10. WATER REQUIREMENTS AND THEIR DETERMINATION

Shoichiro NAKAGAWA*

1. General remarks

(1) Definition

There are three factors to be considered in determining water requirements for submergence irrigation, which is the most popular irrigation method, namely evap-transpiration (ET), percolation and surface runoff. The third one can be disregarded as almost paddy fields are surrounded by border ridges which restrict surface runoff. Percolation is the process by which water is absorbed into the soil or seeps through it to the underground water level or to the adjacent open water surface. In the transpiration process, percolation encourages water reaching the root system. In this publication, however, the term "percolation" signifies the amount of water penetrating into the soil, regardless of its direction, without being utilized for transpiration.

In formulating irrigation development projects, the amount of water needed for the project should first be determined. These water requirements include the field water requirement, the irrigation requirement and the amount of water needed at the head of the irrigation system, i.e. diversion requirement. The water requirement can be determined from climatic data, using an empirical formula, or from field experimental investigation. It is, however, hardly possible to give definite figures for amounts of water needed for crop growth from platning to harvesting as these differ greatly according to soil characteristics, crop growing period and the irrigation method. It is possible though to determine the relative amount of water required for rice crop growth by direct or indirect measurements if these are properly carried out. When planning irrigation projects it should be noted that the water requirement for rice crop growth is not always the same as that for rice cultivation. In most cases the latter is much greater than the former. In this report field water requirements are discussed first, followed by the irrigation requirements and diversion requirements.

Definition of the related technical terms is described for reference.

Evapotranspiration = Evaporation + Transpiration

Field Water Requirement = Evapotranspiration + Percolation

Irrigation Requirement = Field Water Requirement + Farm Waste
− Effective Rainfall

Diversion Requirement = Irrigation Requirement + Distribution Loss

(2) Units of water requirement

The usual practice is to indicate the water requirement by water depth (in most cases in terms of mm/day) as this unit is also used for rainfall and evapotranspiration. In some cases the water requirement is shown by the rate of water discharge (in most cases litres/second/ha), and the water volume needed to irrigate a unit area for a certain period (in most cases m^3 for a total irrigation period). The following

* National Research Institute of Agricultural Engineering, Japan.

table illustrates the relationship between these units:

Table 1. Units of water requirement

litres/sec/ha	mm/day	m^3/day/ha
1.0	8.64	86.4
0.116	1.0	10.0

(3) Average field water requirements in Japan

Field water requirements in most parts of the country range from 10 to 30 mm daily which is equivalent to 1.16–3.48 1/sec/ha. This means that 1 m^3/sec of water can irrigate a field of 900–300 ha. Many experiments show that the average water requirement is 17 mm/day, which is greater than that in most tropical rice growing countries (where evaporation is considered to be much greater than in Japan). It should be noted, however, that more than half of Japan's paddy fields are located on rather high land with relatively pervious soils and that under heavy fertilizer application a certain degree of percolation may be required.

Figure 1 illustrates the results of a recent investigation on the relation between rice yield and water requirements. In view of the fact that the evapotranspiration can be considered as almost constant throughout the country, percolation is the governing factor for water requirement. It can be said that optimum water requirement in Japan under the present cultivation techniques lies between 15 mm to 25 mm daily.

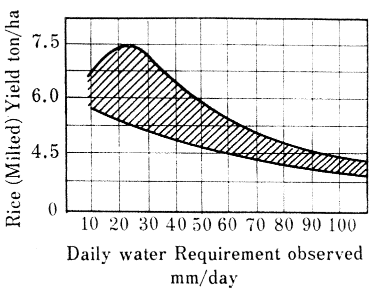
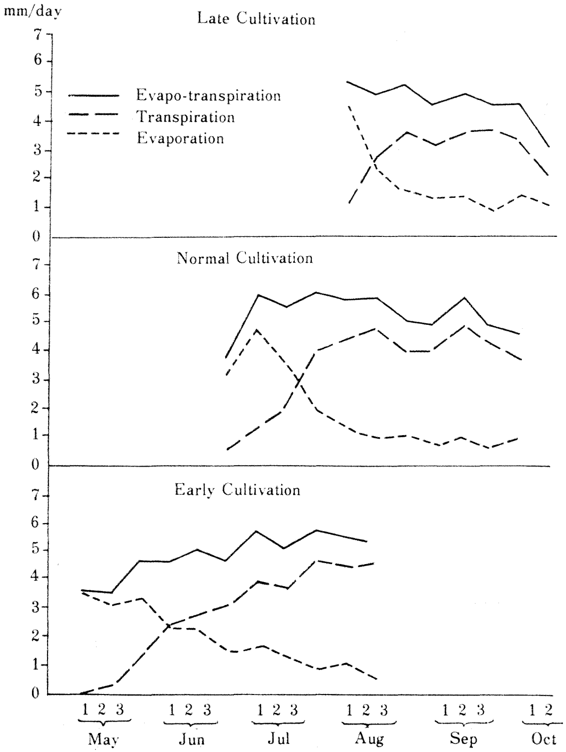


