PHILIPPINE NATIONAL STANDARD

PNS/BAFS/PAES 217:2017
ICS 65.060.35

Determination of Irrigation Water Requirements

DEPARTMENT OF AGRICULTURE PHILIPPINES

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Foreword

The formulation of this national standard was initiated by the Agricultural Machinery Testing and Evaluation Center (AMTEC) under the project entitled "Enhancement of Nutrient and Water Use Efficiency Through Standardization of Engineering Support Systems for Precision Farming" funded by the Philippine Council for Agriculture, Aquaculture and Forestry and Natural Resources Research and Development - Department of Science and Technology (PCAARRD - DOST).

As provided by the Republic Act 10601 also known as the Agricultural and Fisheries Mechanization Law (AFMech Law of 2013), the Bureau of Agriculture and Fisheries Standards (BAFS) is mandated to develop standard specifications and test procedures for agricultural and fisheries machinery and equipment. Consistent with its standards development process, BAFS has endorsed this standard for the approval of the DA Secretary through the Bureau of Agricultural and Fisheries Engineering (BAFE) and to the Bureau of Philippine Standards (BPS) for appropriate numbering and inclusion to the Philippine National Standard (PNS) repository.

This standard has been technically prepared in accordance with BPS Directives Part 3:2003 – Rules for the Structure and Drafting of International Standards.

The word "shall" is used to indicate mandatory requirements to conform to the standard.

The word "should" is used to indicate that among several possibilities one is recommended as particularly suitable without mentioning or excluding others.

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ANNEXES

Determination of Irrigation Water Requirements

1 Scope

This standard provides guidelines and minimum requirements in calculating irrigation water requirements to meet the required performance standards.

2 References

The following normative documents contain provisions, which, through reference in this text, constitute provisions of this National Standard:

ASTM D 422	Standard Test Method for Particle-Size Analysis of Soils
PNS/BAFS/PAES 219:2017	Conveyance Systems Performance Evaluation of Open Channels – Determination of Seepage and Percolation by Ponding Method
PNS/BAFS/PAES 220:2017	Conveyance Systems Performance Evaluation of Open Channels – Determination of Seepage and Percolation by Inflow-Outflow Method

3 Definitions

For the purpose of this standard, the following terms shall apply:

3.1
actual crop evapotranspiration
ET_a
rate of evapotranspiration equal to or smaller than predicted ET_{crop} as affected by the level of available soil water, salinity, field size or other causes

3.2
application efficiency
E_a
ratio of the average depth of irrigation water infiltrated and stored in the root zone to the average depth of irrigation water applied

3.3
conveyance efficiency
E_c
ratio between water received at the inlet for a block of fields to that released at the project's headwork

3.4
crop coefficient
k_c
ratio of the actual crop evpotranspiration to its potential evapotranspiration

3.5
crop evapotranspiration
rate of evapotranspiration of a disease-free crop growing in a large field (one or more ha) under optimal soil conditions, including sufficient water and fertilizer and achieving full production potential of that crop under the given growing environment; includes water loss through transpiration by the vegetation, and vaporation from the soil surface and wet leaves

3.6
cropping pattern
sequence of different crops grown in regular order on any particular field or fields

3.7
crop water requirement
CWR
amount of water used in producing crops which is the sum of evapotranspiration or consumptive use plus seepage and percolation losses

3.8
diversion water requirement
DWR
the total quantity of water diverted from a stream, lake, or reservoir, or removed from the ground in order to irrigate a crop

3.9
effective rainfall
ER
amount of rainwater that falls directly on the field and is used by the crop for growth and development excluding deep percolation, surface runoff and interception

3.10
effective rooting depth
soil depth from which the bulk of the roots of the crop extracts most of the water needed for evapotranspiration

3.11
evapotranspiration
combination of water transpired from vegetation and evaporated from the soil, water, and plant surfaces.

3.12
farm water requirement
FWR
amount of water to replenish the crop water requirement and losses less the effective rainfall

3.13
hydrologic frequency analysis
estimation of the chance or likelihood of occurrence of a given event by determining the frequency curves of best fit to samples of hydrologic data

3.14
land preparation water requirement
LPWR
amount of water required in lowland rice production which includes water losses through evaporation, seepage and percolation and land soaking

3.15
land soaking water requirement
LSR
amount of water required in lowland rice production which is a function of the initial soil moisture and the physical properties of the soil

3.16
pan coefficient
ratio between reference evapotranspiration (ET_o) and water loss by evaporation from an open water surface of a pan

3.17
pan evaporation
rate of water loss by evaporation from an open water surface of a pan

3.18
percolation
vertical flow of water to below the root zone which is affected by soil structure, texture, bulk density, mineralogy, organic matter content, salt type and concentration

3.19
reference crop evapotranspiration
ET_o
rate of evapotranspiration from a reference surface which is a hypothetical reference crop with an assumed crop height of 0.2 m, a fixed surface resisteance of 70 s/m and an albedo of 0.23.

3.20
residual moisture content
moisture left in the soil before the initial irrigation water delivery which describes the extent of water depletion from the soil when the water supply has been cut-off

3.21
seepage
water escaping below or out from water conveyance facilities such as open ditches, canals, natural channels, and waterway

4 Initial Investigation and General Procedures

4.1 Sufficient information shall be known prior to determining irrigation water requirements. Table 1 lists the data required.

4.2 A layout of irrigation components and the general procedures in determining irrigation water requirements and are shown in Figure 1 and Table 2, respectively.

Table 1. Required Information for Initial Investigation

Items	**Description**
Area to be irrigated	Location, layout/shape, fixed boundaries and obstructions in the area shall be determined.
	A copy of the map of the area shall be obtained.
	Details on elevation and topography shall be known.
Water supply	The physical and chemical suitability, location and supply reliability of water supply shall be assessed.
Soil	Physical characteristics and risk to erosion shall be determined.
Crop	The type of crop/s, suitability to climate and soil shall be assessed.
Meteorological Data	Availability of rainfall and evapotranspiration records near the area shall be determined.
	Prevailing wind direction and speed shall be known.
Irrigation Method	The type of irrigation method and future flexibility shall be determined.

SOURCE: Irrigation Code of Practice and Irrigation Design Standards, 2007

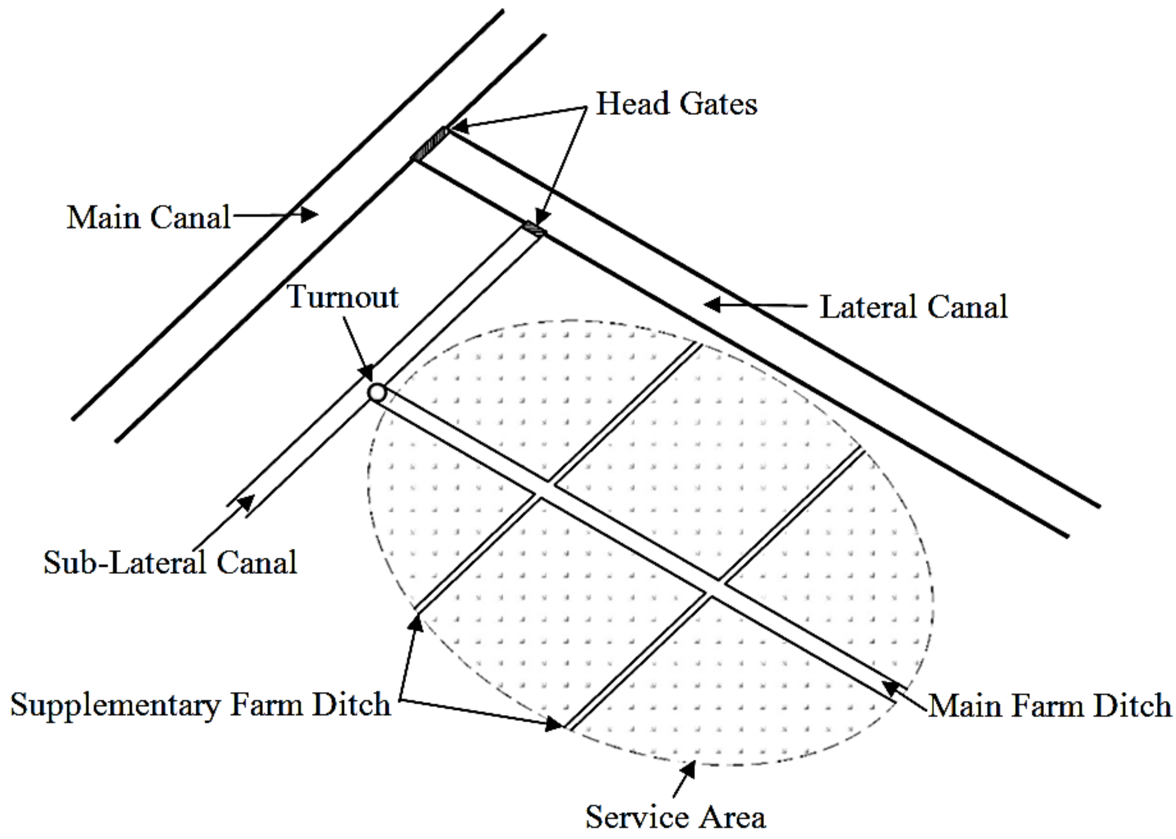


Figure 1. Typical Irrigation System
SOURCE: The Philippine Recommends for Irrigation Water Management Vol.1, 1978

Table 2. General Procedures in Determining Irrigation Water Requirements

Required Data	Relevance	Lowland	Upland
type of crop	planning the cropping calendar and crop coefficient	**CROP WATER REQUIREMENT**	
evapotranspiration and other meteorological data	determination of actual evapotranspiration (ET_a)	$CWR = ET_a + (S\&P)_{field}$	$CWR = ET_a + (S\&P)_{field}$
type of soil	determination of seepage and percolation rate in the field $(S \& P)_{field}$		

		FARM WATER REQUIREMENT	
depth of root zone	determination of land soaking and land preparation water requirement (LPWR)	FWR = CWR - ER + LPWR + farm ditch losses or FWR = (CWR-ER+LPWR)/E_a	FWR = CWR - ER + farm ditch losses or FWR = (CWR-ER)/E_a
soil physical properties			
residual moisture content			
service area			
required standing water	determination of effective rainfall (ER)		
service area			
rainfall data			
type of soil	determination of farm ditch losses		
wetted perimeter and length of farm ditches			
type of field application system	determination of application efficiency		

		DIVERSION WATER REQUIREMENT	
canal lining properties	determination of conveyance losses	DWR = FWR + conveyance losses or DWR = FWR/E_c	DWR = FWR + conveyance losses or DWR = FWR/E_c
wetted perimeter and length of canals: sub-lateral, lateral and main			
leakage through gates			
leakage through canal dikes			

5 Development of Cropping Calendar

5.1 The type of crop appropriate to the type of climate shall be selected to maximize the use of natural elements. Climate description, type of crops ideal to the climate, planting months and growing periods are presented in Table A.1 to Table A.4 of Annex A.

5.2 A cropping pattern should be selected to allow increased production. Cropping patterns that may be employed are:

5.2.1 Crop Rotation - where crops are planted in succession, year after year

EXAMPLE Rice-Soybean-Rice

5.2.2 Multiple Cropping - where four crops are grown in sequence, one after the other

EXAMPLE Rice-Mungbean-Rice-Pechay

5.2.3 Intercropping - where short duration catch crops are grown between rows of long-duration crops

EXAMPLE Coconut-Rice

5.2.4 Relay cropping - where different are planted in a tight schedule

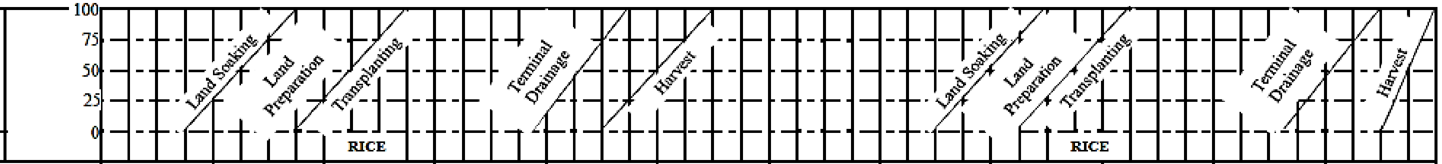
EXAMPLE Rice-Soybean (planted before harvest of rice)-Sweet potato-Mungbean

5.3 Dry season and wet season shall be delineated by using simultaneous plots of rainfall and evapotranspiration in order to determine the start of cropping for each season and to avoid risk periods of water availability throughout the year.

