16. DRAINAGE OF PADDY FIELD IN JAPAN

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I. Purpose of drainage

The purpose of drainage in paddy fields may be summarized as follows:

(1) To avoid or remove overhead flooding water caused by heavy rainfalls (especially in the rainy season or typhoon season).

(2) To drain water and supply air to soils for practicing midsummer drainage and other cultivation management (such as application of weedkiller and liquid fertilizer).

(3) To maintain optimum percolation (15 mm–25 mm) during an irrigation period.

(4) To dry field at the time of harvest for the purpose of facilitating farm works.

(5) To keep soils dry during the non-irrigation period to grow second crops, and to ensure a long lasting "soil-drying effect".

II. Facilitation of drainage in paddy fields

Water inflow and outflow in paddy fields can be illustrated as in Fig. 1.

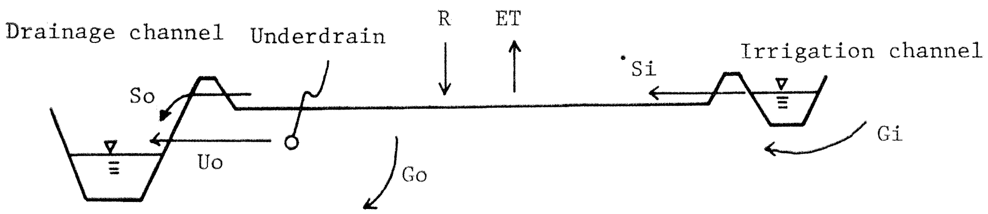

Fig. 1. Inflow and outflow of the terminal paddy field

Inflow water (A) = Irrigation water (Si) + Rainfall (R) + Subsurface inflow from adjacent fields (Gi).

Outflow water (B) = Evapotranspiration (ET) + Surface drainage water (So) + Subsurface drainage water (Uo) + Percolation (Go).

The balance of soil moisture in fields is determined by (A − B), and the soil moisture can be reduced by the following methods:

(1) Interception or prevention of Gi.

(2) Promotion of So.

(3) With respect to Uo and Go; removal of remaining water on field surface and lowering of soil moisture content by underdrain and lowered drainage channel.

(4) Decrease of soil moisture by the acceleration of ET.

In Japan, drainage is usually required in paddy field areas geographically located on an open plain land, particularly as a countermeasure against heavy rainfall in the typhoon or rainy season and against the undesirable rainfall at the time of harvest drainage or non-irrigation period.

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The methods (2) and (3) are more important among the methods described above when drainage is needed as a necessary procedure in the cultivation of rice plants (the method (1) seems to be less important). As a result, the water level management of the drainage channel is especially important for the smooth performance of (2) and (3) methods.

There are two ways in the drainage of paddy fields, that is, surface drainage and subsurface drainage. As to the discharge capacity of these two, the former is far superior to the latter. The excess water in the terminal paddy field, therefore, should be removed by surface drainage at first and then by subsurface drainage (with underdrain etc.) to remove remaining water.

III. Surface drainage of paddy fields (promotion of So)

"*Basic design for planning land improvement projects*" of Japan (hereafter referred to "basic design for planning") describes surface drainage as follows:

"The surface drainage must be intended *to be accomplished within one day after its beginning*,[Note 1] and necessary conditions for this performance should be prepared".

Enlarged size of each field block required for mechanization with large power machines makes surface drainage rather difficult. For example, the extent of land levelling becomes insufficient in large blocks, and rapid drainage of surface water becomes more difficult compared with that of usual small blocks. The necessity of rapid drainage of surface water, however, is increasing in order to reinforce soil bearing capacity for the use of large power machienry and the introduction of new cultivation methods and rotation from paddy to other crops. Therefore, various conditions such as land levelling, soil layer improvement, underdrainage, training field ditch and drainage facility for residual water must be prepared sufficiently.

1. Land levelling

Land levelling should be done sufficiently enough to minimize the residual water in drainage. According to the basic design for planning, "the degree of land levelling should be within the range of ± 5 cm of the average elevation of land, and the include of the land must be zero or be slightly inclined towards drainage channel".

2. Soil layer improvement

The optimum rate of percolation is generally regarded as 20 mm/day for the growth of rice plants and cultivation management. Then the coefficient of water permeability should be more than about $2-5 \times 10^{-5}$ cm/sec.

The percolation becomes few mm/day when coefficient of water permeability of the soil is less than 10^{-6} cm/sec whereas.