Fig. 1. Daily field water requirement and rice yield (Isozaki, 1967)

2. Evapotranspiration (ET)

(1) Relationship between evaporation and transpiration

Transpiration varies greatly with the climate and crop growth stage and tends to increase as leaves grow. Under usual cultivation it is small immediately after transplanting, becomes larger towards tillering and reaches its peak at about the heading and flowering stages, then decreases gradually during the ripening stage. Evaporation varies with the climatological environment and the density of the leaves. The maximum is usually at the time of transplanting, but decrease with the growth of stalks and leaves which create shade in the fields. This relationship is illustrated in Fig. 2.



* Conducted in Shikoku Agri Station
** 1, 2, 3, means 1st 10 days, 2nd 10 days and third 10 days respectively

Fig. 2. Evaporation, transpiration and evapotranspiration

(2) Geographical variation in ET

The result of a countrywide investigation using lysimeters set in the middle of paddy fields is shown in Table 2.

From Table 2 the following results are obtained.

a) Average daily ET ranges from 3.3–7.1 mm/day.

b) Peak ET occurs between late July and mid-August, and it appears that ET is influenced more by climatic conditions than by crop growing stage.

c) Geographical variation in ET is very little. It is only 1–2 mm daily at the maximum.

d) The standard daily ET in the country is 3.5 to 5.0 mm in June, 4.0 to 6.0 mm in early mid-July, 5.5 to 7.5 mm in late July to mid-August, 6.5 to 4.5 mm in late August to early September, and 5.5 to 4.0 mm after mid-September.

e) Total ET during the whole irrigation period for 100 days is 440 to 550 mm, and about 500 mm on the average.

(3) Evapotranspiration (ET) and pan evapolation (Ep)

A recent countrywide investigation shows that ET/Ep varies from 0.9 to 1.7 (averaging 1.3) and tends to increase towards the late growing stage, showing the maximum value in September. The result of such an investigation is seen in Table 3.

Table 2. Actually measured ET in various localities

(Mean values of each ten days, mm/day)

Month	June			July			August			September			Oct.			Mean	Remarks
Ten-days	Beginning	Middle	End	Beginning	Middle	End	Beginning	Middle	End	Beginning	Middle	End	Beginning	Middle	End		
District																	
Hokkaido	3.4	4.9	4.1	4.3	5.0	5.2	5.9	4.4	4.3							4.6	4 districts, average for 21 years in running aggregate
Tohoku	3.8	4.2	3.3	3.7	4.6	5.4	5.5	5.5	4.5	4.4	3.6					4.4	2 〃 13 〃
Kanto			3.4	3.7	4.3	6.4	6.2	6.4	5.6	4.5	4.5	4.5				5.0	1 〃 10 〃
Hokuriku	3.6	3.9	4.1	4.2	4.0	6.1	5.3	6.4	4.8	6.6						4.9	3 〃 4 〃
Tokai			3.8	4.4	3.5	—	5.3	7.1	5.5							4.9	1 〃 1 〃
Kinki				4.2	4.9	5.7	6.1	4.8	6.5	7.3	5.7	4.7				5.5	2 〃 2 〃
San-in			5.0	4.5	5.4	6.0	6.4	5.1	5.0	4.3	3.7					5.0	1 〃 4 〃
Sanyo				4.1	5.0	7.0	6.7	6.6	6.3	4.9	4.4	4.7				5.5	2 〃 4 〃
Shikoku			3.7	4.9	5.6	6.0	5.8	5.9	5.2	5.0	5.9	4.9	4.7			5.2	1 〃 4 〃
Kyushu				3.7	5.9	6.1	6.0	6.5	6.3	5.1	5.4	5.1	5.0	4.8		5.4	3 〃 9 〃
Mean value throughout the country	3.6	4.3	3.9	4.2	4.8	6.0	5.9	5.9	5.4	5.3	4.7	4.8	4.9	4.8		4.9	20 〃 72 〃

Note: —— Above the figure; first rank in each ten days in each district.
...... Above the figure; second rank in each ten days in each district.

