System Analysis of Main Canals for Water Management Planning

By HAJIME TANJI*, KAZUMI IWASAKI**

and RYOICHI OONISHI*

***Water Management Division, **Hydraulics Division**
National Research Institute of Agricultural Engineering
(Yatabe, Ibaraki, 305 Japan)

Introduction

Water management planning in Japan, so far centered on irrigation of paddy has a history of more than 1000 years. However, in recent 30 years, the water management planning in this country has come to a historical turning point, due to changes which occurred in the overall industrial structure, including that of agriculture.

Firstly, the purpose of water management of main canals, so far concentrated on irrigation for paddy fields only, has been diversified into that for irrigation to upland crops and for supply of municipal and industrial water. Secondly, due to improvements in science and technology, automatic control of water utilization facilities, that was impossible before, has become possible at a low cost. Thirdly, in line with the prevalence of democracy in Japanese society, the traditional rule of water management in which upstream water users have a definite priority over those of downstream in the past, has come to be collapsed.

Thus, it can be said that the long-lasted practice of water management has been collapsed, but the new method, which can replace ancient rules, is still to be developed. The method of system analysis of main canals, presented in this paper, is considered to offer a useful contribution to the planning of main canals, and through which to the development of a new water management practice in Japan.

System analysis of main canals[3]

At present, the following problems are taken up in the system analysis of main canals:

1) Analysis of water conveyance capacity of open canals
2) Analysis of travel time of water in open canals
3) Analysis of capacity determination and control operation methods of water-utilization facilities such as pumps, gates, farm ponds, etc..
4) Analysis of flow conditions such as surging and water hammer pressure in pipelines
5) Analysis of flow conditions in combined system composed of canal and closed conduits, and disposal of excess water

Composition of system analysis of main canals

The method of system analysis presented in this paper differs from the conventional method of designing in that the former takes a main canal system into a mathematical model, as software for computer, and trys to grasp its hydraulic characteristics as a whole, by numerical experiments (simulation). For example, by establishing inter-relationships among individual hydraulic phenomena, such as diversion or back-water effect by weir on unsteady flow condition, one can keep water intake and distribution of the whole canal system under optimum control and check up its design.

Methods of system analysis of main canals

The system analysis, mentioned above, solves difference continuity expression of the equation of motion and the equation of continuity by a computer program. Accordingly, as the result of improvement in computer performance, system analysis has got more effective power year after year recently. This paper intends to outline the actual methods of system analysis, with detailed discription and example on how the system analysis is carried out for water management planning.

1) An example of estimation of flow discharge in a canal[1)]

As a part of an analysis on present condition of Hokkai Main Canal which has a total length of about 90 km, with a benefited area of about 30,000 ha of paddy fields, the authors made estimates of flow discharges in the Naie Block (Block length: 2,474 m) located at 20 km downstream from the uppermost intake, and the Minenobu Block (Block length: 2,247 m), 40 km downstream from the uppermost intake. The discharges thus estimated are useful for developing a plan for repair works of the canal system.

This analysis first requires data of detailed bottom elevation and approximate profile of canal cross section for the entire block length together with the data of water level at 3 points, upper, middle and lower reaches of the canal (Fig. 1). It is the prerequisite for selecting the block that the bottom elevation shows approximately uniform gradient. Then the average canal gradient of the whole block is calculated, and by using it, the canal is divided into two parts: the upstream reach starting from the