5.4 Farming activities and the corresponding duration for each cropping within the year shall be identified. The cropping calendar may be planned on a decadal or weekly basis. Projected cropping calendars for various crops are presented in Figures A.1 to A.4 of Annex A. An example of a complete cropping calendar is shown in Table 3.

Table 3. Example of a cropping calendar

Percent of Area



Month		Oct.				Nov.				Dec.				Jan.				Feb.				March				April				May				June				July				August				Sept.			
Week		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
1. Potential evapotranspiration	mm/day																																																
2. Crop coefficient																																																	
3. Fraction of area planted																																																	
4. Weighted crop coefficient																																																	
5. Weighted actual evapotranspiration	mm																																																
6. Weighted seepage and percolation	mm																																																
7. **CROP WATER REQUIREMENT**	mm																																																
8. Effective rainfall	mm																																																
9. Land soaking requirement	mm																																																
10. Standing water	mm																																																
11. Fraction of area used for land soaking																																																	
12. Weighted evaporation	mm																																																
13. Land preparation water requirement	mm																																																
14. Farm ditch losses	mm																																																
15. Application losses	mm																																																
13. **FARM WATER REQUIREMENT**	mm																																																
14. **FARM WATER REQUIREMENT**	lps/ha																																																
15. Canal losses																																																	
16. **DIVERSION WATER REQUIREMENT**	lps/ha																																																

6 Crop Water Requirement

The crop water requirement shall be calculated using Annex H.1.

6.1 Actual evapotranspiration

6.1.1 The actual evapotranspiration shall be calculated using Annex H.2.

6.1.2 ET_o shall be computed using the obtained based on the available meteorological data. The method of selection, details of computation and other requirements are presented in Annex B.

6.1.3 The values of k_c obtained from experimental plots are given in Table 4. It shall be noted that k_c varies by growth stage and must be reflected in the cropping calendar.

Table 4. Crop coefficient for various crops

Crop	Growth Stage in Percent of Total Growth Duration				
	0-20	20-40	40-70	70-90	Harvest
Lowland rice	0.95	1.05	1.10	1.10	0.61
Soybean, cowpea and mungbean	0.60	0.70	0.90	0.75	0.50
Wheat	0.50	0.65	0.90	0.8	0.50
Peanut	0.40	0.55	0.85	0.9	0.50
Tobacco	0.40	0.60	0.75	0.75	0.75
Corn (grain)	0.40	0.70	0.90	0.8	0.55
Cabbage	0.40	0.60	0.70	0.7	0.65

SOURCE: David, W.P. Lysimeter studies, 1983

6.2 Seepage and percolation in the field/service area

Seepage and percolation in the field/service area can be determined by using reference values listed in Table 5. If information on soil texture is not available, procedures listed in Annex C can be used.

Table 5. Percolation Values for Various Soil Textures

Soil Texture	Percolation (mm/day)
Clay	1.25
Silty Clay	1.5
Clay Loam	1.75
Silty Clay Loam	1.75
Sandy Clay Loam	2
Sandy Loam	4

SOURCE: NIA – Design Guides and Criteria for Irrigation Canals, O &M Roads, Drainage Channels and Appurtenant Structures

7 Farm Water Requirement

7.1 The farm water requirement shall be calculated using Annex H.3.

7.2 Effective rainfall

Effective rainfall shall be determined using a minimum of 10-year rainfall data. This can be calculated by using hydrologic frequency analysis (detailed in Annex D) or the Asian Development Bank (ADB) method (detailed in Annex E).

7.3 Land soaking requirement

Information on the crop depth of root zone and soil physical properties shall be obtained. Soil physical properties can be determined based on the soil texture (Annex C). Land soaking requirement shall be computed using Annex H.4. Details of calculation are presented in Annex F.

7.3 Land preparation water requirement

Land preparation water requirement shall be calculated as the total of land soaking water requirement, standing water and replenishment for evaporation. Land preparation water requirement shall be calculated using Annex H.5.

NOTE The recommended value for standing water during land preparation is 10 mm.

7.4 Farm ditch losses

Seepage and percolation in farm ditches can be determined by using reference values of seepage and percolation and canal dimensions or ponding method and inflow-outflow method. These methods can only be used in existing irrigation systems and are presented in PNS/BAFS/PAES 219:2017 – Conveyance Systems Performance Evaluation of Open Channels – Determination of Seepage and Percolation by Ponding Method and PNS/BAFS/PAES 220:2017 – Conveyance Systems Performance Evaluation of Open Channels – Determination of Seepage and Percolation by Inflow-Outflow Method. Farm ditch losses shall be calculated using Annex H.6.

7.5 Application efficiency, E_a

Application losses can be expressed using values of field application efficiency which depends on the type of field application system. Table 6 shows the corresponding values of application efficiency.

Table 6. Field Application Efficiency

Irrigation Method	USDA	US (SCS)	ICID/ILRI
Surface Methods			
light soils	0.55		
medium soils	0.70		
heavy soils	0.60		
Graded border		0.60 – 0.75	0.53
Basin and level border		0.60 – 0.80	0.58
Contour ditch		0.50 – 0.55	
Furrow		0.55 – 0.70	0.57
Corrugation		0.50 – 0.70	
Subsurface		up to 0.80	
Sprinkler, hot dry climate		0.60	
moderate climate		0.70	0.67
humid and cool		0.80	
Rice			0.32

SOURCE: FAO Irrigation and Drainage Paper No. 24, 1977

8 Diversion Water Requirement

8.1 The diversion water requirement shall be calculated using Annex H.7.

8.2 Conveyance losses

Seepage and percolation in the conveyance structures – supplementary farm ditches, main farm ditches, lateral canals, sub-lateral canals and main canal shall be determined to account for the conveyance losses. The process of computation is presented in Annex G.

8.3 For the purpose of planning, reference values for conveyance efficiency (E_c) can be used. Table 7 shows some values of conveyance efficiency based on the canal lining and the technical and managerial facilities of water control.

Table 7. Conveyance Efficiency

Supply System	ICID/ILRI
Continuous supply with no substantial change in flow	0.9
Rotational supply in projects of 3000-7000 ha and rotation areas of 70-300 ha, with effective management	0.8
Rotational supply in large schemes (>10000 ha) and small schemes (<1000 ha) with respective problematic communication and less effective management:	
based on predetermined schedule	0.7
based on advance request	0.65

SOURCE: FAO Irrigation and Drainage Paper No. 24, 1977

9 Bibliography

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ANNEX A
(informative)

Recommended Cropping and Cropping Calendars

Table A.1. Type I Climate

Two pronounced seasons: dry from November to April: wet during the rest of the year. All provinces on the Western part of the rest of the year. All provinces on the Western part of the Islands of Luzon, Mindoro, Negros and Palawan are covered in Type I.

Crops	General Cropping Month	Growing/ Maturity (days)
Corn	October-January	70-90 (Green)
Peanut	November-January	100-125
Mungbean	November-February	60-95
Soybean	October-December	65-75
Cabbage	October-December	55-80
Pechay	October-December	25-45
Eggplant	September-February	50-142
Okra	October-December	55-120
Squash	October-December	70-120
Tomato	October-January	60-100
Watermelon	November-January	70-120
Sweet Potato	December-February	75-130
Radish	October-December	30-100
Garlic	October-December	90-120
Onion	October-December	80-115
Carrot	October-December	40-60

Table A.2. Type II Climate

No dry season with a very pronounced maximum rainfall from November to January. The areas covered are Catanduanes, Sorsogon, the Eastern part of Albay, the Eastern and Northern Parts of Camarines Norte, a great protion of the Eastern part of Quezon, the Eatern part of Leyte and a large portion of Eastern Mindanao

Crops	General Cropping Month	Growing/ Maturity (days)
Corn	March-May	70-90 (Green)
Peanut	January-February	100-126
Mungbean	Fabruary-June	60-95
Soybean	January-March	65-75
Cabbage	January-March	55-80
Pechay	October-December	25-45
Eggplant	January-April	50-142
	August-September	

Table A.2 (*continued)*

Crops	General Cropping Month	Growing/ Maturity (days)
Okra	Whole Year	55-120
Squash	Whole Year	70-130
Tomato	January-April	60-100
Watermelon	January-March	70-120
Sweet Potato	Whole Year	75-130
Radish	March-May	30-100
Onion	December-March	80-115
Carrot	March-April	40-60

Table A.3. Type III Climate

No pronounced season, relatively dry from November to April and wet during the rest of the year. This type of climate covers the Western portion of the Mountain Province, Southern Quezon the Bontoc Peninsula, Masbate, Romblon, Northeast Panay, Eastern Negros, Central and Southern Cebu, part of Northern Mindanao and most of Eastern Palawan.

Crops	General Cropping Month	Growing/ Maturity (days)
Corn	October-December	70-90 (Green)
	December-February	
Peanut	September-October	100-125
Mungbean	December-January	60-95
Soybean	October-December	65-75
Cabbage	October-December	55-80
Pechay	October-December	25-45
Eggplant	November-January	50-142
Okra	October-December	55-120
Squash	October-January	70-120
Tomato	October-January	60-100
Watermelon	October-January	70-120
Sweet Potato	November-January	75-130
Radish	November-January	30-100
Garlic	October-December	90-120
Onion	November-January	80-115
Carrot	October-December	40-60

Table A.4. Type IV Climate

Rainfall more or less evenly distributed throughout the year. The areas covered by Type IV climate are Batanes Province, North-eastern Luzon, Western Camarines Norte and Camarines Sur, Albay, Eastern Mindoro, Marinduque, Western Leyte, Northern Negros and most of Central, Eastern and Southern Mindanao.

Crops	General Cropping Month	Growing/ Maturity (days)
Corn	September-November	70-90 (Green)
	December-February	
Peanut	September-November	100-125
	November-February	
Mungbean	November-January	60-95
Soybean	November-January	65-75
Cabbage	Octiber-January	55-80
Pechay	November-January	25-45
Eggplant	November-January	50-142
Okra	September-October	55-120
	January-February	
Squash	November-January	70-120
Tomato	October-January	60-100
Watermelon	November-January	70-120
Sweet Potato	September-November	75-130
Radish	September-January	30-100
Garlic	September-February	90-120
Onion	September-January	80-115
Carrot	November-January	40-60

ANNEX B
(normative)

Determination of Reference Evapotranspiration

This annex specifies guidelines in calculating the reference crop evapotranspiration using available meteorological data.

B.1 Selection of Appropriate Method

B.1.1 Four methods can be used in calculating reference crop evapotranspiration: Penman-Monteith method, Radiation method, Blaney-Criddle method and pan evaporation method.

B.1.2 The method of calculation should be selected based on the type, accuracy, and duration of available climatic data, natural pattern of evapotranspiration during the year and intended use of evapotranspiration estimates.

B.1.3 The duration and accuracy of the four methods are given in Table B.1, climatic data requirements for each method in Table B.2 and the required minimum length of record based on the application in Table B.3.