Table 3. The ratio of ET/Ep in various localities

District	May	June	July	Avgust	Sept.	Oct.	Remarks
Hokkaido		1. 1-1. 3	1. 3-1. 4	1. 4-1. 6			4 districts, average for 16 years in running aggregate
Tohoku		1. 1-1. 2	1. 2-1. 3	1. 3-1. 4	1. 4-1. 5		2 〃 11 〃
Kanto		1. 3	1. 3-1. 5	1. 4-1. 5	1. 7		1 〃 10 〃
Hokuriku		0. 9-1. 0	1. 0-1. 4	1. 5-1. 7	1. 3		2 〃 2 〃
Tokai		0. 8	1. 0-1. 2	1. 2-1. 6			1 〃 1 〃
Kinki			0. 8-1. 2	1. 2-1. 4	1. 5-1. 7		2 〃 2 〃
San-in		1. 1	1. 1-1. 2	1. 1-1. 2	1. 2		1 〃 4 〃
Sanyo			1. 2-1. 4	1. 4-1. 6	1. 5-1. 7		2 〃 4 〃
Shikoku		1. 1	1. 0-1. 2	1. 0-1. 2	1. 1-1. 5		1 〃 4 〃
Kyushu			1. 0-1. 1	1. 2-1. 4	1. 4-1. 6	1. 5-1. 4	3 〃 9 〃
All over the country		0. 9-1. 2	1. 0-1. 4	1. 1-1. 6	1. 3-1. 7	1. 5-1. 4	19 〃 63 〃
Early-season cultivation	0. 8-1. 0	1. 1-1. 2	1. 3-1. 5	1. 3-1. 4			3 〃 6 〃
Late-season cultivation			0. 8	0. 9-1. 0	1. 1-1. 4	1. 4-1. 1	1 〃 4 〃

A Japanese standard pan (20 cm diameter, 10 cm depth, tin-plated inside) is set horizontally on a lawn without hazards, and measurements of water loss are taken at 24 hour intervals. But, in estimating actual evaporation from a large water surface such as a reservoir, a coefficient of 0.5 is used, but 0.7 is used in the United States Weather Bureau Pan (40 ft diameter, 10 in deep).

3. Percolation

(1) Vertical and horizontal percolation

Percolation is divided into two types, namely horizontal and vertical. Their percolation rates are governed by many factors, such as texture of soil, depth of top soil, groundwater level, etc.

Horizontal or levee percolation usually predominates in terraced paddy fields where the elevation of each field differs considerably. Some studies on horizontal percolation, with special emphasis on potential flow lines, show that horizontal percolation is 3 to 10 times greater than vertical. However, much of the water "lost" in horizontal percolation is available for reuse because it is either collected in the drainage ditches or flows into an adjacent field. Thus, vertical percolation is the most important factor to determine the amount of water requirement in each paddy field. In principle, vertical percolation should be determined by actual measurement.

(2) Governing factors

Generally, in the saturated soil, percolation water flows according to Darcy's law. The vertical percolation of soil in paddy field is not the exception. Darcy's law is expressed as follows:

$$V = k\frac{h}{1}$$

Where velocity, V (cm/sec) is determined by coefficient of permeability, k (cm/sec) and hydraulic gradient between the two points, $h/1$ (h = variation in water heads between the two points, 1 = distance between the two points).

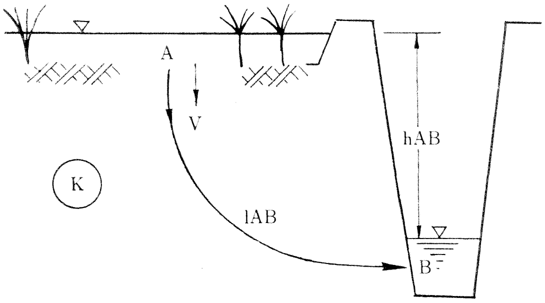


Fig. 3. A diagram of paddy field percolation

Therefore, percolation rates are governed by soil characteristics and hydraulic condition. The former mostly refers to permeability which varies with soil texture and cracks and holes created by plant roots or small worms. The latter concerns the dynamic hydraulic gradient which is governed by the ground water table or water level of nearby canals. The relationship between these two factors is shown in Table 4.

Table 4. Classification of paddy fields in accordance with percolation elements

Hydraulic head \ Permeability (cm/sec)	$K>10^{-3}$	$K=10^{4\sim5}$	$K<10^{-6}$
Large-nearby surface water table is below 1.0 m	A	D	C
Medium-nearby surface water table between 0.3—1.0 m	B	E	H
Small-nearby surface water table 0—0.3 m	C	F	I

From the field survey conducted, B, D and E can be roughly classified as being suitable conditions, while F, H and I belong to the inferior category from the point of view of natural drainage.

