

## Development of new simulator for training of dam operation and its future outlook

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**ABSTRACT:** In recent years, severe floods caused by super-typhoons, linear rain bands and localized torrential rain, etc. occur frequently in Japan. Based on this fact, more advanced and proper dam operation by grasping the water level of the downstream rivers of dams is required to minimize the occurrence of flood damages in downstream of dams, especially in urban areas etc. Japan Water Agency (JWA) has developed a new simulator which enables acquisition of skill for proper dam operation. The developed simulator abounds in ingenuity for training by reproducing close to reality situations for flood control operation through changing the river flow of downstream along with outflow discharge from the dam after reflecting the river flow situations caused by rainfall in upstream and downstream areas. Furthermore, the simulator replicates the transition of rainfall, inflow to the reservoir and water level in downstream of the dam, in addition to the replication of operational feel of dam control facilities and has functions which enable to simulate all of the past floods which have been experienced since beginning of JWA's operation.

**RÉSUMÉ:** Récemment, de graves inondations provoquées par des super typhons, des bandes de pluie linéaires et des pluies torrentielles très ponctuelles surviennent fréquemment au Japon. Compte tenu de ces événements, une exploitation adéquate et plus poussée est requise en tenant compte des niveaux d'eau dans les rivières afin de minimiser les dommages causés par les inondations en aval des barrages, notamment dans les zones urbaines, etc. L'Agence japonaise de l'eau a mis au point un nouveau simulateur qui permet l'acquisition des compétences requises pour l'exploitation adéquate des barrages. Le simulateur développé regorge d'ingéniosité en matière de formation en reproduisant des situations proches de la réalité pour le contrôle des inondations en modifiant le débit de la rivière en aval ainsi que le débit sortant du réservoir en considérant les conditions de débit dans tout le bassin versant provoquées par les précipitations. En outre, le simulateur tient compte de la variation des précipitations, des apports vers le réservoir et des niveaux d'eau en aval du barrage, en plus de reproduire la sensation opérationnelle des installations de contrôle des barrages. Il y a aussi des fonctionnalités permettant de simuler toutes les crues antérieures qui ont été recensées depuis le début des opérations de l'Agence japonaise de l'eau.

### 1 INTRODUCTION

Super-typhoons, linear rain bands and localized torrential rain, etc. occur frequently throughout Japan especially in recent years. Therefore, the role of flood control of dams becomes more important. To decrease damage of the cities located on the lower reaches of the river as far as possible, high-level decision and operation, which brings more flood control effect than do normal operation based on authorized dam operational regulation, and corresponding to the rainfall prediction and the downstream water level different from dam management manual, are needed. High-level operation, a number of operations, knowledge and experience make it possible for staffs to acquire the skill, however, it takes a long time because dam management offices carry out flood control only several times a year. JWA has developed new simulator for dam operation training, NEW S-DOT for short, to master high-level dam

operation skill in a short period of time. The staffs are able to train flood control operation under adjustable rain condition considering water level of downstream river anytime by using the simulator on normal PC in their offices. Moreover, it has been devised to train the situation close to the actual disaster prevention operation by increasing the reproducibility. For instance, it reflects flow regime causing of rain upstream and downstream of the dam, changing the situation of downstream by cooperating with the discharge from the dam, and so on. It is expected to contribute to build the engineering skills of dam management.

## 2 WHAT IS NEW S-DOT?

### 2.1 *The conventional Simulator for Dam Operation Training –summary and issue*

S-DOT, simulator of dam operation training, is a training device to master discharge operation. Its conventional type has been installed at almost all of JWA's dam management offices and utilized for staff trainings. The conventional S-DOT is a simulator which we can train discharge operation from the dam effectively with using actual dam management control facility according to basic rules like authorized dam operational regulation while confirming the inflow to the reservoir which is brought by the rainfall to the catchment area. However, in most cases, the training device is directly connected to dam management control facility and we need to change the mode of actual machine when we implement dam operation training with the device. From this kind of structural background of this system, the training can be carried out only in dam operation room and it is not available during discharge of the dam. Causing of these restrictions, the number of the training times was getting less, and it was required to enhance the usability, such as getting rid of regulations of conventional S-DOT, for skill-up. Moreover, advanced operation skill is necessary in recent years to decrease the damage on the downstream (as 2.2 later) thus developing the quality of the system was needful.

