58 50 55 59 54 56 51 47 55 55 63 63 61999
999999999999999999999 47 52 55 61 44 49 50 61 54 54 58 44 50 54 64 59999
999999999999999999999 55 58 57 60 61 62 57 56 55 53 62 49 49 53 61 61999
999999999999999999 57 54 61 62 59 62 54 47 39 46 47 63 47 53 63 65 62999
999999999999999 55 57 59 59 57 63 55 42 49 55 55 62 45 50 47 50 54999999
999999999999999 60 61 62 61 50 56 44 45 52 54 54 55 55 44 57 52999999999
999999999999999 55 60 59 62 58 55 49 61 51 52 53 53 50 63 62 62999999999
999999999999 52 58 58 62 54 43 53 50 44 55 51 54 61 57 50 61 60 57999999
999999999999 55 54 53 52 53 54 45 46 51 49 56 55 51 56 64 52 64 62 62999
999999999999 55 57 60 60 58 60 56 65 64 42 38 49 55 54 51 50 56 64 62 46
999999999 59 61 60 64 64 64 55 50 62 53 55 42 37 49 53 52 50 46 62 55 55
999999 54 61 62 62 63 55 56 59 57 46 40 54 49 48 54 60 51 55 49 46 62 57
999 52 54 55 54 63 54 54 54 51 59 44 49 53 55 44 57 60 50 59 44 50 55999
 43 50 54 57 60 62 44 39 58 56 56 56 49 54 61 53 45 55 55 49 62 56 55999
999 49 51 56 56 56 59 53 42 44 56 47 60 62 60 57 46 41 53 49 62 65 57999
999999 55 55 60 48 59 48 55 47 45 52 50 63 65 59 60 48 54 53 55 62 59999
999999999 60 57 59 60 58 56 51 54 48 49 53 53 45 39 54 57 59 49 55 60999
999999999 55 54 55 55 58 61 59 58 59 46 45 50 48 48 50 61 60 39 61999999
999999999 58 51 52 54 52 54 54 52 51 47 50 59 61 54 55 59 63 64 65999999
999999999999 56 62 62 55 56 55 59 65 47 54 54 61 49 48 58 57999999999999
999999999999 50 55 61 62 56 56 58 57 59 54 54 57 52 48 50 58999999999999
999999999999 57 53 49 63 65 59 56 61 55 47 55 52 55 57 61999999999999999
999999999999 58 45 60 53 53 57 52 52 45 46 58 61 54 55999999999999999999
999999999999999 55 58 57 55 54 52 55 57 54 54 56 59999999999999999999999
999999999999999 51 53 54 54 58 56 53 53 54 62999999999999999999999999999
999999999999999999 53 52 59 56 53 53 50 50999999999999999999999999999999
------------------------------------------------------------------------
 Table A-5-04 APRIL          MEAN =  54.8     DIV  =   5.7
------------------------------------------------------------------------
```

Table A-5-05 Estimated monthly mean actual evapotranspiration (May mm month^{-1})

```
9999999999999999999999999999999102 95103101 99 97 96 98999999999999999999
999999999999999999999999 99100102 94 87101100 99100102 9499999999999999
999999999999999999999 87 89 99 94 77 90 85 97 84 94104 97 96999999999999
999999999999999999 86 91 91 97101 93 90 87104 75101102101 98 85999999999
999999999999999999 79 86 94 99102 87 79 87 97 75 87 84101 97 85999999999
999999999999999999999 88 89 97 92102101 94 77 83 86 93105100 93999999999
999999999999999999999999 89 98104 93 69 90 91 75 86 75 95103 99 99999999
999999999999999999999999 93 94 99 87 95 99 93 95 87 81 93 93102103100999
999999999999999999999 84 90 94102 76 85 87102 92 92 97 77 85 91104 98999
999999999999999999999 90 95 96101102103 96 96 93 90104 84 83 91103102999
999999999999999999 94 92 99102100102 92 81 69 80 81105 81 90104106102999