(3) Soil layer condition, coefficient of permeability and vertical percolation

Soil of paddy field in general consists of some layers which have different characteristics and different permeabilities from each other, such as surface soil, plow-sole, subsoil, etc. In these layers, the dimension of falling permeability is determined, limited by the poorest permeable layer among the layers.

Therefore, for understanding periodic changes of percolation or tendency of change caused by land improvement and by cultivation method, the following would be necessary:

a) To make clear hydraulic condition at each stage of rice growth and the dimensions of permeability coefficient of each layer.

b) To know which is the poorest permeable layer.

As stated already, vertical percolation follows Darcy's law. Therefore, if hydraulic gradient is equal to 1, coefficient of permability coincides with percolation speed directly.

By using this relationship, coefficient of permeability can be converted into the daily amount of percolation as shown in Table 5. But actually, hydraulic gradient is far smaller than 1 and its order shows 10^{-1} to 10^{-2}.

Table 5. Relation between permeability coefficient and percolation

Permeability coefficient	Percolation	
$n\times10^{-6}$ cm/sec	0.86– 8.6 mm/day	clay
$n\times10^{-5}$ 〃	8.6 – 86 〃	
$n\times10^{-4}$ 〃	86 – 860 〃	
$n\times10^{-3}$ 〃	860 – 8,600 〃	
$n\times10^{-2}$ 〃	8,600 – 86,000 〃	sand

Note: In this table, hydraulic gradient is taken as one.

Therefore, the amount of percolation which corresponds to the coefficient of permeability in this figure would become smaller to about 1 or 2 order. In addition, if the order of permeability coefficient is smaller than 10^{-6} cm/sec., the change of percolation amount appears only about 1 mm/day even if hydraulic condition (hydraulic gradient) such as water table of drainage canal, etc. changes largely, i.e. this change of percolation amount is practically negligible because it can be included in the measuring error. But if the order of permeability coefficient is larger than 10^{-5} cm/sec., the amount of percolation changes because of the change in hydraulic condition, to a degree that it would matter practically.

Therefore, if the order of permeability coefficient in some layers is smaller than about 10^{-6} cm/sec., the amount of percolation in the paddy field is scarcely affected by the change of hydraulic condition, i.e. the amount of percolation is merely determined by the permeability of soil.

On the contrary, if the order of permeability coefficient in all the layers is larger than about 10^{-4} cm/sec., when the hydraulic gradient changes only by 0.1, the change of percolation amount would show more than 10 mm/day. That is to say the amount of percolation responds very sensitively to the change in hydraulic condition.

If the amount of falling percolation is to be controlled artificially, it is desirable to adjust the order of permeability coefficient of poorest permeable layer to a range between $10^{-4}\sim10^{-5}$ cm/sec.

(4) Change of vertical percolation amount in irrigation period

In many irrigation planning in the past, the amount of vertical percolation during one irrigation period was presumed constant throughout the period, i.e. the seasonal change of water requirement in depth was determined by taking into consideration only reasonal change of evapotranspiration. But in actual paddy field, the amount of vertical percolation itself shows certain changes according to such factors as the condition of paddy field, water management, etc. Therefore, the water requirement in depth is largely affected by the change of vertical percolation than the change of evapotranspiration except in the case of ill-drained paddy field. If the percolation amount is about 10 mm/day throughout irrigation period, the seasonal change is negligible. But if the percolation amount is more than about 15 mm/day the following seasonal changes are shown generally in many cases.

That is to say a) the amount of vertical percolation is large in the initial stage of irrigation period, contrary to evapotranspiration amount; b) decreases gradually after surface soil puddling; c) shows minimum in mid-irrigation stage; and d) rather increases again in the latter irrigation stage.

4. Water requirement in depth (net duty of water)

(1) Actual condition of water requirement

The amount of water requirement in depth in one plot is determined by various factors. The systematical summary is shown in Table 5. It will be understood how complex factors are involved in water requirement in depth.

Table 6. Main reasons of change in water requirement

Water requirement in depth in the field	Evapotranspiration	Climatic conditions (Air temperature, Humidity, Solar radiation, Wind direction and velocity etc.)
		Growing conditions of rice (Variety, Soil, Climate, Field management practices etc.)
	Vertical percolation	Hydraulic conditions (Topography, Water level of drainage canal, Ground water table, Evopo-transpiration of rice plant)
		Permeability of soil (Structure of soil layers, Cracks, Oxidation and reductions, volatilization of gas, Cultivation operation, Water management, etc.)
	Percolation from border	Hydraulic conditions (Differences in elevation of neighbouring paddy fields and in their water level, Water management)
		Permeability of border (Materials of soil, Moisture content, Management of border, Fauna in soil etc.)