### 2.2 *The purpose of NEW S-DOT*

We JWA have done the discharging operation cooperating with relative institutions for several times to decrease the damage of downstream of dam. We build the system for the best decision for discharging operation to adapt the situation of downstream cities. The staffs train the system regularly (Table 1.).

The purpose of the NEW S-DOT is to cultivate the ability of JWA's staff on planning and operation of high-level flood control considering water level of downstream area and its inundation risk under predicted rainfall condition (Figure 1.). The training using NEW S-DOT is provided to all JWA staff, not only to engineers but also to clerk, in order to develop the capacity on emergency flood control, especially at the occasion of very heavy rain caused by super-typhoon, linear rain bands, etc. which are increasing recent years.

Table 1. Contents of training for proper flood control operation of the dam.

Purpose	Types of training	Method of learning
Maintenance of operation techniques	Training by simulation	Practice to respond to floods Dam operation training simulator Conventional type of operation training simulator Operation training simulator considering downstream river water level
Improvement of prediction accuracy	Prediction of inflow	Storage function method model/ Distributed runoff model/AI model (in the future)
Training of operation personnel	Learning and practice	Proficiency by the operation rules and management techniques reference, etc.

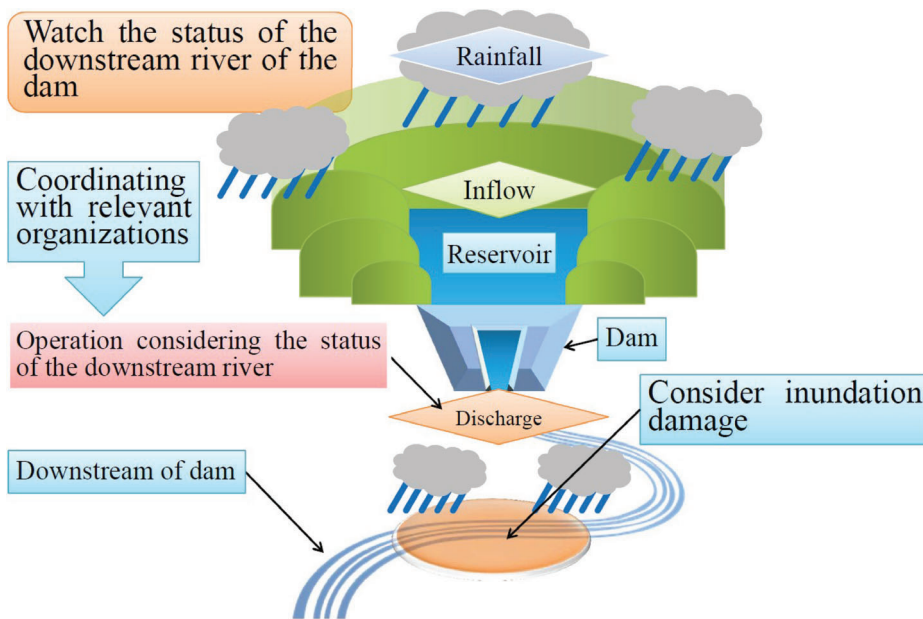


Figure 1. Concept of NEW S-DOT

### 3 IMPORTANCE FOR SYSTEM BUILDING

#### 3.1 Selection of the model dam

We selected the dam which has problems, for example, narrow pass at the downstream, many times of flood control with confirming downstream situation, etc. Also, simple structure of the basin around the dam is better for easy developing the system. For those reasons, we selected “the Hitokura Dam (JWA)” (Figure 2).

