JARQ 24, 100–104 (1990)

Enhancement of Buffer Function in Irrigation Canal Systems

1. Necessity of enhancement of buffer function

Hideo YOSHINO, Sun Joo KUM*, Tatsuo NAKA and Jun ITAKURA**

Abstract

In the course of recent modernization and diversification of agricultural technique as well as of consolidation of terminal irrigation facilities in Japan, water requirement for irrigation has been considerably increased and, at the same time, its fluctuation has also been magnified. To alleviate these constraints, the facilities for effective use of water resources such as main canals have been consolidated under various irrigation projects. However, the present canal systems are still not adequate enough in utilizing water resources effectively, since fluctuation in water requirement is not properly taken into account. Flexible water conveyance is required in order to appropriately correspond to the fluctuating water requirement. In addition, in the case of irrigation canal system consisted of open channels, a time requirement for irrigation water to reach fields has also to be considered. To meet there requirements, an installment of reasonable buffer function becomes important in the system. The buffer function has been incorporated in the systems so far usually by constructing regulating reservoirs, the capacity of which has been designed on the basis of such conditions as topography of land and economic viability. However, the buffer function has to be met by not only reservoirs but also check-gates and other relevant facilities. This paper, first, presents a basic concept of buffer function and necessity of its enhancement, and second, discusses some problems pertaining to the fluctuation water requirement in an irrigation canal system with a limited buffer function. A method for calculating buffer capacity will be presented in the following paper.

Discipline: Irrigation drainage and reclamation
Additional key words: demand point, farm pond, fluctuation of water requirement, water management

Background and objectives[1,3)]

With the expansion of consolidated land areas, paddy irrigation in Japan has been changed from a traditional plot-to-plot irrigation system to a canal irrigation system which has an inlet at every paddy plot. The latter has the advantage of using irrigation water more freely.

The change of irrigation system includes two components; namely, increase in water demand itself and increase in water demand fluctuation. In addition, upland irrigation which has been rapidly expanding since the middle of the 1950s has the same problems with the paddy irrigation. Consequently, it is very important to study suitable irrigation systems which cope properly with the change in water demand and its fluctuation.

Of the above two components, the former has been solved through land improvement projects with irrigation canals to meet the increased demand for water. In fact, however, current irrigation systems

Department of Hydraulic Engineering, National Reserach Institute of Agricultural Engineering (Tsukuba, Ibaraki, 305 Japan)
* Department of Agricultural Engineering, College of Agriculture (Kon-kuk University, Seoul, Korea)
** Yodo-River Basin Agricultural Land and Water Planning and Management Office, Kinki Reasional Agricultural Administration Bureau (Momoyama-cho, Fushimi, Kyoto, 612 Japan)

are not necessarily recognized as highly suitable from the viewpoint of allowability of water demand fluctuation and effective utilization of water resources including rainfall. Consequently, it is important to establish an irrigation canal system to match the water requirement more adequately in the field.

In order to convey required water, amount of which being fluctuated, to certain places, it is important to send variable amounts of water for better management and more effective utilization of water resources. In case of open-canal irrigation system with low buffer function, it is difficult to send properly required amount of water to designated places because of time lag.

When and where the water demand fluctuation is practically small and the water demand and supply is rather balanced, it is enough to spill surplus water from a spillway after the conveyance of a sufficient amount of water to fields.

An increased fluctuation of water demand does not always imply an increase in water demand. However, it may lead to an increased volume in intake water as well as an ineffective discharge, if the canal irrigation systems are designed on the basis of constant discharge. Therefore, it is necessary to set up a new system for canal irrigation and water management on the basis of a new design concept so that the increased demand fluctuation and use of water resources could be dealt with more effectively. In other words, an irrigation canal system which has a suitable buffer function will have to be designed. The new design will also have to consider the possible implications of the new system on natural water resources, especially rivers and reservoirs. This paper proposes, first, a basic direction pertaining to buffer function in irrigation systems, and, second, a method for calculating a buffer volume in improved irrigation canal systems under any given circumstances of agricultural water utilization, such as increased fluctuation of water demand and constraints in water resources.

For reference, in regard to the term of buffer function, this paper gives its definition as follows: "Functions to reserve surplus water and to supply additional water, as induced by water demand fluctuations in an irrigation canal system".

Basic direction and necessity of buffer function in irrigation canal systems

1) Basic direction[3)]

In order to avoid an ineffective discharge in a canal system, irrigation water required should reach the designated place properly. In case of the open canal systems, required irrigation water arrives at the designated place after a few steps such as the estimation of water demand, the water intake and distribution and the running-off for some time. In order to supply a required amount of water on the spot, it is necessary to convey the water to the requested place prior to its actual use for irrigation in the fields. In case where the demand is small, the water has to be stored in the system. Such a buffer function is really needed to meet adequately the conditions as mentioned above.

