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Operating Rules for Mobilizing a Total Capacity of a Group of Dams

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Abstract
In the studies on operations of a group of irrigation dams, the major issues regarding the optimum rules for operations are related to establishment of a method for technical evaluation on operations and objective terms for optimum operation. The present study proposes a method of simulation by a synthetic hydrologic model and an objective variable of total capacity of a group of dams. The existing irrigation scheme in Iwaki river basin is used for modeling t he structure of irrigation and drainage canal and diversion system. The results show that a method of a synthetic hydrologic model taking total capacity of a dam group into account is effective for formulating operating rules. Difference in minimum volume of the total capacity of a dam group caused by a change of operating rules on the priority of outlet discharge reaches 8% of the total water volume, which is the same magnitude with the minimum capacity of middle scale dams.

Discipline: Irrigation, drainage and reclamation
Additional key words: *dam, head works, Iwaki river basin, multiple regression analysis*

Issues and problems in establishing an operating rule

The issue on how to establish a rule for operating a group of dams and head works has been not rarely dealt with within a concept of a kind of optimization problem. In this framework, for example, establishment of the most suitable rule for operation is to find out a set of operation parameters of dams and head works. The authors have been engaged for the last ten years in the studies pertaining to operating rules for dams and head works with a method of computer simulation. The experience gained from those studies indicates that the issues and the problems relevant to operating rules for dams and head works are directly concerned not with the optimization of operations as a whole but with the objective variables for optimization. The latter should be a more reasonable index for evaluating operation and management. In a mathematical theory of optimization, optimization implies to find out a set of values of controllable variables which make an objective variable maximum or minimum. However, it is quite usual in the studies on operating rules for dams and head works that an objective variable is not clearly identified. The real issue therefore consists in: what should be the most suitable objective variable for operating rules? There are two approaches to answer this question. The first is tentatively to define an objective variable and test variations of its values in accordance with changes in controllable variables. The second is to define a set of controllable variables and test variations of their related objective variables.

This paper presents results of a case study based on the first approach above and examines appropriateness of the estimated objective variables in establishing operating rules for a group of dams and head works in Iwaki river basin.

Outline of the basin under study

Iwaki river basin is located in Aomori Prefecture, the northernmost part of Honshuu Island in Japan. An outline of the basin is shown in Fig. 1. More than 10 national and prefectural irrigation projects have been implemented in this area. The total irrigated area under these projects is approximately 20,000 ha, covering almost all the flat part of the