999999999999999 92 94 96 97 95104 92 74 84 93 93104 78 86 83 86 92999999
999999999999999 97 99101 99 84 94 77 79 89 92 91 94 92 77 97 89999999999
999999999999999 93101 98102 97 93 84102 88 89 90 90 86106104103999999999
999999999999 91 96 97103 92 75 90 86 77 93 88 92102 96 86103102 96999999
999999999999 94 94 93 92 94 93 79 80 88 85 95 93 87 95105 89106103103999
999999999999 93 94 97 98 98101 94107107 73 67 84 93 90 87 86 95106103 81
999999999 98 99 98104104105 92 86103 90 93 73 65 84 90 90 90 82104 94 92
999999 93101101101105 91 93 99 97 81 73 92 84 81 91100 87 96 85 81104 96
999 89 93 95 92103 93 93 90 87 98 78 84 90 93 77 96100 86100 76 86 94999
 78 88 93 97100102 76 70 98 96 94 94 85 92104 92 78 93 92 84104 95 94999
999 85 88 95 95 95 99 90 73 77 95 81101103102 96 80 74 90 84104107 99999
999999 93 94 99 83 99 83 93 82 78 88 86104106100100 82 91 90 94104100999
999999999 99 98100102 98 97 87 93 85 84 90 90 80 69 90 96100 85 93102999
999999999 94 94 97 96 99101100 97100 79 79 86 83 83 85103102 71103999999
999999999 97 90 92 94 91 91 92 90 88 82 86 99102 91 93100103106107999999
999999999999 94101100 94 97 95101106 81 90 93102 84 83 98 96999999999999
999999999999 89 94101102 97 97 99 96 99 92 92 99 91 84 88 98999999999999
999999999999 96 92 85103106 97 93101 93 83 94 93 96 97103999999999999999
999999999999 97 77100 91 92 97 90 89 78 81 97100 94 96999999999999999999
999999999999999 96 99 98 95 95 91 95 98 94 95 95 98999999999999999999999
999999999999999 90 93 95 94 98 97 93 93 94100999999999999999999999999999
999999999999999999 92 92 98 97 93 93 90 89999999999999999999999999999999
--------------------------------------------------------------------------
 Table A-5-05 MAY              MEAN =  92.9     DIV  =   8.1
--------------------------------------------------------------------------
```

Table A-5-06 Estimated monthly mean actual evapotranspiration (June mm month^{-1})

```
999999999999999999999999999999 83 78 80 79 77 80 75 77999999999999999999
999999999999999999999999 78 80 83 77 71 83 79 77 79 80 76999999999999999
999999999999999999999 72 73 80 77 64 76 71 80 70 75 82 76 75999999999999
999999999999999999 69 71 73 78 82 77 76 71 82 61 84 83 80 77 69999999999
999999999999999999 63 69 75 79 82 71 66 72 78 62 72 69 81 77 68999999999
999999999999999999999 70 73 79 75 82 85 79 64 70 72 76 83 79 73999999999
999999999999999999999999 72 79 84 76 57 77 74 63 73 63 78 82 78 77999999
999999999999999999999999 75 78 82 72 80 85 76 79 73 67 78 74 81 82 79999
999999999999999999999 70 74 77 82 64 70 72 86 76 77 79 64 70 75 83 78999
999999999999999999999 70 74 77 82 84 85 78 79 79 76 85 70 70 77 84 82999
999999999999999999 74 74 77 81 81 85 75 69 57 67 68 85 69 77 84 84 81999
999999999999999 73 73 75 77 77 83 75 62 71 79 79 86 65 73 69 72 76999999
999999999999999 76 77 79 78 69 78 65 66 74 77 76 77 77 65 79 72999999999
999999999999999 75 80 79 83 82 79 71 86 73 73 77 77 72 86 85 83999999999
999999999999 75 76 77 83 77 62 77 73 64 79 73 77 85 79 72 85 84 78999999