When the coefficient of water permeability is more than 10^{-4} cm/sec, percolation becomes more than 100 mm a day which is greatly affected by a slight change in hydraulic condition.

The "basic design for planning" says, considering the reasonable water management during irrigation period, necessary drainage for the trafficability of large power machinery and the rotation from paddy to other crops, that "with respect to the permeability of the soil of paddy fields, the coefficient of water permeability of the least permeable soil layer is desirable to be in the range from 10^{-4} cm/sec to 10^{-5} cm/sec".

Generally drainage is required in the paddy field of clayey soil. In such fields there are two ways to increase permeability.

(a) Improvement by methods of cultivation and of water management

In this method, soils are dryed by making use of evaporation from the field surface to make cracks by which the permeability will be increased.

Methods of cultivation such as, direct sowing on dry field, non-irrigated cultivation and rotation from paddy to other crops are effective to make cracks on soil and to promote the development of soil structure by drying the surface of paddy fields during the summer season with maximum evaporation.

As for water management, intensive midseason drainage or intermittent irrigation is effective in developing soil cracks by drying the surface of fields for a longer period.

Since the effect of these methods increases when the groundwater table was lowered the combination with underdrainage gives higher effect.

(b) Improvement by working

When the method (a) can not be practically effective because soil cracks develop only in a shallow layer or very slowly, it becomes necessary to destruct the soil layer mechanically down to more than several tens centimeters in depth by means of mole drain or subsoil break to make water paths. This method is highly effective for clayey soil when applied in combination with underdrainage. Deep tillage and reverse plowing may also be effective when an impermeable layer exists in a part of the soil layer.

3. Underdrainage (to be described in IV)

4. Training field ditch

Training field ditches are made to facilitate rapid surface drainage.

Training field ditches are usually arranged to connect at right angles with drainage channels in a lot (usually along the longer side of the lot) at intervals of 10 to 20 m. The ends of these ditches are connected to the drainage facility for residual water. Branches of the ditch should be extended to a depression where water is apt to remain.

In the direct-sowing culture on dry fields, training field ditches are digged with a plow at around the seeding time, and in puddled field the ditches are digged by hand power between rows at the time of midseason drainage.

5. Drainage outlets

A drainage outlet is prepared in each field lot at one place adjacent to drainage channel. In very large field lots, where the side adjacent to the drainage channel is longer than 50 m, two drainage outlets are installed. In case of one outlet for a lot it must be situated in the lower side of the lot.

Profile of the opening of an outlet is less than 50 cm in width, and when more than 50 cm in width is necessary, it must be divided into two outlets. The bed height is kept at 5 to 20 cm below the surface of fields.

IV. Subsurface drainage (promotion of Uo)

Underdrainage is equipped to paddy fields where groundwater table could not sufficiently be lowered even by drainage channels and surface drainage.

From the viewpoint of the soil bearing capacity and growth of upland crop, the necessity of underdrainage is judged on the basis whether the groundwater table can be lowered to 30 to 50 cm below the field surface within two or three days after surface drainage or not.

The recent view on this subject described in the "Underdrainage Planning Standard" (1973, Sept.) will be cited.