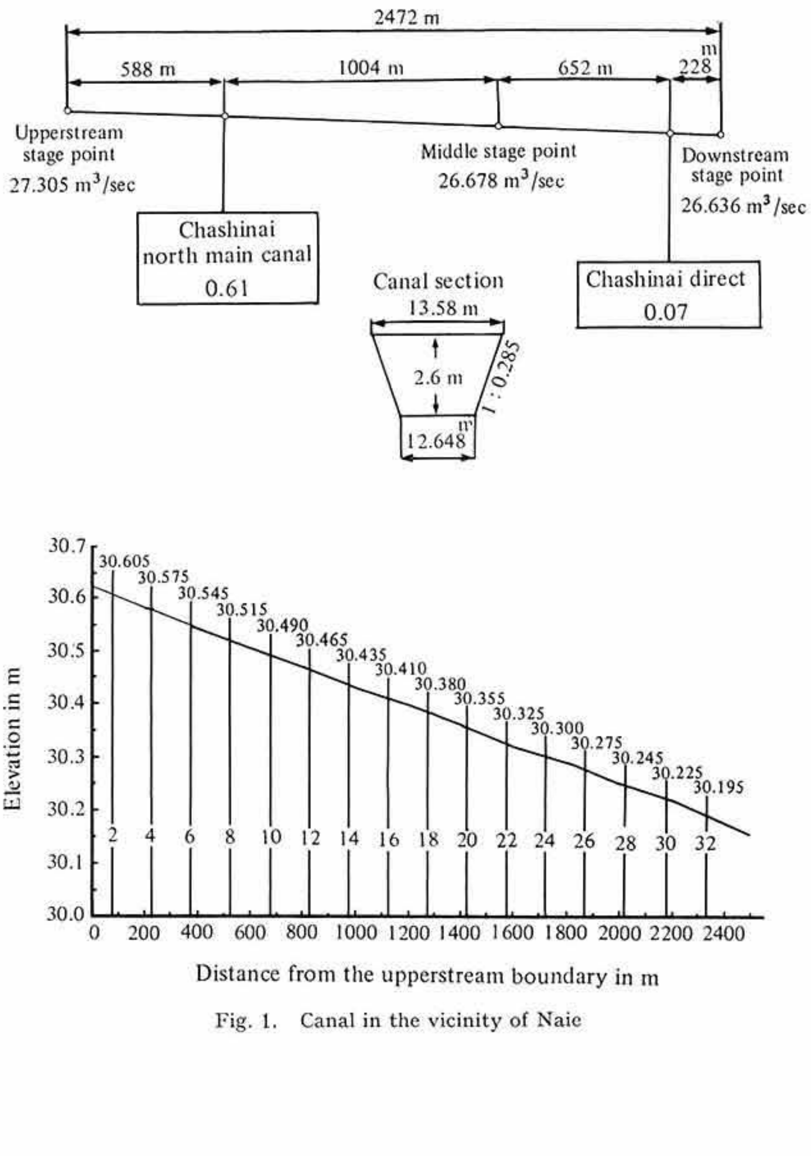


Fig. 1. Canal in the vicinity of Naie

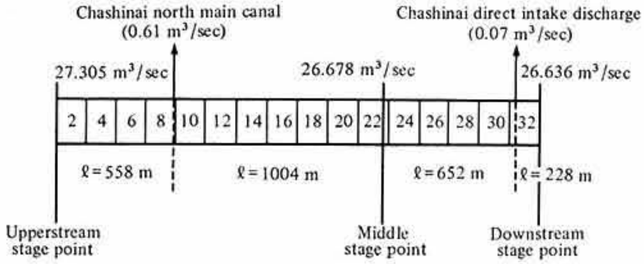


Fig. 2. Model of Naie canal

uppermost point to the middle point and the downstream reach spanning from the middle point to the lowest point. We make two models with water level boundary conditions at the top and the end of the part for both of them. The models were operated assuming a certain coefficient of roughness, n, and the discharge and the coefficient of roughness which will generate a coincide discharge between the upstream and downstream models are taken.

In practice, however, there are various diversion works in the reach of the canal as shown in Fig. 2. Therefore, they should be so included into the model that the given rate of flow is stationarily diverted at each diversion works. For example, water level measuring points in upper, middle, and lower points are Model Site Number 2, 22, and 32, respectively in the Naie block. The diversions have to be taken into consideration both in the upstream and downstream models.

Fig. 3 shows changes in flow rates caused by changing roughness coefficient in the upstream and downstream blocks. From this, the coefficient of roughness in Naie block is determined to

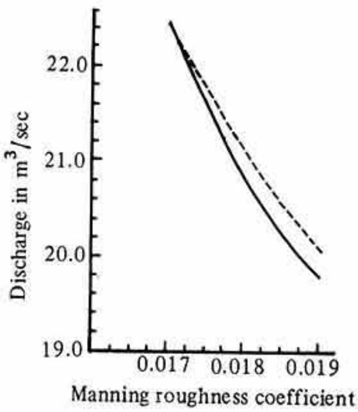


Fig. 3. Roughness in Naie canal

be $n=0.0172$, and similarly that of Minenobu block to be $n=0.0155$.