Table B.1. Duration and Accuracy of the Penman-Monteith, Radiation, Blaney-Criddle and Pan Evaporation Method

Method	Duration	Accuracy/Reliability
Penman-Monteith	daily, monthly, seasonal	reliable for any length period
Radiation	period of 5 days or more	less precise than Penman-Monteith
Blaney-Criddle	period of 5 days or more	less precise than Penman-Monteith
Pan evaporation	period of 10 days or longer	less reliable for short-term estimates than other methods
	if little previous history is available for a pan, caution should be exercised even for computing ETo for longer periods	can be accurate if evaporation pans are well maintained and properly located

SOURCE: National Engineering Handbook, 1993

Table B.2. Climatic Data Requirements

Method	Data
Penman-Monteith	maximum temperature minimum temperature wind speed at 2m dewpoint temperature maximum relative humidity minimum relative humidity actual duration of sunshine
Radiation	maximum temperature minimum temperature solar radiation
Blaney-Criddle	maximum temperature minimum temperature
Pan evaporation	pan evaporation

Table B.3. Minimum length of record required for each application

Application	**Duration of Data Required**
Irrigation Scheduling	daily
Irrigation System Design	historical record of at least 10 years
Reservoir Design, Water Right Determination	monthly water use estimates

NOTE: Adapted fom National Engineering Handbook, 1993

B.2 Calculation

B.2.1 Penman-Monteith Method

Item	**Symbol**	**Unit**
Initial data required		
Maximum temperature	T_{max}	^0C
Minimum temperature	T_{min}	^0C
Elevation above sea level	z	m
Wind speed at 2m	u_2	m/s
Dewpoint temperature	T_{dew}	^0C
Maximum relative humidity	RH_{max}	%
Minimum relative humidity	RH_{min}	%
Latitude		^{0}
Day of the year		

Month		
Actual duration of sunshine	n	h
Parameters used in calculations		
Mean daylight hours	N	h
Slope of vapour pressure curve	Δ	kPa/^{0}C
Psychrometric constant	γ	kPa/^{0}C
Saturation vapor pressure	e_s	kPa
Saturation vapor pressure at maximum temperature	$e^o(T_{max})$	kPa
Saturation vapor pressure at minimum temperature	$e^o(T_{min})$	kPa
Actual vapor pressure	e_a	kPa
Extraterrestrial radiation	R_a	MJ/m2/day
Solar radiation	R_s	MJ/m2/day
Clear-sky solar radiation	R_{so}	MJ/m2/day
Net solar radiation	R_{ns}	MJ/m2/day
Net longwave radiation	R_{nl}	MJ/m2/day
Net radiation	R_n	MJ/m2/day
Soil heat flux	G	MJ/m2/day
Reference evapotranspiration	ET_o	mm/day

B.2.1.1 Parameters

Values of climatic parameters from the daily maximum (T_{max}) and minimum (T_{min}) air temperature, altitude (z) and mean wind speed (u_2) shall be computed.

B.2.1.1.1 T_{mean} shall be computed as

$$T_{mean} = \frac{T_{max}+T_{min}}{2} \qquad \text{(Equation B.1)}$$

B.2.1.1.2 The value of the slope of vapor pressure curve (Δ) shall be determined using T_{mean} and Table B.4.

B.2.1.1.3 The value of the psychrometric constant (γ) shall be determined using T_{mean} and Table B.5.

B.2.1.1.4 Partial values shall be obtained using the following expressions:

$$(1 + 0.34\ u_2) \qquad \text{(Expression B.1)}$$

$$\frac{\Delta}{[\Delta+\gamma(1+0.34\ u_2)]} \qquad \text{(Expression B.2)}$$

$$\frac{\gamma}{[\Delta+\gamma(1+0.34\ u_2)]} \qquad \text{(Expression B.3)}$$

$$\left[\frac{900}{T_{mean}+273}\right] u_2 \qquad \text{(Expression B.4)}$$

B.2.1.2 Vapor Pressure Deficit

The vapour pressure deficit (e_s-e_a) shall be determined as the difference between the saturation vapor pressure (e_s) and the actual vapor pressure (e_a).

B.2.1.2.1 The saturation vapor pressure shall be computed from T_{max} and T_{min}.

B.2.1.2.2 $e^o(T_{max})$ and $e^o(T_{min})$ shall be determined using T_{max} and T_{min} respectively based on Table B.6.

B.2.1.2.3 Saturation vapor pressure shall be computed using Equation B.2.

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2} \qquad \text{(Equation B.2)}$$

B.2.1.2.4 The actual vapor pressure (e_a) shall be determined. Four different formulae can be used depending on the availability of data: using dewpoint temperature (T_{dew}), using maximum (RH_{max}) and minimum (RH_{min}) relative humidity, using maximum relative humidity or using mean relative humidity.

B.2.1.2.4.1 Using T_{dew}, use Table B.6 for $e^o(T_{dew})$ which is the equivalent of (e_a).

B.2.1.2.1.2 Using RH_{max} and RH_{min},

$$e_a = \frac{\left[e^o(T_{min})\frac{RH_{max}}{100}\right] + \left[e^o(T_{max})\frac{RH_{min}}{100}\right]}{2} \qquad \text{(Equation B.3)}$$

B.2.1.2.1.3 Using RH_{max} (recommended if there are errors in RH_{min}),

$$e_a = e^o(T_{min})\frac{RH_{max}}{100} \qquad \text{(Equation B.4)}$$

B.2.1.2.1.4 Using RH_{mean} (less recommended due to non-linearities),

$$e_a = e_s\frac{RH_{mean}}{100} \qquad \text{(Equation B.5)}$$

B.2.1.3 Radiation

The net radiation (R_n) shall be computed from the latitude, day, month, actual duration of sunshine (n), maximum (T_{max}) and minimum (T_{min}) air temperature and actual vapor pressure (e_a).

B.2.1.3.1 The extraterrestrial radiation (R_a) shall be determined using the data on latitude and Table B.7.

B.2.1.3.2 Mean daylight hours (N) shall be determined using the data on latitude and Table B.5.

B.2.1.3.3 If no data on solar radiation (R_s) is available, R_s shall be computed using Equation B.6.

$$R_s = (0.25 + 0.50\ n/N)R_a \qquad \text{(Equation B.6)}$$

B.2.1.3.4 Clear-sky radiation (R_{so}) shall be computed using Equation B.7.

$$R_{so} = \frac{0.75+2(\text{Altitude})}{100\ 000} R_a \qquad \text{(Equation B.7)}$$

B.2.1.3.5 The relative shortwave radiation (R_s/R_{so}) shall be determined.

B.2.1.3.6 The net solar radiation (R_{ns}) shall be calculated using Equation B.8.

$$R_{ns} = 0.77R_s \qquad \text{(Equation B.8)}$$

B.2.1.3.7 $\sigma T_{max,K}{}^4$ and $\sigma T_{min,K}{}^4$ shall be determined using T_{max},T_{min} and Table B.9.

B.2.1.3.8 R_{nl} and R_n shall be computed.

$$R_{nl} = \frac{\left(\sigma T_{max,K^4}+\sigma T_{min,K^4}\right)}{2}\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right)$$

$$R_n = R_{ns} - R_{nl} \qquad \text{(Equation B.10)}$$

B.2.1.3.9 The soil heat flux, G, shall be determined.

B.2.1.3.9.1 If the period considered is for a day or ten-day period, $G_{day} \approx 0$.

B.2.1.3.9.2 If the period considered is for a month period,

$$G_{month,i} = 0.07\left(T_{month,i+1} - T_{month,i-1}\right) \qquad \text{(Equation B.11)}$$

B.2.1.3.9.3 If $T_{month,\,i+1}$ is unknown,

$$G_{month,i} = 0.14\left(T_{month,i} - T_{month,i-1}\right) \qquad \text{(Equation B.12)}$$

B.2.1.3.9.4 If the period considered is for hourly or shorter period,
during daylight: $G_{hr} = 0.1\ R_n$ (Equation B.13)
during night time: $G_{hr} = 0.5\ R_n$ (Equation B.14)

B.2.1.3.10 The soil heat flux shall be subtracted from net radiation and shall be converted to mm/day.

$$0.408(R_n - G) \qquad \text{(Expression B.5)}$$

B.2.1.4 Reference Evapotranspiration (ET_o), mm/day

B.2.1.4.1 Expression B.2 × Expression B.5

$$\frac{\Delta}{[\Delta+\gamma(1+0.34\,u_2)]} \times 0.408(R_n - G) \qquad \text{(Expression B.6)}$$

B.2.1.4.2 Expression B.3 × Expression B.4 × $(e_s - e_a)$

$$\frac{\gamma}{[\Delta+\gamma(1+0.34\,u_2)]} \times \left[\frac{900}{T_{mean}+273}\right] u_2 \times (e_s - e_a) \qquad \text{(Expression B.7)}$$

B.2.1.4.3 Expression B.6 + Expression B.7

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean}+273} u_2\,(e_s - e_a)}{\Delta+\gamma(1+0.34\,u_2)}$$

Table B.4. Slope of vapor pressure curve for different temperatures

T °C	Δ kPa/°C	T °C	Δ kPa/°C	T °C	Δ kPa/°C	T °C	Δ kPa/°C
1.0	0.047	13.0	0.098	25.0	0.189	37.0	0.342
1.5	0.049	13.5	0.101	25.5	0.194	37.5	0.35
2.0	0.05	14.0	0.104	26.0	0.199	38.0	0.358
2.5	0.052	14.5	0.107	26.5	0.204	38.5	0.367
3.0	0.054	15.0	0.11	27.0	0.209	39.0	0.375
3.5	0.055	15.5	0.113	27.5	0.215	39.5	0.384
4.0	0.057	16.0	0.116	28.0	0.22	40.0	0.393
4.5	0.059	16.5	0.119	28.5	0.226	40.5	0.402
5.0	0.061	17.0	0.123	29.0	0.231	41.0	0.412
5.5	0.063	17.5	0.126	29.5	0.237	41.5	0.421
6.0	0.065	18.0	0.13	30.0	0.243	42.0	0.431
6.5	0.067	18.5	0.133	30.5	0.249	42.5	0.441
7.0	0.069	19.0	0.137	31.0	0.256	43.0	0.451
7.5	0.071	19.5	0.141	31.5	0.262	43.5	0.461
8.0	0.073	20.0	0.145	32.0	0.269	44.0	0.471
8.5	0.075	20.5	0.149	32.5	0.275	44.5	0.482
9.0	0.078	21.0	0.153	33.0	0.282	45.0	0.493
9.5	0.08	21.5	0.157	33.5	0.289	45.5	0.504
10.0	0.082	22.0	0.161	34.0	0.296	46.0	0.515
10.5	0.085	22.5	0.165	34.5	0.303	46.5	0.526
11.0	0.087	23.0	0.17	35.0	0.311	47.0	0.538
11.5	0.09	23.5	0.174	35.5	0.318	47.5	0.55
12.0	0.092	24.0	0.179	36.0	0.326	48.0	0.562
12.5	0.095	24.5	0.184	36.5	0.334	48.5	0.574

Table B.5. Psychrometric constant for different altitudes

Z (m)	ϒ kPa/°C	z (m)	ϒ kPa/°C	z (m)	ϒ kPa/°C	z (m)	ϒ kPa/°C
0	0.067	1000	0.06	2000	0.053	3000	0.047
100	0.067	1100	0.059	2100	0.052	3100	0.046
200	0.066	1200	0.058	2200	0.052	3200	0.046
300	0.065	1300	0.058	2300	0.051	3300	0.045
400	0.064	1400	0.057	2400	0.051	3400	0.045
500	0.064	1500	0.056	2500	0.05	3500	0.044
600	0.063	1600	0.056	2600	0.049	3600	0.043
700	0.062	1700	0.055	2700	0.049	3700	0.043
800	0.061	1800	0.054	2800	0.048	3800	0.042
900	0.061	1900	0.054	2900	0.047	3900	0.042
1000	0.06	2000	0.053	3000	0.047	4000	0.041

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

Table B.6. Saturation vapor pressure for different temperatures

T °C	e_s kPa	T °C	e° (T) kPa	T °C	e° (T) kPa	T °C	e_s kPa
1	0.657	13	1.498	25	3.168	37	6.275
1.5	0.681	13.5	1.547	25.5	3.263	37.5	6.448
2	0.706	14	1.599	26	3.361	38	6.625
2.5	0.731	14.5	1.651	26.5	3.462	38.5	6.806
3	0.758	15	1.705	27	3.565	39	6.991
3.5	0.785	15.5	1.761	27.5	3.671	39.5	7.181
4	0.813	16	1.818	28	3.78	40	7.376
4.5	0.842	16.5	1.877	28.5	3.891	40.5	7.574
5	0.872	17	1.938	29	4.006	41	7.778
5.5	0.903	17.5	2	29.5	4.123	41.5	7.986
6	0.935	18	2.064	30	4.243	42	8.199
6.5	0.968	18.5	2.13	30.5	4.366	42.5	8.417
7	1.002	19	2.197	31	4.493	43	8.64
7.5	1.037	19.5	2.267	31.5	4.622	43.5	8.867
8	1.073	20	2.338	32	4.755	44	9.101
8.5	1.11	20.5	2.412	32.5	4.891	44.5	9.339
9	1.148	21	2.487	33	5.03	45	9.582
9.5	1.187	21.5	2.564	33.5	5.173	45.5	9.832
10	1.228	22	2.644	34	5.319	46	10.086
10.5	1.27	22.5	2.726	34.5	5.469	46.5	10.347
11	1.313	23	2.809	35	5.623	47	10.613
11.5	1.357	23.5	2.896	35.5	5.78	47.5	10.885
12	1.403	24	2.984	36	5.941	48	11.163
12.5	1.449	24.5	3.075	36.5	6.106	48.5	11.447