999999999999 77 77 77 77 79 78 66 66 72 70 79 79 71 79 86 73 86 84 84999
999999999999 74 75 75 77 79 83 79 86 86 61 56 71 79 77 73 73 79 86 85 66
999999999 77 77 77 83 81 83 76 72 86 77 79 61 54 71 77 74 75 68 86 79 75
999999 76 80 80 80 84 76 76 85 83 67 61 76 71 69 77 86 71 78 70 66 86 78
999 71 76 77 74 82 76 78 77 73 79 64 70 76 77 64 82 86 71 83 63 71 79999
 63 71 75 78 81 83 63 59 83 80 79 79 71 76 85 77 65 78 77 70 86 79 77999
999 68 72 77 78 79 85 77 61 64 80 69 85 83 83 78 67 61 77 71 86 85 82999
999999 73 75 79 70 84 70 79 68 66 74 73 86 85 85 86 69 77 73 79 85 82999
999999999 78 80 83 84 84 81 73 76 71 70 77 77 67 58 77 82 83 71 76 83999
999999999 77 78 80 80 81 81 82 78 84 66 65 73 68 68 71 85 84 60 85999999
999999999 77 76 77 78 74 75 78 75 73 69 73 83 83 74 79 83 84 85 85999999
999999999999 75 79 78 77 81 78 83 85 66 77 77 84 71 71 83 82999999999999
999999999999 74 77 81 80 81 81 82 79 85 79 76 82 75 70 73 83999999999999
999999999999 77 75 69 81 84 78 74 84 79 69 78 78 80 81 84999999999999999
999999999999 77 62 80 76 77 83 76 76 66 69 79 79 78 80999999999999999999
999999999999999 78 80 80 79 78 75 80 82 78 79 78 78999999999999999999999
999999999999999 75 77 79 78 79 80 78 78 78 79999999999999999999999999999
999999999999999999 77 76 78 79 77 77 74 74999999999999999999999999999999
--------------------------------------------------------------------------
 Table A-5-06 JUNE              MEAN =  76.3     DIV  =   6.1
--------------------------------------------------------------------------
```

Table A-5-07 Estimated monthly mean actual evapotranspiration (July mm month^{-1})

```
999999999999999999999999999999999103 95101 99 97100 95 97999999999999999
999999999999999999999999 99101103 94 86101 99 98 99100 96999999999999999
999999999999999999999 91 93100 95 76 91 85100 84 93103 97 96999999999999
999999999999999999 88 91 93 98102 94 91 87103 74101103101 98 87999999999
999999999999999999 81 89 95100102 87 78 86 96 74 87 83102 97 87999999999
999999999999999999999 90 93 99 93102102 95 77 83 86 93104100 93999999999
999999999999999999999999 92 99104 93 68 91 91 75 86 74 95102 98 98999999
999999999999999999999999 95 98102 87 97101 93 95 87 81 94 92101102100999
999999999999999999999 89 94 97103 76 85 88103 93 92 97 76 84 91104 98999
999999999999999999999 90 95 97102104104 96 97 94 91105 84 83 93104102999
999999999999999999 94 94 98102101103 92 81 68 79 81105 81 91104105102999
999999999999999 93 94 96 98 95104 92 74 84 93 94105 78 86 83 86 92999999
999999999999999 96 97100 99 83 94 77 79 90 93 91 94 92 77 97 88999999999
999999999999999 95101 99103 98 93 84103 87 89 91 91 86106105103999999999
999999999999 95 97 96104 93 74 91 86 77 94 88 92104 96 86104103 96999999
999999999999 97 97 97 97 99 94 78 80 88 85 95 94 86 95106 88106104103999
999999999999 93 94 95 97100103 95107107 73 66 84 94 91 87 86 96107104 80
999999999 98 98 98104102104 92 86104 91 94 73 64 84 91 90 92 82104 94 93
