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***WATER DELIVERY METHOD***

by

*Associate Professor Dr. Varawoot Vudhivanich*

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*Department of Irrigation Engineering , Faculty of Engineering*

*Kasetsart University , Kamphaengsaen Campus , Nakhon Pathom 73140*

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## **1. Introduction**

Water delivery is an important part of irrigation water management. Its objective is to deliver discharge in the right amount (flow rate, frequency and duration) with sufficient head to the right person at the right time and in a reliable and assured way. Many water delivery methods have been developed including continuous, rotation, on-demand and reservoir delivery which is commonly known to irrigation engineers. However the water delivery can also be classified according to the delivery policy into supply-oriented and demand-oriented delivery. In this paper, methods of water delivery, delivery policy, delivery scheduling and flow control are discussed

## **2. Water Delivery Methods**

There are four main methods of water delivery including continuous, rotation, on-demand and reservoir.

### **2.1 Continuous Method**

This is the simplest and most widely used method but it is also the least efficient. The same discharge flows continuously day and night throughout the irrigation season along the canals and flows to irrigation ditch and farms. Each farm receives a small continuous flow (about 1-5 l/s) usually based on the area of land being irrigated.

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<sup>1/</sup> Associate Professor, Dept. of Irrigation Eng., Faculty of Engineering, Kasetsart Univ., Kamphaengsaen Campus, Nakhon Pathon 73140.



Among the three methods of rotation, the rotation in farm ditch has been found to be the most common practices especially where the main crop is paddy. The first method is not economical because it requires large discharging capacity of the main canal and control structures. This disadvantage is also true for rotation in laterals.

### **2.3 On-demand Method**

This can be the most efficient method of water delivery but it is the most difficult to organize properly. Irrigators can take water from the irrigation system whenever they wish. Usually only a few irrigators will take water at a time so that the demand for water will not be excessive. This is very similar to the supply of domestic water in a town. When someone wants water they turn on a tap and the supply is there. They do not expect to wait for water to come one day each week (as in the rotation method) or to have the tap running slowly all the time (as in the continuous flow method). Although it is very convenient for irrigators, this type of system is expensive to construct. Special automatic gates are needed to respond to changes in water demand in the canals. The system does not work well when too many irrigators decide to irrigate at the same time. Cooperation between irrigators is essential to prevent the irrigation system from being over-loaded.

Presently, the use of on-demand method is restricted to a small irrigation project. It requires adequate facilities to completely control water such as pump irrigation from streams or wells.

### **2.4 Reservoir Method**

This combines the easy operation of the continuous method with the convenience of the on-demand for the irrigators. Reservoirs are built along the lateral canals and are filled with water continuously day and night. Irrigators then take the stored water when it is convenient to them.

The reservoirs are sometimes called night-storage reservoir because they store water at night so that irrigators can irrigate during the day. On some projects water is stored in large lateral canals. These are called night-storage canals.

### 3. Delivery Policy

#### 3.1 Division of Responsibilities

It is the role of government, through an irrigation agency, to provide irrigation water at the level where the water users can take over the responsibility, i.e. at the tertiary offtake.

This means that the irrigation scheme is divided into 2 parts, (1) main irrigation system—managed by government, through its irrigation agency and (2) tertiary unit—managed by the farmers themselves, through Water Users' Organization. The main system comprises of the main diversion structure (headworks), the primary canal and the secondary canals with their structures including the tertiary offtakes, see Fig.2 . Tertiary units are the areas served by tertiary offtakes, sometimes called “end unit” or “service unit” or “chack”. The tertiary system comprises of the tertiary, sub-tertiary and quarternary irrigation canals with their structures. The tertiary units comprises of a number of fields or farms, see Fig. 3.

#### 3.2 Types of Delivery Policies

The decision on the water allocation to the tertiary unit can be made in 3 manners : arranged supply, semi-demand and on-demand supply.

##### 3.2.1 Arranged Supply

The arranged supply is the most widely used supply technique. The irrigation agency determines the irrigation delivery to tertiary unit. This can be based on the expected water needed of the crop (“demand oriented”) or on the water availability at the headworks (“supply-oriented”).

The selected flow control system in the main system is normally the “upstream control” . Discharge regulators and often discharge measurement structures are required in an upstream control system. However, it is also possible to use other types of flow control systems such as proportional control.

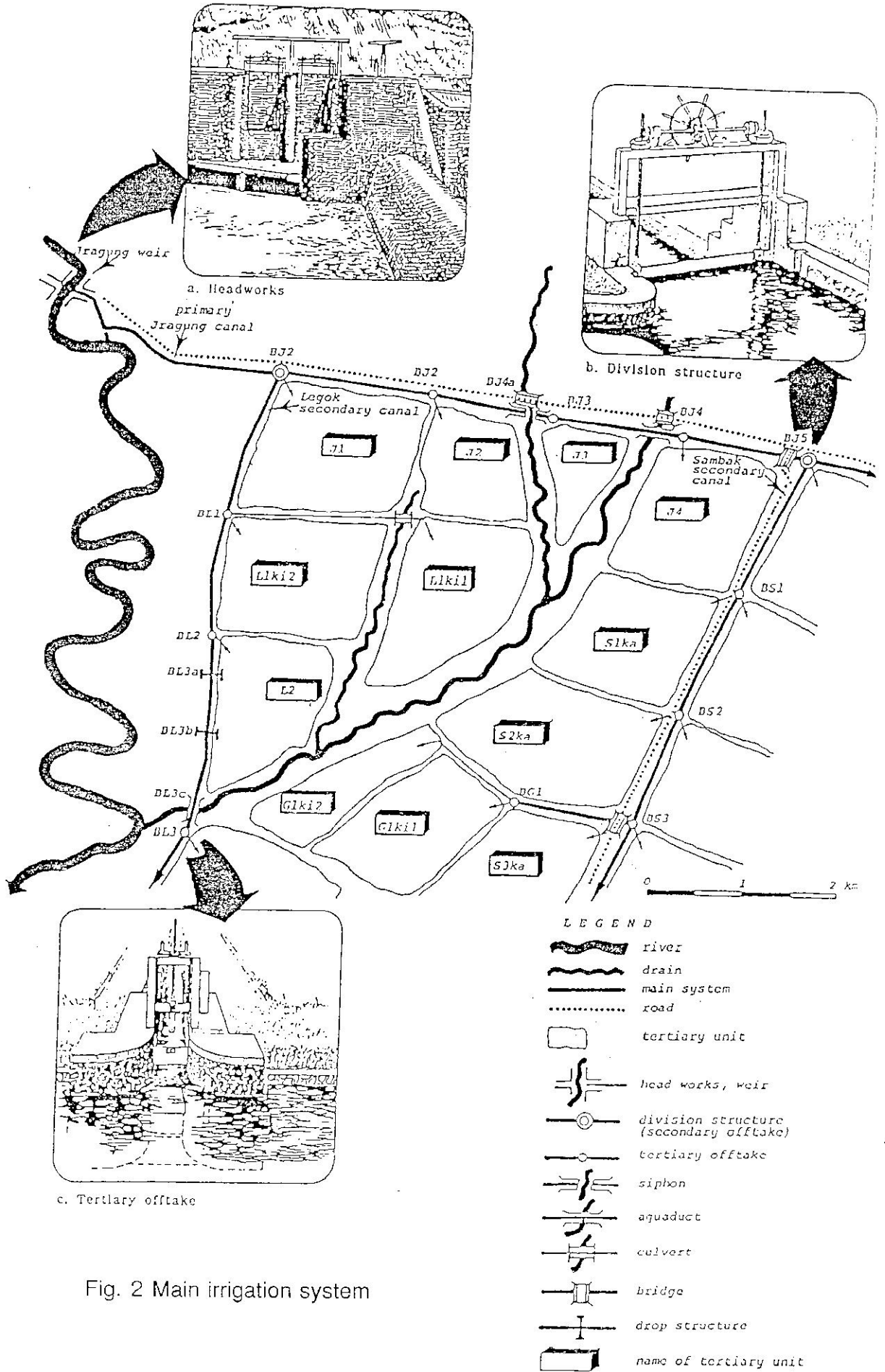


Fig. 2 Main irrigation system

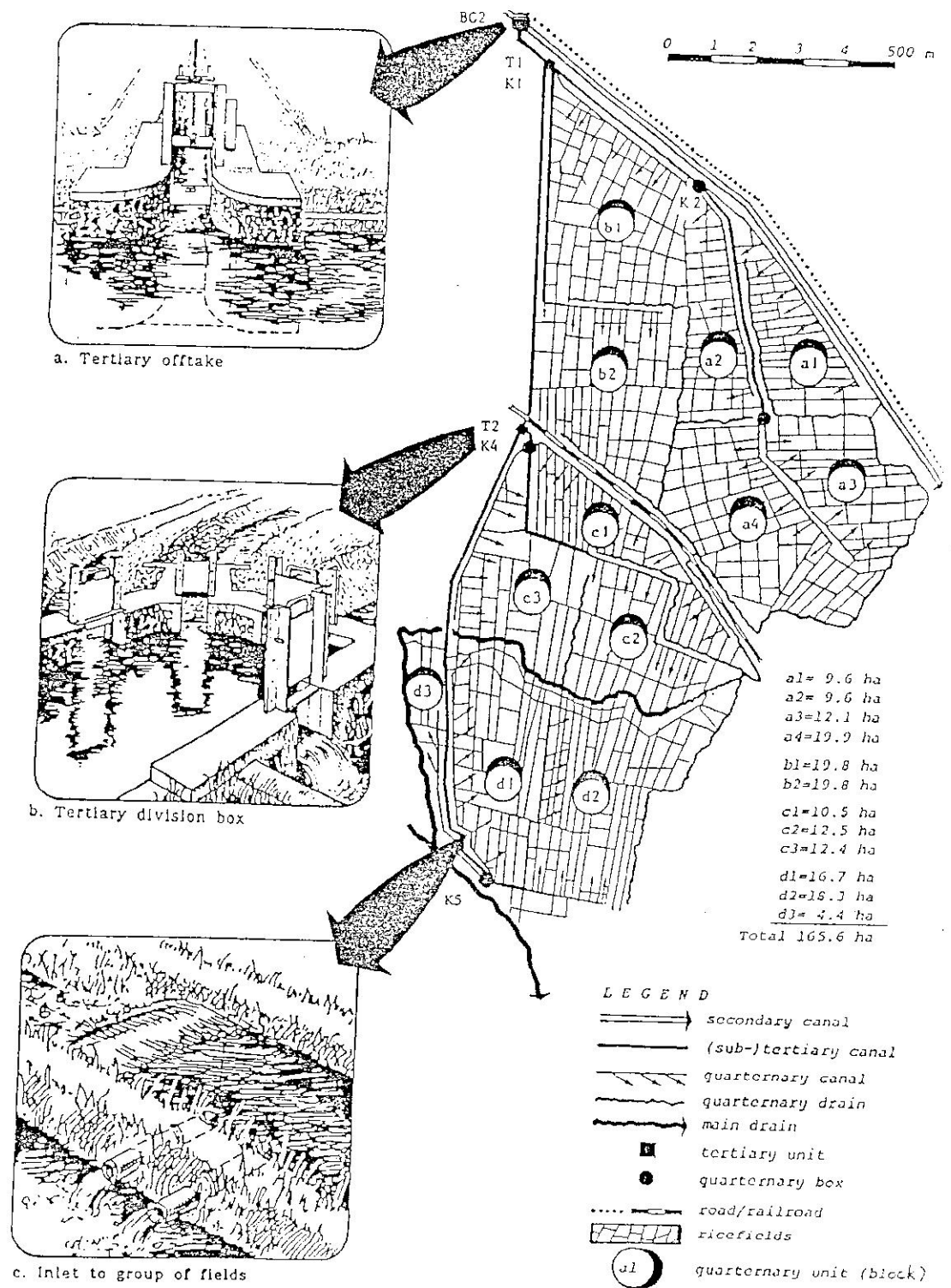
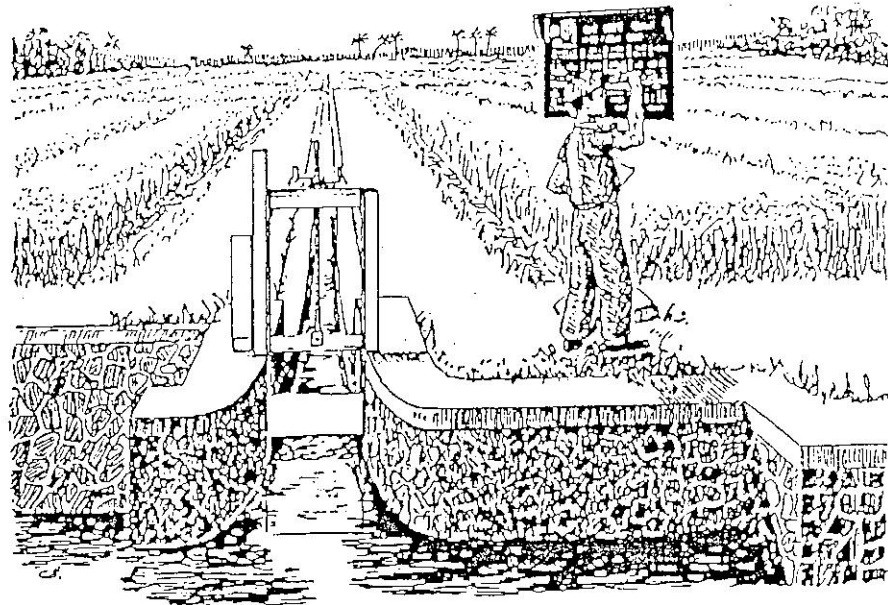


Fig. 3 A typical tertiary unit for paddy.