If there is little buffer function in a system, water users may have to wait for irrigation water, or a special water management may have to be practiced on the basis of an estimate of water requirement at the demand points of irrigation water. However, as the estimate may involve errors, it might lead to an ineffective discharge, since the water supply may occasionally be either too much or too little. In addition, users' waiting of water does not always assure the prevention from ineffective water spillage because of possible rainfall during the waiting period. A buffer function could not be effective until precise information on water demand are available and applied to intake distribution of irrigation water for overall water management.

Therefore, under a given condition, in particular a limited capacity for water management, the buffer function could be highly effective only when it is installed at adequate points in the irrigation system.

On the basis of canal types, present irrigation canal systems are classified into the following four types:

(1) Conveyance and distribution systems are both open types.
(2) Conveyance system is an open type, and distribution system is a pipeline type.
(3) Conveyance system is a pipeline type, and distribution system is an open type.
(4) Both conveyance and distribution systems are pipeline types.

A pipeline type above means a closed-type pipeline. In recent years, the conveyance systems composed of open and pipeline types have been widely employed for practical use in Japan. This system is a modified type of (2) above in its hydraulic property.

In case of type (1) above, demand points are located at the mouth of each field. Therefore, the buffer function should be distributed separately to a number of points. However, this is practically impossible from the viewpoint of water management. It may be the second best way to make buffer function effective by setting demand points at several selected spots.

In case of type (2), demand points are located at the mouth of each field. Total amount of required water in the distribution system is equal to the flow rate at the upstream end of the pipeline; thus, the water supply is always equal to the water demand. If the buffer function is enhanced at this point, ineffective water could be prevented. However, if the water supplied is less than the required level, air can be drawn into the pipe; this phenomenon is hydraulically not desirable. For safety, the amount of water to be kept in the buffer function should always be either, at least, equal to or greater than that of required water.

In case of type (3) above, since the water arrival time is not necessary to be taken into account in pipeline conveyance system, less buffer function may be required than the case of type (1). However, since the distribution system is an open type, the buffer function has to be provided at a number of points as the case of type (1). In practice, it is difficult to adequately operate and manage these buffer facilities.

In case of type (4) above, water supply is always equal to water demand because the fluctuations in water demand at the consumption site directly cause variations in inflow rate at the upstream end of the pipeline, where the water source is located. Consequently, no ineffective water spill takes place even without any buffer function. However, since every fluctuation in water demand reflects on the whole system, the water flow may inevitably be unstable.

The basic direction for improving irrigation canal systems in the future would be toward the case (2) or its modification. In this case, if some sections of the system are replaced by pipelines, the amount of water loss during operations could be reduced in these sections. However, in order to reduce the water loss in the whole system and to raise irrigation efficiency, it is required to enhance the buffer function in the open type of conveyance system.

Possible methods to enhance the buffer function in irrigation canal systems are classified as follows:

(1) Enhancement of buffer function of the canal itself;
   a) Enlargement of the canal's cross section,
   b) Provision of check-gates to regulate water level.
(2) Enhancement of buffer function through storage facilities;
   a) Provision of buffer ponds.
(3) Enhancement of buffer function by utilizing drainage canals;
   a) Provision of reusable drainage facilities.

These methods need not necessarily be adopted individually. The most suitable combination of these methods could be designed to minimize the costs incurred for construction and operation and to secure the necessary buffer function in places where it is needed.

2) Demand fluctuation of irrigation water[2,3]

The results of the studies undertaken so far have indicated that, in dry-field irrigation, water is concentratedly required in the daytime, particularly in the morning and the evening as well; in other words, water use is highly specialized. In this respect, they have demonstrated that an existing farm pond provides a function to regulate a water flow conveyed from the main channel to the fields to some extent. In recent years, a farm pond is equipped with an automatic intake device at the inflow section. However, if the system has only a limited buffer function in a water supply line, the system is not fully capable of storing excess water, which may be caused by a reduced demand for water because of rainfall. As a consequence, such excess water is discharged without any effective use through the water supply system.

A design concept for paddy irrigation has so far been deeply rooted on the premise of steady water supply, without any consideration given to a time-dependent demand fluctuation. In reality, however, such a fluctuation of demand frequently occurs. In particular, the modernization of irrigation canal has been generally accompanied by valve operations for water supply based on a fixed schedule, which has created an increased demand fluctuation. This is the very reason of establishing an appropriate canal system for irrigation that contains a suitable mechanism to deal with the demand fluctuation as stated above. If an ineffective discharge is to be minimized, the buffer capacity in the system has to be determined on the basis of some factors including acceptable demand fluctuation, water arrival time specifically required in a given irrigation system, and duration necessary for operations in the water control system.