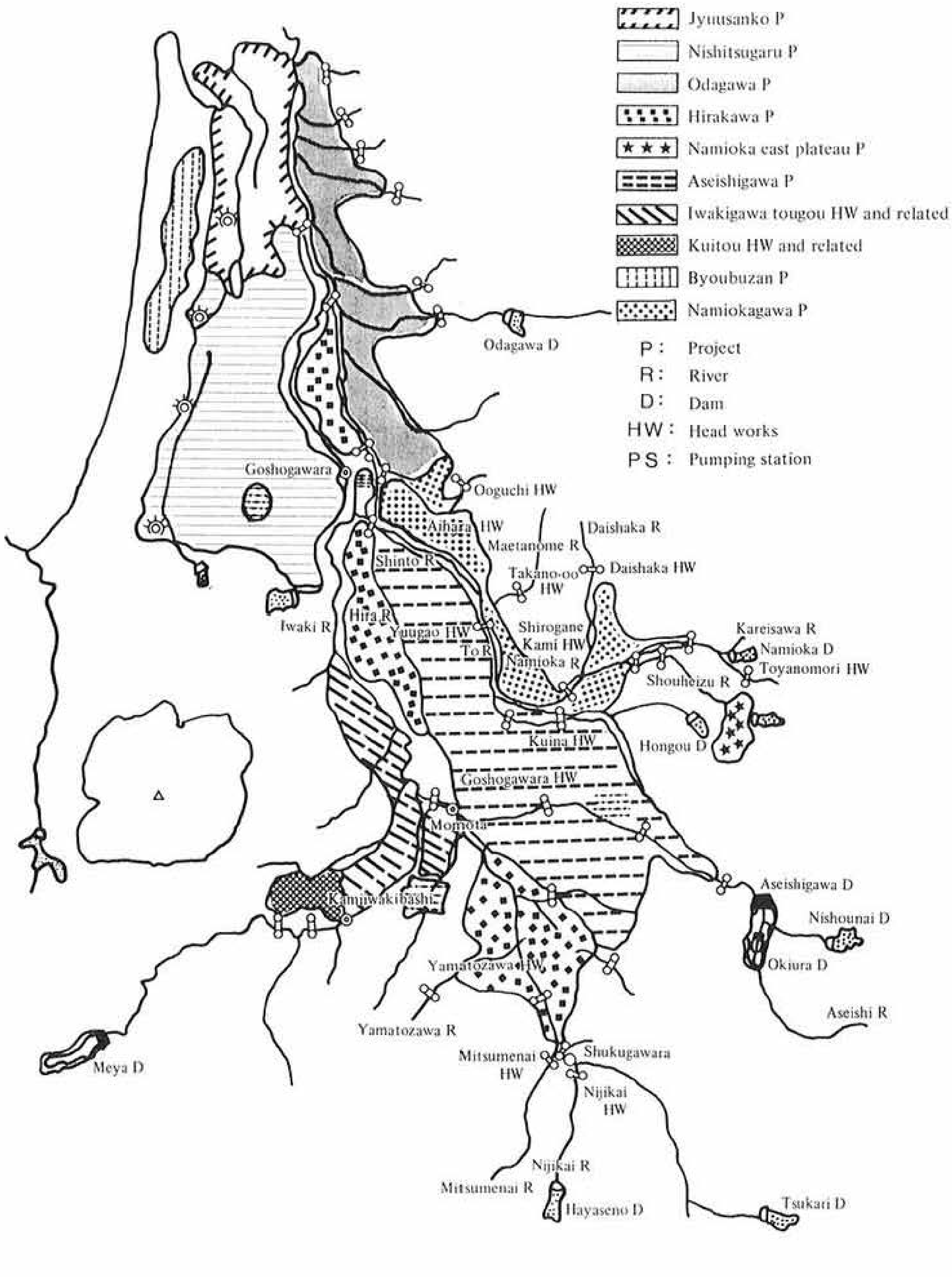

Fig. 1. Irrigation projects in Iwaki river basin

basin. Each of the irrigation facilities has been designed separately to meet the requirement for irrigation water in each project. It is assumed here that the designed droughts do not take place simultaneously throughout all the project areas. In other words, concurrent operations of the irrigation facilities beyond each of the projects are effectively available for establishing better operating rules in the basin as a whole.

This paper deals with the first step to be considered from a viewpoint of outlet discharge from dams. It requires as a condition that the request for irrigation water in paddy fields is dependent on rainfall and type of soils. The whole basin consists of individual irrigation subsystems along a branch of Iwaki river, each of which contains dams, head works and irrigated areas. Because of the isolated location of these irrigation subsystems, it is not possible to supply water beyond each of the project areas.

Method of study

1) Outline of a synthetic hydrologic model

The present study includes formation of a synthetic hydrologic model, which contains a rainfall-runoff model, structure of irrigation-drainage systems and operating models for dams and head works.

2) Method of rainfall-runoff analysis

In expressing rainfall-runoff relations, a Shiraishi's model[1)] of multiple regression analysis is employed in the present study. This model is summarized as follows:

(1) Basic equation

Rainfall-runoff relation is expressed by Volterra series in which the present time 't' is taken as the start.

$$y(t) = \sum_{n=0}^{\infty} \int_{(n)} \cdots \int_{0}^{\infty} \Sigma h_n(\tau_1, \tau_2, \cdots \tau_n) \cdot \prod_{k=1}^{n} x(t-\tau_k) d\tau_1 d\tau_2 \cdots d\tau_n, \quad \ldots\ldots (1)$$

in which $x(t-\tau_k) = A_r \cdot R(t-\tau_k)$,

where A_r: acreage of the area in a basin;

$R(t-\tau_k)$: intensity of rainfall in an area;

$y(t)$: the value of the watershed runoff at time 't';

h_n: runoff kernel of the nth degree;

τ_k: integral variable showing time-lag runoff; and

t: time.