Name Tertiary Unit: S35  
Size Tertiary Unit: 85 ha

Name Tertiary Offtake: s35  
Capacity of Offtake : 140 l/s

TYPE OF CROP	WATER REQUIREMENT (excl. rainfall)		CROP AREA ha	WATER NEED l/s
	wet season l/s.ha	dry season l/s.ha		
Paddy: seed bed	2.0	2.5	....	....
Paddy: land preparation	1.5	2.0	....	....
Paddy: main crop	0.8	1.2	....	....
Paddy: ripening & harvesting	0.0	0.0	....	....
Non-authorized paddy	0.0	0.0	....	....
Misc. Dryland crops	0.0	0.3	....	....
Sugarcane	0.0	0.3	....	....
Fallow	0.0	0.0	....	.... +
Total water need:				.... l/s
K-factor: ...%	Water delivery: .... x ...% =			.... l/s
Date: .. / .. / ..				

Fig. 4 Operation display board at tertiary offtake.

A possibility is to apply a rotational supply, through which the flow rate remains constant but the duration of the water supply are reduced.

Another possibility is to maintain the original supply schedule, but to limit the flow rate. Thus, a “K-factor” is introduced.

The K-factor is a water availability factor, i.e. the ratio between the water availability at the headworks and the accumulated water requests from the tertiary units. The K-factor can be calculated by dividing the available discharge at the headworks by the accumulated water need of all tertiary units in the scheme.

If the K-factor is less than 100% , it means that there is water shortage. The maximum amount of water is taken in at headworks, while the secondary and tertiary offtakes are adjusted accordingly to the K-factor.

If the K-factor is more than 100%, it means that more water is available than requested. Thus, the required discharge is taken in at the headworks and distributed through the system based on the requests.

Water Operation Center. Semi-demand supply requires a strong management in the day-to-day operation of the system, see also Fig. 5. Upstream control under semi-demand management will completely fail without a well-functioning Water Operation Center (WOC).

The water requests from all tertiary units must be handed over to the Water Operation Center, who should make the accumulated water need of the whole system. This information should be sent to the gate operator of the headworks, who should set the gate of the intake accordingly.

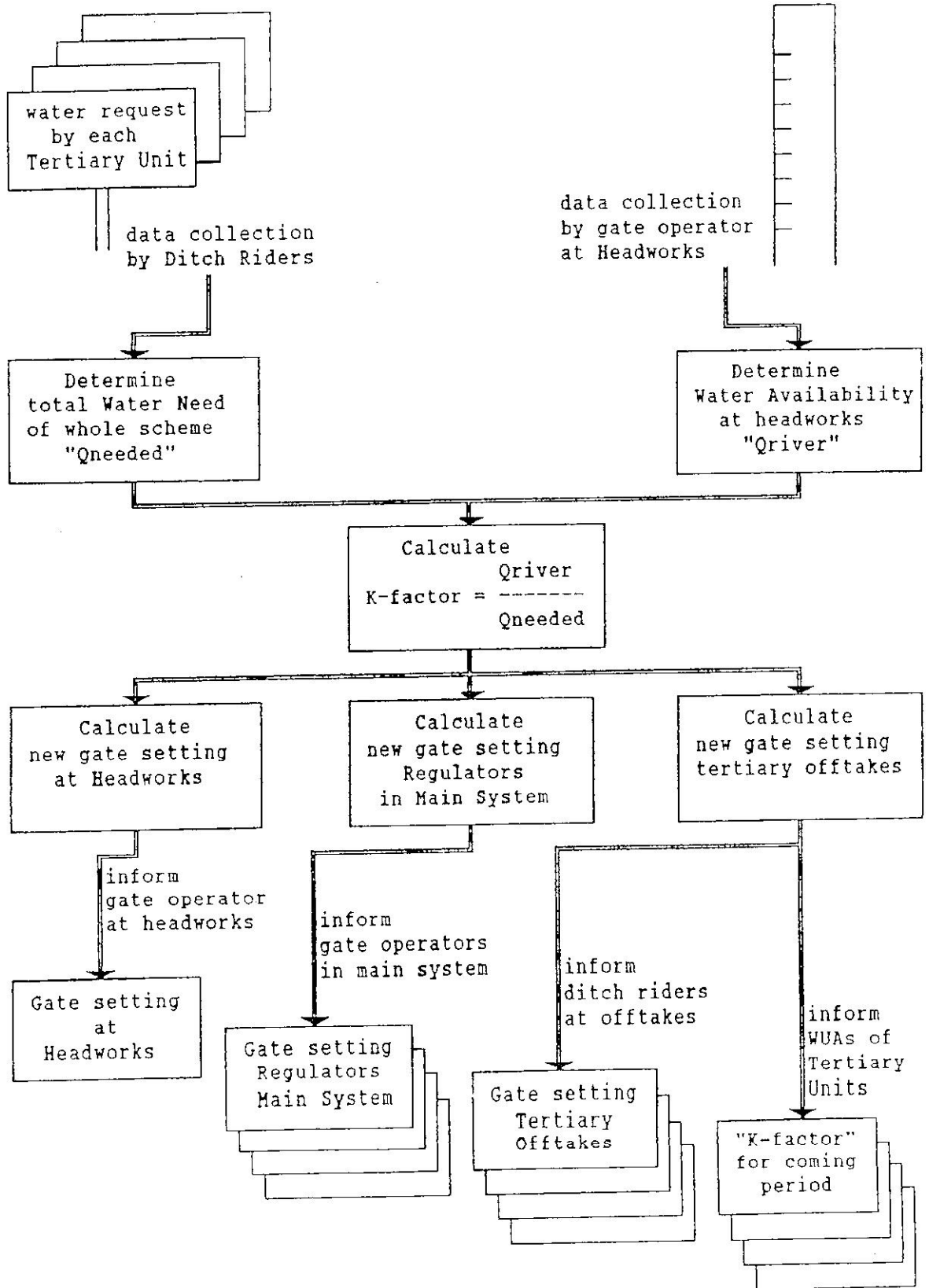


Fig. 5 Data processing at Water Operation Center (Semi-Demand supply)

The new discharge must be diverted through the irrigation system accordingly to the new requests from the tertiary units. So all discharge regulators and water level regulators should change position. This must be informed by the Water Operation Center to each gate operator individually.

Finally, the ditch riders at the tertiary offtakes must be informed so that they can reset the tertiary offtake.

Excess Rainfall. Theoretically, the irrigation requirements of the plants will decrease in case of rainfall. Therefore, the allocations to the tertiary units may be reduced during or just following heavy rainfall.

However, some problems may arise by closing the canals in case of heavy rainfall. A very effective communication system is required because at certain times only part of the system is effected, whereas the remaining area still needs water.

Reopening of canals requires a thorough assessment of the condition of the irrigation area, which can be quite complicated.

Therefore, it is generally not advised to adjust the flow control system for excess rainfall in the area.

### **Advantages**

- (1) It is a flexible system from the water users point of view, requests for more water can be fulfilled when available at headworks.
- (2) The effective use of rainfall is moderate, as the system is reset at the fixed times during the irrigation season.
- (3) The system can meet a water demand that exceeds the water supply from the headworks, by introducing a K-factor.
- (4) Distribution and application efficiency in the tertiary unit can be checked by the Water Operation Center, and guidance to the water users can be given.
- (5) The overall efficiency of the system is moderate.



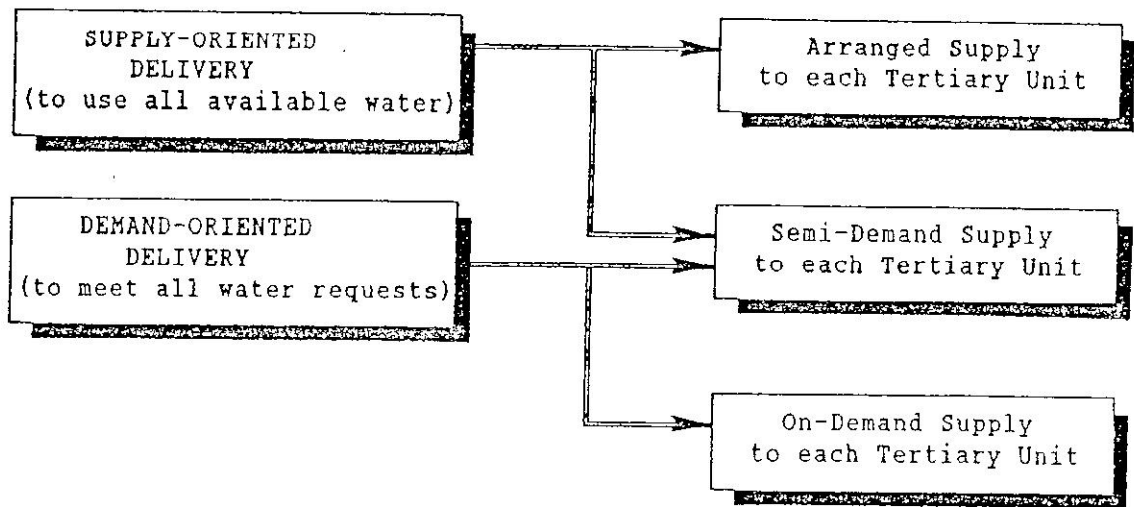


Fig. 6 Delivery policies under Supply- and Demand-oriented delivery.

A simple supply-oriented flow control system is the proportional system, which is at arranged supply and where the available water is diverted at the division structures into fixed ratios.

A more complicated supply-oriented system is upstream control under semi-demand with provisions during water shortages for the K-factor under continuous flow or for the use of a rotational water distribution.

(2) Demand-oriented delivery. Demand-oriented delivery refers to irrigation schemes of which the water allocation is only determined by the water demand of the tertiary offtakes.

An example of a demand-oriented delivery is a downstream control system under on-demand supply, where any request by the water users to the ditch rider is immediately met.

But also an upstream control system under semi-demand belongs to demand-oriented delivery.

In practice, a pure demand-oriented delivery may only be applied for abundant water at the headworks. This is not a normal case. Run-of-the-river schemes may face water shortages during the dry season. But also reservoir schemes may conserve water for other uses at other times. In fact, almost every scheme have been designed and constructed such that limitations should be set at the water demands.

A demand-oriented delivery may need an “authorization” of the cropping pattern, in order to meet the demand with the expected supply at the headworks.

Requests for cultivation of irrigated crops have to be submitted before the growing season. The highest authority should authorize these requests by considering, e.g. : water availability, water need of crop, economic value of crop, social value of crop, earlier authorizations, etc.

#### **4. Irrigation Delivery Scheduling**

The delivery schedule refers to the way of water allocation (continuous, intermittent, etc.) at a certain point in the main system, e.g. at the tertiary offtake , at the secondary offtake.

Each irrigation scheme may have a unique scheduling to its tertiary units, which will have a direct impact on the selection of the flow control system.

Basically, there are three variables of a delivery schedule , see Fig. 7.

- discharge “Q”, or flow rate ;
- irrigation frequency “T” or irrigation interval. The frequency is the elapsed time, in days, from the start of one irrigation gift to the start of the next one to the same area ;
- delivery duration “d”. The duration is the period of time that one (tertiary) unit receives the irrigation gift.

The irrigation delivery schedule must be selected at different levels in the irrigation system, that is at tertiary offtake, throughout the main system, at headworks, etc.

It should be noticed that the irrigation delivery schedule may differ also during the irrigation season. The irrigation schedule may be different during the periods with peak demand as for the period during the off-peak demand.