#### 3.2 The contents of the simulator

The reality of actual dam management is important for building this system. For that reason, various strategic training functions, in Table 2, is equipped with the system.

##### 3.2.1 Reproduction of dam management control facility

Reproduction of the actual dam management control facility at S-DOT is important for training, so the buttons and information (rainfall, water level, etc.) at the Hitokura Dam are truly reproduced.

##### 3.2.2 Calculation

The data of inflow volume, discharge volume, rainfall at the downstream area and water level of downstream river which is impacted by discharge from the dam are shown on the main monitor of S-DOT in every minute. The fluctuation of the discharge is calculated considering the travel time from the dam to monitoring point based on the past records. Since the Hitokura Dam has many narrow places at the downstream river, so that the dam manager has to operate the dam with monitoring the downstream data carefully. The travel time of discharge, in Table 3, is calculated by opinions of the operators at the Hitokura Dam.

The effects of rainfall both at the Dam area and the downstream are included in S-DOT with the flood data from the beginning of the management, and the staffs are able to experience the past flood control vicariously.

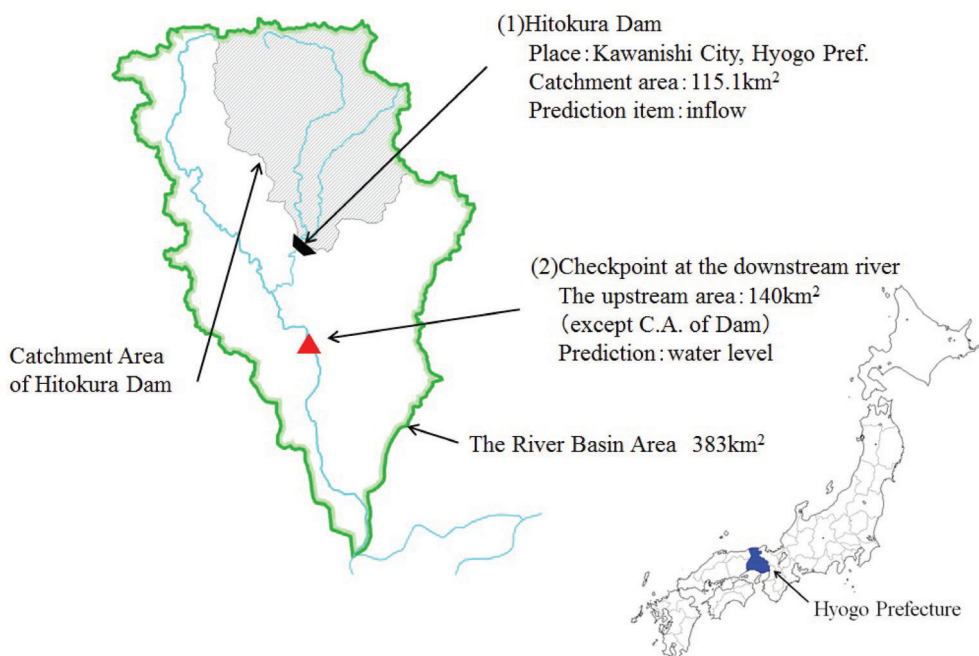


Figure 2. River basin of the Hitokura Dam

Table 2. Strategic training functions installed in the simulator

No	Strategic training functions
1	Reproduction of control processing equipment for dam operation
2	Calculation processing function of inflow/outflow amount to dam/water level fluctuation of downstream river
3	Warning assist function (abnormal water level/operation rule violation etc.)
4	Cooperation with inflow prediction model of existing system (input of data)
5	Review of operational training records
6	Commander mode (planning of discharge and information sharing)
7	Multiple simultaneous training function
8	Change in predicted rainfall
9	Guide function of discharging operation method
10	Disaster prevention operation