By taking the terms up to the second degree of moment and using multiple regression analysis, the equation (1) could be approximated in the following digital form:

$$Y(t) = A_0 + \sum_{i=1}^{n} A_i \cdot X(t-\tau_i) + \sum_{\substack{i=1 \\ i \geq j}}^{m} \sum_{j=1}^{m} B_{ij} \cdot X(t-\tau_i) \cdot X(t-\tau_j) \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The parameters, A_0, A_i and B_{ij}, are determined by the method of least squares, in which, the terms of the first degree, A_0, A_i and the terms of the second degree B_{ij} are determined separately by an FMD method.

(2) Runoff model for a paddy field area

In multiple regression analysis on rainfall-runoff relations, characteristics of runoff on a basin can be expressed by one of the following two models: one is a mountain area model which takes into consideration rainfall alone; and the other is a paddy field model which takes into consideration both rainfall and intake water.

For the mountain area model, the basic equation above can be used directly. But for the paddy field area model, the basic equation has to be modified, putting a sum of rainfall and intake in an input term.

(3) Formulation of rainfall-runoff models

There are two kinds of models available for estimating rainfall-runoff relations in Iwaki river basin: one is old models and the other is new models. The old models were formulated by Shiraishi et al.[2)]. These models were established before the implementation of the series of the irrigation projects in the basin. The irrigation projects have been undertaken during the period of approximately 20 years. During that period, the structure of irrigation and drainage canals and diversion of irrigation water under the projects have changed one after another. Therefore, an adequate runoff model of paddy field areas could not be formulated on the basis of the data from that period. The present study adopts the Momota and Shinto river models of a paddy field area proposed by Shiraishi et al.[2)], for estimating relation of rainfall plus intake and runoff. An attempt was also made to set up models for a mountain area, which were based on the data obtained in the last 20 years.

Table 1. Parameters under the proposed model

No.	Item	Parameter
1	Name	Shukugawara
	River	Hira
	Area	206.3 km^2
	FMD	100 m^3/s
	R	0.458
	RF	0.490
	Period	1972 - 1979, June 1 - Sept. 30
2	Name	Hayaseno dam
	River	Nijikai
	Area	31.0 km^2
	FMD	5.0 m^3/s
	R	0.717
	RF	0.448
	Period	1970 - 1979, June 1 - Sept. 30
3	Name	Okiura dam
	River	Aseishi
	Area	200.8 km^2
	FMD	20.0 m^3/s
	R	0.732
	RF	0.205
	Period	1962, June 1 - Sept. 30
4	Name	Odagawa dam
	River	Oda
	Area	16.0 km^2
	FMD	5.0 m^3/s
	R	0.567
	RF	0.214
	Period	1976 - 1986, June 1 - Sept. 30
5	Name	Meya dam
	River	Iwaki
	Area	171.6 km^2
	FMD	30.0 m^3/s
	R	0.724
	RF	0.576
	Period	1970 - 1979, June 1 - Sept. 30

The results are shown in Table 1. Rainfall-runoff models of a mountain area are identified for each of Shukugawara, Hayaseno dam, Okiura dam, Odagawa dam and Meya dam. In addition to these models, the Kawakura model which was also identified by Shiraishi et al. was used in the present study because of the lack of new discharge data.