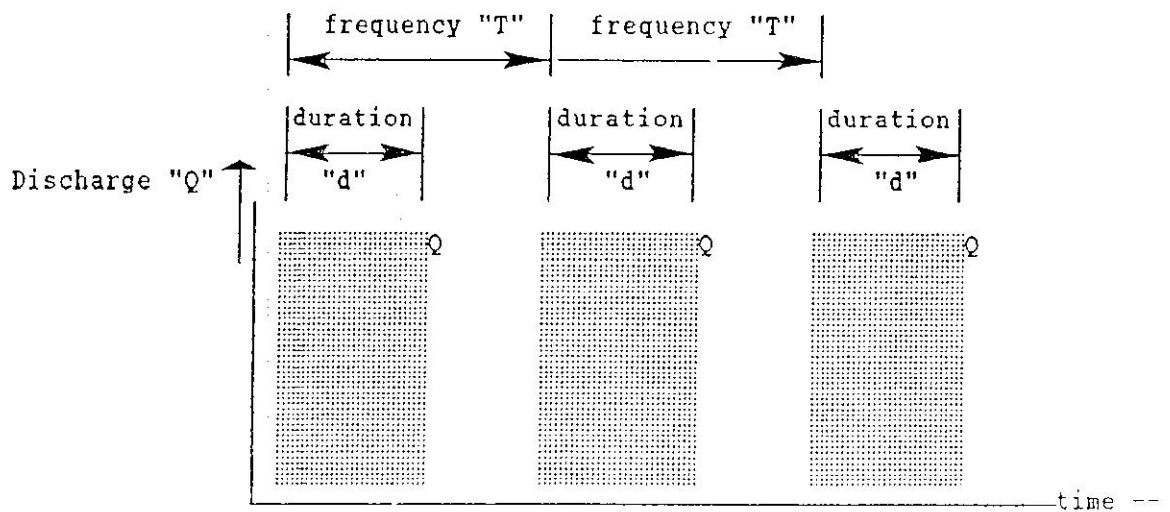


Fig. 7 Frequency, duration and discharge.

Basically, there are three levels in irrigation delivery scheduling :

- **Delivery Schedule** to the tertiary offtake, where water is supplied to the tertiary offtake. The clear specification of the schedule is essential for the cooperation between the Irrigation Agency and the Water Users Association ;
- **Conveyance Schedule** throughout the irrigation main system. This schedule is only important for the staff of the Irrigation Agency in order to meet the requirements at the tertiary offtake;
- **Diversion Schedule** at headworks. This schedule is important because it should meet the water availability at headworks.

#### 4.1 Delivery Scheduling to the Tertiary Unit

Different types of irrigation delivery schedules can be used to irrigate a tertiary unit, see also Fig. 8.

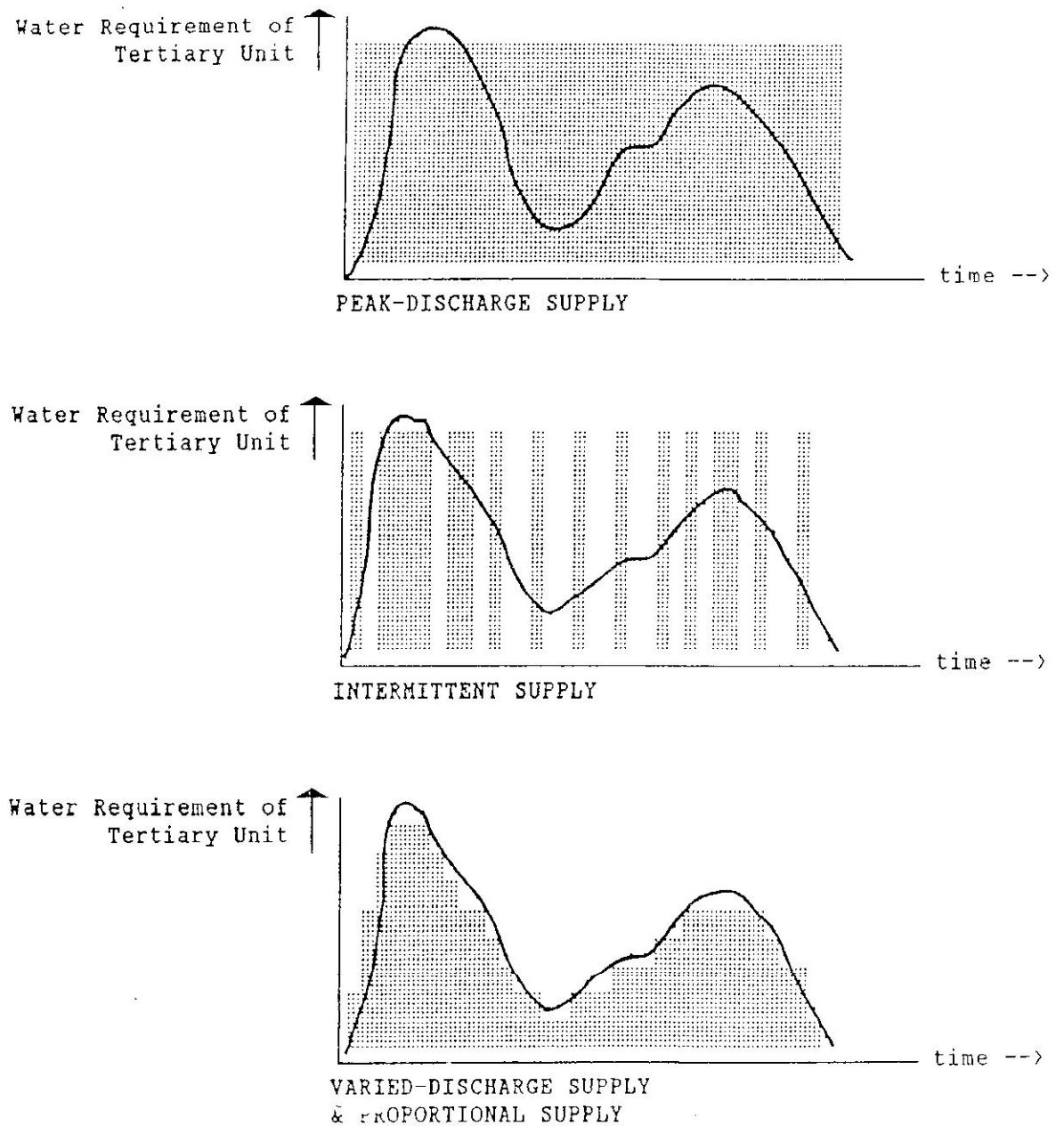


Fig.8 Delivery Schedule to one tertiary unit.

- **peak - discharge supply**, i.e. continuous supply at a constant (=peak) discharge during the whole irrigation season. A proportional tertiary offtake will be required to divert the pre-set ratio of the maximum discharge from the main system ;

- **intermittent supply** , i.e. intermittent supply at a constant discharge, by an on/off gate at the tertiary offtake ;

- **proportional supply**, i.e. continuous supply at a varied discharge, by a proportional tertiary offtake ;

- **varied-discharge supply**, i.e. continuous supply at a varied discharge, by an adjustable discharge regulator and a discharge measurement structure at the tertiary offtake.

Other delivery schedules to the tertiary units are usually less relevant for government-managed irrigation systems, such as :

- **Intermittent supply at varied discharge**. This irrigation scheduling will require sophisticated flow control and water measurement structures at the tertiary offtake, which may permit also the continuous flow at varied discharge.

Day-irrigation only. Tertiary units with only day-irrigation will require the water allocation as an intermittent supply with an interval of 12 hours only. Such an intermittent supply may be imposed on top of the delivery schedule to meet the off-peak requirements of the tertiary unit.

Only day-irrigation to the tertiary unit can be achieved by three means, see Fig. 9.

- to deliver the irrigation flow at a 24-hours basis and storing the night flow in a night reservoir,

- to extend the duration of the water allocation to the tertiary unit from “d” to “2d”.

- to increase the discharge to the tertiary unit to “2Q”.

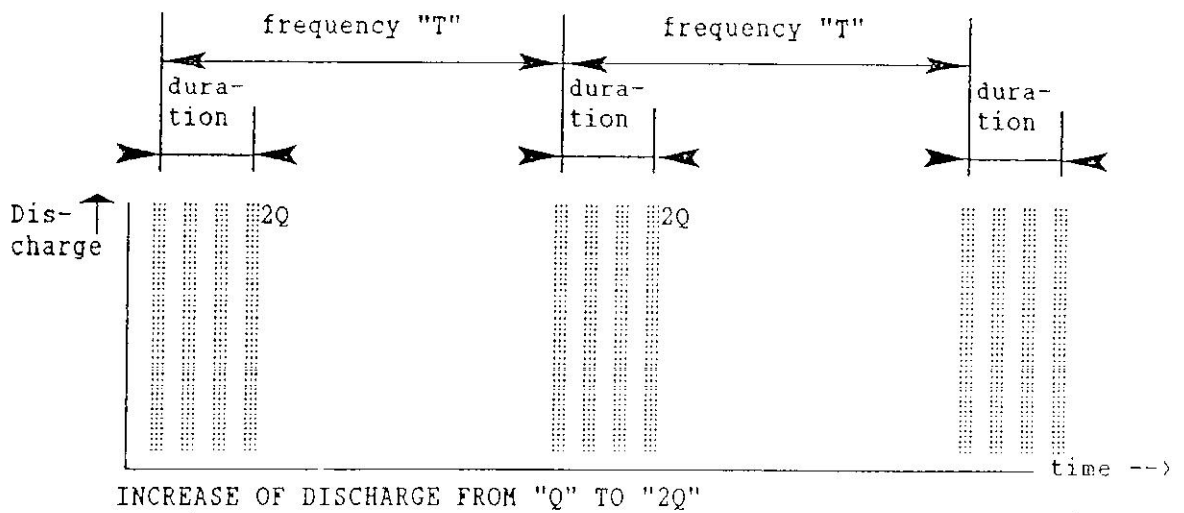
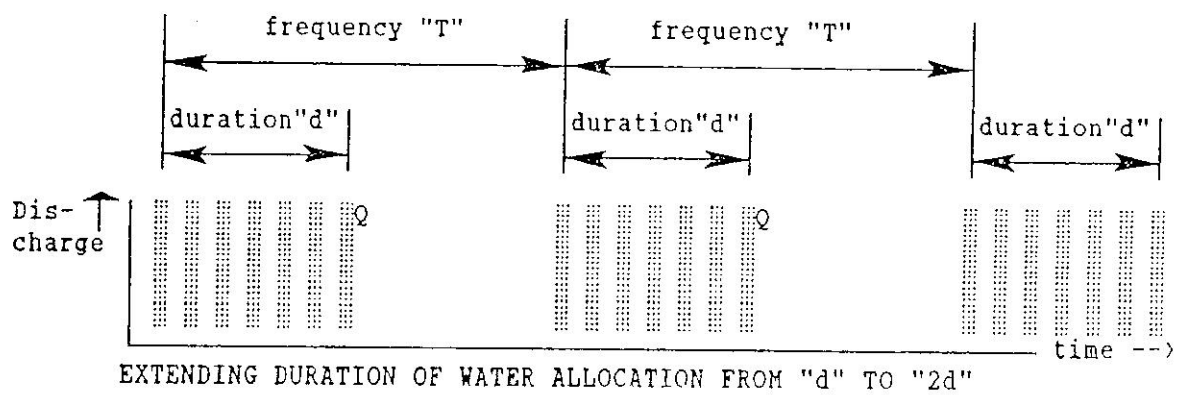
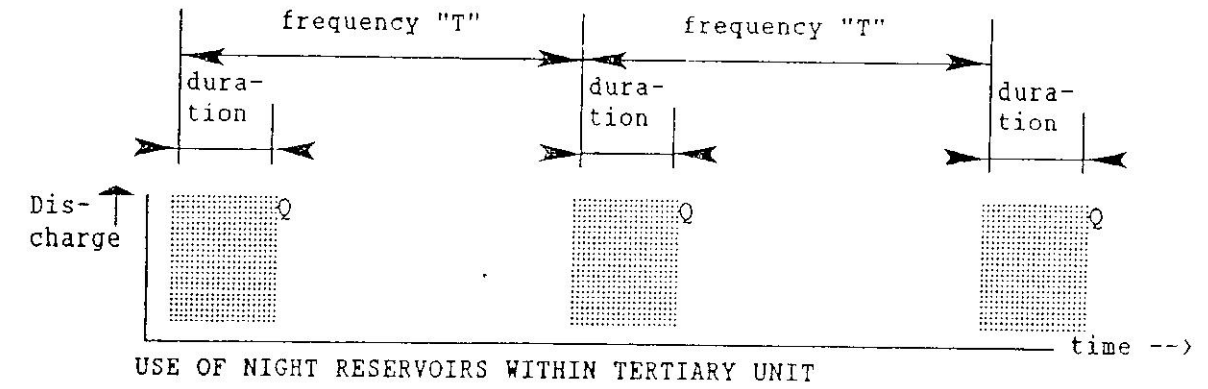


Fig. 9 Delivery schedules to a tertiary unit under day-irrigation.

#### 4.2 Conveyance Scheduling through Main System

Conveyance scheduling through the main system should follow earlier assumptions made on how to allocate water to the tertiary unit, i.e. **peak-discharge supply, proportional supply, intermittent supply, or varied-discharge supply**.

The same scheduling types are available for the main system, while also “rotational supply” can be applied, when the units are intermittently supplied by the same discharge.

The selection of the conveyance schedule should be done at different levels through the main system. At each (sub-)secondary offtake another conveyance schedule can be selected.

However, such a schedule must meet the requirements at lower levels, as it should satisfy the earlier defined delivery schedule of the tertiary offtake. It will appear that only few following combinations are realistic, see Fig. 10

- proportional supply through main system
- varied-discharge supply through main system
- intermittent supply
- rotational supply (An example of rotational schedule is presented in Table 1.)
- day irrigation only.

