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IRRIGATION WATER CONTROL AND MANAGEMENT INFORMATION SYSTEMS IN JAPAN

LE CONTROLE DE L'IRRIGATION ET LES SYSTEMES INFORMATIQUES DE GESTION AU JAPON

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ABSTRACT

The efficient use of water and its management have become key issues for irrigation in Japan. Limited water resources must be shared among irrigation, industrial and domestic use. Labor-saving is important not only in industry but also agricultural activities. Large-scale irrigation systems including pipeline systems and computer-based water management systems together with telemonitoring and telemechanical control have been introduced to help address the situation.

In this paper, the authors describe the history, problems and trends of irrigation technology in Japan. The water control systems of pipelines are different from those of open channels. The water control systems of open channels are "supplier-led" systems, which farmers are accustomed to. Those

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of pipelines are "user-led" systems, in which farmers can use water at will. We clarify the characteristics of the two systems and show that regulating ponds are needed to cope with fluctuations in water use. We describe the importance of water storage in irrigation systems and the water management method in droughts.

Advanced water management using computers should be performed in view of the special characteristics mentioned above. We have introduced numerical simulations into computer-based water management systems, and derived practical target indexes such as flow arrival time in a canal system. A simulator was developed to simulate the operation at the training site and thus improve water management.

We give an overview of water management information systems and show the important issues such as the key index for information processing.

RESUME ET CONCLUSIONS

L'utilisation rationnelle et la gestion de l'eau sont à présent des questions clés en ce qui concerne l'irrigation au Japon. Il est très difficile de développer de nouvelles ressources en eau à cause des limites imposées par la nature, surtout dans les zones où les ressources en eau sont déjà développées. Ces ressources limitées en eau doivent servir plusieurs usages: l'irrigation, l'usage industriel et l'usage domestique. L'irrigation compte pour 60% de l'utilisation d'eau au Japon. Une amélioration de l'efficacité de l'irrigation est donc vitale pour permettre l'utilisation d'eau pour les autres usages.

La main d'oeuvre agricole au Japon diminue et son coût demeure élevé. Ainsi, l'économie de main d'oeuvre est importante non seulement pour l'industrie, mais aussi pour les activités agricoles. Des systèmes d'irrigation de grande échelle comprenant des réseaux de pipe-lines et des systèmes de gestion informatique de l'eau, accompagnées de contrôles télécommandés et télémécaniques, ont été introduits pour répondre aux besoins.

Dans ce rapport, les auteurs retracent l'histoire et les tendances majeures de la technologie de l'irrigation au Japon. Nous analysons les problèmes de ces systèmes, puis, présentons les contre-mesures touchant à la gestion de l'eau. Nous décrivons, ensuite, l'état actuel des systèmes informatiques de gestion en irrigation et présentons des orientations pour le développement futur.

Les systèmes de contrôle de l'eau utilisant les pipe-lines diffèrent de ceux utilisant des canaux ouverts. Les systèmes de contrôle d'eau à canaux ouverts sont des systèmes "activés par les fournisseurs", auxquels les agriculteurs sont habitués. Les systèmes à pipe-lines sont "activés par les utilisateurs", ce qui permet aux agriculteurs de faire usage de l'eau en toute liberté. De la sorte,

l'introduction des pipe-lines apporte un changement radical dans la méthode de gestion de l'eau.

Les auteurs précisent les caractéristiques des deux systèmes et, montrent que des étangs régulateurs pour pipe-lines sont nécessaires afin de faire face aux fluctuations dans l'utilisation d'eau.

Il n'est pas possible d'observer et de contrôler les conditions de l'écoulement de l'eau dans toutes les parties d'un réseau d'irrigation de grande échelle. Il peut y avoir, notamment durant les périodes de sécheresse, une pénurie d'eau. Nous décrivons l'importance du stockage d'eau dans un système d'irrigation et une méthode de gestion de l'eau à travers une étude de cas.

La méthode évoluée de la gestion informatique de l'eau doit être appliquée en tenant compte des caractéristiques mentionnées ci-dessus. Les systèmes de contrôle par télécommande et télémécanique sont installés au sein des systèmes informatiques de gestion de l'eau. Les données de contrôle sont enregistrées et peuvent être utilisées pour le contrôle de l'eau.

Nous avons réalisé des simulations numériques sur des systèmes informatiques de gestion de l'eau et avons obtenu des indices-cibles tels que le "temps d'arrivée du flux' dans un système à canaux.

Les ingénieurs réalisant la gestion de l'eau contrôlent, d'habitude, les installations d'irrigation, en se basant sur leur connaissance empirique. Mais ils n'ont pas l'expérience de systèmes évolués et ne peuvent donc mener des opérations sans entraînement. Par conséquent, un "simulateur" a été développé pour simuler l'opération sur le site d'entraînement. Nous décrivons la situation générale des systèmes informatiques de gestion de l'eau, en mentionnant des problèmes importants comme la réalisation d'un index pour le traitement des informations.