(4) Evaluation of rainfall-runoff characteristics

After the establishment of rainfall-runoff models, patterns of rainfall-runoff are identified in due consideration on the difference in a branch river, rainfall and an irrigation project. The relationships between a branch river and hydrologic characteristic of models are shown in Fig. 2. Each model of a branch river consists of sub-models of an upstream point of dams, an upstream point of head works and a downstream point of head works.

3) Modelling of irrigation and drainage system

The existing scheme in Iwaki river basin is used for modelling the structure of irrigation and drainage canal and diversion of irrigation water system. The structure was identified through intensive field surveys. Fig. 3 shows a schematic diagram of irrigation and drainage canals. Diversion rate in each irrigation canal is settled after the rate of irrigation areas or the rate of designed diversion water has been fixed. This schematic diagram and diversion system is formulated in order to apply variables and equations for a synthetic hydrologic model in the computer language WML[3].

4) Modelling of operating rules

There are a number of points in rivers, where the requirement for downstream discharge in each spot can be confirmed on the basis of the request in river management. For example, the following 15 points are available for confirmation of downsream discharge in the Namioka project area:

(1) Downstream point of Namioka dam,
(2) Downstream point of Toyanomori head works,
(3) Upstream point to the cross point of Namioka river and Kareisawa river,
(4) Cross point of Namioka river and Kareisawa river,
(5) Upstream point to the cross point of Namioka river and Shouheizu river,
(6) Upstream point to Yuugao head works,
(7) Upstream point of a cross point to Namioka river and To river,
(8) Middle point of Kuina head works and a cross point of To river,
(9) Upstream point of Kuina head works,
(10) Upstream point of Namioka river and Daishaka river,
(11) Downstream point of Daishaka head works,
(12) Upstream point of a cross point of Maetanome river and To river of Maetanome river,
(13) Upstream point of Takano-oo head works,
(14) Downstream point of Ooguchi head works, and

Block name	River [Block]	Model of mountain area (Rainfall)	Model of paddy field area
Hirakawa	Iwaki R	Meya dam (Meya dam)	Momota (Goshogawara)
	Hira R [Nijikai]	Hayaseno dam (Hirosaki)	None
	Hira R [Except Nijikai]	Shukugawara (Hirosaki and Ookawara)	Momota (Hirosaki and Kuroishi)
Aseishi	Aseishi R [Upstream of Aseishigawa dam]	Okiura dam (Ookawara)	None
	Aseishi R [Left bank return flow]	None	Momota (Goshogawara)
	Aseishi R [Upstream of Tayama head works, right bank return flow]	Kawakura (Ookawara)	Shinto R (Ookawara)
Namioka	Namioka R [Upstream of Shirogane head works] and To R [Upstream of Kuina head works]	Hayaseno dam (Ookawara)	Shinto R (Ookawara)
	Namioka R [Downstream of Shirogane head works] and To R [Downstream of Kuina head works]	Kawakura (Ookawara)	Shinto R (Ookawara)
Odagawa	All	Odagawa dam (Ookawara)	Shinto R (Kanaki and Goshogawara)

Fig. 2. Characteristics of hydrologic models

(15) Downstream point of Aihara head works.

The downstream discharges confirmed at these 15 points were compared with the actual discharge by simultaneous observations as well as with he estimated discharges predicted by the synthetic hydrologic model as mentioned above. The downstream discharges confirmed at the points 1, 2, 5, 9, 11 and 15 were occasionally larger than those of the measured or estimated discharges. Therefore, further examinations of operating rules for these points were required. Since the downstream discharges confirmed at the other points were smaller than those of the measured or estimated discharges, these points were not included in the additional examinations.

The following points were selected in the whole area of Iwaki river basin for further examinations with the same procedure as above mentioned. These points are shown as "●" in Fig. 3.

(1) To river and Namioka river
  a) Downstream point of Kuina head works,
  b) Downstream point of Daishaka head works,
  c) Downstream point of Namioka dam,
  d) Downstream point of Toyanomori head works,
  e) Downstream point of Yuugao head works,
  f) Downstream point of Aihara head works.