Table 1. Example of a rotational schedule.

At Headworks	Primary Canal	Secondary Canal	Tertiary Offtake
75% to 100% of $Q_{design}$	Continuous Flow 75%-100% of $Q_{design}$ at 100% of time	Continuous Flow 75%-100% of $Q_{design}$ at 100% of time	Continuous Flow 75%-100% of $Q_{design}$ at 100% of time
50% to 75% of $Q_{design}$	Continuous Flow 50%-75% of $Q_{design}$ at 100% of time	Continuous Flow 50%-75% of $Q_{design}$ at 100% of time	Intermittent Flow 67%-100% of $Q_{design}$ at 75% of time
25% to 50% of $Q_{design}$	Continuous Flow 25%-50% of $Q_{design}$ at 100% of time	Intermittent Flow 50%-100% of $Q_{design}$ at 50% of time	Intermittent Flow 50%-100% of $Q_{design}$ at 50% of time
0% to 25% of $Q_{design}$	Continuous Flow 0%-25% of $Q_{design}$ at 100% of time	Intermittent Flow 0%-50% of $Q_{design}$ at 50% of time	Intermittent Flow 50%-100% of $Q_{design}$ at 0-25% of time



It is experienced that a certain unit flow should have a proper size (some 15 to 40 l/s) to be controlled well by one farmer.

Application of irrigation water. The irrigation frequency “T” depends on the effective storage in the root zone and on the consumptive use, being evapo-transpiration and percolation losses minus the effective rainfall.

The depth of the watergift (“h” in mm) during the intermittent delivery is based on the consumptive use during the irrigation interval.

The delivery period “d, in hours” during which the farmer receives his unit flow “Qu, in l/s” depends on the watergift “h, in mm” and the area “a, in ha” of the farm. Thus:

$$Q_u \times d = 2.8 [h \times a]$$

The term “[h x a]” is known, while the delivery time “d” and the unit flow “Qu” should be assessed, satisfying conditions :

- the unit flow should be in the range of 15–40 l/s.
- the delivery time should easily measurable by the farmer.

Example. A dryland crop is irrigated by furrow irrigation at the frequency of T = 7 days, when a watergift of h = 30 mm is applied. For the farm size of a = 5 ha :

$$Q_u \times d = 2.8 \times (h \times a) = 2.8 \times 30 \times 5 = 420.$$

The delivery time for the unit flow is d = 28.0 hours at the lower limit of 15 l/s , and 10.5 hours at the higher limit of 40 l/s.

Consequently, the delivery period can be selected at 12 hours with a corresponding unit flow Qu = 35 l/s. Furrow irrigation may allow only day-time irrigation, so one farmer will irrigate during 1 day.

The size of the tertiary unit follows from the assumption that one unit flow rotates through the unit during the irrigation interval, irrigating a number of farms.

Here, 7 farms @ 5 ha can be irrigated during one interval by one (each) unit flow, so the size of the tertiary unit should be a multiple of 35 ha for each available unit flow.

The capacity curve can be determined, assuming a certain operation schedule. The maximum value of the (relative) water requirement will be reached at the farm outlet where one unit flow irrigates one farm.

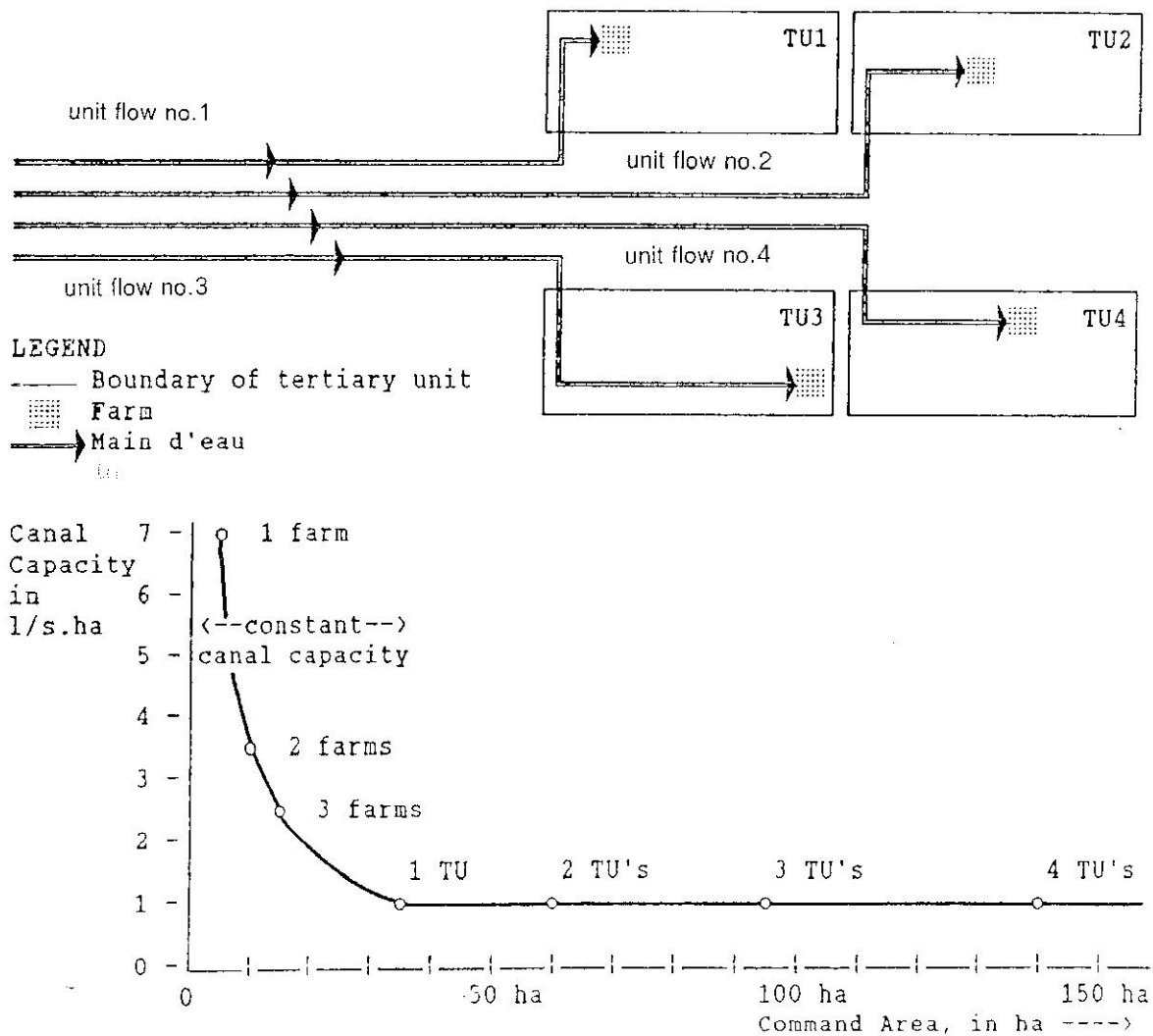


Fig. 11 Capacity Curve for Arraged Supply to Dryland Crops.

Example. The unit flow of 35 l/s in the above example irrigates one farm of 5 ha, so the farm outlet should have a capacity of 7.0 l/s. ha. This is a point on the capacity curve, see Fig. 11.

The canal system within the tertiary unit has a fixed capacity of 35 l/s. So, the canal capacity to two farms, i.e. to  $2 \times 5 = 10$  ha, leads to the relative water requirement of 3.5 l/s.ha. The flow to three and more farms remains the rate of one unit flow, thus the relative water requirement decreases for the increasing command area.

The tertiary offtake will have a relative capacity of 1.0 l/s.ha. Similarly, the secondary and primary system should also provide a net water requirement of 1.0 l/s.ha.

## **5.2 Canal Capacity for Paddy at Arranged Supply**

There is an essential difference between paddy and dryland crops, as the peak water requirements at field level for paddy appears to be during the land preparation stage.

Social conditions mainly determine the period of land preparation of each individual field, i.e. the time between the first water delivery and transplanting (e.g. 30 days).

The progress of the land preparation determines the canal capacities of irrigation systems for paddy. This concept has been developed by Van De Goor/Zijlstra.

It considers that a constant supply of irrigation water is supplied to a tertiary unit that is under land preparation. During this period, water fills the fields progressively. While lower fields are being filled via overflow from upper fields which have already been filled, it is assumed that the upper fields are being continuously topped up to overcome percolation and evaporation losses.

The Van De Goor/Zijlstra formula defines the peak irrigation requirement to the area under land preparation :

$$q = \frac{w e^k}{e^k - 1} \text{ and } k = \frac{W D}{S}$$

where :

- q is the peak water requirement, in mm/day,
- W is the topping up requirement, in mm/day,
- D is the duration of land preparation , in days,
- S is the water depth required for land preparation, in mm,
- e is the base of the natural logarithm.

Note that the size of irrigated area (A) does not appear in the formula.

Example Land preparation may require a dose of  $S = 300$  mm to saturate the soil and to establish the water layer. The duration of land preparation, from first delivery to transplanting, amounts  $D = 30$  days. The topping up requirement to maintain the water layer amounts  $w = 0.5$  l/s. ha = 4.3 mm/day.

A peak water requirement of  $q = 12.2$  mm/day = 1.4 l/s.ha can be calculated. The net water need during the normal growing period of paddy equals the topping up requirement of 0.5 l/s.ha and is much lower than during the land preparation period.

The capacity curve can be determined from the Van De Goor formula by varying the duration of the period (D) of land preparation with the size of the command area.

Example. Fig. 12 presents an irrigation scheme where a land preparation of a quarternary block of 20 ha may require 14 days, while some 30 days is needed for each tertiary unit. The land preparation of a whole scheme of 10,000 ha may be extended to some 45 days.

The corresponding peak requirements can be calculated and are presented the Table 3. These values match well with the experimental Tegal curve, as used in Indonesia, for the assumed durations of the land preparation at the different levels.

Provisions for the irrigation efficiency may increase the canal capacities for the larger command areas.

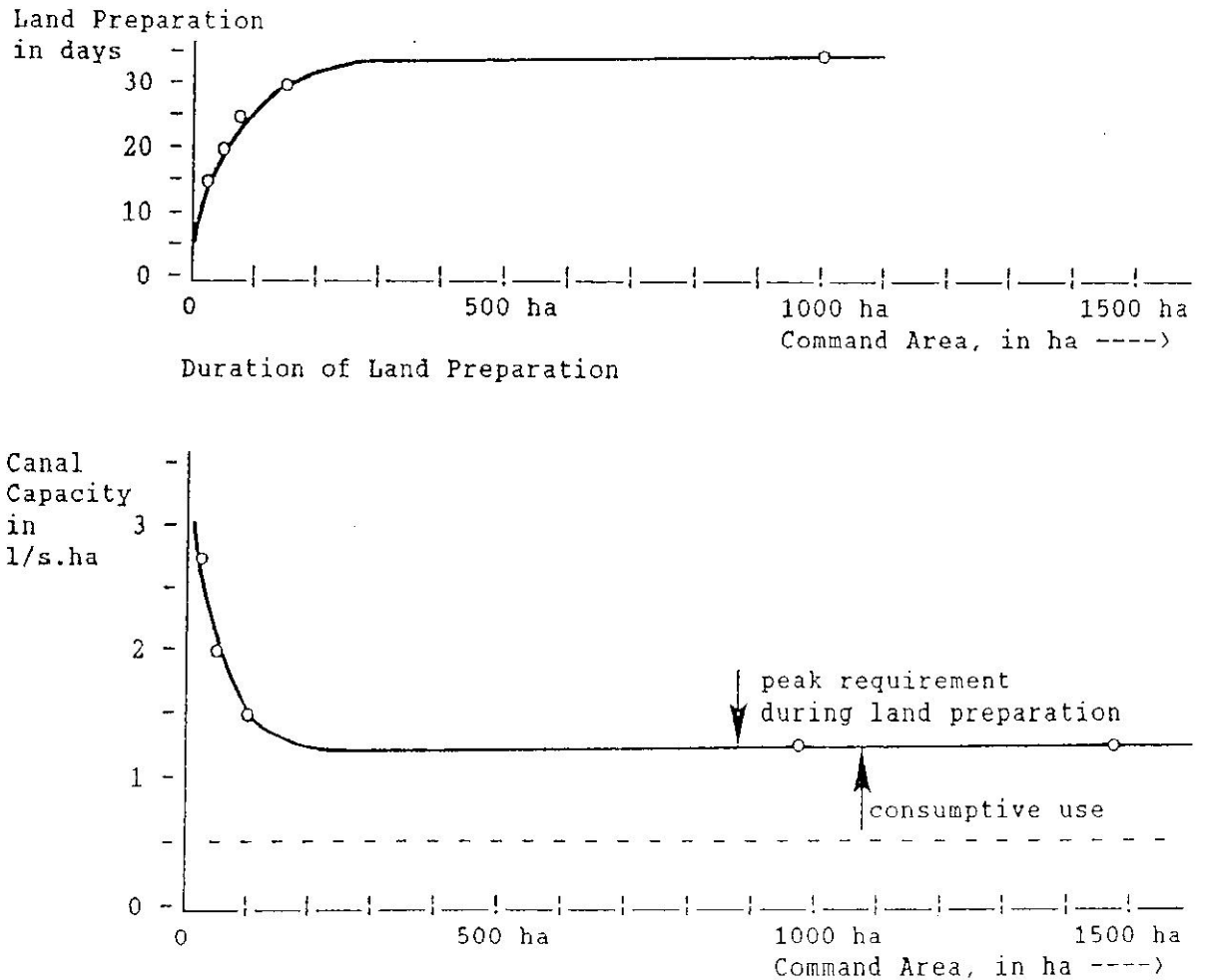


Fig. 12 Capacity Curve for Arranged Supply to Paddy.