1. DEVELOPMENT OF IRRIGATION TECHNOLOGY IN JAPAN

Modern irrigation systems in Japan were first introduced in the 1950s. The Aichi Irrigation Project created one of the first modern irrigation facilities which used automatic checks along the trunk canals. Such facilities allow constant, stable water distribution.

We have established irrigation systems based on the open channel type in main and branch lines. These systems integrated traditional small-scale irrigation systems and canals were lined with concrete. The main objectives of the irrigation projects were to supply water to paddy fields and to increase rice production. The irrigation systems are mostly open channel, hence water management is carried out by the traditional method based on the experience of the old irrigation systems. The operators and farmers use the method without difficulty. A pipeline system for irrigation started to be introduced in the 1960s for upland crops. Pipelines began to be used for the trunk line of paddy field irrigation in the 1970s.

Social and economic changes in Japan have forced agricultural structural reform. Therefore, agricultural productivity and quality must be increased. However, water resources are limited and irrigation water accounts for around 60 percent of total water consumption in Japan. For irrigation, the following countermeasures are needed to promote agricultural development and reform :

(1) Reduction of water management cost not only for the main irrigation systems but also at the farm level to improve productivity;

(2) More efficient water management to cope with the lack of labor;

(3) Improved water supply system to suit the farming technology for high quality products; and

(4) Conservation of irrigation water and increase in water use efficiency

Pipeline irrigation systems have been widely developed both for paddy and upland fields in line with this policy since the 1980's. The pipeline system for trunk and branch lines aims to decrease the water losses of conveyance and distribution and also to reduce the water management workload. Pipelines have also been introduced to replace farm ditches. Farmers are thus able to irrigate their fields whenever needed, and can draw water individually according to their farming schedule.

A water management system with telemonitoring and telecontrol has also been introduced to save labor made possible by dramatic developments in computer technology and telecommunications. Pipeline systems and computer-based water management systems have only recently been introduced in irrigation projects in Japan, and so some problems remain, especially concerning water control and management.

2. WATER CONTROL FOR OPEN CHANNELS AND PIPELINES

2.1 Water control system

In the traditional irrigation system using open channels, the irrigation water is taken at the head and is distributed from the upstream offtake. Modern irrigation systems using open channels are managed in the same way as the traditional system. The supplier determines the intake discharge at the head and watches the distribution at the offtakes. It is not necessary to change the intake discharge even if a downstream offtake cannot take enough water due to excessive withdrawal of upstream offtake. The supplier calls on farmers to arrange the allocation of water.

Thus, the system is a "supplier-led" water control system. From a hydraulics point of view, the supplier, irrespective of the water demand, can control the intake discharge at the head in the system. This supplier-led system is the traditional one, and farmers are accustomed to it. Accordingly, modern open channel irrigation systems have been managed without difficulty.

However, the introduction of the pipeline system for irrigation produced a radical change in the supplier-led water control system. A benefit of the pipeline system is that farmers in the system can take as much water as they want. If they open or close the valve at the end of the system, water will come out or stop. In the pipeline system users control the water, and thus it is a "user-led" water control system.

The user-led system cannot be controlled at the head of the system. Usually, the head of the pipeline is located comparatively high. If we install and control the valve at the head, cavitation or air entrainment in the pipe easily occur. Air will also enter the pipe if water supply is insufficient. Consequently, the user-led water control system is possible only when there is an adequate water supply at the head.

In the user-led water control system, the supplier does not need to control the facilities under usual conditions, but must ensure an adequate supply of water at the head of the pipeline, even in case of overuse by the farmers. The introduction of a pipeline system requires the water control system to be changed from the traditional supplier-led one to the user-led one.

2.2 Systematic design of facilities

The water requirement varies mainly with the rainfall. Frequency of changing water supply to suit the requirement used to be weekly or seasonally. After introducing a pipeline hourly changes in water requirement cannot be ignored. Figure 1 shows a typical example of the water requirement changing hour by hour in one day. As the pipeline system should be operated using the user-led water control, the supplier must supply water at the head of the pipeline. However, it is very difficult to monitor and operate the facilities while flow condition in the irrigation system is fluctuating.