999999 95101101101105 91 92101 99 80 72 93 84 82 91102 86 96 85 80104 96
999 91 96 97 92103 94 94 91 87 98 77 84 91 94 77 98102 85101 76 85 95999
 82 90 95 98101102 75 70 99 97 95 95 85 93105 94 78 94 93 84104 96 94999
999 87 91 97 98 97101 91 72 78 97 82102104104 96 79 73 91 84104106102999
999999 93 95100 85101 83 93 82 79 89 86104105102102 82 91 89 95105102999
999999999 99100102103101100 88 94 87 84 91 91 79 68 91 98101 85 93104999
999999999 97 97100100101101101 97101 80 78 86 83 83 85104104 72105999999
999999999 97 95 96 98 93 91 93 91 90 84 86101102 91 94101104105106999999
999999999999 95 99 98 97100 96103105 81 91 94104 84 84100 98999999999999
999999999999 93 97101101101101102 98101 93 94102 93 85 90100999999999999
999999999999 97 94 86101105 96 92102 94 83 97 98100100104999999999999999
999999999999 97 77100 91 94101 91 91 79 83 99 99 98100999999999999999999
999999999999999 98100100 99 98 92 98101 98 99 97999999999999999999999999
999999999999999 94 96 98 98100100 98 98 98999999999999999999999999999999
999999999999999999 96 96 98 99 97 97 94 93999999999999999999999999999999
------------------------------------------------------------------------
 Table A-5-07 JULY           MEAN =  93.7     DIV  =   8.4
------------------------------------------------------------------------
```

Table A-5-08 Estimated monthly mean actual evapotranspiration (Aug. mm month^{-1})

```
999999999999999999999999999999103 95109106105104104105999999999999999999
999999999999999999999999106107108 94 85 99106107106108102999999999999999
999999999999999999999 95 98106 99 74 82 84103 79 98110105103999999999999
999999999999999999 94100 99104107 93 82 90109 76 93104107105 92999999999
999999999999999999 86 95101105107 90 76 86101 73 86 82107103 92999999999
999999999999999999999 96 98104 97107 94 90 75 78 81 93110107100999999999
999999999999999999999999 98105109 92 69 82 94 73 81 73 95109106106999999
999999999999999999999999101102106 90 92 89 96 90 86 83 89 95108109106999
999999999999999999999 93 98102108 74 87 86 94 92 88101 75 84 91110105999
999999999999999999999 99103103107104100100 96 85 82105 79 78 88104107999
999999999999999999101100106108106 99 91 76 69 77 76110 77 82105111108999
999999999999999 99102103104 99109 91 72 79 85 85105 80 81 81 85 92999999
999999999999999104106107107 83 90 75 77 93 92 86 97 88 75101 91999999999
999999999999999101106104104 90 85 79 94 86 91 83 83 80111105108999999999
999999999999 99103102109 88 72 82 81 79 85 86 88 99 96 81104103 99999999
999999999999101101100100102 89 76 81 91 87 90 85 89 90106 91111104104999
999999999999 98100102104105103 90112111 74 67 79 85 83 86 81 95111100 82
999999999104106105110110110 87 81100 82 85 71 65 79 83 93 95 84100 90 96
999999100107107108110 87 93 88 90 82 73 92 79 77 83 89 89100 87 82100 99
999 97101101 96109 97 89 82 86102 78 82 85 93 78 89 89 84 96 77 84 90999
 87 96100104106103 74 66 90 92 90 90 83 92109 93 80 89 88 83100 95 98999
999 94 96102103 96 88 82 71 80 92 77 94109107100 77 74 83 79100112105999