The land preparation period over a whole irrigation scheme can be further extended by introducing a number of crop-rotational zones. These zones have different starting dates of land preparation, e.g. over a period of 3 months, thus reducing the diversion requirement at headworks to 0.7 l/s.ha, excluding provisions for efficiency.

### 5.3 Canal Capacity for On-Demand Supply

Capacity curves can also be calculated in a statistical analysis, considering the probability that a certain outlets is used. This approach is presented often in the French literature and is based on the on-demand supply system.

It assumes that an outlet is operated by the users on an off/on basis : the necessary water depth on the fields is maintained by the peak discharge during a limited duration, and the outlet is closed when irrigation water is not needed.

An irrigation efficiency is normally not included into these calculations. Spillage of irrigation water into the drain cannot be allowed as it will disturb the whole supply system.

The water consumption of the fields (evapo-transpiration and percolation, minus effective rainfall) amounts to  $w$  in l/s. ha, and is supplied by a unit flow ( $q_u$ , in l/s.ha) during a part of the day ( $r\%$  of the time). The outlet supplies an area ( $a$ ), in ha.

The probability that one or more outlets are in use can be statistically assessed.

Formula of Clément. The formula of Clément determines the canal capacity as a function of the command area ( $A$ , in ha) and depending on the characteristics of the outlets (peak flow, area, frequency).

Moreover, the reliability of the system is introduced which allows a chance that not all outlets can be served when water is needed. Usually, the chance of failure is 5%. The formula of Clément is:

$$q = \frac{w}{r} + U \frac{w}{r} \left( \frac{q_u r a}{w \Lambda} - \frac{a}{\Lambda} \right)^{0.5}$$

where :

- $q$  is the (relative) canal capacity, in l/s.ha,
- $w$  is the water consumption of the fields, in l/s.ha,

$q_u$  is the peak flow through each outlet, in l/s.ha,  
 $r$  is the part of the day that irrigation is done,  
 $a$  is the irrigation area of the outlet, in ha,  
 $A$  is the command area, in ha,  
 $U$  is a coefficient, depending on the reliability of the system to satisfy all water requests at the outlets:

$U$	=	0.53	for	70%	- probability
$U$	=	0.84	for	80%	- probability
$U$	=	1.28	for	90%	- probability
$U$	=	1.65	for	95%	- probability (a normal value),
$U$	=	2.32	for	99%	- probability
$U$	=	3.09	for	99.9%	- probability

Example. As an example, dryland crops have a water consumption of  $w = 0.5$  l/s.ha and are supplied by furrow irrigation. Only day-time irrigation is applied, so that  $r = 0.50$ . The outlets irrigate  $a = 5$  ha each, while the outlet has a capacity of  $q_u = 35$  l/s ( $q_u = 7.0$  l/s.ha). The reliability of the system should be 95%, so  $U = 1.65$ .

The canal capacity for a command area of  $A = 35$  ha to supply the 7 outlets, should be :

$$q = \frac{0.5}{0.5} + 1.65 \frac{0.5}{0.5} \left( \frac{7 \times 0.5 \times 5}{0.5 \times 35} - \frac{5}{35} \right)^{0.5} = 1.00 + 1.53 = 2.5 \text{ l / s.ha.}$$

The canal capacity can be reduced to 1.4 l/s.ha, 1.3 l/s.ha and 1.1 l/s.ha at a command area of 500 ha, 1,000 ha and 5,000 ha, respectively, see also Table 2 and Fig. 13.

Table 2. Capacity curve for dryland crop irrigation.

command area in ha	number of outlets	ARRANGED SYSTEM canal capacity in l/s.ha	ON-DEMAND SYSTEM canal capacity in l/s.ha
5	1	7.0	7.0
10	2	3.5	3.9
35	7	1.0	2.5
100	20	1.0	1.9
500	100	1.0	1.4
1000	200	1.0	1.3
5000	1000	1.0	1.1
10000	2000	1.0	1.1

Note: no provision for losses yet, so efficiency is 100%.

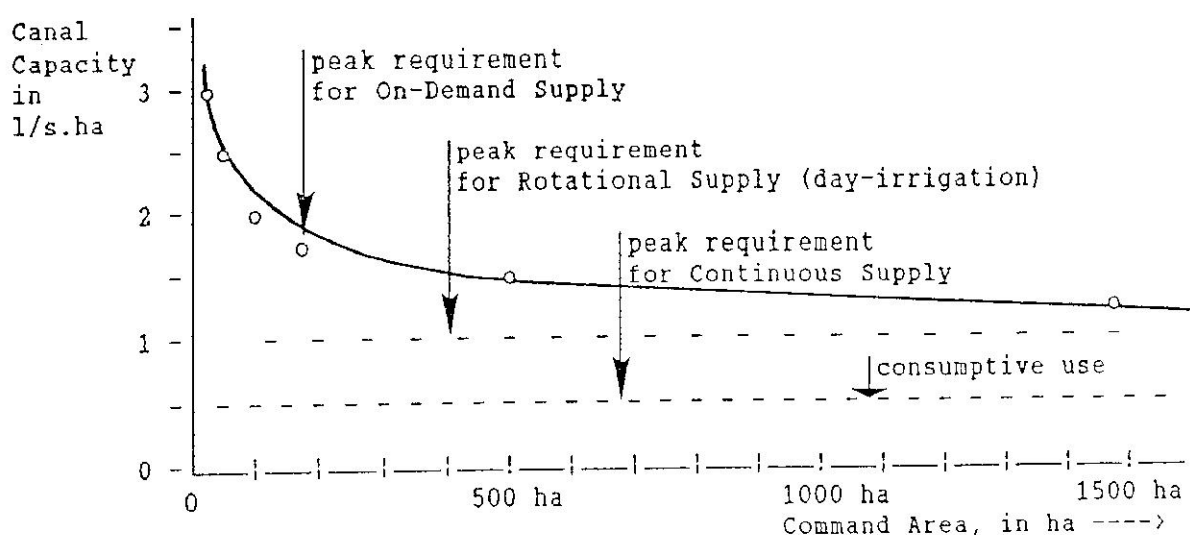


Fig. 13 Capacity Curve for On-Demand Supply to Dryland Crops.

Dryland Crops. Dryland crop irrigation at field level is usually applied by rotational supply. The canal capacities can be calculated by a systematic analysis of the irrigation process and are at lowest when the rotation is arranged by an agency.

Comparing irrigation systems with arranged and on-demand supply, the canal capacities of the secondary and primary canal system should be increased with some 40-10% to provide for an on-demand supply

Paddy crop. The formula of Clement may also be used for irrigation of paddy when the application losses are low.

For instance, the water consumption is  $w = 0.5$  l/s.ha on a continuous basis. The water users rotate the water supply within the tertiary unit between series of ricefields of  $a = 1$  ha at a rate of  $q_u = 20$  l/s.ha. Day-irrigation is applied, so  $r = 0.5$ . The reliability of the system should be 95%, so  $U = 1.65$ . The capacity curve can be calculated and the results are listed in Table 3. and presented in Fig. 14.

The figures can be compared with the experimental Tegal curve, which values for  $q_{140} = 1.4$  l/s.ha, are shown between parenthesis. The two capacity curves agree well for the above assumptions.

Table 3. Capacity curves for paddy irrigation.

Command Area in ha	VAN DE GOOR FORMULA		CLEMENT FORMULA	
	Land Prep. Period in days	Canal* Capacity in l/s.ha	Outlets in Use in %	Canal* Capacity in l/s.ha
20	14	2.7	13	2.6
30	16	2.4	11	2.3
50	20	2.0	10	2.0
70	23	1.8	10	1.9
90	26	1.6	9	1.8
110	28	1.5	8	1.7
140	30	1.4	8	1.6
500	33	1.3	7	1.3
1000	35	1.2	6	1.2
10000	45	1.1	6	1.1

\* excluding operational and seepage losses

Notes: - Van de Goor Formula:

land preparation dose  $S = 300$  mm,

water consumption  $w = 0.5$  l/s.ha = 4.3 mm/day.

- Clément Formula:

water consumption  $w = 0.5$  l/s.ha,

outlet area  $a = 1$  ha at rate  $q_u = 20$  l/s.ha, i.e. 85 mm/12hrs, day-irrigation  $r = 50\%$ , reliability 95%.

#### 5.4 Canal Capacity and Irrigation Efficiency

It is very simple to include the efficiencies of an irrigation system into the capacity curve. The capacity curve presents the relation between the command area and the (relative) canal capacity. But also, the efficiency is related to the command area.

Together, they form the capacity curve for the real conditions. The values are calculated with the formula :

$$q \text{ (actual)} = \frac{q(100\%)}{\text{efficiency}} \text{ in l/s.ha.}$$

Example. A capacity curve for a certain operation schedule might be calculated for an efficiency of 100%, see Fig. 15 . The efficiency at different levels follows from assumptions or from experiences.

For instance, the overall efficiency of the irrigation scheme is 60%, while the field efficiency amounts to 90%. The actual canal capacity, in l/s.ha, is shown in Fig. 15.