Among these factors, the following can be said. The amount of evapotranspiration is affected decisively by the meteorological condition. On the other hand, the amount of falling percolation is affected difinitely by the hydraulic gradient and by the permeability of the most impermeable soil layer. In general hydraulic gradient is represented by water level of drainage canal, etc. In addition the amount of percolation from borders is affected decisively by the permeability of borders. As stated already, among these consumptive uses, the water requirement in depth is affected most greatly by the dimension of falling percolation amount. According to existing data or to the author's experience, average value of water requirement in depth in our land ranges approximately as follows: Ill-drained paddy field area, 5–10 mm/day; imperfectly drained paddy field area, 10–20 mm/day; well-drained paddy field area, 15–30 mm/day; and leaking paddy field area 30–100 mm/day. Average value of whole paddy fields in our land may be about 18 mm/day. But these values are mere standard, i.e. in actual irrigation planning, these average values are not so useful. In order to estimate the present irrigation requirement in selected paddy field area, actual survey of water requirement in depth must be carried out.

(2) Periodical change of water requirement

Periodical change of water requirement in depth which is most important in irrigation requirement planning is affected by such factors as follows: Topography, soil texture, groundwater level, cultivation method and method of water management.

The outline of existing measurements or experimental results will be described below. When ill-drained paddy fields in which water requirement in depth is small are compared with well-drained paddy fields in which water requirement in depth is considerably large, there are some characteristic differences as follows.

In the paddy field in which percolation rate in not large and in which the evapotranspiration is a decisive factor and in which water requirement is less than about 15 mm/day, periodical change of percolation rate is relatively negligible.

Therefore, periodical change of water requirement in depth shows the same tendency as periodical change of evapotranspiration, i.e. in many cases, it shows somewhat convex change and its peak appeas from the last ten days in July to the middle ten days in August as shown in Fig. 4 (a). On the contrary, in the paddy field in which water requirement in depth is more than 20 mm/day, the percolation rate becomes a decisive factor. The periodical change in the falling percolation in the paddy field shows concave change as shown in Fig. 4 (b). This tendency is contrary to the case of evapotranspiration as stated already. In addition, the periodical change of falling percolation ranges more widely than that of evapotranspiration.

In case paddy field in which permeability of subsoil is large, when the permeability of surface soil increases caused by drainage, the amount of percolation tends to increase also as shown in Fig. 4 (c).

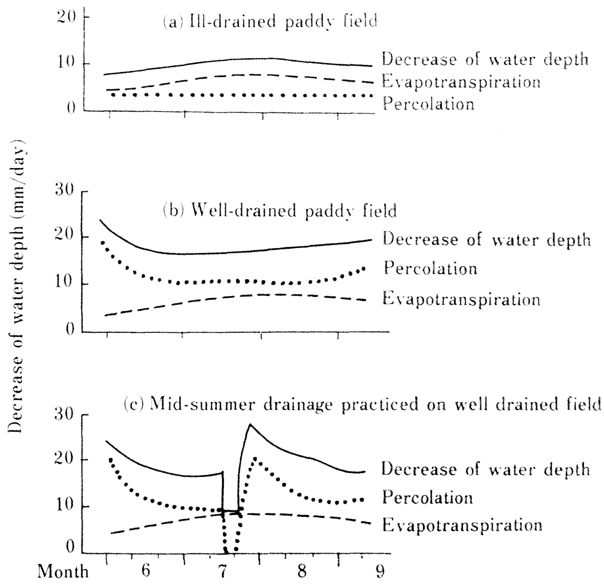


Fig. 4. Diagrammatic illustration of water depth decrease

(3) Measurement method of water requirement in depth

1) Maps

In most fields percolation takes up major part of the water requirements and its rate varies considerably with natural conditions. It is therefore a prerequisite to investigate the various factors affecting percolation, such as soil, groundwater and topography.

The following maps are usually prepared or made available for this purpose:

a) *Topography*
Topographical survey maps, 1/50,000 or 1/25,000; 1/3,000 if needed.

b) *Groundwater*
Water table map indicating the depth of groundwater.

c) *Soil and Stratification*
Soil profile map, showing the thickness of the top soil and the texture of the subsoil.