As to the discharge of flow, the flow condition such as shown in Fig. 4 is considered to occur when this coefficient of roughness is used. In Naie and Minenobu blocks, not only water level measurements but also the discharge measurements were carried out simultaneously at both upstream and downstream points, in this survey. Comparison of these measured discharge with

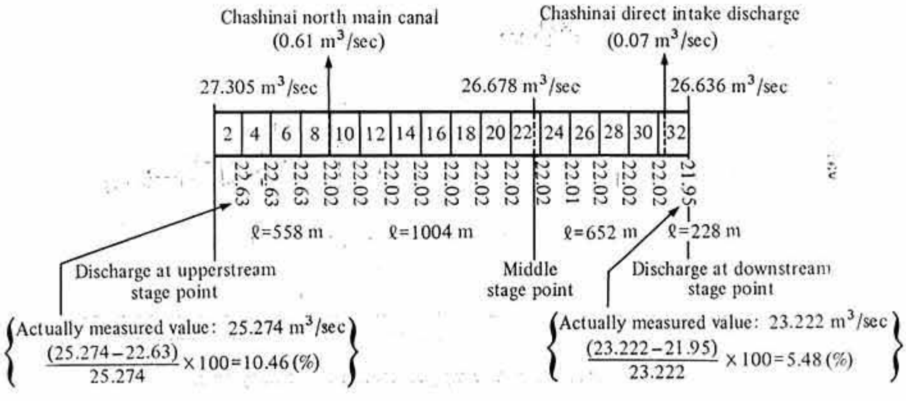


Fig. 4. Flow pattern in the case of $n=0.0172$ in Naie canal

the values obtained by the system analysis gave the deviation within about ±10%, which is generally said to be errors of discharge measurements. It seems that the discharge estimated by system analysis using only values of water level measurement can sufficiently substitute for measured flow discharge values.

2) Study on gate operation in an open canal[2]

A stretch with a length of about 43 km was selected for model preparation. In this stretch it is considered important to shorten the travel time required for irrigation water to reach given points. It appeared to be desirable, for this purpose, to construct a reservior at a downstream point of the canal, but it was found difficult to obtain the site for the reservior. Therefore, a comparison was made between (1) automatic control to maintain downstream water level constant and (2) remote control of gate operation by considering total volume changes in the reaches which would be caused by predicted flow conditions. The gate operation by automatic control (1) is the control with a dead water zone and a certain unit change per each operational step as shown in Fig. 5. The gate operation based on changes in total volume in the reaches (2) is done by the following procedure. Method of gate operation is set in advance as shown below, and each gate is operated simultaneously by a remote control system. Giving initial steady flow condition and flow discharge and changing them in accordance with delivery schedule, the steady flow condition after the gate operation is obtained by numerical simulation. Then the sum, Vi, of the changes in retarded/stored volume in the reach ΔVi, between these two steady flow profiles is obtained. At the same time, the gate opening at the final steady flow condition is obtained. Next, the operational allowance volume of the day Sq, is determined. Based on this, and considering Vi, the gate is so operated as to keep the opening at G_{2i} which is a bit greater or smaller than the pre-set opening for steady flow, G_{1i}, for a certain period, t_o, and then adjust G_{1i} (Fig. 6, and Fig. 7).

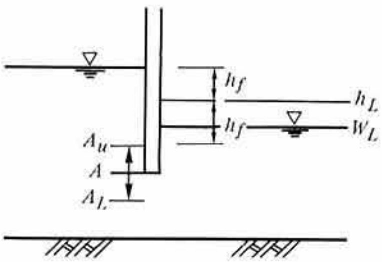


Fig. 5. Water levels at automatic gate operation and relation between dead zone and gate openings

$$Vi=\sum_{j=1}^{n-1}\Delta V_i t_o = Vi/Sq$$

$$G_{2i}=(Q_i+S_q)/(C_iB_i\sqrt{2g\Delta h_i})$$

$$G_{1i}=Q_i/(C_iB\sqrt{2g\Delta h_i})$$

where, Vi: the total volume change in reaches occurring in the downstream point from the ith gate

G_{2i}: the pre-set opening of the ith gate at the time of adjusting

G_{1i}: the pre-set opening of the ith gate

C_i: the coefficient of discharge

B_i: the length of the gate

Using the above two methods of gate operation, gate opening and hydraulic conditions adjacent to near the gate at the time when flow condition changes in a canal reach were simulated