Table 3. Setting of travel time of dam discharge water in the downstream river

Item	Point T	Point G	Point O
Cumulative distance [m]	6,900	9,600	12,200
Section distance [m]	6,900	2,700	2,600
Travel time [min.]	20	28	35

### 3.2.3 Warning assist function

For proper operation, it is essential to carefully read and observe operational regulations. In order to make it easier to understand the relation with operational regulations in the course

of training, the S-DOT has a function of sending warning messages in the same manner as actual dam management control unit, concerning various warnings, such as reservoir water level, downstream river water level. As shown in Table 4, a function to display a message on the monitor is equipped when a discharging operation which is different from operation regulations is performed or when the water level or the discharge volume has been reached the alert value. These warnings and messages can be stored together with the flood control record operated by the trainee. It means, when we conduct a training by NEW S-DOT, even after the training, we can get useful feedbacks through checking the operation and the warning records.

### 3.2.4 Data import function

It is possible to create and edit arbitrary inflow volume data with S-DOT. New floods that occurred after development can be easily installed in Comma-Separated Values (CSV) format. Inflow amount with virtual data is also available for trainings. Moreover, the analysis data based on the distributed runoff model which is adopted in each JWA office is assumed to be importable into S-DOT.

### 3.2.5 Data output function

In S-DOT, it is possible to output operation record data during training. Furthermore, it can be reproduced on the training system and reviewed later.

### 3.2.6 Commander mode

Operations at the time of flooding are carried out with multiple staffs assigned to each other. S-DOT has the function to train the roles of not only the actual operator but also the commander of them. Based on the predicted inflow amount, the commander can formulate a future discharge plan, and can input the planned execution time such as notification/report to the concerned persons, discharge warning (see Figure 3)

The discharge plan is displayed as follows; Hydrograph (dam inflow amount, discharge amount, reservoir level) is displayed at the upper stage of discharge operation time flow, the status of implementation of related institution notice, report, discharge warning etc. are in the middle, and, the gate operation status is displayed in the low. These situations are indicated in chronological order. All instruction contents of the commander are recorded, and after completion of the operation the contents of the instruction can be reviewed.

### 3.2.7 Multiple simultaneous training functions

In the actual discharge operation of the dam, a plurality of roles are shared and carried out such as confirmation of inflow amount, confirmation of degree of opening and those who operate gates in addition to the commander. For this reason, the training simulator has the function of allowing a plurality of persons to participate at the same time on the business PC of each staff as in the actual operation (see Figure 4).

Table 4. Main messages displayed on the screen

Message	What the message points to
Messages for reservoir water level	Overtopping/Design flood level/Surcharge water level/Normal water level/ Water level for operation deviating from the rule at flooding over design flood
Messages for inflow	Flood volume/Planned maximum discharge amount/70 % of planned high water flow rate
Messages for downstream water level	Water level for flood-prevention team standby that should be noted flooding for evacuation judgement at which the risk of inundation
Warnings	Operation rule violation, etc.

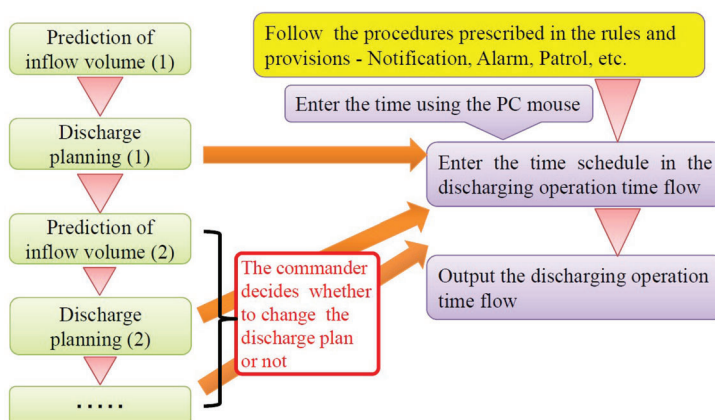


Figure 3. Flowchart of “Commander mode”