1. Design of underdrainage discharge

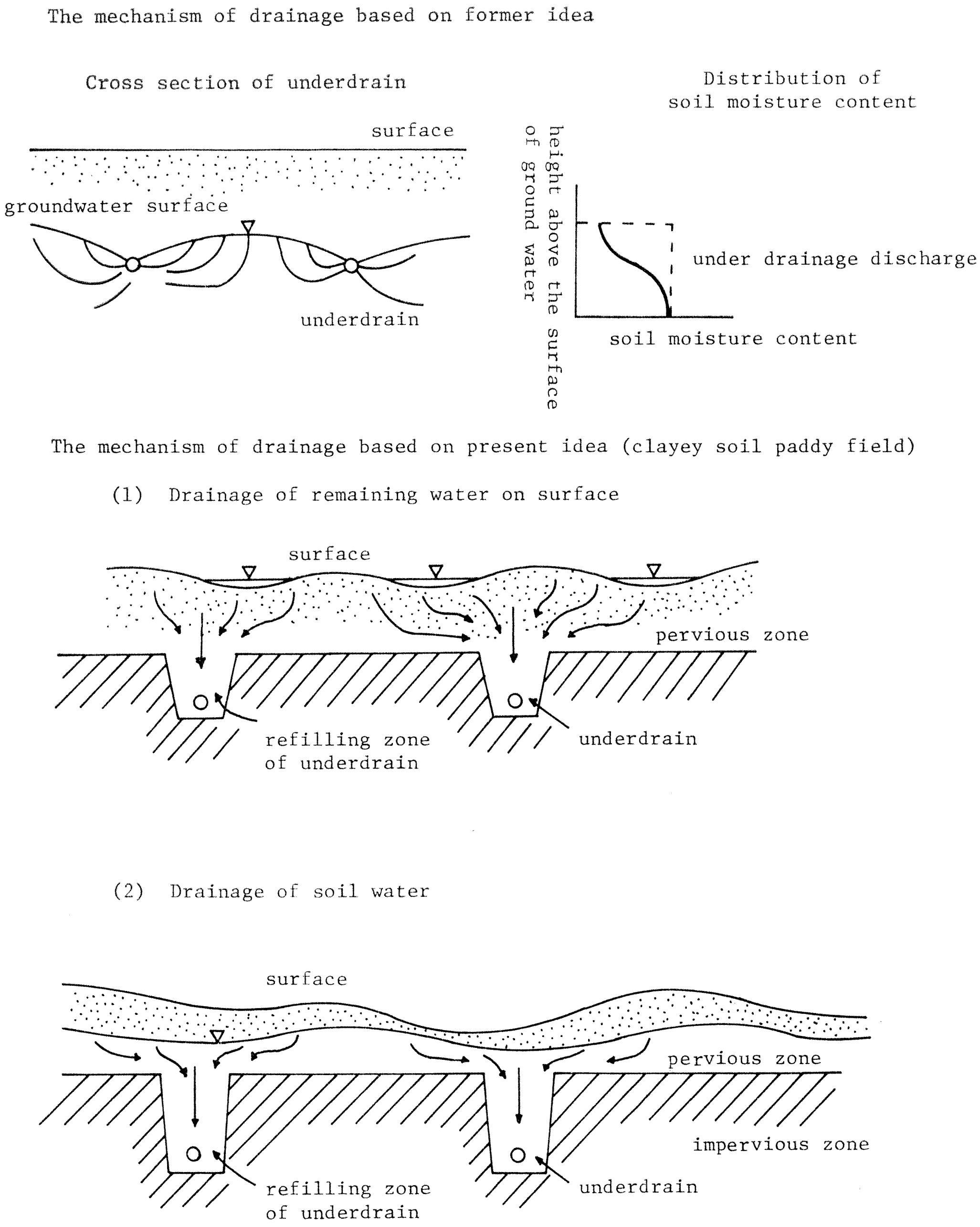

Fig. 2. Mechanism of drainage by underdrain

"Underdrainage discharge should be designed to be 20 to 50 mm/day, depending on land levelling, field size and permeability of soil in a block (a border lot). There is no difference between paddy field and upland field with this discharge".

Two kinds of excess water to be removed by the underdrainage are the remaining surface water and the gravitational water in soil according to this "standard". The principal role of the underdrainage was formerly considered to remove the latter, but recently, the removal of remaining surface water is regarded as the important role of the underdrainage based on results of surveys and researches.

Especially in the clayey soil paddy field, it is considered, from its pF — soil moisture curve, that the drainage discharge of soil water is not abundant and the majority of the underdrainage discharge is derived from the remaining surface water. The refilling part of underdrain, and cracks in top soil and subsoil exhibit also a great draining effect.

These mechanisms are summarized schematically in Fig. 2.

As to the amount of remaining surface water, it may reach about 50 mm in average under the worst condition when the land levelling was made with a standard of ±5 cm of the average elevation.

Actual measurements of the remaining surface water indicate 21 mm or 30 mm in the paddy fields at Shonakanoko in Shiga prefecture (16–17 years after land draining and farm block is 15 a) and 35 mm in the paddy fields at Komino in Saitama prefecture (55 years after farm land consolidation and farm block area is 10 a). It may be about 20 to 30 mm in general.

Measurements conducted by the author at paddy fields in Hachirogata polder reclamation (5 years after land draining and under first cropping) showed 10 mm to 15 mm, unexpectedly low values.

The underdrainage discharge designed to be 20 to 50 mm/day means that the amount of remaining surface water is taken as 20 mm to 50 mm and this amount of water is discharged in a day as described in III.

2. Design of groundwater level and its lowering velocity

Groundwater level is an important index showing drainage condition of soil water.

Table 1 shows the groundwater level and its lowering velocity standardized according to the land use classification.