(2) Aseishi river and Hira river

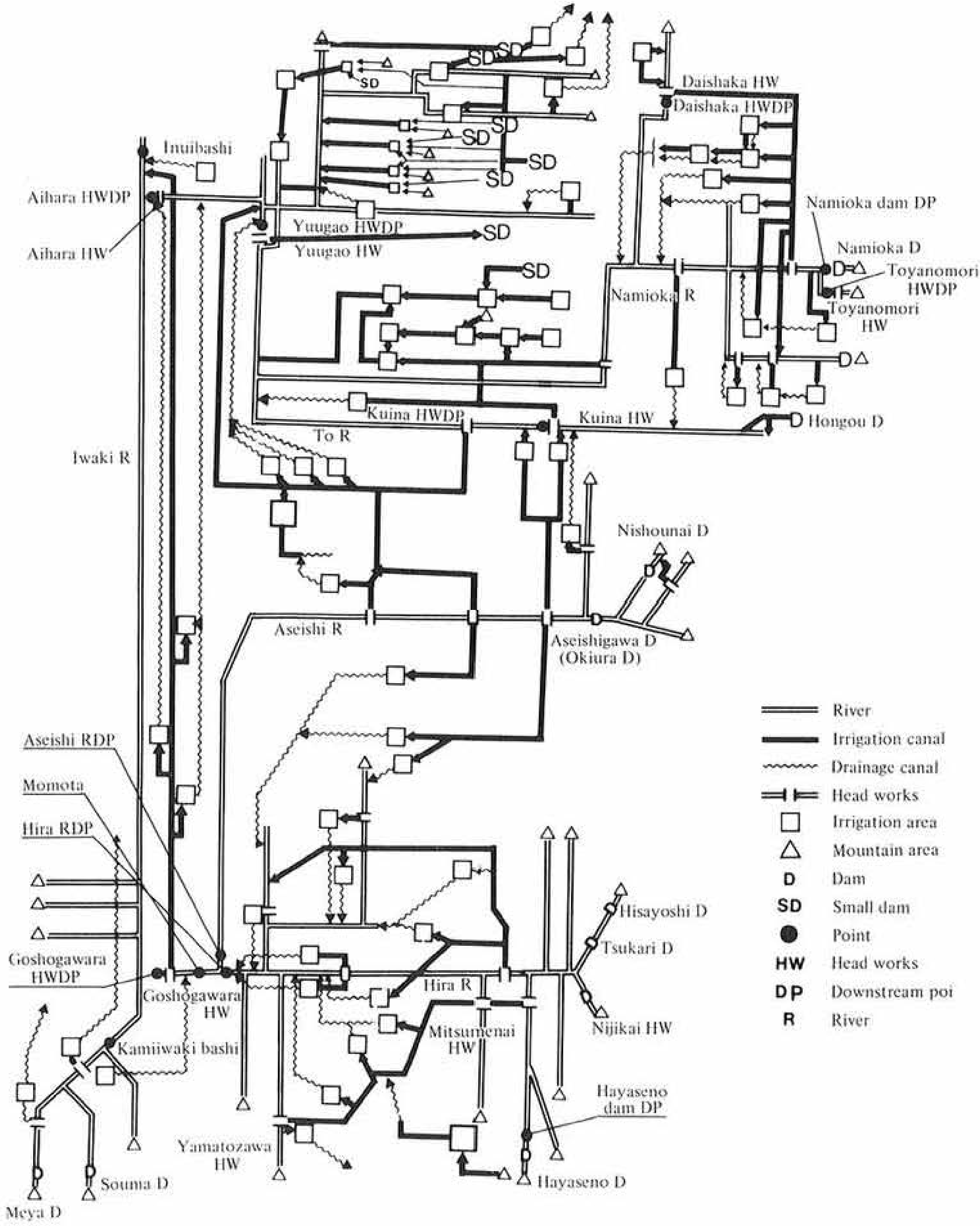

Fig. 3. Schematic diagram of irrigation and drainage canals

g) Downstream point of Aseishi river,
h) Downstream point of Hayaseno dam,
i) Downstream point of Hira river,
j) Momota,
k) Downstream point of Goshogawara head works.