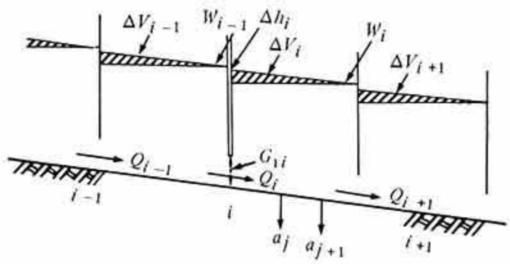


Fig. 6. Volume changes in reaches with the changes of supplied water

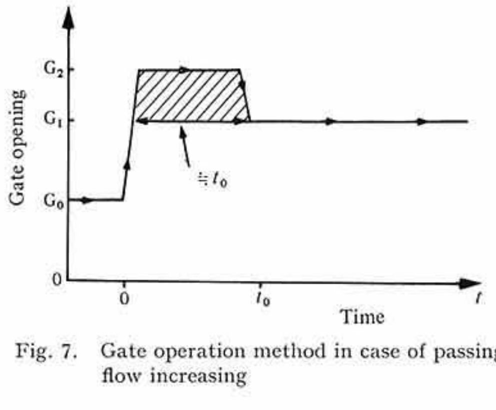
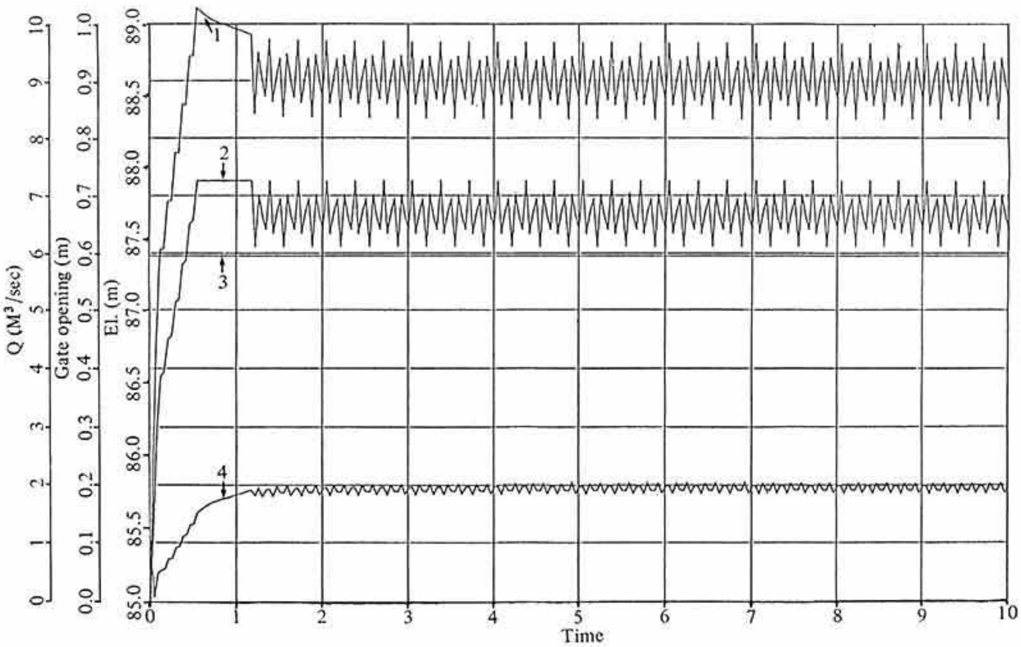
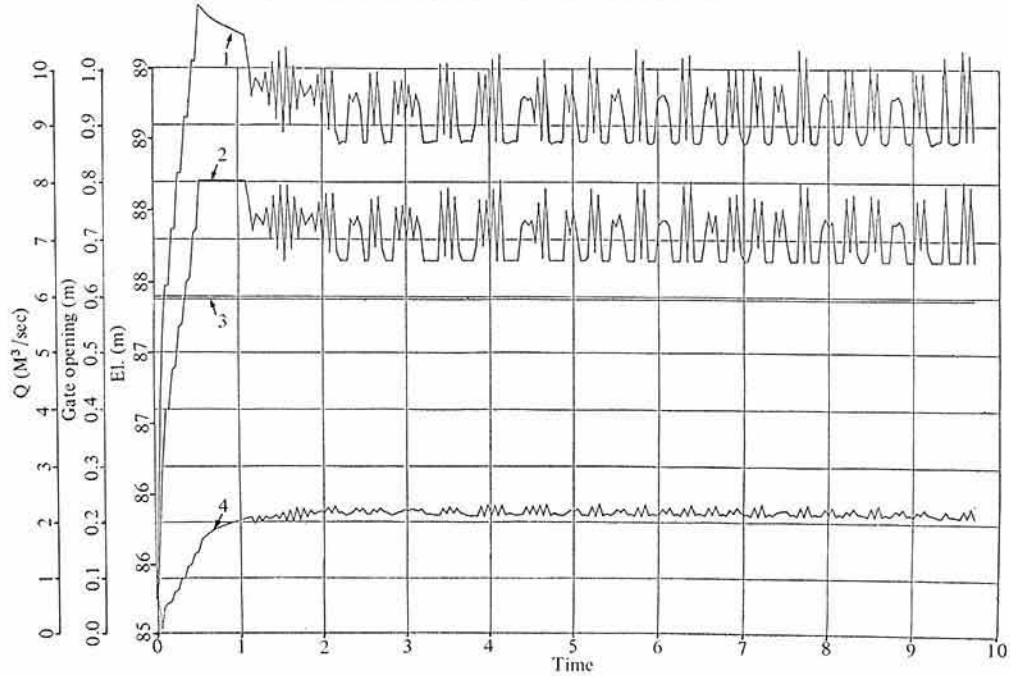