If we have a stock of water in the system, stored water can be allocated to balance supply and demand. A regulating pond at the end of a main irrigation system obviates the need for frequent operation and water control (see Figure 2). Then, supplier has enough time to observe and to determine how to control the facilities properly. Information on any imbalance of water supply and

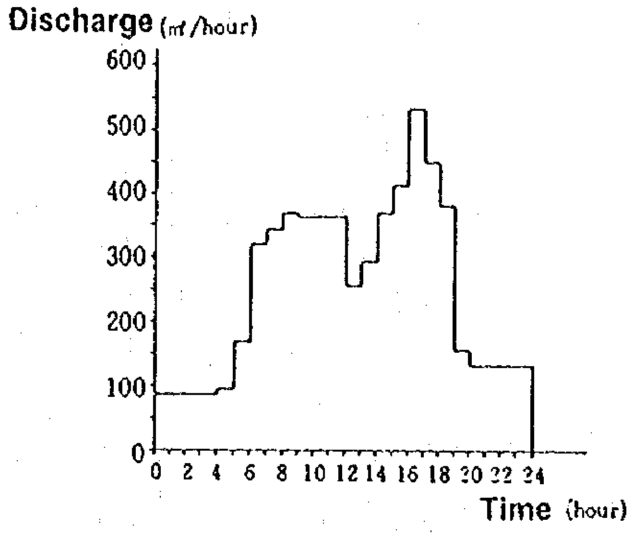


Figure 1. Changes of water requirement in a project (Les changements des besoins en eau dans le projet)

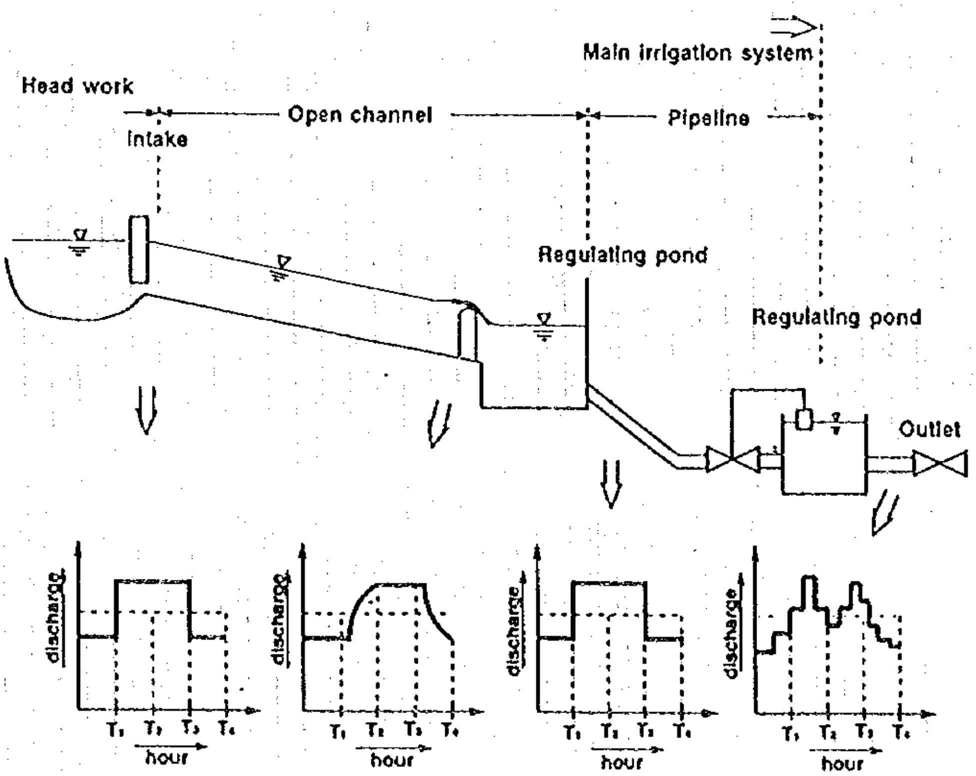


Figure 2. Time - discharge relation in irrigation system (Le rapport temps / déversement dans le système d'irrigation)

demand is shown by the water level and its change. Especially during droughts, this information is a key index which the supplier can use to supply water to specific area where the water shortage is serious.

There is another type of regulating pond necessary for reasonable water management. At the head of the pipeline, we mentioned the needs of sufficient water supply. The response to the change of flow in the open channel is slow, and it takes time for the discharge to change from one point to another. We call this the "flow arrival time". If the supplier knows the change of demand in the pipeline and changes the intake discharge at the head of the open channel, enough water cannot be supplied to the pipeline timely because of the flow arrival time.

Therefore a regulating pond at the connecting point of two systems is required (Figure 2). A regulating pond provides stored water to the pipeline during the flow arrival time in case the demand increases, and stores water if the demand falls. Water stocks such as regulation ponds in the irrigation systems should be taken into account for smooth and efficient water management.

3. WATER MANAGEMENT USING TELECOMMUNICATIONS

3.1 Outline of irrigation and telecommunication system

Here, we describe general telecommunication systems in Japan using Meiji irrigation system as an example.