(3) Iwaki river
l) Kamiiwakibashi,
m) Goshogawara.

Some relationships for supplementing irrigation water among the outlet discharges from the relevant dams and the downstream discharges confirmed at the abovelisted points are shown in Table 2. The head works at Daishaka and Toyanomori presented in the table are placed at the points to which the dams can supply supplemental irrigation water, as needed. Toyanomori head works can take supplemental inflow to Namioka dam. If the discharge at Toyanomori head works is not sufficient to fully meet the water demand, that shortage could be fulfilled by reducing supplemental inflow to Namioka dam. The water demand in this case includes the supplemental inflow to the dam plus the confirmed downstream discharge. Numbers in Table 2 indicate the priority of water supply from dams to head works. Any change in these numbers inplies a priority shifting in the management rule for a group of dams. The following sections of this paper will discuss merits and demerits that could be caused by those changes in operating rules for dams and head works.

Condition of simulation

1) Input data and boundary condition

Simulation based on a synthetic hydrologic model is undertaken with use of the rainfall data in 1962, which was a design year of the irrigation projects in Iwaki river basin. A synthetic hydrologic model consists of some block models for segmental basins along the branch rivers. Each block model contains only one governmental irrigation project. An irrigated area in each block model contains some sub-areas, in each of which soil types are assumed to be homogeneous. Demand for intake water is given for each of sub-areas, and it is added to the total effective rainfall and water requirement in depth based on type of soil. In case where an irrigation acreage has been changed, the alternation of water demand is given on the basis of a proportional rate of the changed area to the original one.

If there are some irrigated areas under water intake from some sources, priority of intake should be assumed for calculation. Here is a sample of such prioritization: the case of Yamatozawa head works, Mitsumenai head works and Nijikai head works are shown in Fig. 4. Resources for irrigation water consist of Yamatozawa head works, Nijikai head

Table 2. Downstream intake confirmed at the selected points

River name	Point name*	Confirmed downstream discharge (m^3/s)	Meya dam	Tsukari, Hayaseno dam	Nishounai, Aseishigawa dam	Namioka dam	Hongou dam
To river	Kuina HWDP	0.07	–	–	–	–	1
	Daishaka HWDP	0.02	–	–	–	–	–
Namioka river	Namioka dam DP	0.03	–	–	–	1	–
	Toyanomori HWDP	0.05	–	–	–	–	–
	Yuugao HWDP	0.21	–	–	–	1	2
	Aihara HWDP	0.70	–	–	–	1	2
Aseishi river	Aseishi river DP	2.20	–	–	1	–	–
	Hayaseno dam DP	0.07	–	1	–	–	–
Hira river	Hira river DP	3.10	–	1	–	–	–
	Momota	8.90	–	1	2	–	–
	Goshogawara HWDP	2.57	–	1	2	–	–
Iwaki river	Kamiiwakibashi	4.10	1	–	–	–	–
	Goshogawara	17.0	1	2	3	4	–

* HW: Head works, DP: Downstream point.