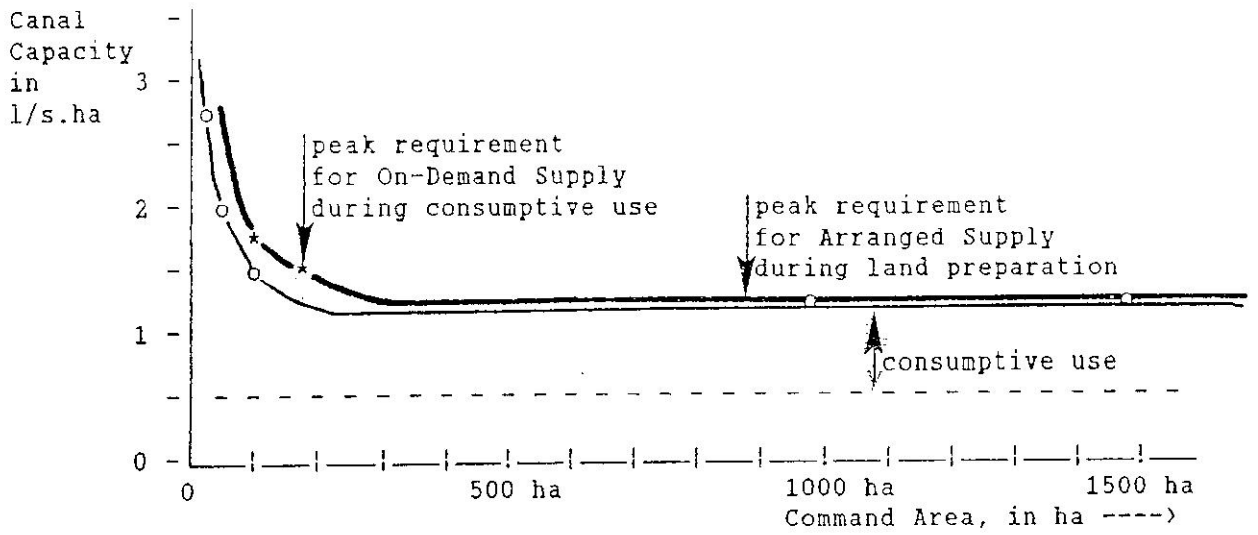


Fig.14 Capacity Curve of On-Demand Supply to Paddy

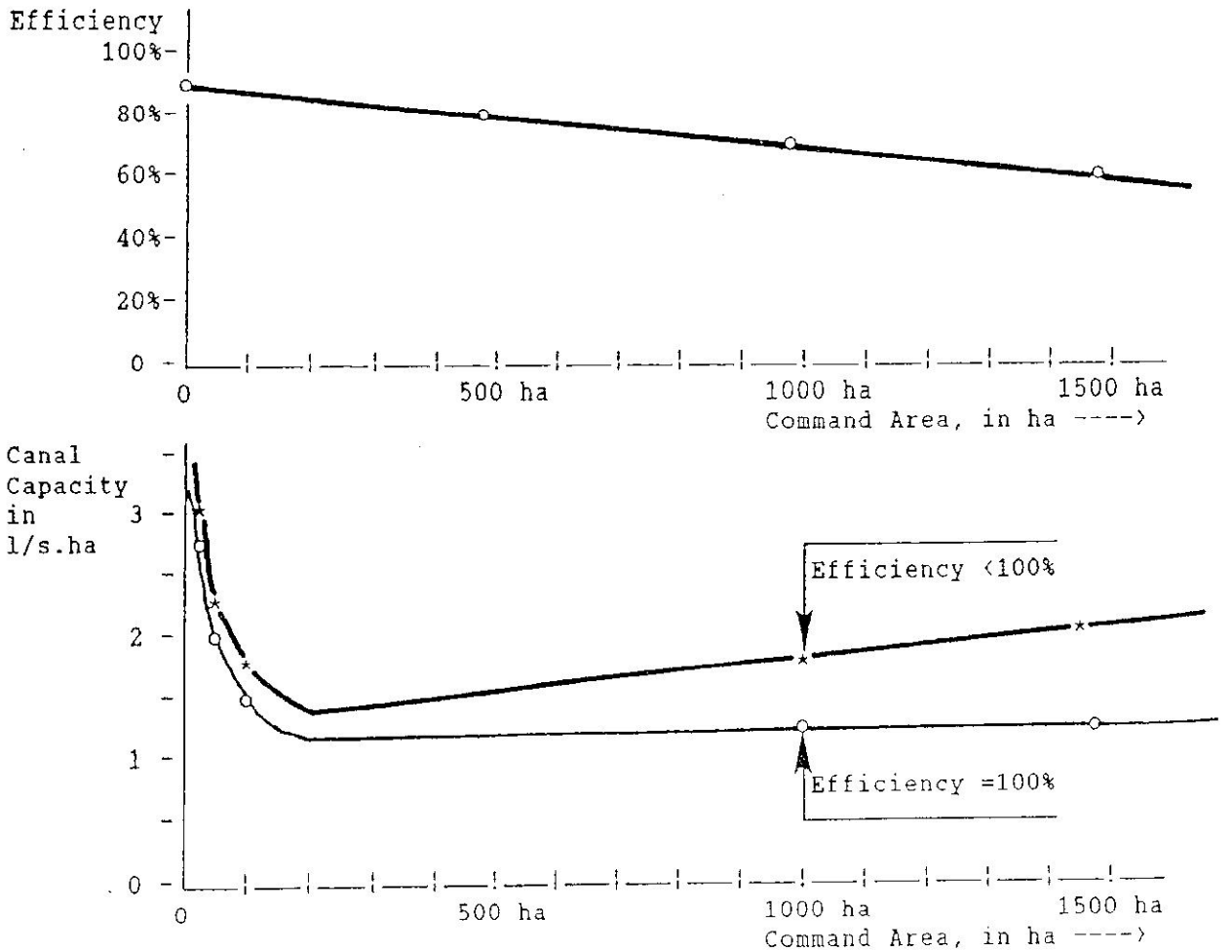


Fig. 15 Capacity Curve for Efficiency < 100%.

## 6. Flow Control Systems

### 6.1 Purpose of Control Systems

Function of flow control systems. The function of a flow control system is to regulate irrigation water in a timely and reliable manner, so that water may be efficiently used for crop production. The large flow volume at the headworks must be divided into small flow portions, each supplying a small part of the irrigation area.

Furthermore, the irrigation canals are designed for a capacity determined by the maximum irrigation requirements, while for part of the time they will be flowing at less than this maximum flow. It is therefore necessary to control the water levels by means of water level regulators, or cross regulators, in order to maintain a sufficient depth at offtakes.

Structures in flow control systems. Flow control systems have usually water level regulators in the ongoing (parent) canal, and discharge regulators in the offtaking canals. Moreover, discharge measurement structures may be required.

An overview of some well-known structures is presented in Table 4. Some of these structures can be used in dual functions.

Control of tertiary offtake. It is assumed that the supply to the tertiary unit is done through an offtake that is operated by the irrigation agency, at a preset or arranged schedule, or as a response to requests of farmers at a semi- or on-demand schedules.

Flexibility. Generally, the flow control system becomes more complex for an increasing flexibility of the system. Water users can take any amount of irrigation water, at any time, for a full-flexible flow control system. Such a system must be fully automatised and is self-regulating.

Efficiency. Improved efficiencies on main system level will decrease the volume of water needed at the headworks. This is achieved by an easy operational flow control system.

Table 4. Types of flow control structures.

WATER LEVEL REGULATORS (cross regulators)	DISCHARGE REGULATORS	DISCHARGE MEASUREMENT STRUCTURES
Stop-logs		
Sliding Gate . . . . .	Sliding Gate	
Automatic Gate		
Weir		
Control Notch	Proportional regulator	Broad-crested Weir
	Romijn Weir . . . . .	Romijn Weir
	Crump-DeGruyter Gate . .	Crump-DeGruyter Gate
	Constant Head Orifice . .	Constant Head Orifice
	Baffle Distributor . . .	Baffle Distributor
		Parshall Flume
		Cipoletti Weir

## 6.2 Classification of Flow control Systems

Self-regulating systems. Flow control systems can be divided into non self-regulating systems and in self-regulating systems, see Fig. 16 The term “self-regulating system” means that the system itself converges to a new equilibrium state.

An automatic system means that the regulators of the control system are set by hydraulic or electronic devices. The role of the gate operator has just been taken over. Thus, a self-regulating system can also be obtained by certain instructions to the gate operator, i.e. maintain the downstream water level. It is mainly the frequency of operation that determines the need for automation.

Proportional systems have no adjustable regulators, they have been set in a fixed manner.

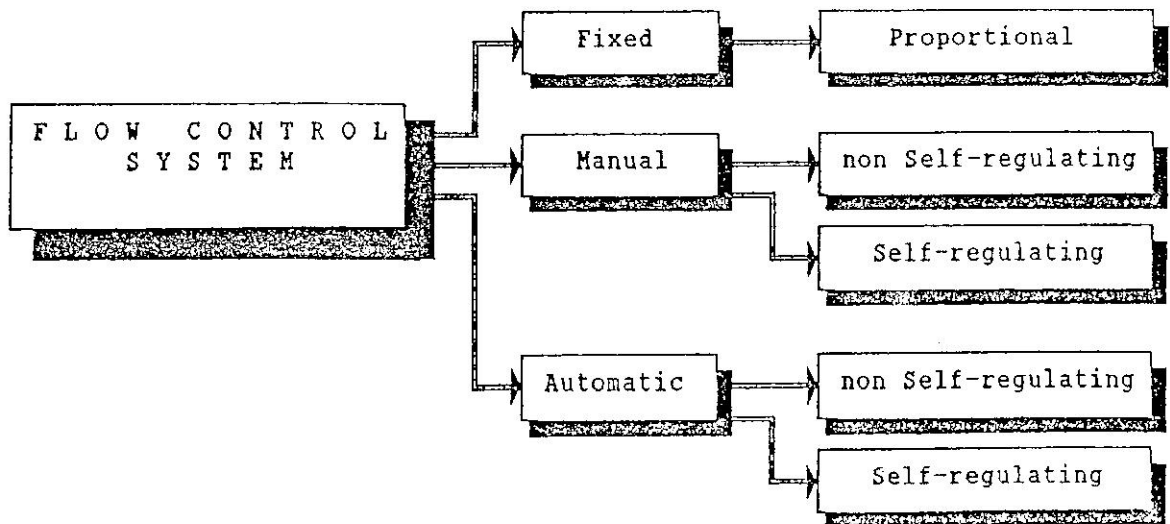


Fig. 16 Non self-regulating and self-regulating systems.

Classification. A number of flow control systems is increasing rapidly with the availability of telemetry and of computers. Therefore, it is practically to have a classification available on control parameters, see Fig. 17.

- orientation of control : none, upstream or downstream oriented control ;
- mode of control : fixed, manual or automatic control ;
- location of control : local control, remote control or centralized control ;
- parameter for control : discharge or water level.

Orientation of control. Upstream water level control is the control of a water level regulator, based upon changes in the water level immediately upstream of it. A canal operated under "upstream control" must be operated on a scheduled basis, unless spillage is allowed from the tail end of the canal. Upstream control systems may be manual or automatic.

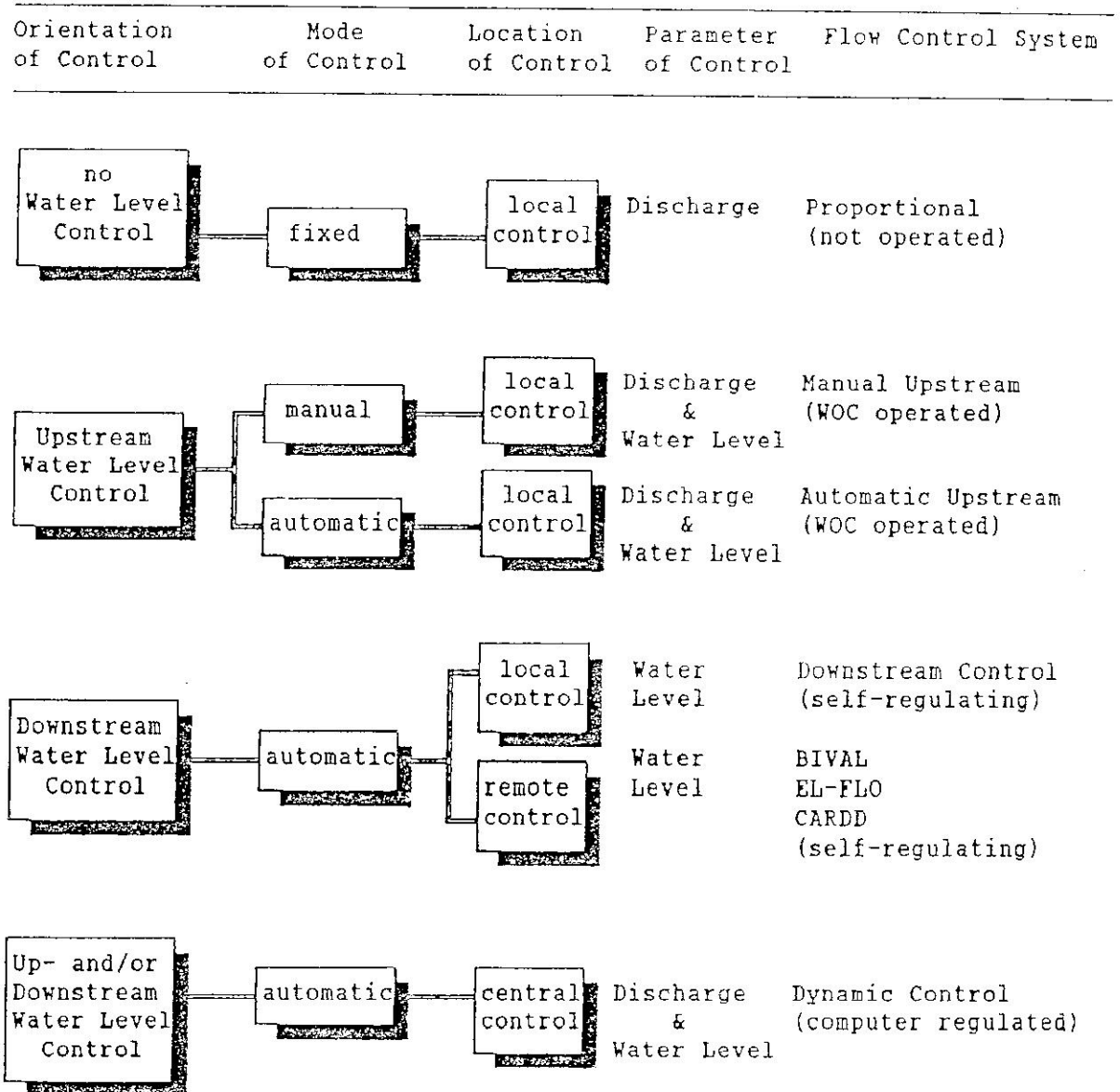


Fig. 17 Classification of Flow Control systems.

Downstream water level control implies a gate reaction to changes on the downstream water level. A change in any canal reach will cause a subsequence of proper compensating actions to be made in the upstream structures, all the way back to the headworks. Downstream control is demand oriented. Downstream control systems are normally automated as self-regulating flow control systems. However, it is also possible to operate a downstream control system manually. The gate keeper is instructed to operate the gate upon changes in downstream water level, instead of upstream water levels.

Proportional control is not a form water level control, but merely a splitting of the available discharge.

Mode of control. Manual control implies that the regulators of the control system are set by gate operators. Manual control is applicable as long as the frequency of gate setting is limited.

Manual control becomes labour-intensive when the flow is regularly changing. The accuracy of such a manual operated system is low, because of the gradual system response time of the irrigation system.

Automatic control implies that the human function of water level control is taken over by hydraulic or electronic devices. It is used to simplify the operation and to increase the efficiency of the flow control system by a more accurate regulation. Such an automatic control replaces only the activities of the individual gate operator. Often, automatic flow control systems will not lead to a reduction of the operating staff as many other functions remain. However, automatic systems will improve the performance of the irrigation system.