The Meiji irrigation system is located at Aichi Prefecture. The initial system were completed in the 1880s. Since then, various revamping projects have been carried out. The outline of present canal system is shown in Figure 3. Irrigation water is withdrawn upstream from the Meiji diversion dam, and its maximum design discharge is 35.25 m^3/s. The trunk canal is 11.5 km long of which the upstream 7.7 km is concrete-lined open channel, and the rest is low-pressurized pipeline. Distribution systems fall into two categories, open channel system and pipeline system.

The telecommunication system has been completed in 1989. A telecontrol system in a central office next to the barrage connects to the following points with private lines. Incidentally, public telephone lines are usually used nowadays for the irrigation telecommunication system in Japan.

- Gates of barrage and intake works;
- 18 gates or valves of division works having a design flow-rate of 0.3 m^3/s or more.

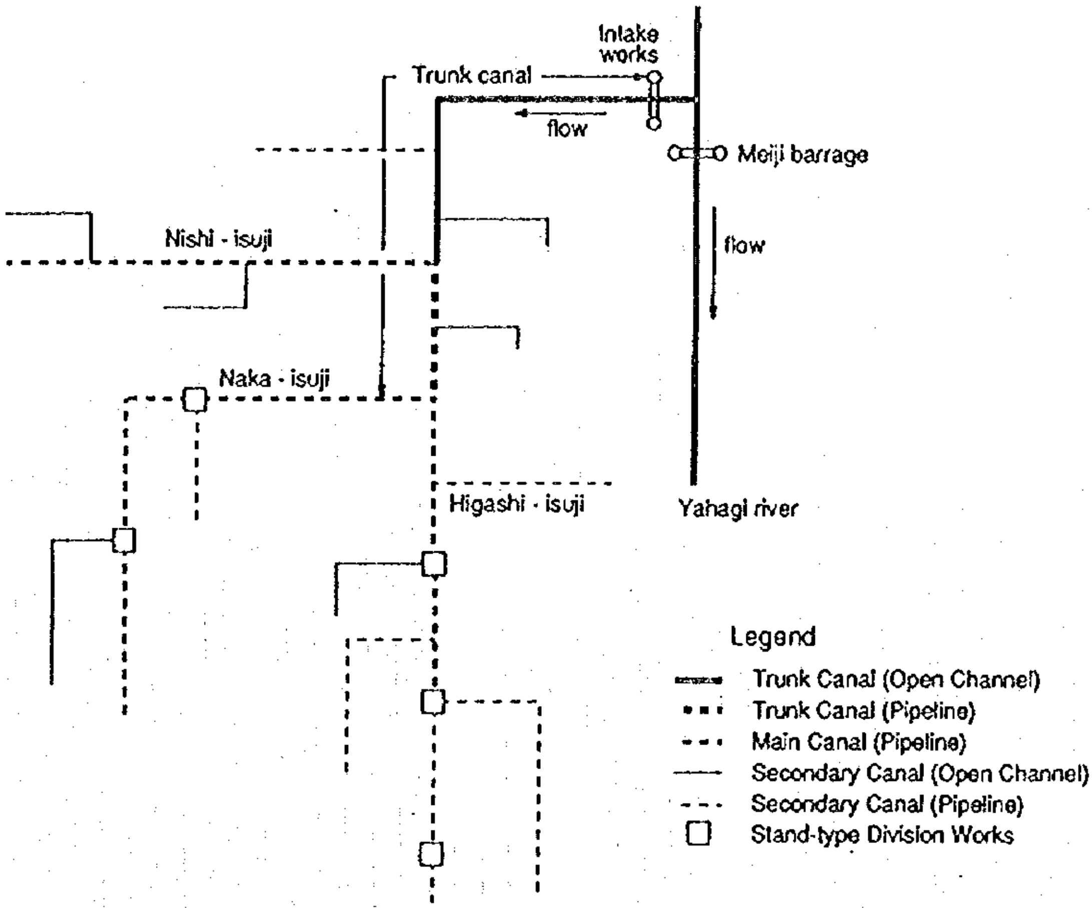


Figure 3. Outline of Meiji irrigation canal system (Présentation de système de canaux d'irrigation de Meiji)

Besides the telecontrol system, the telemonitoring system connects to the following points :

- 10 flow rates at division works of which design flow rate is 0.1 m^3/s or more;
- 15 water levels at the trunk canal and main canals.

Telecontrol points can be operated from the central office, and these points and monitoring points can be monitored on a graphic panel and the data are printed on recording paper.