Table 1. Lowering velocity of groundwater level and ordinary groundwater level

Land use classification	Groundwater level 2–3 days after a rainfall	Ordinary groundwater level (7 days after a rainfall)
	cm below surface	cm below surface
Single cropping of rice	30–40	40– 50
Grassland upland-lowland rotational paddy field Upland crop	40–50	50– 60
Perennial crop	50–60	60–100

V. Block drainage (lowering water level in drainage canal)

Water level in drainage canal must be kept at a low level to facilitate surface and subsurface drainage.

The water level in terminal drainage canals adjacent to paddy fields is especially important for making vertical water management possible with regard to water movement in soil layer about one meter below the field surface, that is related to bearing capacity reinforcement, optimum percolation and rotation from paddy to other crops.

Sub-main and main drainage canals and pumping drainage facilities are necessary to keep the water level of terminal drainage canals at low level. The cost of repair and maintenance of the whole drainage facilities becomes very expensive. Consequently, a drainage system for individual small block of fields was invented. In this system, the drainage for each small block is usually carried out with a pump of small type.

This block drainage system makes repeated use of water possible to meet an increasing irrigation requirement caused by recent advances of rice culture techniques and farm land consolidation, and it has been practiced effectively in the advanced rice areas such as Niigata, Nōbi and Saga plains. An adequate unit of area for this block drainage may be about 30 to 50 ha.

VI. A notion of designing drainage discharge

It is a very important problem how to design drainage discharge in the planning of drainage for an unit of large area. A general notion on this point is described in the "basic design for planning" as follows.

(1) "The surface drainage in the case of single cropping of paddy is designed on the basis of daily rainfall and daily drainage while that in the case of second crop or rotation from paddy to other crops is designed as four hour rainfall and four hour drainage, not allowing field submergence as a rule". However, in areas of single cropping of rice where drainage is performed by pumping, investments for drainage facilities such as pumps become too much if field submergence is not allowed. In such a case, field submergence is allowed within a limit of less than 30 cm, and when it is over 30 cm, flooding hour should be less than 24 hours.

(2) "Daily rainfall which occurs at 1/10 of probability is taken as the rainfall to be used as the base for planning, and the runoff coefficient should be determined by referring to the data actually measured in similar areas".

As it is not economically feasible to take the heaviest rainfall in the past or a heavy rainfall which comes once during several decades as the basic rainfall for planning, like in the case of a large river, it is suitable to adopt 1/10 of probability.

The universal value of runoff coefficient cannot be obtained easily because this coefficient is fairly variable according to the conditions and rainfall patterns in the subject area.

A desirable method for determining runoff coefficient is to estimate the peak runoff coefficient of the subject area by considering characteristics of that area, based on the values shown in the "*Actually measured data*"[Note 2)] collected from similar areas in which land consolidation has been accomplished.

As to the main and sub-main drainage canals which cover more than several tens hectare area, the unit area drainage discharge is designed by using "*the rational formula*".[Note 3)]

The data actually measured in paddy field areas in the past shows that most of the direct runoff coefficients were 70 to 80% with a daily rainfall at a level of 100 mm and were 80 to 85% with a daily rainfall at a level of 200 mm during the irrigation period in low and plain land.

In the comparison of runoff coefficient before and after land consolidation the total runoff coefficient was nearly the same, but the peak runoff coefficient appeares to increase slightly after land consolidation.

Now the real value of the designed drainage discharge per unit area will be described briefly.

The drainage of the paddy fields in swampy lowland of Japan is mostly performed by pumping drainage with drainage pumps, and the draining effect depends upon the power of the pump and the flowing capacity of drainage canals.

The unit area drainage discharge increased owing to recent intensive land use in a drainage basin and developed management of rice culture.

The specific discharge of pumping drainage was about 0.3 m^3/sec per 1 km^2 in the past. This low value is due to the poor flowing capacity of the drainage canal and abundant flooding water expected in the paddy fields.

The specific discharge should be more than 1 m^3/sec when rotation from paddy to other crops, change of paddy fields to upland fields, and also are intended as well

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Note 1) Allowable days for surface drainage of paddy field.