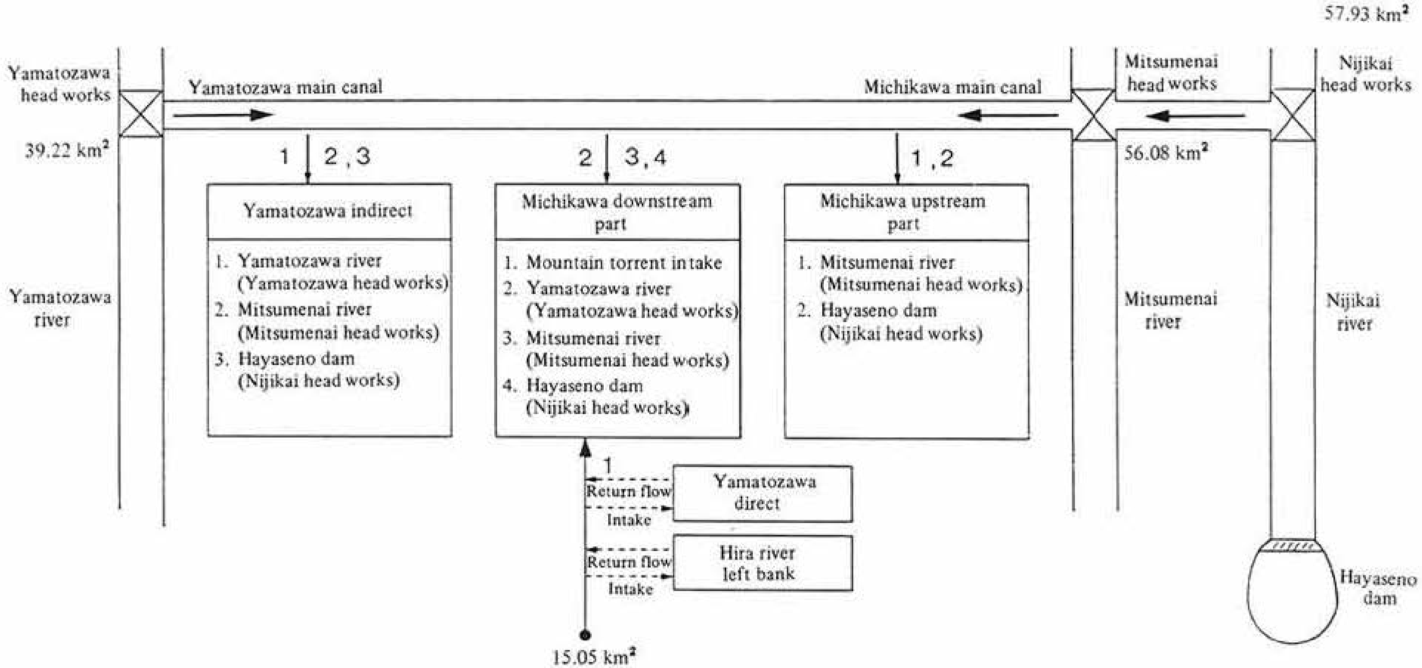

Fig. 4. An example of priority of intake

works, Mitsumenai head works and mountain stream intake. Irrigated sub-areas consist of Yamatozawa direct, Michikawa downstream, Michikawa upstream, Yamatozawa indirect and Hira river left bank site, etc. Priority of intake is shown as numbers in Fig. 4.

2) Priority setting for discharging from dams

In examining appropriateness of operations of dams and head works, the top-priority factor to be considered related to the recovery of reservoir capacity under drought. Outlet water from dams should be discharged in accordance with the necessity in capacity recovery. Examination cases are stipulated for terms of priority of dams on the viewpoint of outlet discharge of dams. The following three cases are set for simulation to formulate operating rules for dams:

- Case 1: Discharging separately according to the priority of: Meya dam, Hayaseno dam, Tsukari dam and Namioka dam;
- Case 2: Discharging with a rate of Meya dam : Hayaseno dam : Namioka dam accounting for 6 : 3 : 1; and
- Case 3: Discharging with a rate of Meya dam : Hayaseno dam : Namioka dam accounting for 5 : 4 : 1.

Results of analysis

1) Evaluation of operating rules

Simulation results are evaluated from the following two points of view: one is whether the downstream discharge estimated is enough or not; and the other is whether the volume of supplemental outlet discharge from dams is large or not. Through the separate examinations on the relevant parameters at each point, the tolerance to droughts of each segmental basin in the respective project areas could be evaluated from the viewpoint of confirmed downstream discharge.