3.2 Problems of Meiji irrigation system

There are some problems remaining to be solved in this project. The main problem is that this system has no regulating pond along the canal system. As noted in previous chapter, pipeline is inevitably a "user-led" system, which means that water suppliers are hardly able to control the water flow at the head of the pipeline and the flow rate can suddenly change according to users' operation. In the case of the Meiji canal systems, pipelines are employed for a part of the main canal and distribution systems.

On the other hand, the upper most of trunk canal is open channel requiring a certain time for the flow to move from one point to another. It is estimated to take about one hour for water to reach the head of the pipe from the intake works in this system. Therefore, the supplier must exactly estimate the change in the flow rate of the pipeline one hour in advance in order to use the water effectively, but this is impossible in practice. In reality, the supplier withdraws more water from the river than is actually used in order to prepare for any unexpected increase in the flow rate of the pipeline.

The excess unused water discharge is 2 m^3/s, and this flow rate is almost constant. The ratio of 2 m^3/s to total irrigation water (30 m^3/s) is around 7 percent. Without telecommunication system, the efficiency of water use would decrease in this system. However, even if a telecommunication system is installed and staff are skilled, efficiency cannot be improved dramatically if there is no regulating pond along the canal.

A harmonized irrigation system which combines the system with regulating pond and telecommunication system is indispensable in order to create an effective irrigation system.

4. WATER MANAGEMENT METHOD DURING DROUGHTS

4.1 Water management during droughts

Rainfall was light throughout Japan in 1994, and shortage was so serious that its recurrence period is once every 100 years. In the Kagawa Irrigation District, the June to August rainfall was the lowest ever recorded, at about 1/3rd of that of an average year. As the district is in one of the lowest rainfall parts of Japan, all agricultural land in the district obtains water from one of over 16,000 irrigation ponds constructed to deal with the chronic water shortage.

The Kagawa Irrigation Project was initiated in 1968 in order to improve the water situation in the region. The plan called for the Sameura Dam to serve as the water source, and for 106 km trunk channel to supply water for agricultural use (31,000 ha) and to public water supply systems.

Water management measures implemented to deal with the drought at the Kagawa Irrigation District trunk channel level included overall reduction of the volume taken, transfer of water among different users and "priority distribution" to the area where the drought was particularly sever.

4.2 Water management method

Because the irrigated land area relative to the storage volume of each irrigation pond varies within the district, differences in the degree of danger from drought conditions between farmland grow as the severity of drought conditions increases. But because each section of the district is served equally by its modern irrigation system, water management system should be carried out in such a way that the degree from drought is the same throughout the entire district.

Water management using groups of ponds based on the "storage volume depth" method has been proposed as equalizing the risk. Storage volume depth (pond water storage volume V / irrigated land area A) will be defined for each pond as an index indicating its irrigation capacity. This index, which will represent a depth of water, will indicate the water volume that can irrigate the land for each pond at that point in time.

The goal, equal storage volume depth in all parts of the irrigation systems, is expressed as shown below. The calculation units can be thought of as either one day or one week.

$$\frac{V(1,k)}{A(1)} = \frac{V(2,k)}{A(2)} = \ldots = \frac{V(n,k)}{A(n)} = \frac{\sum_{i=1}^{n} V(i,k)}{\sum_{i=1}^{n} A(1)} \tag{1}$$

where,

- $V(i,k)$: Storage volume in calculation period unit k for pond i
- $A(i)$: Irrigated land area served by pond i
- n : Number of ponds in operation.

The average storage volume depth P and adjustment volume Cv that equalizes the safety factor for pond i are determined using the following formulas :

$$P(k) = \frac{\sum_{i=1}^{n} V(i,k)}{\sum_{i=1}^{n} A(i)} \tag{2}$$

$$Cv(i,k) = P(k)\, A(i) - V(i,k) \tag{3}$$

And the pond storage volume V for the following calculation unit can be represented by following formula :

$$V(i,k+1) = V(i,k) - QD(i,k) + QI(i,k) + Cv(i,k) \tag{4}$$

where,
QD(i,k) : Water volume required for fields irrigated by pond i
QI(i,k) : Volume of water flowing into pond i

Table 1 presents a sample trial calculation for an irrigation system of branch canal level in the district shown in Figure 4. When for example, the actual and trial calculation minimum storage volume depth are compared, the trial calculation reduces the gap between ponds, equalizing the degree of danger at each one.