The standard allowable days for surface drainage of paddy fields in each period throughout a year are determined as follows from the data and experiences in the past.

a. Irrigation period

At the application of weedkiller and liquid fertilizer........................Within 1–2 days

The stage of drainage after sprouting in direct sowing on submerged soil ....Within 1 day

Midseason drainage stage ....Within 2–3 days

At the end of irrigation ....Within 3–5 days

Drainage of flooding water caused by heavy rain (flooding water more than 10 cm)..Within 1–2 days

b. Non-irrigation period (drainage for rain water)

The stage of plowing and harrowing ....Within 1–3 days

The seeding stage of direct sowing on dry field.............................Within 1–2 days

The germination stage of direct sowing on dry field ....Within 1–2 days

Harvest stage ....Within 1–2 days

Upland cropping stage (as second cropping or rotation from paddy to other crops)...Within 1–2 days

Autumn plowing stage ....Within 3–5 days

Accordingly, it is desired that flooding water on surface should be drained sufficiently within one day. This is one of the necessary conditions for the surface drainage in paddy fields.

Note 2) Examples of runoff coefficient.

Example 1) Swampy low paddy fields

Shibatagawa area on the right bank of the Agano river in Niigata prefecture. Basin area

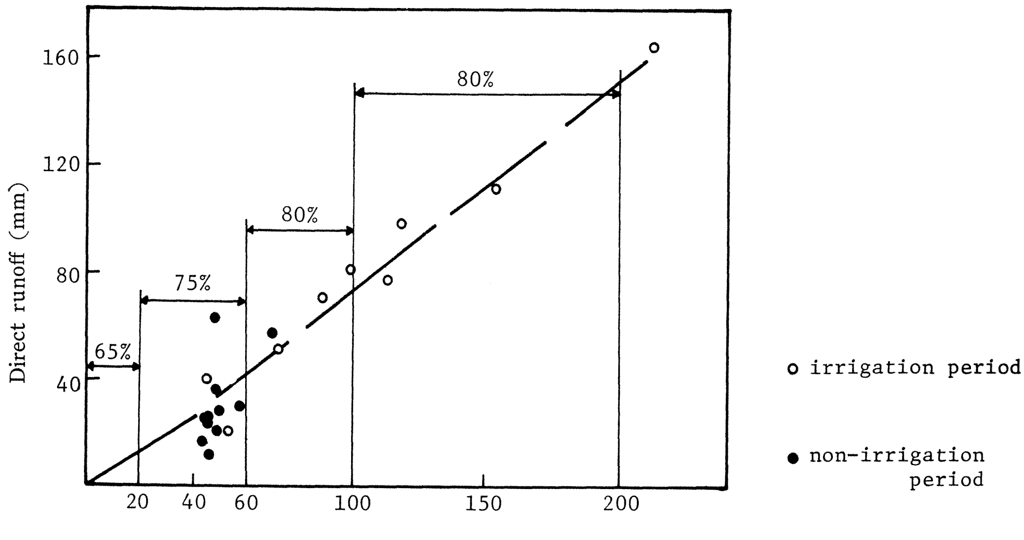

Fig. 3. Total rainfall and direct runoff (Shibatagawa district area, 6,003 ha)

Table 2. Direct runoff coefficient in Shibatagawa area (irrigation stage)

Precipitation (mm)	Direct runoff coefficient (%)
0– 20	65
20– 60	75
60–100	80
100–200	80

60. 03 km^2, percentage of area under paddy fields 79. 5%, average incline of the land 1/4, 000. Fig. 3 shows the relationship between the direct runoff and total rainfall derived from the record of precipitation registered more than 50 mm in 1958–61. Table 2 shows the direct runoff coefficient classified by the precipitation during the irrigation stage in this area.

Example 2) Upland field area

Twelve dry field areas at Obihiro district in Hokkaido. Catchment area 2. 88–33. 20 km^2, mountain ratio 0–69%. Table 3 shows the surface runoff coefficient derived from the record registered for about 10 years before 1964. It must be considered that the runoff of these upland field areas may be changed after land improvement.

Teble 3. Surface runoff coefficient of upland area (by T. Chano)

Total precipitation (mm)	20	40	60	80	100	120	140	160	180	200
Surface runoff coefficient (%)	6	20	25	28	30	30	37	41	47	49

Example 3) Total runoff coefficient of the rivers in the mainland of Japan at the time of flooding.

Table 4.

Lay of the land or river	Steep mountainous land	Tertiary layer mountain	Undulating land or woods & forest	Plain dry fields	Paddy fields under irrigation	Rivers in mountain	Streams in plain land	Large rivers, More than half of the basin is plain land
Runoff coefficient (%)	75–90	70–80	50–75	45–60	70–80	75–85	45–75	50–75

Note 3) Rational formula

$$Q=0.2778f\cdot\gamma_t\cdot A$$

Q: Peak discharge (m^3/sec), f: peak runoff coefficient,

γ_t: intensity/hour of the maximum precipitation within the concentration time (mm/hr),

A: catchment area (km^2).