Fig. 7. Gate operation method in case of passing flow increasing



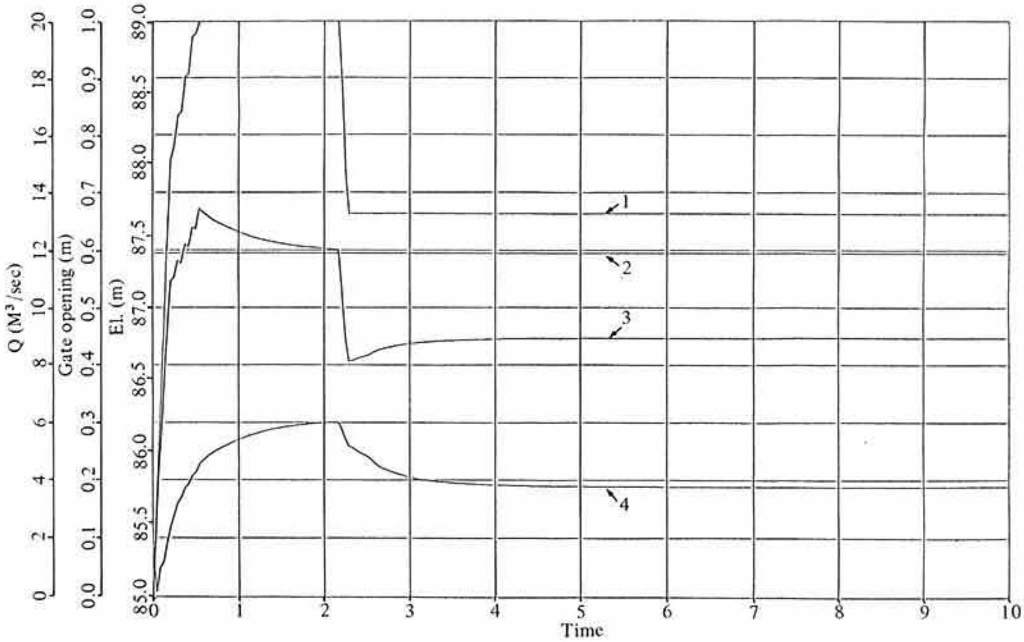
1. Gate passing discharge
2. Gate opening
3. Water level at immediate upstream of the gate
4. Water level at immediate downstream of the gate