999999100101106 84 93 78 84 80 77 84 81100106 93 89 77 83 92 90105107999
999999999106105102103 92 99 87 97 89 83 83 83 77 69 83 90101 84 91108999
999999999101101104103104105101101 93 78 80 81 85 85 84 99108 72104999999
999999999104 98100101 97 90 84 89 93 86 81 96102 95 85 96105111112999999
999999999999101107106101100 99107111 83 83 97104 79 79 91 89999999999999
999999999999 97101107107104104105 98 89 84 97105 95 87 92 95999999999999
999999999999103 98 88107111101 96 98 85 82101100103 99108999999999999999
999999999999104 79105 87 93 96 86 82 77 81104105102103999999999999999999
999999999999999102105103102102 95 97100101102102105999999999999999999999
999999999999999 98100102102105103101101101107999999999999999999999999999
999999999999999999100100105103100101 97 96999999999999999999999999999999
------------------------------------------------------------------------
 Table A-5-08 AUGUST         MEAN =  94.3     DIV  =  10.8
------------------------------------------------------------------------
```

Table A-5-09 Estimated monthly mean actual evapotranspiration (Sep. mm month^{-1})

```
999999999999999999999999999999 64 60 68 66 65 62 65 64999999999999999999
999999999999999999999999 65 65 66 58 54 63 65 67 65 67 61999999999999999
999999999999999999999 55 57 64 60 46 53 53 61 51 61 68 65 63999999999999
999999999999999999 54 61 59 63 64 58 53 55 67 47 61 64 65 65 53999999999
999999999999999999 49 56 61 63 65 55 48 54 63 45 54 51 65 63 54999999999
999999999999999999999 57 57 63 59 65 61 57 47 50 52 58 68 66 61999999999
999999999999999999999999 58 63 66 57 42 53 57 45 52 45 59 67 66 66999999
999999999999999999999999 60 61 63 55 58 58 59 57 54 51 57 59 67 67 65999
999999999999999999999 53 58 61 65 46 54 54 61 57 56 62 47 52 57 68 64999
999999999999999999999 61 63 62 65 64 63 61 60 55 53 65 50 50 55 64 65999
999999999999999999 61 60 66 66 64 63 57 48 42 49 48 67 49 53 66 69 66999
999999999999999 59 63 63 64 61 67 57 45 50 55 55 65 49 52 50 53 57999999
999999999999999 64 65 66 66 52 57 47 48 57 57 55 60 56 47 62 56999999999
999999999999999 60 64 64 65 58 55 50 61 54 56 53 53 51 67 65 66999999999
999999999999 57 63 62 66 56 45 53 52 48 55 54 56 63 60 52 64 63 61999999
999999999999 59 59 58 58 59 56 48 50 55 53 57 55 55 58 66 56 68 64 64999
999999999999 58 61 63 64 64 63 57 69 68 45 41 50 55 54 54 52 59 68 63 50
999999999 63 65 65 68 68 68 56 52 63 53 55 44 40 50 53 57 57 52 63 57 59
999999 59 65 66 67 67 56 58 58 58 50 45 57 50 49 54 59 55 61 54 50 64 61
999 57 59 60 58 67 59 56 53 54 62 48 51 54 58 48 57 59 53 61 47 53 57999
 50 56 59 62 64 64 46 41 58 58 57 57 52 57 66 57 49 57 56 52 63 59 59999
999 55 56 61 61 60 58 53 44 48 58 48 60 66 64 61 49 46 54 50 63 69 63999
999999 60 61 65 51 59 50 55 50 48 53 52 64 67 60 59 49 54 57 57 65 64999
999999999 65 63 63 63 59 60 54 58 54 52 53 54 49 43 54 58 62 52 57 65999
999999999 60 60 61 61 62 64 62 62 60 48 49 52 52 52 52 63 65 43 64999999