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

Table B.7. Daily extraterrestrial radiation (MJ/m²/day) for different latitudes for the 15th day of the month

Northern Hemisphere												Lat.
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**deg.**
0	2.6	10.4	23	35.2	42.5	39.4	28	14.9	4.9	0.1	0	70
0.1	3.7	11.7	23.9	35.3	42	38.9	28.6	16.1	6	0.7	0	68
0.6	4.8	12.9	24.8	35.6	41.4	38.8	29.3	17.3	7.2	1.5	0.1	66
1.4	5.9	14.1	25.8	35.9	41.2	38.8	30	18.4	8.5	2.4	0.6	64
2.3	7.1	15.4	26.6	36.3	41.2	39	30.6	19.5	9.7	3.4	1.3	62
3.3	8.3	16.6	27.5	36.6	41.2	39.2	31.3	20.6	10.9	4.4	2.2	60
4.3	9.6	14.7	28.4	37	41.3	39.4	32	21.7	12.1	5.5	3.1	58
5.4	10.8	18.9	29.2	37.4	41.4	39.6	32.6	22.7	13.3	6.7	4.2	56
6.5	12	20	30	37.8	41.5	39.8	33.2	23.7	14.5	7.8	5.2	54
7.7	13.2	21.1	30.8	38.2	41.6	40.1	33.8	24.7	15.7	9	6.4	52
8.9	14.4	22.2	31.5	38.5	41.7	40.2	34.4	25.7	16.9	10.2	7.5	50
10.1	15.7	23.3	32.2	38.8	41.8	40.4	34.9	26.6	18.1	11.4	8.7	48
11.3	16.9	24.3	32.9	39.1	41.9	40.6	35.5	27.5	19.2	12.6	9.9	46
12.5	18	25.3	33.5	39.3	41.9	40.7	35.9	28.4	20.3	13.9	11.1	44
13.8	19.2	26.3	34.1	39.5	41.9	40.8	36.3	29.2	21.4	15.1	12.4	42
15	20.4	27.2	34.7	39.7	41.9	40.8	36.7	30	22.5	16.3	13.6	40
16.2	21.5	28.1	35.2	39.9	41.8	40.8	37	30.7	23.6	17.5	14.8	38
17.5	22.6	29	35.7	40	41.7	40.8	37.4	31.5	24.6	18.7	16.1	36
18.7	23.7	29.9	36.1	40	41.6	40.8	37.6	32.1	25.6	19.9	17.3	34
19.9	24.8	30.7	36.5	40	41.4	40.7	37.9	32.8	26.6	21.1	18.5	32
21.1	25.8	31.4	36.8	40	41.2	40.6	38	33.4	27.6	22.2	19.8	30
22.3	26.8	32.2	37.1	40	40.9	40.4	38.2	33.9	28.5	23.3	21	28
23.4	27.8	32.8	37.4	39.9	40.6	40.2	38.3	34.5	29.3	24.5	22.2	26
24.6	28.8	33.5	37.6	39.7	40.3	39.9	38.3	34.9	30.2	25.5	23.3	24
25.7	29.7	34.1	37.8	39.5	40	39.6	38.4	35.4	31	26.6	24.5	22
26.8	30.6	34.7	37.9	39.3	39.5	39.3	38.3	35.8	31.8	27.7	25.6	20
27.9	31.5	35.2	38	39	39.1	38.9	38.2	36.1	32.5	28.7	26.8	18
28.9	32.3	35.7	38.1	38.7	38.6	38.5	38.1	36.4	33.2	29.6	27.9	16
29.9	33.1	36.1	38.1	38.4	38.1	38.1	38	36.7	33.9	30.6	28.9	14
30.9	33.8	36.5	38	38	37.6	37.6	37.8	36.9	34.5	31.5	30	12
31.9	34.5	36.9	37.9	37.6	37	37.1	37.5	37.1	35.1	32.4	31	10
32.8	35.2	37.2	37.8	37.1	36.3	36.5	37.2	37.2	35.6	33.3	32	8
33.7	35.8	37.4	37.6	36.6	35.7	35.9	36.9	37.3	36.1	34.1	32.9	6
34.6	36.4	37.6	37.4	36	35	35.3	36.5	37.3	36.6	34.9	33.9	4
35.4	37	37.8	37.1	35.4	34.2	34.6	36.1	37.3	37	35.6	34.8	2
36.2	37.5	37.9	36.8	34.8	33.4	33.9	35.7	37.2	37.4	36.3	35.6	0

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

Table B.8. Mean daylight hours for different latitudes for the 15th day of the month

Northern Hemisphere												Lat.
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**deg.**
0	6.6	11	15.6	21.3	24	24	17.6	12.8	8.3	2.3	0	70
2.1	7.3	11.1	15.3	19.7	24	22.3	17	12.7	8.7	4.1	0	68
3.9	7.8	11.2	14.9	18.7	22	20.3	16.4	12.7	9	5.2	1.9	66
5	8.2	11.2	14.7	17.9	20.3	19.2	16	12.6	9.3	6	3.7	64
5.7	8.5	11.3	14.4	17.3	19.2	18.4	15.7	12.6	9.5	6.6	4.8	62
6.4	8.8	11.4	14.2	16.8	18.4	17.7	15.3	12.5	9.7	7.1	5.6	60
6.9	9.1	11.4	14.1	16.4	17.8	17.2	15.1	12.5	9.9	7.5	6.2	58
7.3	9.3	11.5	13.9	16	17.3	16.8	14.8	12.4	10.1	7.9	6.7	56
7.7	9.5	11.5	13.8	15.7	16.8	16.4	14.6	12.4	10.2	8.2	7.1	54
8	9.7	11.5	13.6	15.4	16.5	16	14.4	12.4	10.3	8.5	7.5	52
8.3	9.8	11.6	13.6	15.2	16.1	15.7	14.3	12.3	10.4	8.7	7.9	50
8.6	10	11.6	13.4	15	15.8	15.5	14.1	12.3	10.6	9	8.2	48
8.8	10.1	11.6	13.3	14.8	15.5	15.2	14	12.3	10.7	9.2	8.5	46
9.1	10.3	11.6	13.2	14.6	15.3	15	13.8	12.3	10.7	9.4	8.7	44
9.3	10.4	11.7	13.2	14.4	15	14.8	13.7	12.3	10.8	9.6	9	42
9.5	10.5	11.7	13.1	14.2	14.8	14.6	13.6	12.2	10.9	9.7	9.2	40
9.6	10.6	11.7	13	14.1	14.6	14.4	13.5	12.2	11	9.9	9.4	38
9.8	10.7	11.7	12.9	13.9	14.4	14.2	13.4	12.2	11.1	10.1	9.6	36
10	10.8	11.8	12.9	13.8	14.3	14.1	13.3	12.2	11.1	10.2	9.7	34
10.1	10.9	11.8	12.8	13.6	14.1	13.9	13.2	12.2	11.2	10.3	9.9	32
10.3	11	11.8	12.7	13.5	13.9	13.8	13.1	12.2	11.3	10.5	10.1	30
10.4	11	11.8	12.7	13.4	13.8	13.6	13	12.2	11.3	10.6	10.2	28
10.5	11.1	11.8	12.6	13.3	13.6	13.5	12.9	12.1	11.4	10.7	10.4	26
10.7	11.2	11.8	12.6	13.2	13.5	13.3	12.8	12.1	11.4	10.8	10.5	24
10.8	11.3	11.9	12.5	13.1	13.3	13.2	12.8	12.1	11.5	10.9	10.7	22
10.9	11.3	11.9	12.5	12.9	13.2	13.1	12.7	12.1	11.5	11	10.8	20
11	11.4	11.9	12.4	12.8	13.1	13	12.6	12.1	11.6	11.1	10.9	18
11.1	11.5	11.9	12.4	12.7	12.9	12.9	12.5	12.1	11.6	11.2	11.1	16
11.3	11.6	11.9	12.3	12.6	12.8	12.8	12.5	12.1	11.7	11.3	11.2	14
11.4	11.6	11.9	12.3	12.6	12.7	12.6	12.4	12.1	11.7	11.4	11.3	12
11.5	11.7	11.9	12.2	12.5	12.6	12.5	12.3	12.1	11.8	11.5	11.4	10
11.6	11.7	11.9	12.2	12.4	12.5	12.4	12.3	12	11.8	11.6	11.5	8
11.7	11.8	12	12.1	12.3	12.3	12.3	12.2	12	11.9	11.7	11.7	6
11.8	11.9	12	12.1	12.2	12.2	12.2	12.1	12	11.9	11.8	11.8	4
11.9	11.9	12	12	12.1	12.1	12.1	12.1	12	12	11.9	11.9	2
12	12	12	12	12	12	12	12	12	12	12	12	0

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

Table B.9. σT_K^4 (Stefan-Boltzman law) at different temperatures

T (°C)	σT_K^4 (MJ $m^{-2}d^{-1}$)	T (°C)	σT_K^4 (MJ $m^{-2}d^{-1}$)	T (°C)	σT_K^4 (MJ $m^{-2}d^{-1}$)
1	27.7	17	34.75	33	43.08
1.5	27.9	17.5	34.99	33.5	43.36
2	28.11	18	35.24	34	43.64
2.5	28.31	18.5	35.48	34.5	43.93
3	28.52	19	35.72	35	44.21
3.5	28.72	19.5	35.97	35.5	44.5
4	28.93	20	36.21	36	44.79
4.5	29.14	20.5	36.46	36.5	45.08
5	29.35	21	36.71	37	45.37
5.5	29.56	21.5	36.96	37.5	45.67
6	29.78	22	37.21	38	45.96
6.5	29.99	22.5	37.47	38.5	46.26
7	30.21	23	37.72	39	46.56
7.5	30.42	23.5	37.98	39.5	46.85
8	30.64	24	38.23	40	47.15
8.5	30.86	24.5	38.49	40.5	47.46
9	31.08	25	38.75	41	47.76
9.5	31.3	25.5	39.01	41.5	48.06
10	31.52	26	39.27	42	48.37
10.5	31.74	26.5	39.53	42.5	48.68
11	31.97	27	39.8	43	48.99
11.5	32.19	27.5	40.06	43.5	49.3
12	32.42	28	40.33	44	49.61
12.5	32.65	28.5	40.6	44.5	49.92
13	32.88	29	40.87	45	50.24
13.5	33.11	29.5	41.14	45.5	50.56
14	33.34	30	41.41	46	50.87
14.5	33.57	30.5	41.69	46.5	51.19
15	33.81	31	41.96	47	51.51
15.5	34.04	31.5	42.24	47.5	51.84
16	34.28	32	42.52	48	52.16
16.5	34.52	32.5	42.8	48.5	52.49

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

B.2.2 Radiation Method

B.2.2.1 Calculation using the basic radiation formula

Item	Symbol	Unit
Initial data required		
Daily values of maximum temperature for the month considered	T_{max}	^0C
Daily values of minimum temperature for the month considered	T_{min}	^0C
Altitude	z	m
Latitude		^{0}
Actual duration of sunshine	n	h
Solar radiation	R_s	mm/day
Parameters used in calculations		
Extraterrestrial radiation	R_a	mm/day
Mean daylight hours	N	h
Mean daily temperature	$T_{daily\ mean}$	^0C
Weighting factor	W	-
Reference evapotranspiration	ET_o	mm/day

B.2.2.1.1 If measured R_s is not available, the formula below shall be used.

$$R_s = \left(0.25 + 0.50\ \frac{n}{N}\right) R_a$$

B.2.2.1.2 For values of n/N, measured sunshine duration (n) records shall be used and Table B.8 for values of mean daylight hours (N) for different months and latitudes.