Table 1. Calculation of storage volume depth (Calcul du volume d'eau en stock)

Pond number	Location	Storage volume depth (S.V.H) (mm)*	Average S.V.D. (mm)		Lowest S.V.D. (mm)	
			Actual	Calculation	Actual	Calculation
3	Upper	156.3	71.15	119.05	17.19	81.25
4	"	1203.1	685.8	632.3	228.6	127.1
7	"	190.9	104.5	156.6	57.3	96.8
8	"	137.1	86.8	106.5	49.4	70.5
9	"	339.0	249.9	291.6	169.5	224.5
10	"	109.5	69.5	90.4	34.0	70.1
11	"	543.0	306.3	403.0	76.0	248.7
12	"	356.3	90.4	274.3	7.1	209.6
13	Lower	428.3	218.0	353.4	21.4	220.8
14	"	532.5	358.7	348.5	159.7	167.2
16	"	433.5	292.9	346.3	0.0	181.9
17	"	362.3	182.5	317.0	0.0	234.2
18	"	180.0	153.0	153.6	108.0	124.2
19	"	115.0	90.5	93.5	51.8	56.9
21	"	125.0	110.3	104.8	62.5	73.0
Average		347.5	204.7	252.7	69.5	145.8

* Storage volume depth = Storage volume/irrigated area

There are two features of this method. It is based on indices conforming with clear fundamental specifications that users can agree on without difficulty, and unclear elements are, as a result of its use, reflected in the volume of water stored in each pond. And it is possible to equalize conditions throughout the entire district, because the amount of water to be circulated between blocks can be calculated by applying this method to all blocks in the district.

5. WATER MANAGEMENT INFORMATION SYSTEM

5.1 Water management systems

Irrigation facilities such as dams, headworks, pumping stations and check and offtake gates, have traditionally been individually monitored, operated and controlled at each site. Such individual management systems are now being

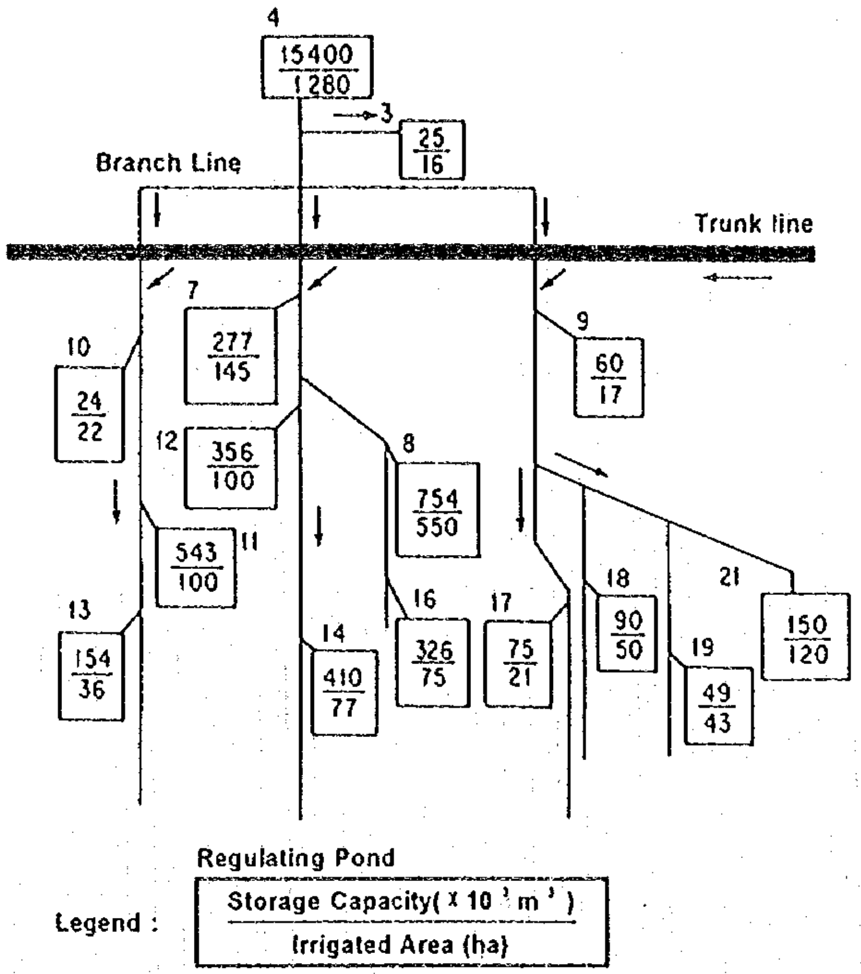


Figure 4. Irrigation network (Réseau d'irrigation)

replaced by a centralized control and management system in which all the main facilities are monitored and controlled from a central station.

The reasons for the introduction of central water management systems are as follows :

(i) Effective water use with the least losses
(ii) Proper water supply and distribution to meet the water requirement
(iii) Harmonized water management in all the irrigation systems
(iv) Reduction of management cost
(v) Others, such as prevention of disaster.

A telemonitoring and telecontrol system is necessary for centralized water management.

As this system can only be realized with computers and computer-based technology, attempts have been made to develop information processing and automatic control method. Thus, some management information systems have already been developed and central control systems introduced.