999999999 62 57 58 60 58 56 55 55 56 52 52 61 64 58 55 61 65 68 68999999
999999999999 61 66 66 60 60 60 64 69 51 54 59 64 50 50 59 58999999999999
999999999999 56 60 65 66 61 61 63 60 58 55 59 63 57 53 55 60999999999999
999999999999 61 58 53 66 69 63 59 62 55 51 61 58 61 61 66999999999999999
999999999999 63 48 64 55 57 59 54 53 48 50 63 65 60 61999999999999999999
999999999999999 61 63 62 60 60 57 59 61 60 60 61 64999999999999999999999
999999999999999 57 59 60 60 63 61 59 59 60 66999999999999999999999999999
999999999999999999 58 58 64 61 58 59 56 56999999999999999999999999999999
------------------------------------------------------------------------
 Table A-5-09 SEPTEMBER       MEAN =  58.1      DIV  =   6.1
------------------------------------------------------------------------
```

Table A-5-10 Estimated monthly mean actual evapotranspiration (Oct. mm month^{-1})

```
999999999999999999999999999999 33 31 39 36 36 31 37 35999999999999999999
999999999999999999999999 35 35 35 30 27 34 35 38 35 37 32999999999999999
999999999999999999999 26 28 33 31 23 27 26 31 25 33 37 36 35999999999999
999999999999999999 26 34 31 33 33 29 27 28 37 23 32 34 35 35 25999999999
999999999999999999 22 28 31 33 34 28 24 27 34 22 27 26 34 33 26999999999
999999999999999999999 29 28 33 31 35 32 29 23 25 26 30 37 37 32999999999
999999999999999999999999 30 33 35 30 20 27 29 22 26 22 31 37 36 37999999
999999999999999999999999 31 31 32 28 29 30 30 29 27 26 29 31 37 37 35999
999999999999999999999 24 29 31 35 23 27 27 31 29 28 32 23 27 30 37 35999
999999999999999999999 34 35 32 34 33 33 32 31 28 27 34 25 25 28 34 34999
999999999999999999 33 31 37 36 34 33 29 24 21 24 24 35 24 27 35 38 36999
999999999999999 31 34 35 34 32 36 29 22 25 28 28 34 24 26 25 26 29999999
999999999999999 36 37 36 37 27 30 23 24 29 29 28 31 28 23 32 29999999999
999999999999999 31 34 34 34 30 28 25 32 27 29 27 27 26 35 34 35999999999
999999999999 28 34 32 35 28 22 27 26 24 28 27 28 32 31 26 33 32 31999999
999999999999 30 29 28 28 29 28 23 25 28 27 29 28 28 29 35 29 36 33 34999
999999999999 29 32 34 35 33 33 29 37 36 22 20 25 28 27 27 26 30 36 33 25
999999999 34 36 36 37 38 37 29 26 33 27 28 22 19 25 27 29 29 26 33 29 31
999999 30 35 36 37 36 29 31 30 30 25 22 29 25 24 27 30 28 32 27 25 33 31
999 29 30 30 30 37 30 28 27 27 33 24 26 27 30 23 29 30 27 32 23 27 29999
 23 27 30 32 34 34 23 20 30 30 29 29 26 29 34 29 24 29 29 26 33 30 30999
999 28 28 32 31 31 30 27 22 24 30 24 31 35 33 32 24 22 27 25 33 37 31999
999999 31 31 35 25 30 25 28 25 24 27 26 34 36 31 30 24 27 29 29 34 33999
999999999 35 32 32 32 30 30 27 30 27 26 27 27 24 21 27 29 32 26 29 34999
999999999 30 29 30 30 31 33 32 32 31 24 25 26 26 26 26 33 33 21 33999999
999999999 33 27 28 29 28 28 28 28 28 26 26 31 33 30 28 32 35 37 37999999
999999999999 32 37 36 30 30 31 32 37 26 27 30 33 25 25 30 29999999999999
999999999999 27 30 34 35 31 30 32 31 30 27 30 32 29 26 28 31999999999999
999999999999 32 29 26 35 38 34 32 32 28 25 30 28 30 31 34999999999999999