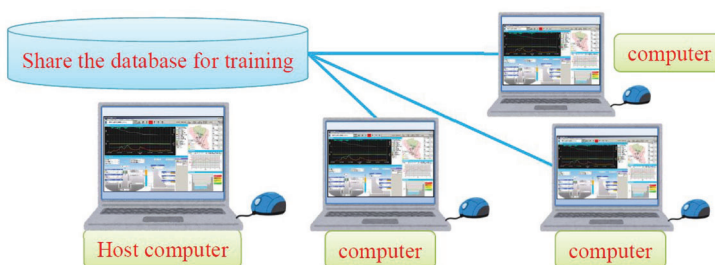


Figure 4. Simultaneous training by multiple people

### 3.2.8 Replication of real flood control

Even now, prediction of precipitation at watershed area of the dam in Japan keeps its accuracy to some extent for approximately next three hours long. However, the prediction accuracy of the precipitation beyond three hours gradually decrease comparing to ones in next three hours. Therefore, we’ve been highly depending on the skilled staff with accumulated and valuable experiences on reservoir management and the prediction technology of the rainfall and inflow to the reservoir. By considering above mentioned challenges, NEW S-DOT has enabled us to experience real flood by adding function which fluctuates the amount of rainfall and inflow data of an upstream and a downstream of the reservoir.

The simulator can replicate the change of predicted amount of inflow to the reservoir by adding error rate to the selected flood waveform. Although, the error rate has sufficient accuracy in the most recent predictions, it expects the decreasing of the predictions in future predictions.

Average of the error rate (Initial Setting Rate) is as shown on Table 5. The error rate was set by considering the current rainfall prediction at the Hitokura Dam, and the specs of the simulator can change the error rate due to the expectations to decreasing of the error rate by considering the development of the prediction accuracy.

Table 5. Average of the error rate of rainfall (Flexible)

Time course	in 1 hour	in 3 hours	in 6 hours	in 12 hours	in 24 hours	48 hours~
Error (%)	20	30	150	200	300	400

\* The time which is not mentioned is same as after. ex) in 2 hours = 30%

Furthermore, the simulator is tailored to calculate the amount of predicted inflow to the reservoir by changing the error rate through random numbers, because if the error rate has been fixed, amount of the predicted inflow would be always same.

### 3.2.9 Guide function on the method of discharge operation

The simulator helps the beginner of the dam operator by the illustrating the patterns of discharge which would be affected by the amount of the inflow through dashed line on the screen. Mounting the guide function of the method of discharge which has not been introduced to the conventional training simulator to the simulator has enabled it. By introducing the new function, the beginners of the dam operator are able to acquire proficiency in dam operation and achieve their goals through learning the operation.

### 3.2.10 Operation for disaster prevention

Currently, making maxim use of the functions of the dams at extreme flood caused by the heavy rainfall and concentrated heavy rainfall at specific areas due to climate change is required. We've developed NEW S-DOT by considering the special situation of the Hitokura Dam which is needed to consider the delay of the river improvement work in the reservoir downstream in dam operation for flood control. Specifically, the simulator has a function of indicating the hydrograph of the discharge by dashed line on the screen as an example of the hydrograph when we changed the function to the extreme flood control mode.

The special function tentatively enables us to experience the advance discharge operation, sequential revision of discharge curve method and special disaster prevention operation.

### 3.3 Ingenious point in system development

Developed system adopted the multi-screens up to 5 screens for substantialize the real training on dam operation. It enables us to exercise vividly as if we're in the operation room.