Fig. 8. Flow condition nearby the gate No. 3, case 1—1



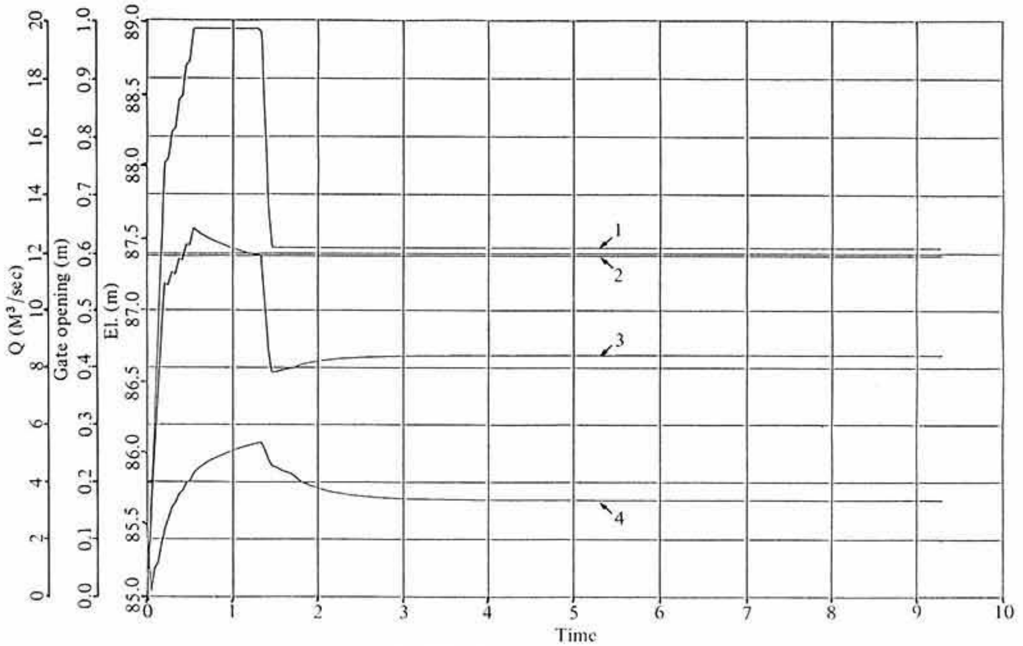
1. Gate passing discharge
2. Gate opening
3. Water level at immediate upstream of the gate
4. Water level at immediate downstream of the gate

Fig. 9. Flow condition nearby the gate No. 3, case 1—3



1. Gate opening
2. Water level at immediate upstream of the gate
3. Gate passing discharge
4. Water level at immediate downstream of the gate

Fig. 10. Flow condition nearby the gate No. 3, case 2—1



1. Gate opening
2. Water level at immediate upstream of the gate
3. Gate passing discharge
4. Water level at immediate downstream of the gate

Fig. 11. Flow condition nearby the gate No. 3, case 2—2

by means of system analysis for the following 4 cases.

The case 1–1: The above method (1) was used, for the case where a discharge of 3.6 m^3/sec is demanded at the downstream end of the canal, and increase of flow rate from the initial steady flow of 5.0 m^3/sec (by bypass) to 8.6 m^3/sec was made in 30 min period.

The case 1–3: Similarly the method (1) was used. Starting with the initial 5.0 m^3/sec, a total of 3.1 m^3/sec required for 7 diversion works located in the course of the canal was added in 30 min period, resulting in the increase of intake to 8.1 m^3/sec.

The case 2–1: The above method (2) was used for the same condition as the case 1–1, and the case 2–2: the method (2) was used for the same condition as case 1–3.

As shown in Fig. 8, 9, 10, and 11, the gate operation by the method (1) caused a haunting problem, and not suitable for practical use. On the contrary, the gate operation by the method (2) can be adopted as it gave stable flow conditions.

Concluding remarks

In this paper concept and usefulness of system analysis of main canals in water management planning were discussed with examples. As understood with these examples the system analysis technique can apply to offering constructive advices for water management both at the stage of planning of main canals and/or at the stage of system operation.

On the other hand, the system analysis has characteristics that it can solve the contradictory problem, i.e., it can give theoretical and accurate solution by the use of computer, while it can give results at flexible levels corresponding to the data available. System analysis for water management has substantially progressed in Japan in recent 10 years in parallel with the development of computer techniques as well as development of data structures. In this sense, it seems that the methods of system analysis will usefully be employed in paddy cultivation areas in Asian countries.

Acknowledgment

The authors wish to thank Dr. M. Nakahara, Head of Hydraulics Division, and Dr. H. Shiraishi, Head of Research Planning and Coordination Division, the National Research Institute of Agricultural Engineering, for their kind suggestions to this study.

References

1) Shiraishi, H., Iwasaki, K. & Matsumoto, Y.: On estimation of prototype coefficients and similarity between prototype and mathematical model. *Bull. NRIAE*, No. 13, 111–137 (1975) [In Japanese with English Summary].
2) Shiraishi, H., Iwasaki, K. & Ito, Y.: Design of water supply systems. IV. *Tech. Rept. NRIAE*, B. No. 49, 1–32 (1981) [In Japanese].
3) Shiraishi, H.: Mathematical model simulation of unsteady flow in open channels, closed conduits, lakes, estuaries and bays. Seminar on Water Management and Control for Agriculture, Tokyo Oct. 2–14 (1972).

(Received for publication, July 31, 1982)