These evaluations may reveal a difference, if any, among the segmental areas in the basin in regard to water discharge. However, they might not be effective, or even misleading, in formulating adequate rule for the overall management of the irrigation systems from the viewpoint of the total benefit for the whole basin. The question is: what an index should be adopted to indicate a benefit for the whole basin? To answer this question, the present study proposes that total volume of reserved water in the five dams be suited as an index for managing not the individual dams but all the dams in the basin as a whole. The five dams here include Meya, Hayaseno, Tsukari, Namioka and Hongou dams.

Fig. 5 shows the total volume of reserved water in these five dams estimated under the three conditions as referred to the above. Among those three cases, the Case 1 is ranked as the most suitable. The maximum difference of the total volume of reserved water reaches 30,000,000 m^3. The maximum rate of difference is approximately 8% of the total volume at the lowest water level. For example, minimum capacity of reserved water at the Case 1 shows 3,563,000 m^3 at Hayaseno dam, 341,000 m^3 at

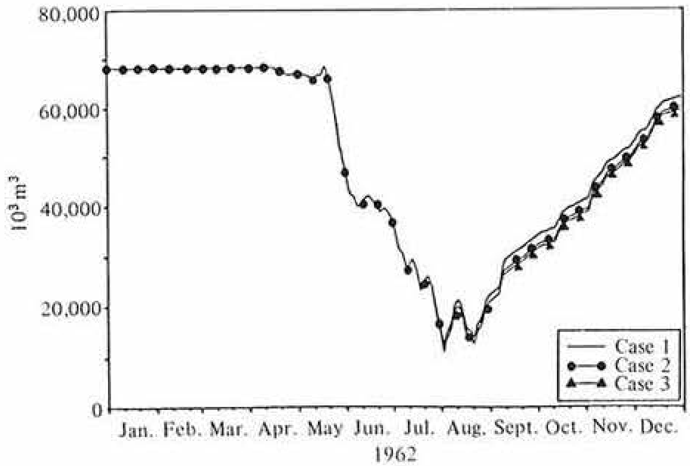

Fig. 5. Total capacity of a group of dams

Tsukari dam, 4,353,000 m^3 at Nishounai dam, 3,655,000 m^3 at Aseishigawa dam and 1,390,000 m^3 at Namioka dam. Therefore, the volume of 30,000,000 m^3 is equal to the two-thirds of minimum capacity of reserved water in Nishounai dam (the largest dam), the minimum capacity of reserved water at Hayaseno dam (the 2nd largest dam) and the minimum capacity of reserved water at Aseishigawa dam (the 3rd largest dam). This result indicates that the effect of overall management of dams and head works is large enough at the time when the water level of a dam is the lowest.

2) Simulation based on a synthetic hydrologic model

The present study employs a simulation method of a synthetic hydrologic model for evaluating rules of operation. Toward this end, three cases of operations are here subjected to comparison as stated above.

A basin system contains irrigation and drainage system: i.e., irrigation canals, drainage canals, dams and head works. Optimum operating rules cannot be solved analytically because the whole basin system is highly complex. As a consequence, the only possible procedure to identify optimum operating rules is, first, to set assumed optimum operating rules, and then, second, to make a simulation under those rules. Based on the results of the present study, it is proposed that use of a synthetic hydrologic model and an index of total volume of the dams contained in the whole basin be effective.

Conclusion

The present study has attempted to confirm effectiveness of the simulation based on a synthetic hydrologic model of a basin, with an objective of establishing a suitable model and evaluating operations of irrigation facilities from a viewpoint of total benefit for the whole basin. Toward this end, it is concluded that total capacity of reservoir is available as an effective objective variable: i.e., an index for effective use of water resources in a basin, and that combined operating rules of dams and head works in the basin as a whole should be considered.

Regarding the effectiveness of the combined control for operating dams and head works in Iwaki river basin, the results of the above simulation indicate that the water saving under the combined control deserves the minimum reserved discharge in a middle size reservoir. The magnitude of the difference in water requirements among the operating rules is as large as the smallest scale dam.

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