2) Determination of the number of measuring points

Percolation rates vary from place to place in accordance with soil and groundwater conditions. Based upon the soil and groundwater investigations, grouped lands and measuring points are determined, in most cases at the following rate:

Table 7. Number of measuring points

Area of group (ha)	Number of measuring point
0– 20	3
20– 40	4
40– 60	5
60– 80	6
80–100	7
100–150	8
150–200	9
200–250	10
250–300	11
300–350	12
400–500	13

3) Selection of test fields

Although the location of test fields varies with the measuring method to be adopted, the fields possessing the following conditions are usually selected:

a) Complete border ridges must be present.
b) The field should be a typical example of the locality.
c) Water should be obtainable directly from the irrigation ditch in a short time.
d) A considerable hydraulic head (15–20 cm) between the ditch and field surface should exist.

4) Direct measurement in the field (Decreased water depth measurement)

Water depth decreased is measured on a daily basis, in principle, throughout the entire irrigation period. In some cases, however, water measurement takes place once or twice in every ten days. The water level is measured by hookguage or scale once a day, usually at 9 a.m. (refer to Fig. 5).

This measurement indicates the water requirement as a whole as the sum of evapotranspiration and percolation (both horizontal and vertical). As the former is considered as constant to some extent, and can be determined by various methods, the percolation rate can be easily obtained. This method is widely practiced to determine the unit water requirement.

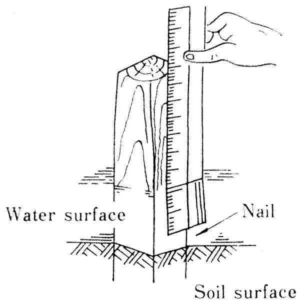


Fig. 5. Measuremenet of decreased water depth by using a stake and a scale

There are several methods for measurement of water requirement in depth and percolation but they are omitted in this paper.

5. Water requirement for puddling

(1) Puddling work

The transplanting system is most often used in Japan's rice culture. Paddy fields are ploughed, harrowed and supplied with water in order to soften the soil for transplanting. Puddling by harrowing makes paddy soil muddy, saturated with water. Such mud can, to some extent, prevent excessive percolation.

Puddling work, customarily followed by transplanting, is carried out in the rainy season which usually prevails throughout the month of June.

(2) Puddling water requirements

The quantity of puddling water can be determined by soil depth to be saturated and soil porosity. The average puddling water varies from 100 to 300 mm in depth (1,000–3,000 m^3 per hectare). Assuming that the thickness of top soil (which is to be saturated) is 30 cm, its porosity is 50% and submergence depth after puddling is 5 cm, the amount of water required for puddling is: $(30\text{ cm} \times 0.5) + 5 = 20\text{ cm}$

(3) Maximum water requirement during the puddling period

Puddling works usually require a considerable amount of water varying from 100m to 300 m. The maximum water requirement exists during this period if there is no rainfall or the whole area is puddled within a very limited period of time. In practice, however, puddling is carried out over a considerable period ranging from 3 to 10 days depending upon the availability of water and labour. It can be said that peak demand of water occurs on the last day of the puddling period if the daily puddling area and daily irrigation requirements are constant. Water requirement for the puddling period can be calculated as follows:

$$Rp=[As+Ad(n-1)/2]\times 10\ (\mathrm{m}^3) \cdots\cdots (1)$$

Where

Rp=Water requirement during the puddling period
n=Number of puddling days
s=Puddling water depth (mm)
d=Unit water requirement (mm) (evapotranspiration + percolation)
A=Area to be puddled (ha)

Daily water requirement for the x th day is:

$$Rpx=\frac{A}{n}[s+(x-1)d]\times 10\ \text{m}^3 \quad \cdots\cdots(2)$$

6. Water requirement in large area

(1) Hydrological balance

Water consumption within a given area comprising many plots of paddy field is determined by this method. The method is applied to an area in which at least the surface inflow and outflow can be measured.

$$I_s+R+I_g=O_s+O_g+E+S \quad \cdots\cdots(3)$$

Where

I_s=Surface Inflow (Irrigation)

R=Precipitation

I_g=Subsurface Inflow

O_s=Surface Outflow

O_g=Subsurface Outflow

E=Evapotranspiration

S=Storage in or on the soil

Total Water Consumed (W) can be shown as:

$$W=E+O_g-I_g \quad \cdots\cdots(4)$$

$$W=I_s+R-O_s-S \quad \cdots\cdots(5)$$

Surface inflow and outflow is measured, in principle, on a daily basis. There is an instance, however, that the measurements take place 3–5 times during the irrigation period (3–5 days for each time) when no rainfall is present. In most cases, water is measured by flumes or weirs with water level recorders.