In this generally used practical formula, the rainfall distribution in a river basin, retardation and regulation in a river basin or river course are not taken into consideration.

Calculation process

(1) Determination of the area (A) classified by land category in the region and runoff coefficient (fi).

(2) Determination of daily rainfall (design basic precipitation): $\gamma 24$.

(3) Determination of river's incline.

L_{AB}: Distance from the extreme upper stream to the inflexion point of incline in the water course.

L_{BC}: Distance between the inflexion point and measuring position (in the case of no inflexion point, $L_{BC}=0$).

H_{AB}: Head between the extreme upper stream and inflexion point.

H_{BC}: Head between the inflexion point and measuring position (in the case of no inflexion point, $H_{BC}=0$).

(4) Determination of concentration time (by Rziha's formula)

$$W_{AB}=72\left(\frac{H_{AB}}{L_{AB}}\right)^{0.6}, \quad W_{BC}=\left(\frac{H_{BC}}{L_{BC}}\right)^{0.6}, \quad T_{AC}\frac{L_{AB}}{W_{AB}}+\frac{L_{BC}}{W_{BC}}$$

(5) Determination of average runoff

$$f_c=\frac{\sum(fi\cdot Ai)}{\sum Ai}$$

(6) Determination of hourly rainfall within concentration time (by Ito's formula)

$$\gamma_c=\frac{\gamma 24}{24}\left(\frac{24}{T_{AC}}\right)^{\frac{2}{3}}$$

(7) Determination of runoff

$$Q_c=0.2778\cdot f_c\cdot\gamma_c\cdot A_c \qquad (A_c=\text{total area})$$

drainage of building lot are considered and furthermore it should be around 2 m^3/sec in the future.

Question and Answes

T. Nishio, Japan: Regarding optimum percolation, I understand that percolation is very important to have rice grow well and to prevent fertilizer loss. But I cannot understand this optimum range should be so serious. Still are you minding to keep this value of percolation for recent land improvement project?

Answer: Significance of optimum percolation 15–25 mm/day is as explained in Dr. Nakagawa's report. But this does not mean that optimum percolation for land consolidation should be always within this range. In order to get high yield of more than 6 ton/ha in paddy fields in which water requirement in depth is less than 10 mm/day or more than 50 mm/day, soil layer improvement or underdrainage are necessary in impermeable soil, and subsoil compacting or soil dressing are in leaking paddy fields. Optimum percolation is regarded between 15 and 25 mm/day as a recomendable target range for land consolidation projects.

T. Nishio, Japan: In page 1 you mentioned 15–25 mm is optimum as percolation, but in page 6 you mentioned that design of underdrainage discharge should be 20 to 50 mm/day. Are they same things?

Answer: 15–25 mm/day mentioned in page 1 is optimum quantity of percolation, and 20–50 mm/day is designed underdrainage discharge. They are founded on different views. The designed underdrainage discharge 20–50 mm/day means to drain standnig water within one day (24 hours) after surface drainage, and this is a designed value to cope with advancement of cultivation techniques and high utilization of paddy fields i.e. introduction of second crops or rotation from paddy to other crops. It is described in the former Mannual that the unit discharge of underdrainage systems is in the range of 0.70–1.66 l/sec/ha, and the average of them is 1.10 l/sec/ha (equivalent to about 9.5 mm/day). The designed underdrainage discharge 20–50 mm/day based on the recent view was reformed to very large value more than twice of of the former.

Sebastian I. Julian (Philippines)

How much is the cost of underdrainage in Japan?

Answer: According to the example in Hachirōgata polder, the standard plan of the underdrainage system is as illustrated in Fig. 4. Excavatoin of the water absorption conduits depends on Drain-Master, and collecting conduits on Large Lidar.

Works except them are carried out by human power.

Cost per hectare (1975) is as follows.

Machinery cost	31,509	yen
Labor cost	47,561	
Material cost	174,506	
Direct cost of construction	253,576	
Overhead cost	119,180	(253,576 × 0.47)
Construction cost	372,756	

Cost of underdrainage differs due to conditions of objective area or design specifications, but generally it seems to be about 300,000–500,000 yen/ha. Of course, there are methods to reduce this cost. We can reduce it to about 50–70 percent by the above way. For example, in the case of the Hachirōgata, the materials of the under-drain is vinyle chloride pipes, which can be replaced with cheaper materials such as vinyle chloride films or pervious materials like chaff, chip, fine gravel, coarse sand etc.