B.2.2.1.3 For values of R_a for different months and latitudes, Table B.10 shall be used.

B.2.2.1.4 Compute for $T_{daily\ mean}$.

$$T_{max} = \frac{\sum T_{max} \text{daily values}}{\text{number of days in the month considered}}$$

$$T_{min} = \frac{\sum T_{min} \text{daily values}}{\text{number of days in the month considered}}$$

$$T_{daily\ mean} = \frac{T_{max} + T_{min}}{2}$$

B.2.2.1.5 Using Table B.11, values of $T_{daily\ mean}$ and altitude (z), the weighting factor (W) shall be determined.

B.2.2.1.6 ET_o shall be determined using the formula below.

$$ETo = W \times R_s$$

Table B.10. Extraterrestrial radiation expressed in equivalent evaporation (mm/day) for different latitudes

Northern Hemisphere												Lat.
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**deg.**
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48
4.9	7.1	10.2	13.3	16	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	3.1	38
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32
8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3	30
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0

SOURCE: FAO Irrigation and Drainage Paper No. 24, 1977

Table B.11. Values of Weighting Factor (W) for the Effect of Radiation ET_o at Different Temperatures and Altitudes

Temperature (ºC)	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Altitude (z)	**Weighting Factor (W)**																			
0	0.43	0.46	0.49	0.52	0.55	0.58	0.61	0.64	0.66	0.68	0.71	0.73	0.75	0.77	0.78	0.8	0.82	0.83	0.84	0.85
500	0.45	0.48	0.51	0.54	0.57	0.602	0.62	0.65	0.67	0.7	0.72	0.74	0.76	0.78	0.79	0.81	0.82	0.84	0.85	0.86
1000	0.46	0.49	0.52	0.55	0.58	0.61	0.64	0.66	0.69	0.71	0.73	0.75	0.77	0.79	0.8	0.82	0.83	0.85	0.86	0.87
2000	0.49	0.52	0.55	0.58	0.61	0.64	0.66	0.69	0.71	0.73	0.75	0.77	0.79	0.81	0.82	0.84	0.85	0.86	0.87	0.88
3000	0.52	0.55	0.58	0.61	0.64	0.66	0.69	0.71	0.73	0.75	0.77	0.79	0.81	0.82	0.84	0.85	0.86	0.88	0.88	0.89
4000	0.55	0.58	0.61	0.64	0.66	0.69	0.71	0.73	0.76	0.78	0.79	0.81	0.83	0.84	0.85	0.86	0.88	0.89	0.9	0.9

SOURCE: FAO Irrigation and Drainage Paper No. 24, 1977

B.2.2.2 Calculation using graphs developed based on the basic radiation formula

Data Required	Symbol	Unit
Estimate of daytime wind	U_{day}	^{0}C
Estimate of mean relative humidity	RH_{mean}	%
Elevation above sea level	z	m

B.2.2.2.1 General levels of RH_{mean} and U_{day} shall be determined using Table B.12. If estimates of 24-hour mean wind are available, convert these to daytime wind using the correction factor, shown in Table B.13.

B.2.2.2.2 ET_o shall be obtained using Figure B.1, previously determined W × R_s from section B.2.2.1.6 and general levels of RH_{mean} and U_{day}.

Table B.12. Estimates of RH_{mean} and U_{day} translated to general levels

RH_{mean}	REMARKS
low <40% medium-low 40-55% medium-high 55%-70% high >70%	RH_{mean} is the average of maximum and minimum relative humidity. Whereas RH_{min} will vary strongly, if RH_{max} equals 90 to 100% for humid climates, equals 80 to 100% for semi-arid and arid climates where T_{min} is 20-25 ºC lower than T_{max}. In arid areas RH_{max} may be 25-40% when T_{min} is 15ºC lower than T_{max}.
WIND	
light <2 m/s moderate 2-5 m/s strong 5-8 m/s very strong >8 m/s	2m/s : wind is felt on face and leaves start to rustle 5m/s : twigs move paper blows away, flags fly 8m/s : dust rises, small branches move >8 m/s : small trees start to move, waves form on inland water For rough estimation purposes, sum of several wind-speed observations divided by number of readings in m/s.

SOURCE: FAO Irrigation and Drainage Paper No. 24, 1977

Table B.13. Correction Factors for 24-hour mean wind estimates to obtain U_{day}

U_{day}/U_{night} ratio	1.0	1.5	2.0	2.5	3.0	3.5	4.0
correction factor for U_{day}	1.0	1.2	1.33	1.43	1.5	1.56	1.6

SOURCE: FAO Irrigation and Drainage Paper No. 24, 1977

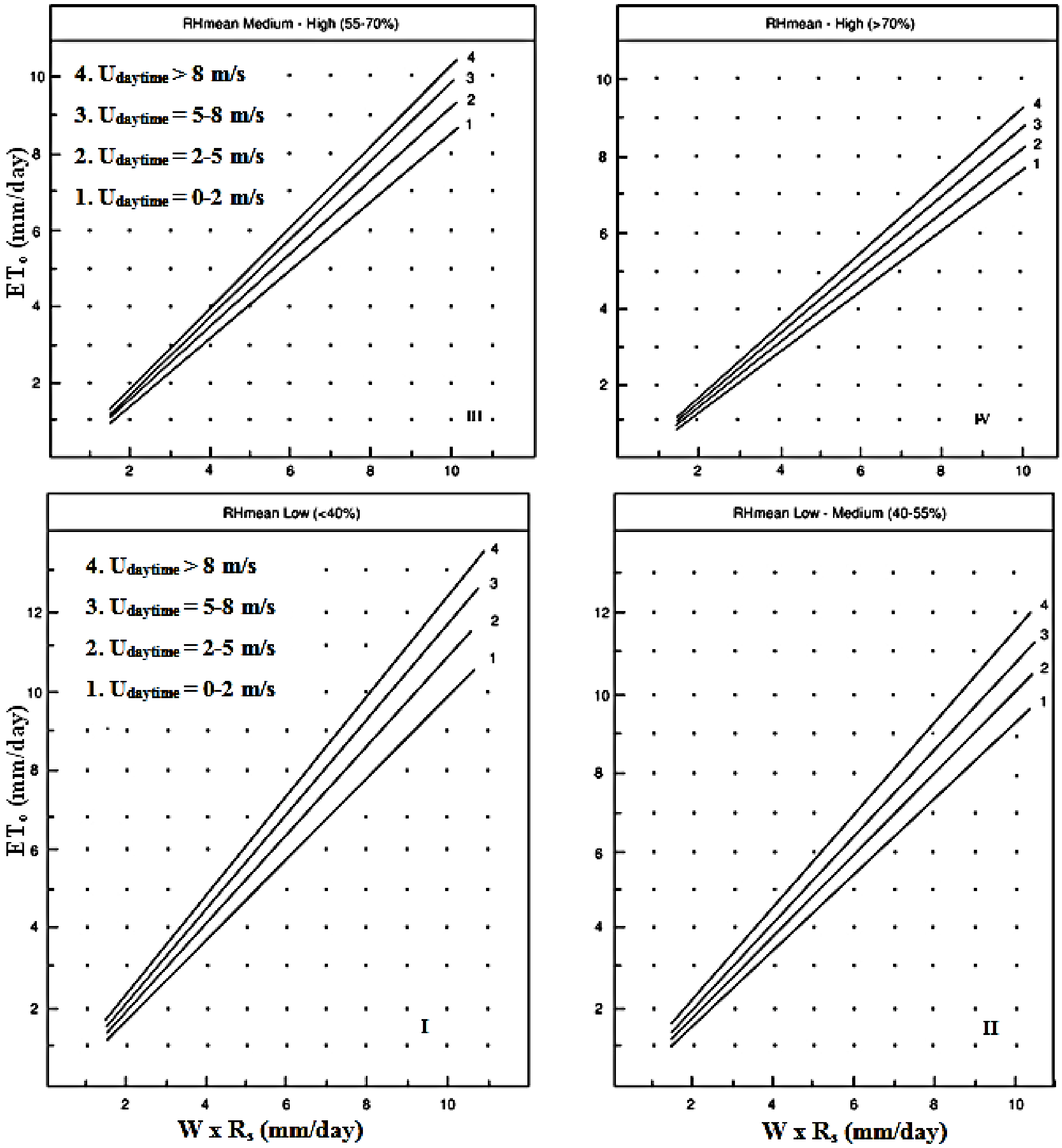

Figure B.1. Prediction of ET_0 from W x R_s for different conditions of mean relative humidity and day time wind

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

B.2.3 Blaney-Criddle Method

B.2.3.1 Calculation using the basic Blaney-Criddle Formula

B.2.3.1.1 The following data shall be obtained:

- maximum temperature daily values for the month considered
- minimum temperature daily values for the month considered
- latitude

B.2.3.1.2 The mean daily temperature (T_{mean}) shall be computed as follows:

$$T_{max} = \frac{\sum T_{max} \text{daily values}}{\text{number of days in the month considered}}$$

$$T_{min} = \frac{\sum T_{min} \text{daily values}}{\text{number of days in the month considered}}$$

$$T_{daily\ mean} = \frac{T_{max} + T_{min}}{2}$$

B.2.3.1.3 The mean daily percentage of annual daytime hours (p) shall be determined using the latitude of the area considered and Table B.14.

Table B.14. Mean daily percentage (p) of annual daytime hours for different latitudes

Latitude	North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
	South	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
60		0.15	0.2	0.26	0.32	0.38	0.41	0.4	0.34	0.28	0.22	0.17	0.13
55		0.17	0.21	0.26	0.32	0.36	0.39	0.38	0.33	0.28	0.23	0.18	0.16
50		0.19	0.23	0.27	0.31	0.34	0.39	0.35	0.32	0.28	0.24	0.2	0.18
45		0.2	0.23	0.27	0.3	0.34	0.35	0.34	0.32	0.28	0.24	0.21	0.2
40		0.22	0.24	0.27	0.3	0.32	0.34	0.33	0.31	0.28	0.25	0.22	0.21
35		0.23	0.25	0.27	0.29	0.31	0.32	0.32	0.3	0.28	0.25	0.23	0.22
30		0.24	0.25	0.27	0.29	0.31	0.32	0.31	0.3	0.28	0.26	0.24	0.23
25		0.24	0.26	0.27	0.29	0.3	0.31	0.31	0.29	0.28	0.26	0.25	0.24
20		0.25	0.26	0.27	0.28	0.29	0.3	0.3	0.29	0.28	0.26	0.25	0.25
15		0.26	0.26	0.27	0.28	0.29	0.29	0.29	0.28	0.28	0.27	0.26	0.25
10		0.27	0.27	0.27	0.28	0.28	0.29	0.29	0.28	0.28	0.27	0.26	0.26
5		0.27	0.27	0.27	0.28	0.28	0.28	0.28	0.28	0.28	0.27	0.27	0.27
0		0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27

B.2.3.1.1 ET_o shall be computed using the formula below.

$$ETo = p(0.46T_{mean} + 8)$$

B.2.3.2 Calculation using graphs developed based on Blaney-Criddle Formula

B.2.3.2.1 General levels of RH_{min}, n/N, and U_{day} shall be determined using the Table B.14. If estimates of 24-hour mean wind are available, these shall be converted to daytime wind using the correction factor, shown in Table B.15.

B.2.3.2.2 ET_o shall be obtained using Figure B.2 and previously determined general levels of RH_{min}, n/N, and U_{day}.

Table B.15. Estimates of RH_{min}, n/N and U_{day} translated to general levels

RH_{min}		REMARKS
low medium high	<20% 20-50% >50%	RH_{min} is the lowest humidity during daytime and is reached usually at 14.00 to 16.00 hours from hygrograph or wet and dry bulb thermometer. For rough estimation purposes, when read at 12.00 hrs, subtract 5 to 10 for humid climates and up to 30 for desert climates.
n/N		
low medium high	<0.6 0.6-0.8 >0.8	n/N > 0.8 : near bright sunshine all day n/N 0.6-0.8 : some 40% of daytime hours full cloudiness or partially clouded for 70% of daytime hours
U_{day}		
light moderate strong very strong	<2 m/s 2-5 m/s 5-8 m/s >8 m/s	2m/s : wind is felt on face and leaves start to rustle 5m/s : twigs move paper blows away, flags fly 8m/s : dust rises, small branches move >8 m/s : small trees start to move, waves form on inland water For rough estimation purposes, sum of several wind-speed observations divided by number of readings in m/s.