In the case of intensive measurement for a short period, R and S can be ignored, and the following relation exists:

$$(I_s-O_s)=(O_g-I_g)+E \quad \cdots\cdots(6)$$

Total water consumed in the area is the sum of evapotranspiration and groundwater increased/decreased. As a part of the percolated water can be re-utilized for irrigation purposes (while the rest flows out from the area), the following equation is established:

$$(O_g-I_g)=P-G_s \quad \cdots\cdots(7)$$

$$W=(P-G_s)+E=H-G_s \quad \cdots\cdots(8)$$

Where

P=Percolation

G_s=Percolated water being used for irrigation purposes within the area

H=Water requirement in depth in the fields

The water requirement for a large area, W, is usually smaller than the average water depth decreased (the larger G_s, the smaller $(P-G_s)$, and W approaches E). In lower stretches of alluvial plains, where rice is usually cultivated, there exists almost no groundwater movement and W is almost equal to E, which in most cases ranges from 5 to 10 mm/day.

In the upper part of an alluvial fan area or in the terraced land, the greater part of percolation flows out from the area, and total water requirement, W, becomes greater than F approaching H (this tendency is remarkable where the area becomes smaller). In such a case consumed water ranges from 10 to 30 mm/day.

There is the case where 0_g is smaller than I_g, usually occurring where groundwater springs are present. There are instances where W is smaller than E, thus forming waterlogged (poorly drained) land.

(2) Relationship between the sum of plot water requirements and large area water requirement

The relationship between the water requirement for a small area and that for a large area is very complicated and varies with topography, geography and hydrological features. However, the following tendencies are found:

a) The rate of reusable groundwater varies with the size of the area being irrigated—the smaller the area, the lower the rate. The amount of water required for all the individual plots is equal to that required for an area smaller than 100 ha.

b) In areas (such as an alluvial fan) where most of the percolated water runs out from the area as subsurface flow, reusable groundwater should not be taken into account unless the area is larger than 1,000 ha.

c) In areas where no groundwater movement exists, the system of reutilizing drained or percolated water should be investigated in the first instance. It is therefore necessary to divide the area into smaller blocks in which a detailed hydrological study can be carried out and the hydrological relation of each block investigated.

7. Determination of irrigation water requirements

(1) Basic year for planning

An irrigation project is planned and designed on the basis of a drought year. In order to determine the amount of water to be supplied to the field, and to design the irrigation systems, the basic year must be decided. Precipitation data during the past 40–50 years are carefully examined and a drought year which occurred once in 15–20 years is usually selected. When enough data are not available, rainfall in the basic year is estimated by super-probability calculation or other statistical methods.

(2) Irrigation requirement for a basic year

When the amount and distribution of rainfall in the basic year differ greatly from those in the year when actual measurement takes place, irrigation requirement in the basic year is calculated by the following way:

$$Ir=\sum[(ET\times r)+P-Re] \quad \cdots\cdots (9)$$

Where

Ir=Irrigation

ET=Evapotranspiration actually observed

P=Percolation

R_e=Effective rainfall in the basic year

$$r=\frac{\text{Pan evapo. in the standard planning year}}{\text{Pan evapo. in the actually investigated year}}$$

The investigation is carried out on a 10-day basis. Assuming that the total irrigation period is 110 days, the equation (9) becomes:

$$Ir=\sum_{n=1}^{n=11}[(ET\times r_n)+P_n-R_{en}] \quad \cdots\cdots (10)$$

(3) Effective (available) rainfall

Irrigation requirement is determined by deducting effective rainfall from the net water requirement.

Effective rainfall is the amount of rainfall falling during the crop growing period, and being utilized to meet water requirements. As crops are not able to utilize fully the total amount of rainfall available in the growing period, effective rainfall cannot be expressed in terms of the total precipitation. In most cases 70–90% of total rainfall during the irrigation season is assumed to be effective. Effective rainfall is calculated on the basis of the basic year as follows:

a) Daily rainfall of more than 50–80 mm, depending upon the conditions, is considered as non-effective since this may overflow the levee of the paddy fields and cannot be stored in the fields.

b) Daily rainfall of less than 5 mm is considered as non-effective.