999999999999 33 24 33 27 28 29 27 26 24 24 33 35 30 30999999999999999999
999999999999999 30 32 30 29 29 29 29 30 29 29 30 34999999999999999999999
999999999999999 28 29 29 30 33 30 28 28 29 37999999999999999999999999999
999999999999999999 28 28 34 31 28 29 26 26999999999999999999999999999999
------------------------------------------------------------------------
 Table A-5-10 OCTOBER         MEAN =  29.8      DIV  =   4.1
------------------------------------------------------------------------
```

Table A-5-11 Estimated monthly mean actual evapotranspiration (Nov. mm month^{-1})

```
9999999999999999999999999999 14 13 18 17 17 12 18 169999999999999999
99999999999999999999999 16 15 15 12 11 15 16 18 16 17 1399999999999999
99999999999999999999  9 11 14 13  9 11 10 12 10 14 17 17 16999999999999
999999999999999999 10 16 13 14 14 12 11 11 17  9 14 15 15 16   999999999
999999999999999999  8 11 13 14 15 11  9 11 15  9 11 10 15 15 1199999999
99999999999999999999 11 11 14 13 15 14 12  9 10 10 13 17 17 1499999999
999999999999999999999999 12 14 15 13  7 11 12  9 10  9 13 17 17 18999999
999999999999999999999999 13 12 13 11 12 13 12 12 11 10 12 13 17 17 16999
99999999999999999999  8 11 12 15  9 11 11 14 12 12 14  9 11 13 17 16999
99999999999999999999 16 16 14 15 14 15 14 13 11 11 14 10 10 11 15 15999
999999999999999999 15 13 18 16 15 14 12 10  7  9 10 15 10 11 16 17 16999
999999999999999 13 16 16 15 14 16 12  8 10 11 11 15  9 10 10 10 12999999
999999999999999 17 17 17 17 11 12  9  9 12 12 12 13 12  9 13 11999999999
999999999999999 13 15 15 15 13 11 10 14 11 11 11 11 10 15 14 16999999999
999999999999 10 15 14 15 12  8 11 10  9 11 11 12 14 13 10 14 14 13999999
999999999999 12 11 10 10 11 12  9  9 11 11 12 12 12 12 15 12 16 15 15999
999999999999 12 14 16 16 14 14 12 16 16  9  7 10 11 11 11 10 13 16 14  9
999999999 15 17 17 17 18 17 12 10 14 11 12  9  7 10 11 12 10  9 15 12 13
999999 12 15 16 17 16 12 13 13 12  9  7 12 10 10 11 13 12 12 10  9 15 13
999 12 12 12 12 17 12 11 11 11 14  9 10 11 12  9 12 13 11 13  9 11 12999
  8 10 12 14 14 15  9  7 13 13 12 12 10 12 14 11  9 12 12 11 14 12 13999
999 11 10 13 13 13 13 11  8 10 13 10 13 15 13 13  9  8 11 10 14 17 12999
999999 13 13 16 10 13 10 11 10  9 11 10 15 16 13 13 10 11 12 12 14 14999
999999999 16 13 13 13 12 12 11 12 11 10 11 11  9  8 11 12 14 10 12 14999
999999999 12 11 11 11 13 15 13 14 13 10  9 10 10 10 11 14 14  7 14999999
999999999 14 10 10 11 11 12 11 11 12 10 10 13 15 13 11 14 15 17 17999999
999999999999 14 17 17 12 12 12 13 17 11 11 12 14 10 10 13 13999999999999
999999999999 10 12 15 16 12 12 13 13 13 11 12 13 11 10 11 13999999999999
999999999999 13 12 11 16 18 15 14 14 11 10 12 10 11 13 1499999999999999
999999999999 15 10 15 11 11 12 11 11  9  9 14 16 11 11999999999999999999
999999999999999 12 13 12 11 11 12 12 12 11 11 12 1599999999999999999999
999999999999999 10 11 11 11 14 12 10 10 11 179999999999999999999999999
999999999999999999 10 10 15 12 10 11  9  99999999999999999999999999999