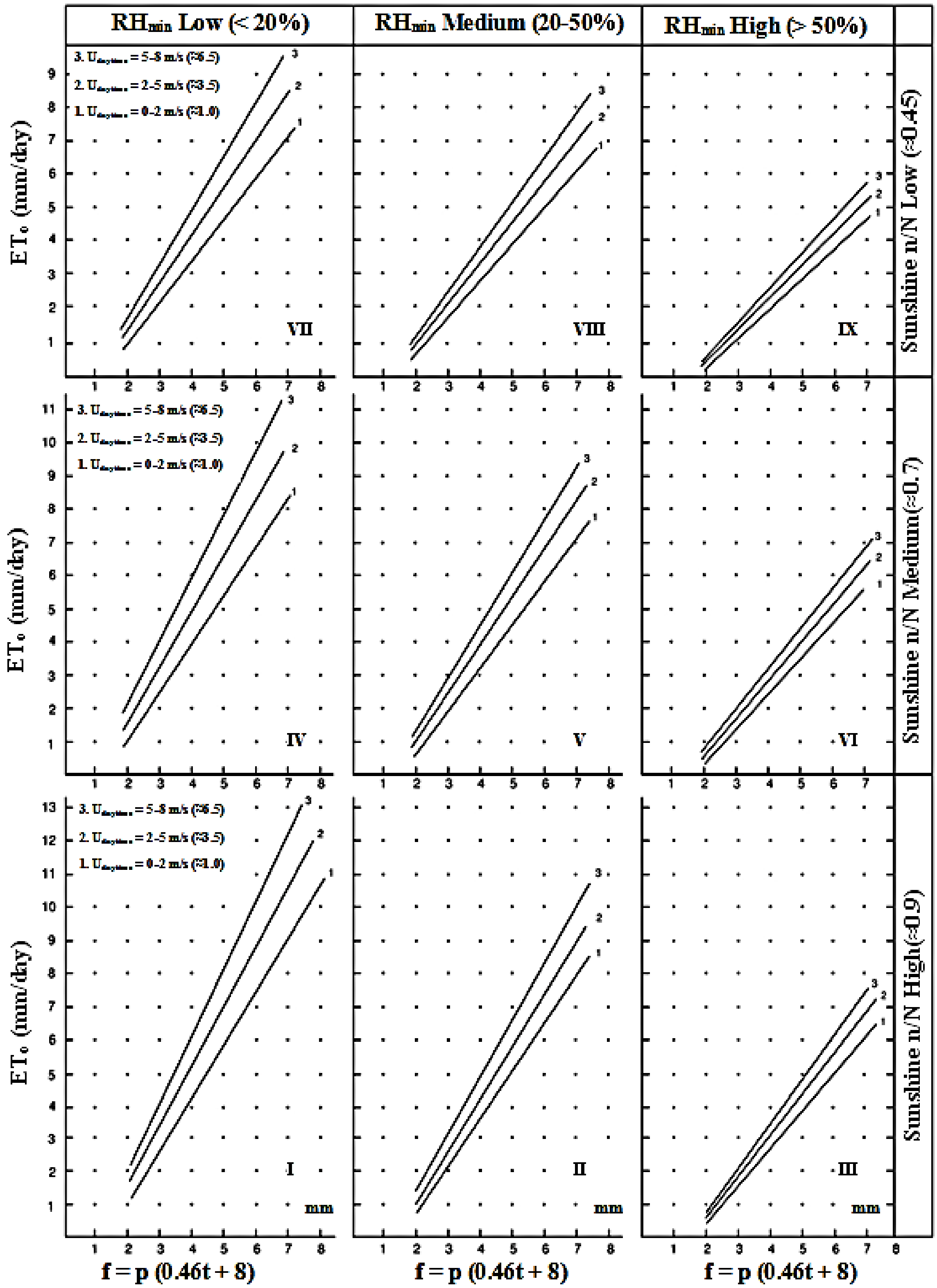

Figure B.2. Prediction of ET_0 from Blaney-Criddle f factor
Where f = p(0.46t + 8), for different conditions of minimum relative humidity, sunshine duration and daytime wind
SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

B.2.4 Pan Evaporation Method

B.2.4.1 The following data shall be obtained:

- pan evaporation data
- type of pan used
- pan environment
- mean relative humidity
- windspeed at 2m (u_2)

B.2.4.2 The type of evaporation pan shall be determined. It can be either Class A pan, shown in Figure B.3 or Colorado sunken pan, shown in Figure B.4. Description of both pans is listed in Table B.16.

Table B.16. Description of Class A Pan and Colorado Sunken Pan

Items	Class A Pan	Colorado Sunken Pan
Shape	circular	square
Diameter, cm	120.7	92 or 100
Depth, cm	25	46 or 50
Material	gauge 22 galvanized iron or 0.8 mm Monel metal	3mm thick iron
Position	mounted on a wooden pen frame platform 15 cm above ground level	in the ground with the rim 5cm above the soil level
Water Level	filled to 5 cm below the rim and not allowed to drop more than 7.5 cm below the rim	at or slightly below ground level i.e, 5-7.5 cm below the rim
Maintenance	-water is regularly renewed at least weekly -if galvanized, painted annually with aluminum paint -no screens over the pan protected by fences to keep animals from drinking	-water is regularly renewed at least weekly -painted with black tar paint -no screens over the pan protected by fences to keep animals from drinking
Site	-under grass, 20 m by 20 m, and open on all sides -located in the center or on the leeward side of large cropped fields	-under grass, 20 m by 20 m, and open on all sides -located in the center or on the leeward side of large cropped fields
Stilling Well	-situated in the pan near one edge -metal cylinder about 10 cm in diameter and 20 about cm deep with a small hole in the bottom	-situated in the pan near one edge -metal cylinder about 10 cm in diameter and 20 about cm deep with a small hole in the bottom

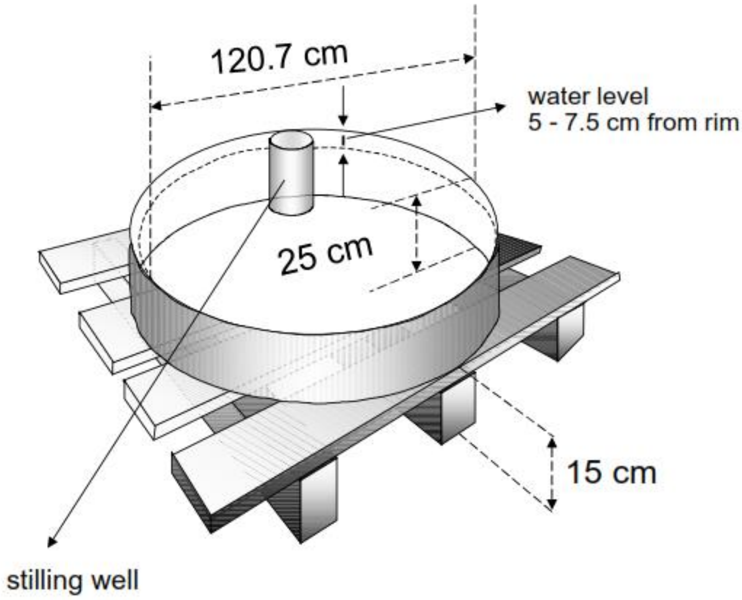

Figure B.3. Details of a Class A pan
SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

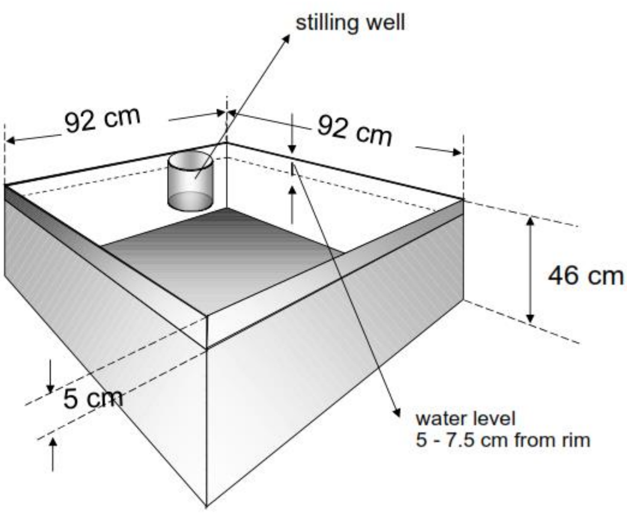

Figure B.4. Details of a Colorado Sunken Pan
SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

B.2.4.3 Pan siting shall be evaluated**.** Figure B.5 and Figure B.6 illustrates two cases of pan siting. The fetch shall determine the state of the upwind buffer zone. The first case, shown in Figure B.5, the pan is situated on a short green (grass) cover and surrounded by fallow soil. The second case on the other hand, shown in Figure B.6, the pan is situated on a fallow soil and surrounded by green crops.

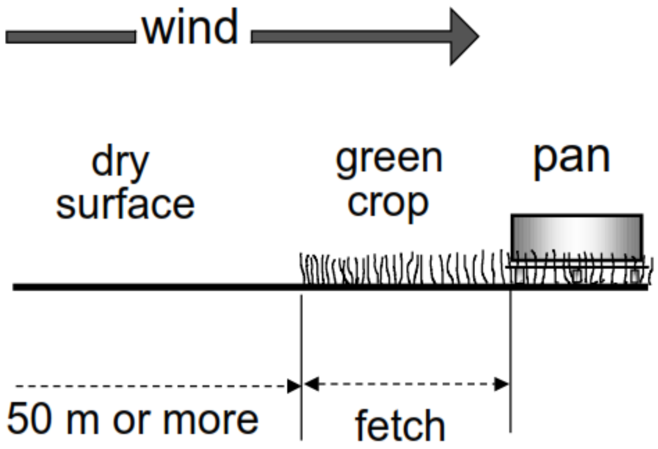

Figure B.5. Pan situated on a green cover

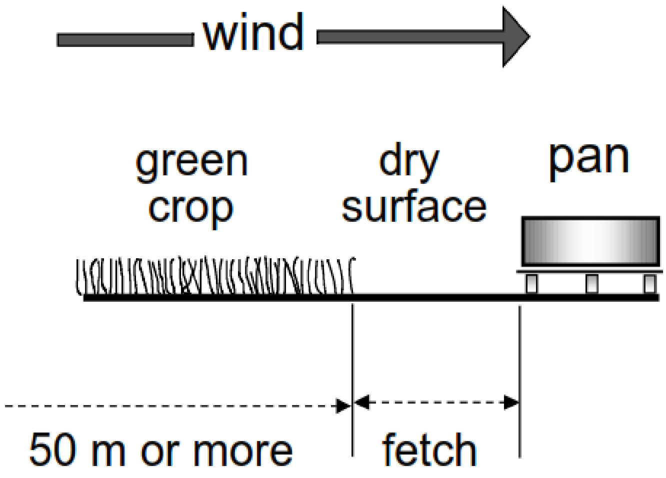

Figure B.6. Pan situated on fallow soil
SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

B.2.4.4 The appropriate pan coefficient shall be determined using wind data, mean relative humidity. Pan coefficients for Class A pan are given in Table B.17. For Colorado sunken pans, Table B.18 shall be used.

B.2.4.5 Table B.19 presents equations that can be used in determining K_{pan}.

B.2.4.6 In case of missing data, for wind speed (u_2), a global value of 2 m/s can be used. For RH_{mean}, it can be approximated as $RH_{mean} = \frac{50\ e^o(T_{min})}{e^o(T_{max})+50}$. Values for $e^o(T_{min})$ and $e^o(T_{max})$ shall be obtained using Table B.6.