(4) Maximum seasonal irrigation requirement

As water requirement varies with weather conditions and crop growth stages, daily net water requirement is not constant throughout the irrigation season. In order to determine the capacity of canal systems, the maximum irrigation requirements should be decided. This is found when evapotranspiration is maximum, with no effective rainfall. When the mean daily evapotranspiration is known, this may be calculated as follows:

$$RI\ max = 1.7\ ET\ mean + P\ mean - R\ mean$$

Where

RI max=Maximum seasonal irrigation requirement
ET mean=Mean daily evapotranspiration
P mean=Mean daily percolation
R mean=Mean effective rainfall

(5) Total irrigation requirements

It may be concluded that total irrigation requirements in the country range from 750 mm to 1,900 mm, based upon the following:

Unit water requirement	10–20 mm/day
Puddling water requirement	150–200 mm
Irrigation period	110 days
Effective rainfall	500 mm

8. Diversion requirement

(1) Conveyance losses

The diversion requirement is the sum of the irrigation requirement and the water losses in an irrigation system. Such losses include evaporation from the water surface, percolation from canals and operational losses. Among these components evaporation is negligibly small (5 percent of total loss) and further restriction is not practicable. Loss by percolation, which forms a major portion of conveyance losses, is greatly reduced by lining canals. Since most of the irrigation canals in the country are lined with concrete or stone, conveyance loss is relatively small, varying from 5 to 20%.

(2) Determination of canal capacity under intermittent irrigation

There are two major irrigation methods, namely the continuous method and the intermittent one. The former is the more popular where plentiful water suply is available, whilst the latter is applied in areas subject to water shortage or where the cost of water is relatively high. The continuous method usually requires less canal capacity than the intermittent one, which demands concentrated flow to the field within a limited time.

There are two basic patterns in intermittent irrigation. The first is when the whole area is irrigated intermittently and the second is when the whole area is divided into several blocks which receive water rotationally within a limited time. In ed by the following equation: the latter case, the canal capacity is decid

$$Q=\frac{M\times N\times A\times D_{\max}(1+\alpha)}{T}\quad (m^3/sec) \cdots\cdots\cdots(11)$$

Where

Q=canal capacity (m^3/sec)

T=time needed for delivering water (seconds)

M=number of plots commanded by one canal

N=irrigation interval (days)

A=area of one plot (m^2)

α=water conveyance loss varying from 0.05 to 0.2

D max=maximum daily water requirement (m/day)

9. Some factors affecting water requirements

(1) Soils

As already discussed, water requirements differ from place to place according to environmental conditions. Such difference is mainly due to soil and groundwater characteristics and drainage conditions which are the factors governing percolation. The following table, the results of which were obtained by experiment, shows this point:

Table 8. Soils and average net water requirement mm/day

Sand	27
Sandy loam	23
Loam	17
Clay loam	14
Clay	10

(2) Water sources

Water requirements also vary with the irrigation method and operation of irrigation systems. These problems are not discussed in this paper. It should be noted, however, that the amount of irrigation water actually used differs greatly according to the source of the water and the cost; the higher the water cost and the smaller the available supply of water, the less the amount of water consumed. This fact is illustrated in the following table:

Table 9. Average irrigation requirement and type of water sources

Water source	Number of surveys	Water required m^3/sec/ha	mm/day
Reservoir	103	0.00140	12.1
River	86	0.00295	25.5
Groundwater	12	0.00300	25.8
Pumped water	101	0.00129	11.6
Combined sources	6	0.00197	17.0
Total/average	308	0.00225	19.4

(3) Water requirement for newly reclaimed fields

In newly reclaimed paddy fields, especially those in mountainous areas, the ground-water table is generally low while soil permeability is relatively high, thus causing a high rate of percolation. Percolation, however, decreases gradually year by year as the field matures with the development of an impervious soil layer (plough pan). Results of investigations in this regard are seen in Table 10.

Table 10. Change inpercolation rates

Year after reclamation	Normal paddy field percolation rate 1. 40–1. 66 1/sec/ha	Pervious paddy field percolation rate 2. 22–2. 77 1/sec/ha
½	5. 0 times	—
1	2. 0 times	3. 5-4. 0 times
2	1. 7 times	2. 0–2. 5 times
3	1. 2 times	1. 5–1. 7 times
4	1. 0 times	1. 3–1. 5 times
5	1. 0 times	1. 2 times
6	1. 0 times	1. 0 times

It can be said that percolation rates will be reduced to 1/3–1/5 within a few years of the paddy fields having been reclaimed. Particular attention should be paid to this phenomenon when estimating water requirements and determining the capacity of water delivering systems. Irrigation requirements in newly reclaimed paddy fields should not be over-estimated and land under irrigation should be extended systematically in order to utilize fully the limited water resources, avoiding the construction of irrigation systems with an excessive capacity when the fields reach maturity.

The same conception is applicable to paddy fields reclaimed from tidal land, as abundant water will be required during the first few years to leach excessive salt.

References

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