Automatic control can also replace the whole decision-making process of the combined gate operators throughout the system by creating a self-regulating flow control system. A self-regulating system will supply more water when the demand increases.

Automatic control may only be applied when the function of these automatic controllers is well understood by the irrigation agency. Otherwise, adjustments might be difficult to implement, and the automatic system runs the risk that it is damaged or completely overruled by some type of manual operation.

Proportional control is neither manual nor automatic in the above senses, but is merely a fixed splitting of the available flow.

Location of Control. Local control is the flow control on basis of the conditions in the canal system at that location. Local control can be: fixed control by flow-splitting, manually control by a gate operator, or automatic control without moving parts (e.g. duckbill weir), or automatic control by using hydro-mechanical parts (e.g. AMIL, AVIS/AVIO, Vlugter) and electro-mechanical parts (e.g. PID-controller).

Remote control is the regulation of a gate according to the situation in the canal system at some distance. The signal is transmitted from a sensor to the gate over electric lines. The gate is operated by electro-mechanical parts.

With centralized control, all the gates have electro-mechanical parts and are controlled from a single location. Typically, a computer program dictates the movements of all gates. In that case, sensors constantly monitor water levels and other parameters, and an electro-mechanical controller regularly updates the gate setting.

Parameters of control. Conveyance systems for “discharge control” concentrate upon dividing known discharges. The primary purpose of a structure is then to maintain a known discharge to a downstream destination. Discharge control may or may not be a major concern throughout the main system, but it is certainly important at the tertiary offtake.

Proportional control is a pure type of discharge control. Discharge control in upstream water level control systems is actually another type of water level control, as the water level overweirs is kept constant in order to obtain a constant discharge.

Downstream water level control systems are designed to provide flexible demand deliveries to offtakes, without ever knowing the actual discharges. The regulators concentrate upon maintaining constant water levels throughout the system at all offtakes.

### 6.3 Selection Criteria for Flow Control Systems

Selection Criteria. The selecting of a type of flow control system depends on the applicability and the desired function of the flow control system. But also the physical economic and social constraints must be considered in the selection procedure. The specific hardware to be used follows from these criteria.

A few important criteria which will affect the selection of a flow control system are :

- Costs. The cost of the flow control system will be a major determining factor in the selection. The cost can well be determined in the pre-design of the system.
- Need for operation staff. All types of flow control systems rely on operating staff, some more than the others, while also the level of skill may differ, see Table 5.

Table 5. Staffing needs

Type of Distribution	Type of Structures	Number of Staff	Skill of Staff
Proportional	flow splitting	+	+
Intermittent	on/off gates	+ + +	+
Gradually adjustable	gates + flow measurement	+ + + +	+ + +
Self-regulating	hydro-mechanical gates	+	+ + + +
Remote-control	electro-mechanical gates	+	+ + + + +

Manual flow control systems that is crucial to the proper operation of a canal must be serviceable or replaceable almost immediately. Poorly trained service personnel and the dependability upon long distance support will result in failure.

- Logistic support. Everything that is crucial to the proper operation of a canal must be serviceable or replaceable almost immediately. Poorly trained service personnel and the dependability upon long distance support will result in failure.

- Efficiency. The efficient use of water will be another important factor for the selection of the system. The efficiency of water use will be very high in the self-regulating downstream control system. However, efficient water use will not be a factor in schemes with re-use of drainage water.

- Water shortages. Self-regulating flow control systems in run-of-river schemes may fail during water shortages at headworks.

- Response time. Upstream control systems without night irrigation will be have a very low efficiency when upstream control is selected. However, the use of night reservoirs will increase the efficiency to some extent.

- Steepness of terrain. The level-top canals for downstream control can become very expensive for steep terrains, and upstream control or computerized control may be recommended.

- High silt loads. Sufficient high velocities must be maintained for high silt loads in the water to prevent settling out, and it may be required to change the water depth for changing discharges. Water level regulators which can only control for one target depth are unsuitable for high silt loads if the discharges change significantly.

- Electrical power. Many newer automation flow control systems require a dependable quantity and quality of electrical power. Many locations have neither, requiring the use of manually or hydraulically operated controls.

- Measuring devices. Many flow control systems require flow measurements at the tertiary offtakes only, others also at the headworks and at all bifurcation points throughout the flow control system. These structures may need additional headloss.

- Water level variations. The water level variations in the supply canal depend on the type of the flow control system. Some systems permit large fluctuations through the scheme during the irrigation season.

- Power generation. Schemes which serve a multi-purpose of providing power plus irrigation water may present special control problems. Discharges from a dam may be timed to coincide with electrical demands and not with the irrigation demands. A buffer reservoir at the head of a canal may be necessary or computerized controls in the canal system.

- Need automation. In practice, automation control rarely must handle fluctuations of more than 20% of the total flow in canal. Therefore, it is seldom a need to automate all gates in a water level regulator. Typically one out of three gates in a single location will be automated. This not only saves costs, it can also provide better control because of the capability to make small movements.

#### **6.4 Selection of Flow Control Systems**

The selection procedure for the most appropriate flow control system appears to be very complex, see Fig. 18. Many parameters have to be selected, and the effects of each selected parameter cannot easily be understood.

First of all, it is necessary that the ultimate goal of the flow control system is well defined, i.e. what is the water need of the tertiary unit through the irrigation season.

Secondly, the irrigation management philosophy must be determined, in respect to demand- or supply-oriented system, how to schedule the irrigation flow, what mode of flow control is required, etc.

On basis of these assumptions, the actual selection of Water Level Regulators and Discharge Regulators must be done, see also Fig. 18 for some combinations.

The resulting flow control system must be well evaluated on the above selection criteria.

Selection procedure. The selection procedure may follow the following steps, each of them is more or less independent on the previous step, see also Fig. 18.

- Step 1. Determine the water requirement of the tertiary unit, i.e. the unit to be supplied by the flow control system on basis of some sort of agreement with the users ;
- Step 2. Select the delivery policy to supply one tertiary unit :  
(i) arranged supply , (ii) semi-demand supply, (iii) on-demand supply ;
- Step 3. Select the delivery schedule to one tertiary unit :  
(i) peak-discharge supply, which is a proportional supply at a constant discharge, (ii) proportional supply at a variable discharge, (iii) intermittent supply at an on/off basis of the maximum discharge, (iv) varied-discharge supply, a continuous supply adjusted by a discharge regulator ;
- Step 4. Select the conveyance schedule through the main system : (i) peak-discharge supply, (ii) proportional supply, (iii) intermittent supply through the whole scheme, (iv) rotational supply between different units, (v) varied-discharge supply.
- Step 5. Select the mode of flow control :  
(i) none, i.e. proportional with flow-spitting, (ii) manual control, (iii) automatic control, (iv) self-regulating control ;
- Step 6. Select the type of water level regulators, and the type of discharge regulators at offtakes, see also Fig. 19.
- Step 7. Make an evaluation of the selected flow control system, i.e. on performance ratio, efficiency, construction costs, manpower requirement, etc.

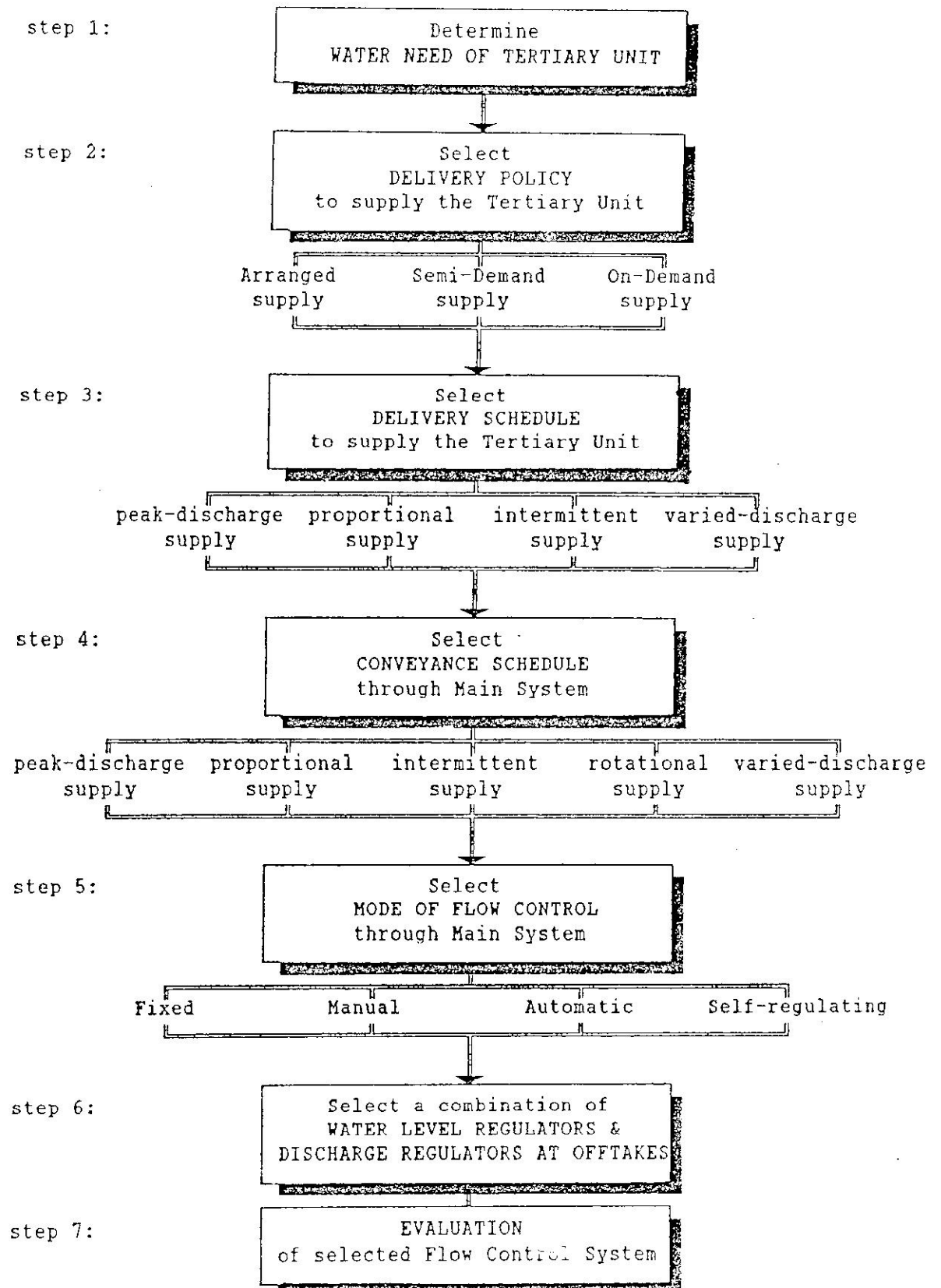
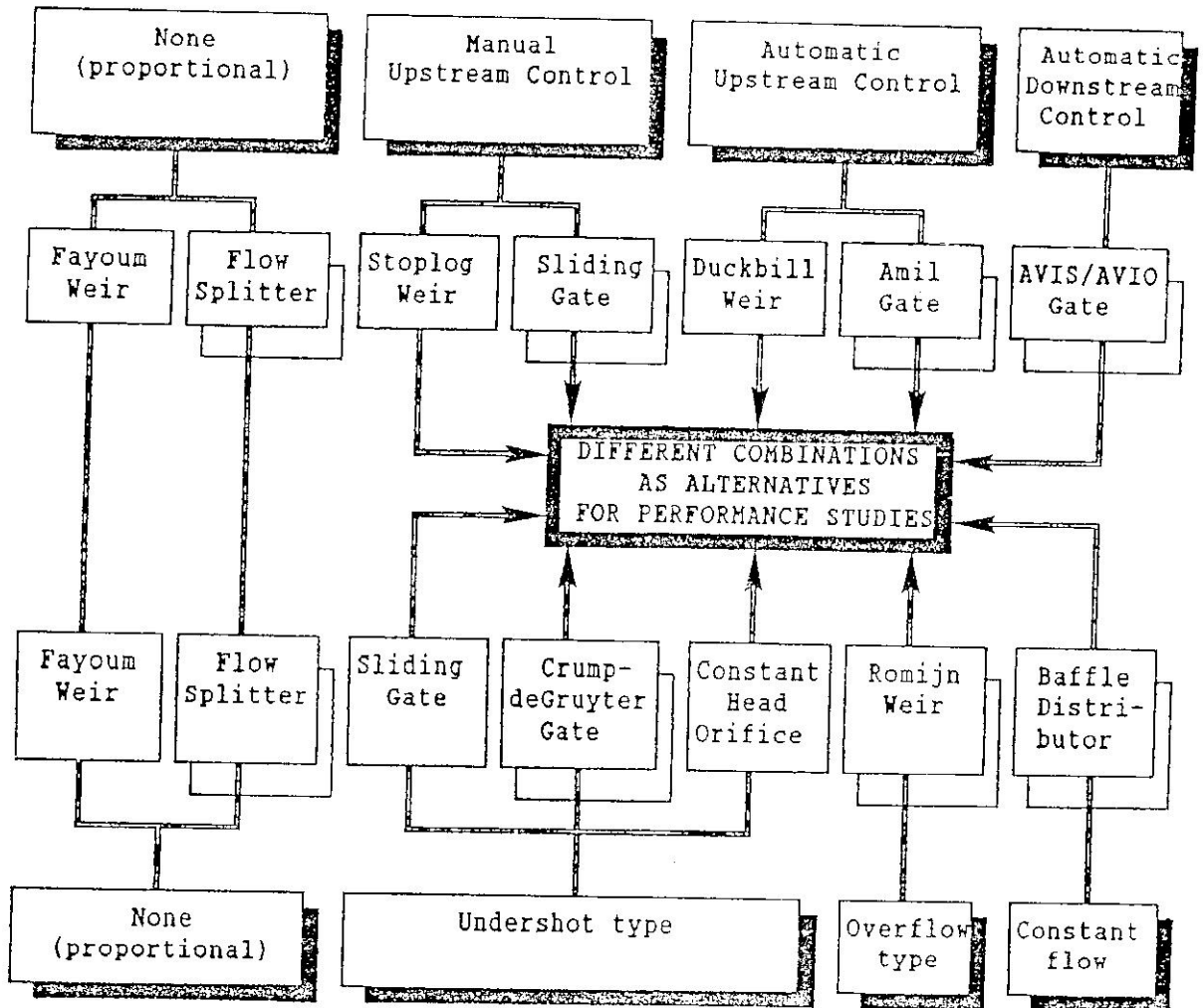


Fig. 18 Selection of Flow Control Systems.