Table B.17. Pan coefficients (K_p) for Class A pan for different pan siting and environment and different levels of mean relative humidity and wind speed

Class A pan	Case A: Pan placed in short green cropped area				Case B: Pan placed in dry fallow area			
RH mean (%) →		low < 40	medium 40-70	high > 70		low < 40	medium 40-70	high > 70
Wind speed (m/s)	Windward side distance of green crop (m)				Windward side distance of dry fallow (m)			
Light < 2	1	0.55	0.65	0.75	1	0.7	0.8	0.85
	10	0.65	0.75	0.85	10	0.6	0.7	0.8
	100	0.7	0.8	0.85	100	0.55	0.65	0.75
	1000	0.75	0.85	0.85	1000	0.5	0.6	0.7
Moderate 2 to 5	1	0.5	0.6	0.65	1	0.65	0.75	0.8
	10	0.6	0.7	0.75	10	0.55	0.65	0.7
	100	0.65	0.75	0.8	100	0.5	0.6	0.65
	1000	0.7	0.8	0.8	1000	0.45	0.55	0.6
Strong 5 to 8	1	0.45	0.5	0.6	1	0.6	0.65	0.7
	10	0.55	0.6	0.65	10	0.5	0.55	0.65
	100	0.6	0.65	0.7	100	0.45	0.5	0.6
	1000	0.65	0.7	0.75	1000	0.4	0.45	0.55
Very Strong > 8	1	0.4	0.45	0.5	1	0.5	0.6	0.65
	10	0.45	0.55	0.6	10	0.45	0.5	0.55
	100	0.5	0.6	0.65	100	0.4	0.45	0.5
	1000	0.55	0.6	0.65	1000	0.35	0.4	0.45

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

Table B.18. Pan coefficients (K_p) for Colorado sunken pan for different pan siting and environment and different levels of mean relative humidity and wind speed

Sunken Colorado	Case A: Pan placed in short green cropped area				Case B: Pan placed in dry fallow area			
RH mean (%) →		low < 40	medium 40-70	high > 70		low < 40	medium 40-70	high > 70
Wind speed (m/s)	Windward side distance of green crop (m)				Windward side distance of dry fallow (m)			
Light < 2	1	0.75	0.75	0.8	1	1.1	1.1	1.1
	10	1	1	1	10	0.85	0.85	0.85
	≥ 100	1.1	1.1	1.1	100	0.75	0.75	0.8
					1000	0.7	0.7	0.75
Moderate 2 to 5	1	0.65	0.7	0.7	1	0.95	0.95	0.95
	10	0.85	0.85	0.9	10	0.75	0.75	0.75
	≥ 100	0.95	0.95	0.95	100	0.65	0.65	0.7
					1000	0.6	0.6	0.65
Strong 5 to 8	1	0.55	0.6	0.65	1	0.8	0.8	0.8
	10	0.75	0.75	0.75	10	0.65	0.65	0.65
	≥ 100	0.8	0.8	0.8	100	0.55	0.6	0.65
					1000	0.5	0.55	0.6
Very Strong > 8	1	0.5	0.55	0.6	1	0.7	0.75	0.75
	10	0.65	0.7	0.7	10	0.55	0.6	0.65
	≥ 100	0.7	0.75	0.75	100	0.5	0.55	0.6
					1000	0.45	0.5	0.55

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

Table B.19. Regression equations for determining pan coefficients

Class A pan with green fetch	$K_p = 0.108 - 0.286u_2 + 0.0422\ln(FET) + 0.1434\ln(RH_{mean}) - 0.000631[\ln(FET)]^2\ln(RH_{mean})$
Class A pan with dry fetch	$K_p = 0.61 + 0.00341RH_{mean} - 0.000162u_2RH_{mean} - 0.00000959u_2FET + 0.00327u_2\ln(FET) - 0.00289u_2\ln(86.4u_2) - 0.0106u_2\ln(86.4u_2)\ln(FET) + 0.00063[\ln(FET)]^2\ln(86.4u_2)$
Colorado sunken pan with green fetch	$K_p = 0.87 + 0.119\ln(FET) - 0.0157[\ln(86.4u_2)]^2 - 0.0019[\ln(FET)]^2\ln(86.4u_2) + 0.013\ln(86.4u_2)\ln(RH_{mean}) - 0.000053\ln(86.4u_2)\ln(FET)RH_{mean}$
Colorado sunken pan with dry fetch	$K_p = 1.145 - 0.080u_2 + 0.000903(u_2)^2\ln(RH_{mean}) - 0.0964\ln(FET) + 0.0031u_2\ln(FET) + 0.0015[\ln(FET)]^2\ln(RH_{mean})$
Coefficients and parameters	K_p pan coefficient u_2 average daily wind speed at 2m height (m/s) RH_{mean} average daily humidity (%) = $(RH_{max} + RH_{min})/2$ FET fetch, or distance of the identified surface type (grass or short green agricultural crop for case A, dry crop or bare soil for case B upwind of the evaporation pan)
Range for variables	1m ≤ FET 1000m 30% ≤ RH_{mean} ≤ 84% 1m/s ≤u_2 ≤ 8m/s

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

B.2.4.7 For some conditions not accounted for in Table B.17 and Table B.18, adjustments for K_p may be necessary. Refer to Table B.20- for the adjustments.

Table B.20. Suggested Adjustments for K_p

Conditions		**Adjustments for K_p**
Location	**Climate**	
no agricultural development, extensive areas of bare soils, desert or semi-desert	arid, windy	may need to be reduced up to 20%
	moderate levels of wind, temperature and relative humidity	may need to be reduced up by 5-10%
	humid, cool	no or little reduction
pans in small enclosure but surrounded by tall crops	dry, windy	may need to be increased by up to 30%

	calm, humid	may need to be increased by 5-10%
pan is painted black		results may increase by up to 10%
when water level in Class A pan fall 10 cm below the accepted standard of between 5 to 7.5 cm below the rim		may result in errors of up to 15%
screens mounted over pan		may reduce by 10%

SOURCE: FAO Irrigation and Drainage Paper No. 56, 1998

B.2.4.8 The average pan evaporation (E_{pan}) for the period considered shall be computed.

B.2.4.9 ET_o shall be computed using the formula below.

$$ET_o = K_p \times E_{pan}$$

where ET_o = reference evapotranspiration, mm/day
K_p = pan coefficient
E_{pan} = pan evaporation, mm/day

ANNEX C
(normative)

Determination of Soil Texture

C.1 The standard method in determining soil texture is described in ASTM D 422 – Standard Test Method for Particle-Size Analysis of Soils

C.2 If the necessary laboratory equipment are not available, soil texture can be determined through feel analysis as shown in Figure C.1

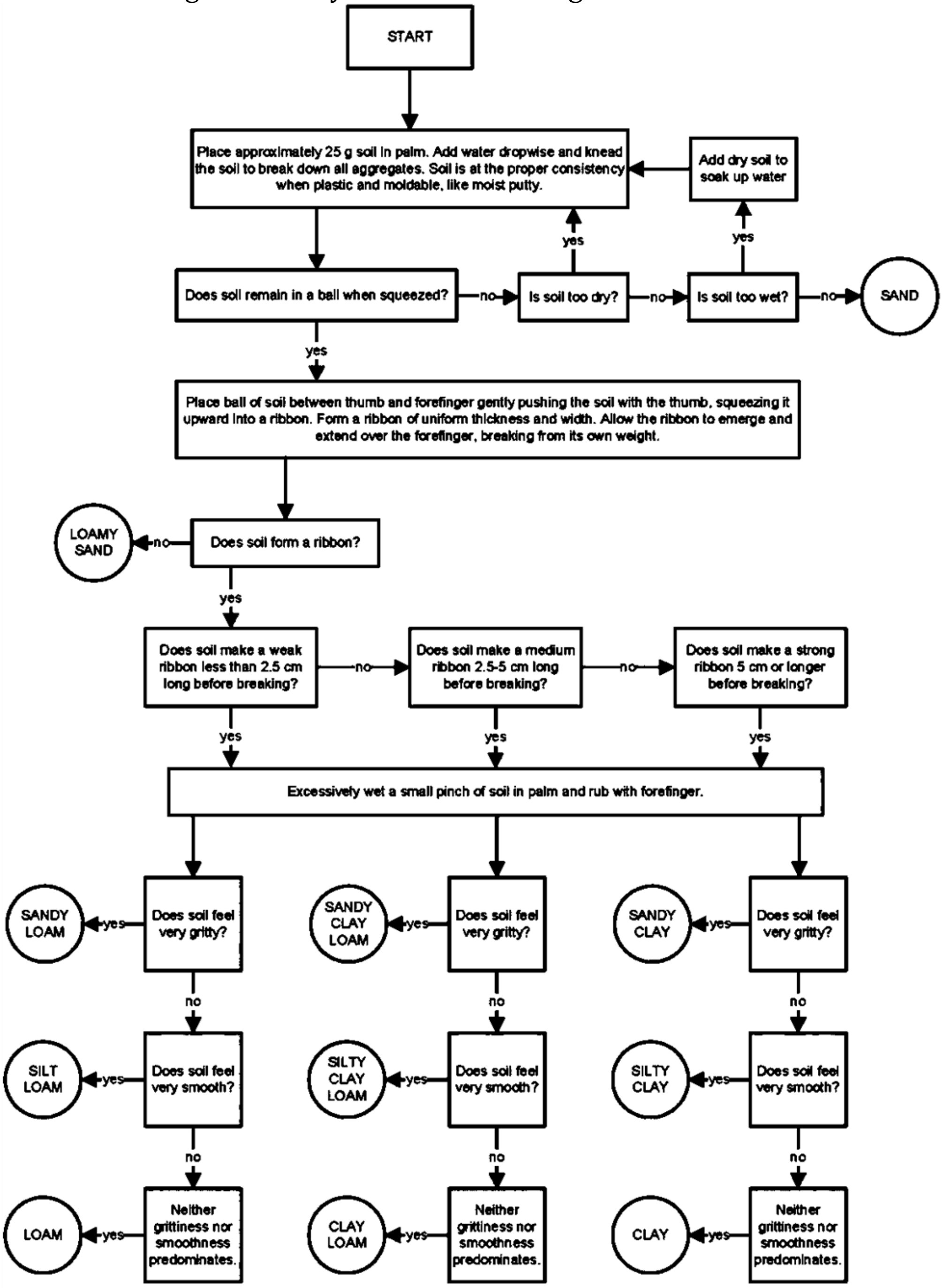

Figure C.1. Flow diagram in determining soil texture by feel analysis
SOURCE: USDA, National Engineering Handbook, 1993

ANNEX D
(informative)

Hydrologic Frequency Analysis

D.1 Selection of data

D.1.1 Annual Series

Only the largest event for each year shall be selected and shall be used when design is controlled by the most critical condition.

D.1.2 Partial Duration Series

All values above a given minimum value shall be chosen regardless of the frequency within a given time period. This shall be used if the second value (or lower) of the year would also affect the design of structures.

D.2 Determination of Statistical Parameters

D.2.1 Normal Distribution Method

D.2.1.1 Events shall be ranked from the highest to the lowest with the largest event being given a rank, m= 1, the second largest event, m = 2, and so on.

D.2.1.2 The arithmetic mean, M shall be computed.

$$M = \frac{\sum X}{N}$$

where:

X is the magnitude of events
N is the number of events

D.2.1.3 The standard deviation shall be computed.

$$S = \sqrt{\frac{\sum X^2 - \frac{(\sum X)^2}{N}}{N - 1}}$$

where:

X is the magnitude of events
N is the number of events

D.2.1.4 Using arithmetic-probability plotting paper, the following values shall be plotted at their corresponding probabilities as listed below and shall form a straight line.

- M at 50
- M + S at 15.9 %
- M – S at 84.1%

D.2.1.5 A rough estimate of the goodness of fit of the distribution to the data shall be determined by plotting the probability of occurrence (P) of the events using the equation

$$P = \frac{m}{N + 1}$$

where:

m is the rank

N is the number of events

D.2.1.6 The goodness of fit is an eyeball estimate. If found satisfactory, the resulting straight line may be used in predicting the frequency of occurrence of an event of a given magnitude.

D.2.2 Log-Normal Distribution Method

D.2.2.1 Events shall be ranked from the highest to the lowest with the largest event being given a rank, m= 1, the second largest event, m = 2, and so on.

D.2.2.2 The variables shall be transformed in their corresponding logarithmic values and the mean shall be computed as follows:

$$M = \text{Anti}\log\frac{\sum(\log X)}{N}$$

D.2.2.3 The standard deviation (S) shall be computed as follows

$$S = \text{Anti}\log\sqrt{\frac{\sum(\log X)^2 - (\sum\log X)^2 / N}{N - 1}}$$

D.2.2.4 Using a log-probability paper, the values shall be plotted at their corresponding probabilities as listed below and shall form a straight line.