----------------------------------------------------------------------
 Table A-5-11 NOVENBER          MEAN =  12.4      DIV  =    2.5
----------------------------------------------------------------------
```

Table A-5-12 Estimated monthly mean actual evapotranspiration (Dec. mm month^{-1})

```
9999999999999999999999999999  9  9 13 12 12  7 12 119999999999999999
99999999999999999999999 10 10  9  8  7 10 11 13 11 12   899999999999999
99999999999999999999  5  6  9  8  6  7  6  7  7 10 12 12 11999999999999
999999999999999999  5 10  8  8  8  7  7  7 11  6 10  9 10 11   6999999999
999999999999999999  5  7  8  9  9  7  5  7 10  6  7  7  9 10   7999999999
99999999999999999999  7  6  8  8 10  9  8  6  6  7  9 11 11   9999999999
999999999999999999999999  7  9  9  8  5  7  8  6  6  6  9 11 11 12999999
999999999999999999999999  8  7  7  7  8  8  8  8  7  6  8  9 12 11 11999
99999999999999999999  4  6  7  9  6  7  7  8  8  8  8  6  7  8 11 10999
99999999999999999999 11 11  8  9  8  9  9  8  7  7  9  6  6  7  9  9999
999999999999999999  9  8 12 11  9  9  8  6  5  6  6 10  6  7 10 12 11999
999999999999999  9 11 11 10  9 10  8  5  6  7  7  9  6  6  6  6  8999999
999999999999999 11 12 11 12  7  8  6  5  7  7  8  8  8  5  8   7999999999
999999999999999  8  9 10 10  8  7  6  9  7  7  7  7  6  9  9 10999999999
999999999999  5 10 10  9  7  6  7  6  6  7  7  7  8  8  7  8  8  9999999
999999999999  6  6  5  5  5  7  5  6  7  7  8  7  8  8 10  8 10  9  9999
999999999999  8  9 12 11  9  8  8 10 10  6  5  6  7  7  6  6  8 10  9  6
999999999 10 11 12 11 13 11  8  6  9  7  7  6  5  6  7  7  6  6  9  7  8
999999  7 10 10 12 10  8  9  8  8  6  5  7  6  6  7  8  8  8  6  6  9  8
999  7  7  7  8 11  7  7  7  7  9  6  6  7  8  5  8  8  7  8  6  7  7999
  4  6  7  8  9 10  6  5  8  8  8  7  6  7  8  6  6  8  8  7  9  8  8999
999  6  6  8  7  8  8  7  6  6  8  6  8  9  7  8  6  5  7  6  9 11  6999
999999  8  8 10  6  7  6  7  6  6  7  6 10 11  8  8  6  7  7  7  9  8999
999999999 11  8  8  8  7  7  7  7  6  6  7  7  5  5  7  7  8  7  8  8999
999999999  7  6  6  5  7 10  8  9  8  6  6  6  7  6  7  9  8  4  8999999
999999999  9  4  5  6  7  8  7  7  7  6  6  8  9  8  7  9 10 11 11999999
999999999999  9 12 12  7  6  7  7 11  7  7  7  8  7  6  8  8999999999999
999999999999  5  7 10 11  6  6  7  8  8  7  7  7  6  6  6  8999999999999
999999999999  8  7  7 11 12 10  9  9  7  6  7  4  6  7  9999999999999999
999999999999  9  6 10  7  6  6  7  7  6  5  9 11  6  6999999999999999999
999999999999999  6  8  7  6  6  7  7  6  6  5  7 109999999999999999999999
999999999999999  5  6  6  6  9  7  5  5  6 12999999999999999999999999999
999999999999999999  5  5 10  7  5  6  5  59999999999999999999999999999999
----------------------------------------------------------------------
 Table A-5-12 DECEMBER          MEAN =   7.7      DIV  =    1.9
----------------------------------------------------------------------
```

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