5.2 Diffusion of water management technology

Water management of irrigation systems usually has been undertaken by a Land Improvement District (association of farmers in a certain area). However, the management engineer of the district is not accustomed to operating a central control system, which is very hard to operate without necessary knowledge and experience.

A simulator has been developed to teach how to use the central control system. The simulator consists of the console, display and computer system shown in Figure 5. A mathematical model of an irrigation system is used to calculate the canal flow condition in the computer. When we push a control button for the intake gate, for instance, the computer system calculates the flow condition at certain times, and the display system shows the calculated flow condition continuously same as actual operation.

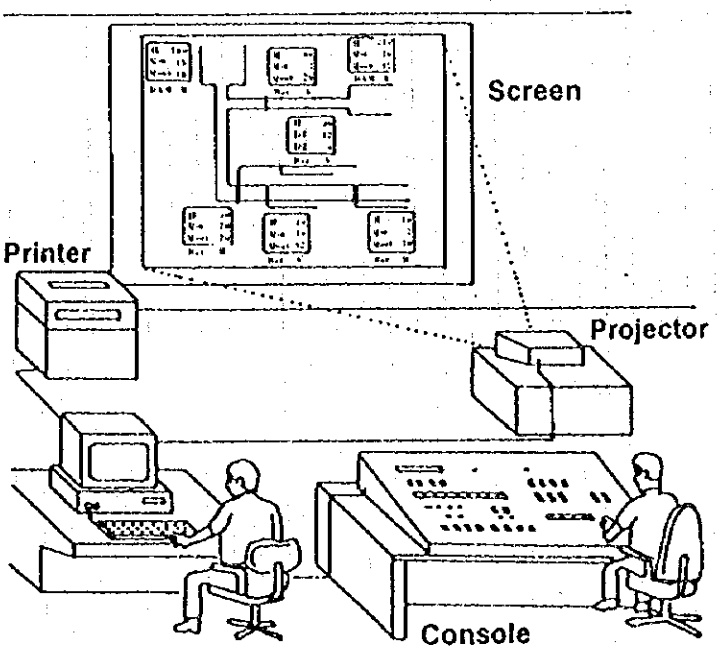


Figure 5. Outline of simulator (Présentation du simulateur)

The trainee can thus learn how to operate the control system, and an abnormal condition can be simulated without danger. Computer-based water management systems are not easy for operating staff without experience to use. Therefore, the simulator is important for the dissemination of computer-based water management technology.

5.3 Computer support for water management

Analyses using mathematical simulation models became popular. Hydraulic model experiments have been conducted to study the unsteady flow condition in irrigation systems. We have been using such mathematical models for the planning and design of irrigation facilities. It is also possible to employ such computer-based mathematical analysis for water management, but the analysis of unsteady flow is complicated and takes time and expertise.

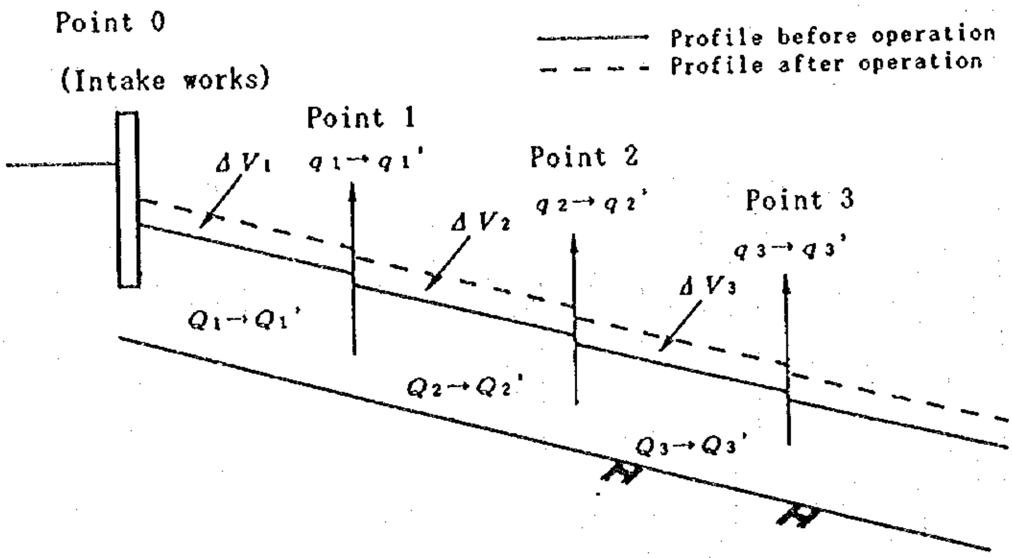
A computer program called "Nuflow" has been developed for the daily water management in open channel irrigation systems. This program uses the mathematical model of non-uniform flow, and can calculate the flow arrival time in an open channel quickly and display the information visually. It is not so difficult for the operator to perform the simulation and it is easy to understand the information visually. Thus, the operator can determine suitable time to operate the check gates and offtake gates along the canal considering the flow arrival time. The flow arrival time is analyzed by the method shown in Figure 6.