- M at 50%
- M x S at 15.9%
- M / S at 84.1%

D.2.2.5 A rough estimate of the goodness of fit of the distribution to the data shall be determined by plotting the probability of occurrence (P) of the events using the equation

$$P = \frac{m}{N + 1}$$

D.2.2.6 The goodness of fit is an eyeball estimate. If found satisfactory, the resulting straight line may be used in predicting the frequency of occurrence of an event of a given magnitude.

D.2.3 Pearson Type III Method

D.2.3.1 Variables shall be transformed into their logarithms and the mean shall be computed using the equation

$$M = \frac{\sum \log X}{N}$$

D.2.3.2 The standard deviation of the logarithms shall be computed.

$$S = \sqrt{\frac{\sum(\log X)^2 - (\sum \log X)^2/N}{N-1}}$$

D.2.3.3 The coefficient of skewness (g) shall be computed.

$$g = \frac{\sum[\log X - (\sum \log X/N)]^3}{(N-1)S^3} \text{ x } \frac{N}{N-2}$$

D.2.3.4 Logarithms of the variable at selected recurrence intervals or percent chance shall be computed.

$$\log X = M + KS$$

D.2.3.5 K shall be obtained from the Table D.1 using the computed value of g and recurrence interval.

Table D.1. K values for positive skew coefficients

Skew coefficient (g)	1.0101	1.053	1.111	1.250	2	5	10	25	50	100	200
	Recurrence Interval In Years										
	Percent Chance										
	99	95	90	80	50	20	10	4	2	1	0.5
3.0	-0.667	-0.665	-0.660	-0.636	-0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.9	-0.690	-0.688	-0.681	-0.651	-0.390	0.440	1.195	2.277	3.134	4.013	4.909
2.8	-0.714	-0.711	-0.702	-0.666	-0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.7	-0.740	-0.736	-0.724	-0.681	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.769	-0.762	-0.747	-0.696	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.799	-0.790	-0.771	-0.711	-0.360	0.518	1.250	2.262	3.048	3.845	4.652
2.4	-0.832	-0.819	-0.795	-0.725	-0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.3	-0.867	-0.850	-0.819	-0.739	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.905	-0.882	-0.844	-0.752	-0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.1	-0.946	-0.914	-0.869	-0.765	-0.319	0.592	1.294	2.230	2.942	3.656	4.372
2.0	-0.990	-0.949	-0.895	-0.777	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-0.984	-0.920	-0.788	-0.294	0.627	1.310	2.207	2.881	3.553	4.223
1.8	-1.087	-1.020	-0.945	-0.799	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.140	-1.056	-0.970	-0.808	-0.268	0.660	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-1.093	-0.994	-0.817	-0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.5	-1.256	-1.131	-1.018	-0.825	-0.240	0.690	1.333	2.146	2.743	3.330	3.910
1.4	-1.318	-1.168	-1.041	-0.832	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.333	-1.206	-1.064	-0.838	-0.210	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-1.243	-1.086	-0.844	-0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.1	-1.518	-1.280	-1.107	-0.848	-0.180	0.745	1.341	2.066	2.585	3.087	3.575
1.0	-1.588	-1.317	-1.128	-0.852	-0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.9	-1.660	-1.353	-1.147	-0.854	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-1.733	-1.388	-1.166	-0.856	-0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.7	-1.805	-1.423	-1.183	-0.857	-0.116	0.790	1.333	1.967	2.407	2.824	3.223
0.6	-1.880	-1.458	-1.200	-0.857	-0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.5	-1.955	-1.491	-1.216	-0.856	-0.083	0.808	1.323	1.910	2.311	2.686	3.041
0.4	-2.029	-1.524	-1.231	-0.855	-0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.3	-2.104	-1.555	-1.245	-0.853	-0.050	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-2.178	-1.586	-1.258	-0.850	-0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.1	-2.252	-1.616	-1.270	-0.846	-0.017	0.836	1.292	1.785	2.107	2.400	2.670
0.0	-2.326	-1.645	-1.282	-0.842	0.000	0.842	1.282	1.751	2.054	2.326	2.576

ANNEX E
(informative)

Determination of Effective Rainfall Using ADB Method

E.1 Daily rainfall data of at least 10 years shall be obtained.

E.2 The average values of rainfall for each decade shall be computed. The rainfall distribution shall be determined from these values as shown in Figure E.1

E.3 The crop water requirement in decadal basis shall be known and represented in the graph. It must be noted that the crop water requirement changes by growth stage.

E.4 Rainfall values below the determined decadal crop water requirement shall be the effective rainfall and the values above become surface waste.

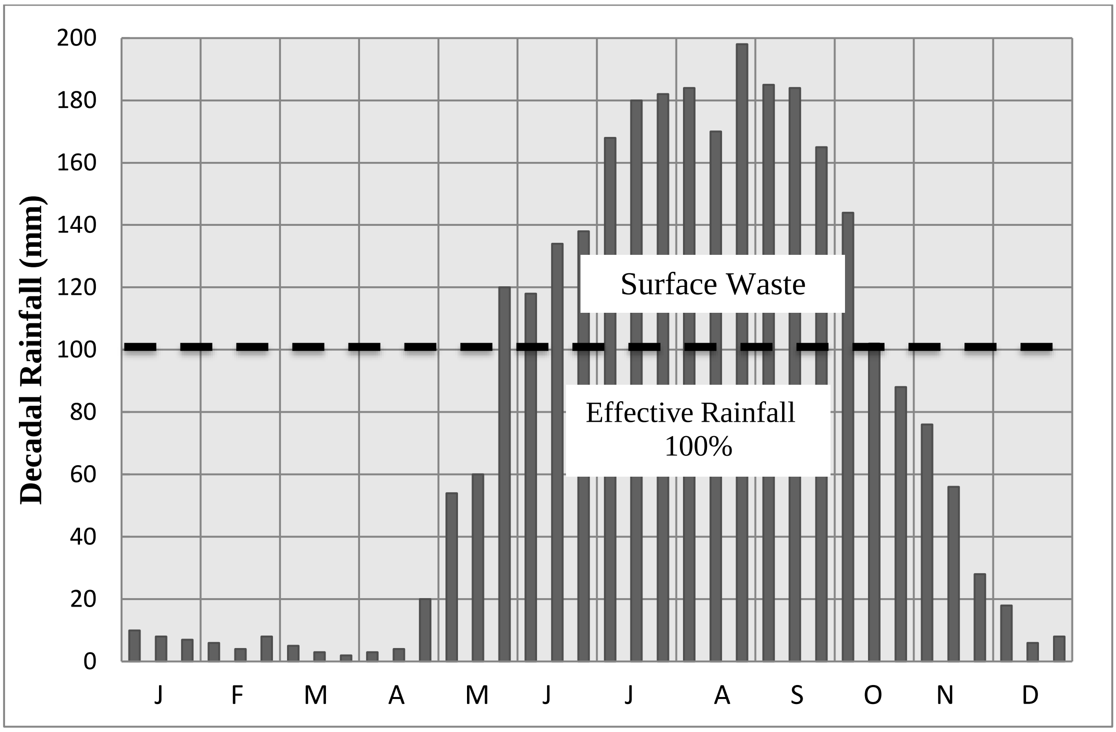

Figure E. 1 Rainfall distribution Diagram

E.5 The percent effective rainfall shall be computed using the formula:

$$\text{Percent effective rainfall} = \frac{\text{effective rainfall}}{\text{total rainfall}} \times 100$$

ANNEX F
(normative)

Determination of Land Soaking Requirements

F.1 The following physical properties of soil based on textural shall be determined: porosity (n), field capacity (FC), permanent wilting point (PWP) and apparent specific gravity (A_s).

Table F.1. Representative physical properties of soils

Soil Texture	Infiltration* and Permeability (cm/hr)	Total Pore Space (%)	Apparent Specific Gravity(%)	Field Capacity (%)	Permanent Wilting Point (%)
Sandy	5 (2.5-25)	38 (32-42)	1.65 (1.55-1.80)	9 (6-12)	4 (2-6)
Sandy Loam	2.5 (1.3-7.6)	43 (40-47)	1.50 (1.40-1.60)	14 (10-18)	6 (4-8)
Loam	1.3 (0.8-2.0)	47 (43-49)	1.40 (1.35-1.40)	22 (18-26)	10 (8-12)
Clay Loam	0.8 (0.25-1.5)	49 (47-51)	1.35 (1.30-1.40)	27 (23-31)	13 (11-15)
Silty Clay	0.25 (0.03-0.50)	51 (49-53)	1.30 (1.30-1.40)	31 (27-35)	15 (13-17)
Clay	0.5 (0.01-0.1)	53 (51-55)	1.25 (1.20-1.30)	35 (31.39)	17 (15-19)
NOTE Normal ranges re shown in parentheses *Intake rates vary gently wih soil structure and structural stability, even beyond the normal ranges shown above					

F.2 The depth of root zone (d_{rz}) of the crop shall be determined. For lowland rice, d_{rz} = 300 mm.

F.3 Residual moisture content (RMC) shall be obtained.

F.4 Land soaking requirement (LSR) shall be computed using the formula

$$LSR = \frac{[n - (RMC \times A_s)] \times d_{rz}}{100}$$

ANNEX G
(informative)

Determination of Conveyance Losses

G.1 Conveyance loss is the sum of the seepage and percolation losses in the conveyance structures (main canal to the sub-laterals), leakage through gates and left-over water in the canals and leakage through canal dikes.

G.1.2 Seepage and percolation losses in the conveyance structures (unlined canals)

$$(\text{S\&P})_{\text{canals}} = \text{A}_{\text{w}} \times \text{S\&P rate}$$

where:

$(S \& P)_{canals}$	is the seepage and percolation losses in the canals
A_w	is the wetted area = wetted perimeter x length of canal
S & P rate	is the rate of seepage and percolation

G.1.3 Leakage through gates and left over water in the canal shall be estimated as 5% of the total farm water requirement.

G.1.4 Leakage through canal dikes shall be computed the same way as the seepage and percolation losses in canals

ANNEX H
(normative)

Formulas

H.1 Crop Water Requirement

$$CWR = ET_a + (S \,\&\, P)_{field}$$

where:

CWR	is the crop water requirement (mm/day)
ET_a	is the actual evapotranspiration (mm/day)
$(S \& P)_{field}$	is the seepage and percolation in the field (mm/day)

H.2 Actual Evapotranspiration

$$ET_a == ET_o \times k_c$$

where:

ET_a	is the actual evapotranspiration (mm/day)
ET_o	is the reference evapotranspiration (mm/day)
k_c	is the crop coefficient

H.3 Farm Water Requirement

FWR = CWR - ER + LPWR + farm ditch losses

$$FWR = \frac{CWR - ER + LPWR}{E_a}$$

where:

CWR	is the crop water requirement (mm)
ER	is the effective rainfall (mm)
LPWR	is the land preparation water requirement (mm)
E_a	is the application efficiency (mm)

H.4 Land Soaking Requirement

$$LSR = \frac{[n - (RMC \times A_s)] \times D_{rz}}{100}$$

where:

LSR	is the land soaking requirement (mm)
n	is the soil porosity
RMC	is the residual moisture content
A_s	is the apparent specific gravity
D_{rz}	is the depth of root zone (mm)

H.5 Land Preparation Water Requirement

$$LPWR = LSR + SW + ET_o$$

where:

LPWR is the land preparation water requirement (mm)
LSR is the land soaking requirement (mm)
SW is the standing water (mm)
ET_o is the reference evapotranspiration (mm)

H.6 Farm Ditch Losses

$$Farm\ ditch\ losses = (S\ \&\ P)_{farm\ ditch} \times P \times L$$

where:

$(S\ \&\ P)_{farm\ ditch}$ is theseepage and percolation rate (mm/day)
P is the wetted perimeter (m)
L is the length of farm ditch (m)

H.7 Diversion Water Requirements

DWR = FWR + conveyance losses or

$$DWR = \frac{FWR}{E_c}$$

where:

DWR is the diversion water requirement (mm)
FWR is the farm water requirement (mm)
E_c is the conveyance efficiency

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