The demand fluctuation is greatly dependent on the cropping systems as well as on the size of an irrigation system. A field survey result indicated that in an irrigation system which contained a benefited area of 20–40 ha comprising a number of rather small-size paddy fields, a demand fluctuation per hour reached 60–80% of the design flow rate. It also indicated that the demand fluctuation per 2 hr was equal to the design flow rate. In the other irrigation system which covered a wide range of paddies with a total benefited area of 5,400 ha, it was found that the water demand fluctuation per hour and 2 hr accounted for 27% and 34% of the design flow rate, respectively[2]. In fact, this survey confirmed that the time-dependent demand for paddy irrigation varied to a great extent.

3) Problems in water control in the irrigation channel system with a small buffer function[2,3]

There is a wide range of irrigation channel systems with a small buffer function in Japan. They often give rise to serious problems from the viewpoint of effective utilization of limited water resources.

An example of the problematic use of water resources in an irrigation project is subjected to analysis hereafter. The project covers paddy fields with a total benefited area of 7,400 ha and a design flow rate of 30.0 m^3/sec. The water supply system consists of two types: open and pipeline. Two thousand ha of the project area is under a pipelined system, which is designed as a demand-oriented type throughout the water supply system. This irrigation project has only a limited buffer function which is provided by an excessive cross section of the canal. Therefore, the system intakes more water than required, resulting in an ineffective discharge of excess water at a rate of approximately 2 m^3/sec over a long period through the spillways in the water supply system. The ratio of ineffective discharge is equivalent to about 7% of the design flow rate for the entire benefited area. Assuming that the design flow rate is simply proportional to the benefited area, the corresponding rate in the demand-oriented block under the pipeline system is 8.1 m^3/sec. Providing that the ineffective discharge takes place only in this block, the relevant rate is as large as 25% of the design flow rate of the block.

4) Calculation and problem of present regulating pond capacity[3]

Although there is no standardized method for calculating a buffer function, a capacity of regulating pond, which may be an effective means to enhance the buffer function, is estimated in accordance with the Design Standard for Land Improvement Project Plan set forth by the Ministry of Agriculture, Forestry and Fisheries, Japan. This Standard, prepared in 1971, specified the criteria for canal works, which included a uniform stipulation, indicating that the capacity of the regulating pond should be equal to the water inflow for approximately one day, and that the capacity is subjected to further reviewing on feasibility as well as on economic viability. This reviewing was needed since the remote monitoring and control system was then introduced only to a limited area, and a longer time was required to collect sufficient data and operate facilities properly, as compared with the method based on a water arrival time.

In 1986, the above Standard was revised, stipulating that the regulating pond could be designed so that a capacity of absorbing the water arrival time be taken into account, and that the capacity would be calculated on the basis of the unsteady flow analysis. A series of the studies undertaken by the authors are incorporated into that revision.

A regulating pond is a kind of farm pond installed at the upstream end of the water supply system for field irrigation facilities. The capacity of farm pond is so designed as to store a balance of water supply, which is a steady water flow for 24 hr minus actual demand for irrigation water. This means that the pond capacity is determined independently from the size of water supply system. If the farm ponds are scattered around, they cause another problem; i.e. the data on water demand are least likely to be fed back to the operation center responsible for water intake and distribution. This implies that the farm pond has only a poor buffer function.

A remote monitoring and control system has been recently introduced into the irrigation canal system in Japan. The system is expected to collect data properly and operate the facilities within a shorter time. Even though only a limited capacity is available due to some socio-economic constraints, it is still expected that a buffer capacity which may be smaller than the capacity for 24 hr flow would ensure proper water control, providing that an adequate water control operation is carried out. It has to be noticed, however, that a minimum buffer capacity necessary for proper water control is subject to the total capacity inherent to the irrigation canal system. The latter capacity has also to be estimated on the basis of the unsteady flow analysis.

Use of electronic computers widespread in recent years has facilitated the analyses of unsteady water flow. However, the conditions that have to be met in computerized analyses on unsteady flow of water have not been properly taken into account at the design stage in planning each project containing various irrigation systems with a variety of structures.

There is another example of the design that has failed in employing adequately an unsteady flow analysis and faced troubles in controlling water in practice. That design failed in estimating accurately a minimum buffer capacity necessary for irrigation canal system. It was formulated on the basis of the estimate that the expected capacity of storing intake water would be maintained for about 10 min under given conditions such as land and other natural environments. It is strongly required to develop a new approach which provides information on buffer capacities rapidly, simply and precisely.

(References cited in this report, Part 1, will be listed together with those cited in Part 2 to be published in the next issue.)

(Received for publication, Aug. 30, 1989)