5.4 Water management information system

Water management is like a loop from observation and data collection to data processing, analysis, operation planning and operation of facilities, then back to observation and data collection. There are many kinds of information for water management shown in Figure 7. To establish water management information systems, the accuracy and reliability of the data are critical. Indices for water management information are also important and should be selected carefully.

The discharge amount at a certain time is very common index used for water management. In this paper, we showed the importance of water stocks in the irrigation system. The volume of water is thus a key index for proper water management.

Because of the fluctuations of water demand and frequent changes of water supply, the volume of water supply and consumption in a day and week is perhaps now the main index for daily water management. The water management information systems are still being established, and the storage, supply and consumption volume of water in the irrigation system should be considered as a key information index for effective water management.



$$T_n = \sum_{i=1}^{n}(\Delta V_i / \Delta Q_i) = \sum_{i=1}^{n}\left\{\Delta V_i/(Q_i' - Q_i)\right\}$$

$$Q_m = \sum_{i=m}^{n} q_i$$

T_n : Flow arrival time (s)
ΔV_i : Change in storage volume between point (i-1) and point (i) (m^3)
Q_i : Flow rate between point (i-1) and point (i) before operation or at the present condition (m^3/s)
Q_i' : Flow rate between point (i-1) and point (i) after operation or at the target condition (m^3/s)
q_i : Distribution flow rate at point (i) before operation
q_i' : Distribution flow rate at point (i) after operation

Figure 6. Calculation method of flow arrival time (Méthode de calcul du temps d'arrivée du flux)

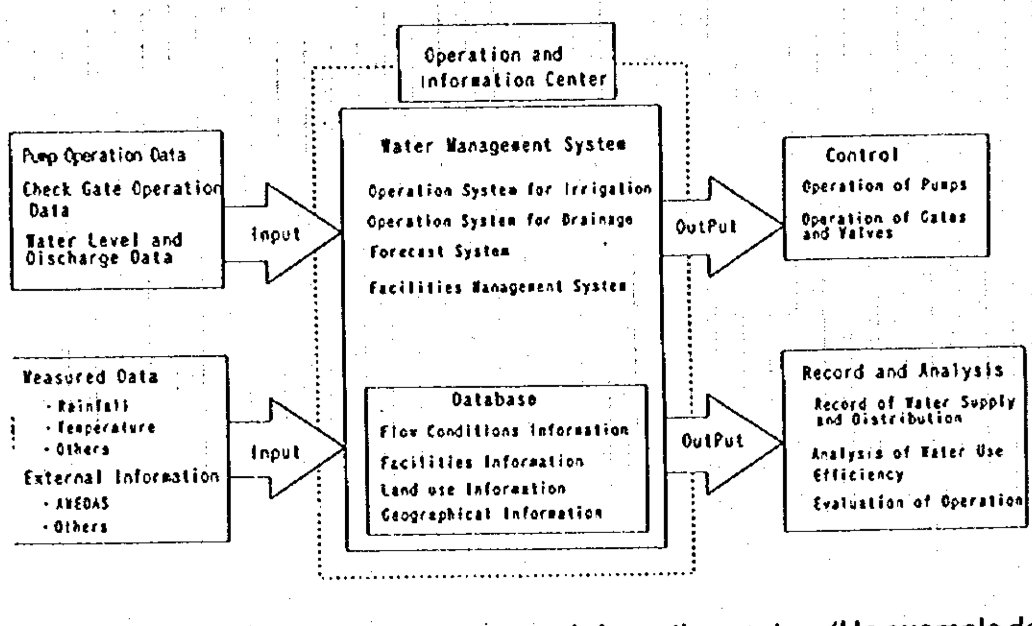


Figure 7. Example of water management information system (Un exemple de système informatique de gestion de l'eau)

6. CONCLUSIONS

The authors have discussed the planning and control of irrigation systems for proper water management, and the key issues for establishment of water management information systems. Our conclusions are as follows :

(1) Water control systems such as "user-led" or "supplier-led" systems should be considered for the establishment of water management systems.

(2) Facilities such as regulation ponds are required for effective water management to counter fluctuations of water demand.

(3) Numerical simulation is helpful for computer-based water management systems, but software must be user-friendly.

(4) Water management engineers must be trained for proper water management and training systems such as simulator should be developed.

(5) Information indices such as water storage in the irrigation system and volume of water supply and use should be considered in the water management information system.

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以上