WATER LEVEL REGULATOR IN CANAL



DISCHARGE REGULATOR AT OFFTAKE

Fig. 19 Selection of Water Level Regulators and Discharge Regulators.

### 6.5 Performance of the Flow Control System

In order to compare and to evaluate different types of flow control systems, it is necessary to define certain performance criteria.

Both the irrigation water demand of the tertiary unit, as well as the irrigation supply are usually variables that change considerable throughout the season. The matching of these two variables is a performance criteria.

Scheme Efficiency. The performance of an irrigation system is traditionally defined by the scheme efficiency of the system, i.e. the ratio between the volume of irrigation water that is needed, and the volume of irrigation water supplied. Thus :

$$\text{Efficiency} = V_{\text{needed}}/V_{\text{supplied}}$$

Such a ratio does not take into account the intended use of the water, which may differ from the needed volume. Also aspects like the timing of the supply, an insufficient head during low flow are not considered here, and may provide inaccurate information on the actual performance of the system.

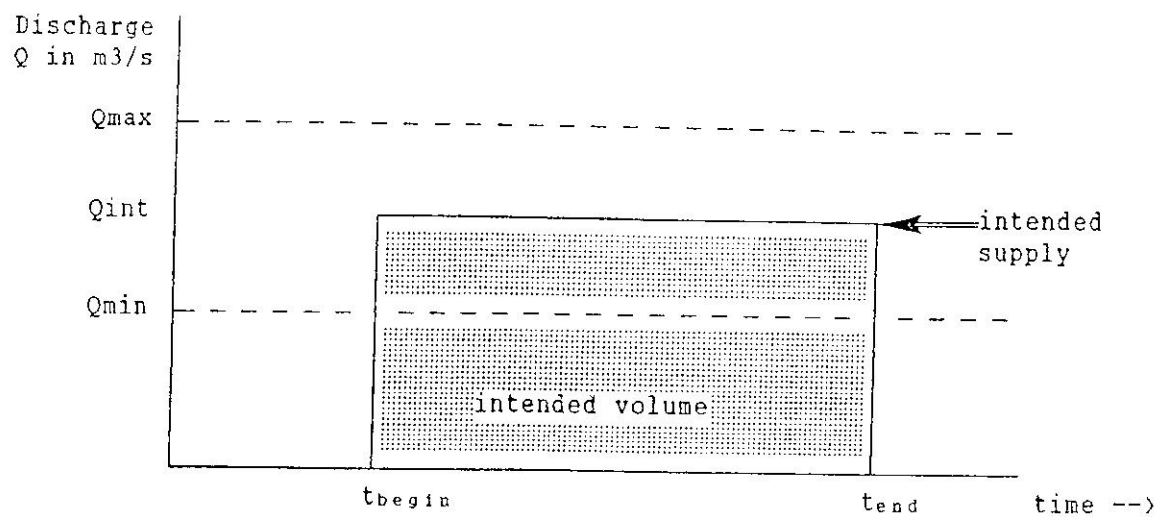
Thus, the above scheme efficiency is not the proper criteria for describing the performance of the flow control system.

Parameters. The performance of a flow control system can better be described by considering three volumes of water, see Fig. 20.

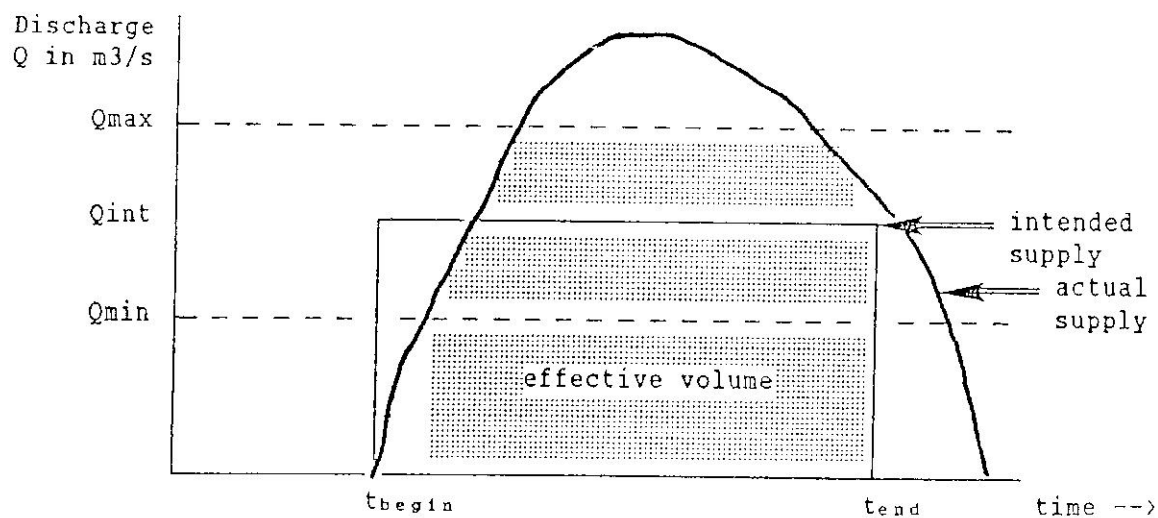
- the intended volume of water ( $V_{\text{int}}$ , in  $\text{m}^3$  per irrigation gift or period) to be supplied to the tertiary unit or to the crop ;

- the supplied volume of water ( $V_{\text{sup}}$ , in  $\text{m}^3$  per irrigation gift or period) that has been supplied to the tertiary unit or to the crop ;

- the effective volume of water ( $V_{\text{eff}}$   $\text{m}^3$  per irrigation gift or period) that can be used by the tertiary unit or by the crop.



INTENDED SUPPLY OF IRRIGATION WATER TO A TERTIARY UNIT



EFFECTIVE SUPPLY OF IRRIGATION WATER TO A TERTIARY UNIT

Fig. 20 Irrigation performance of a tertiary offtake.

Effective volume. The effective volume of irrigation must be fall between certain limits of discharge and of time.

There is a maximum limit to the discharge of the flow, determined by the canal capacity or by the capability of the irrigator to handle the flow. There is also a minimum limit to the discharge, when the water head falls unacceptable during low flow conditions.

The timing of the flow is also important and is related i.e. to the stage of the crop, water storage in the rootzone.

Delivery Performance Ratio. A practical parameter to describe the performance of irrigation through an offtake is the delivery performance ratio (DPR).

The delivery performance ratio is defined as the ratio between the effective volume and the intended volume, thus :

$$DPR = \frac{V_{eff}}{V_{int}} \times 100\%$$

where : DPR is the Delivery Performance Ratio , in % ;

$V_{eff}$  is the effective volume (in  $m^3$ ) of irrigation water per period ;

$V_{int}$  is the intended volume ( in  $m^3$  ) of irrigation water to be supplied per period.

Operation Efficiency. The delivery performance ratio provides information on the irrigation performance of the offtake, but does not provide information on the amount of irrigation water needed to obtain such a performance. This can be measured by the operation efficiency,  $E_o$ , being the ratio between the effective volume and the supplied volume. Thus :

$$E_o = \frac{V_{eff}}{V_{sup}} \times 100\%$$

where :  $E_o$  is the operation efficiency of the offtake, in % ;

$V_{eff}$  is the effective volume (in  $m^3$ ) of irrigation water per period ;

$V_{sup}$  is the supplied volume (in  $m^3$ ) of irrigation water per period.

Performance of an offtake. The Delivery Performance Ratio (DPR) judges the quality of irrigation delivery through an offtake, i.e. the extent the desired irrigation flow has been satisfied by the actual flow.

The Operation Efficiency ( $E_o$ ) determines the operation losses at the offtake, in terms of how much water has been actual used.

Thus, the performance of an offtake has to be described by both the DPR and the  $E_o$ . An operation efficiency of 100% does not indicate that the offtake is receiving enough water, it only indicates that all water is efficiently used. A delivery performance ratio of 100% only indicates that all needs are satisfied, but says nothing about the losses.

When both DPR and  $E_o$  are less than 100% , the water manager knows that there is still room for improvement.

Performance of an irrigation system. The Delivery Performance Ratio and the Operation Efficiency as described above, deals with the quality of irrigation towards one offtake, e.g. a tertiary offtake, but does say anything about the performance of the secondary canal or of the whole system.

The performance of an irrigation system does not depend only on the performance of the individual offtakes, but also on the performance of the canal reaches. For instance, the filling time of an empty canal reach upto to the operation water level has a negative effect on the performance of the irrigation as a whole.

The performance criteria of a canal system can be defined by :

$$\begin{aligned} \text{DPR}_{\text{sys}} &= \frac{\sum V_{\text{eff}}}{\sum V_{\text{int}}} \times 100\% \\ \text{E}_{\text{osys}} &= \frac{\sum V_{\text{eff}}}{\sum V_{\text{sys}}} \times 100\% \end{aligned}$$

Where :

$DPR_{sys}$  is the delivery performance ratio of the system, in %;

$E_{osys}$  is the operation efficiency of the system, in %;

$V_{int}$  is the intended volume (in  $m^3$ ) of irrigation water to be supplied per period, at an offtake ;

$\sum V_{sys}$  is the supplied volume (in  $m^3$ ) of irrigation water per period, to the system ;

$V_{eff}$  is the effective volume (in  $m^3$ ) of irrigation water per period, at an offtake.

Example. An example of the system performance can be given for a secondary canal with three tertiary offtakes, see Fig. 21

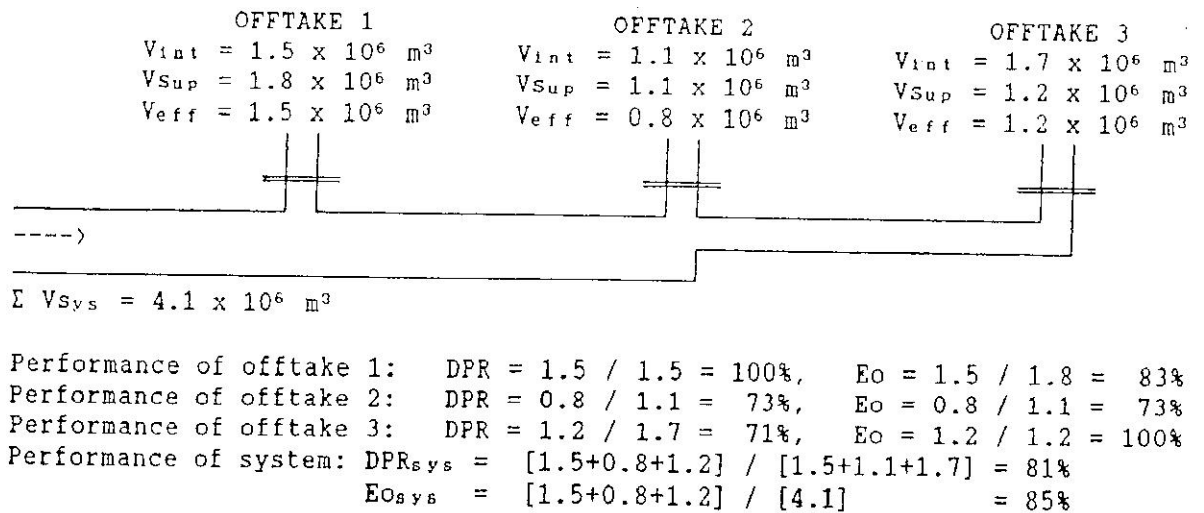


Fig.21 Performance of a secondary canal.

### References

1. Ankum, P., Flow Control in Irrigation System, Technical University, Delft, The Netherland, 1991.