## 4 COMPLETED NEW S-DOT

Figure 5 shows the completed NEW S-DOT. Main screen shows the basic information, and other screens indicate situation of operation, result of the gate aperture calculation, water level

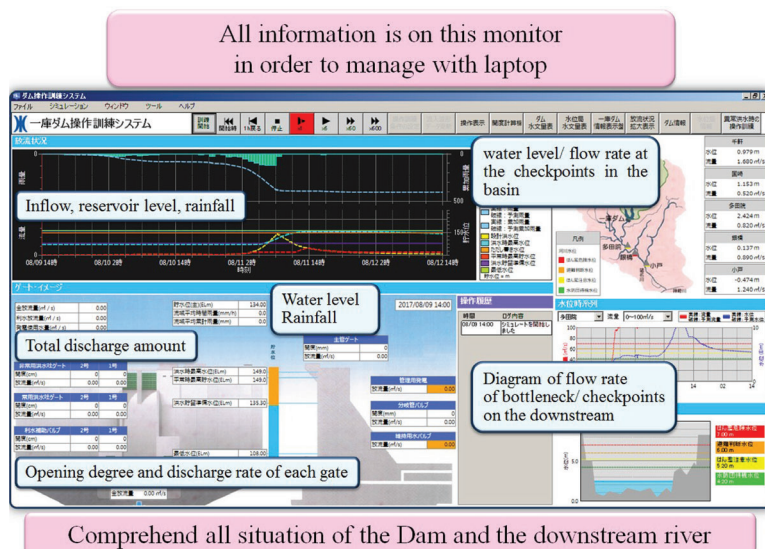


Figure 5. Completed simulation system

Table 6. System configuration and requirement

Monitor	Visual Basic .NET
Data	CSV
Calculation	Visual Fortran
OS	Windows7, 10 ( 32bit,64bit )
Execution environment	Microsoft .NET Framework 4.5.1~
Memory	Over 2GB
CPU	Intel Core i3~

information in upstream and downstream and information about the rainfall as shown on Figure 5. Table 6 shows the operable system requirements of the training simulator on laptops.

## 5 CURRENT SITUATIONS

We've been conducting the trial operation of NEW S-DOT. Results of the trial operation will feed back, and improved simulator will be installed to dams which are requested to install. Then, training by using the developed simulator would be conducted to hand dam operation technology to the next generation.

## 6 TRAINING

JWA has conducted some training courses by using NEW S-DOT since 2017 for the purpose of enhancing the capacity of staff in case of appropriate dam operation at an unforeseen circumstance. Training course consists of i: Basic training for beginners of dam operation and ii: Extremely advanced training for experienced dam operators with basic dam operation technology. Target of the training course is covering from operator of gates to conductor of dam operation, and the training has contributed to achieve higher level of dam operation with proficiency at all layers of JWA staff.



Figure 6. The pictures of dam flood control training

## 7 WAYS FORWARD

Now, we've completed the development of the basic simulator for dam operation training, the NEW S-DOT. JWA is going to install the developed simulator to the dam operation offices which need to install for supporting operation. After the completion of the installation to all JWA dams, JWA's organizational capacity on dam operation in flood control would be extremely strengthened. As a next step, we're now considering to develop more effective

methodologies which support dam operations and decisions by JWA staff through introduction and adoption of AI technologies in dam operation for the purpose of establish accurate discharge principles.

## 8 CONCLUSIONS

Development of JWA's new simulator for dam operation training, the NEW S-DOT, makes it possible for the staff to train planning and operation for discharging with confirming downstream situation. Also, various strategic training functions were introduced to enhance the quality of flood control operation trainings. Most of them are new function for existing dam operation simulators. In addition, since the NEW S-DOT can be installed in normal PC in the office, it brought easier environment for providing opportunities of dam operation training to JWA staff. Therefore, JWA staff members are now able to master advanced discharging operation in short time. Furthermore, since super-typhoons, linear rain bands and localized torrential rain occur frequently throughout Japan in recent years, the NEW S-DOT is suitable for simulating advanced discharging operation which makes the best use of dam's capacity possible even in those severe cases. It must be the most advanced simulator in the world having such various functions.

The NEW S-DOT enabled JWA to improve their staff's flood control operation skill for disaster prevention drastically.

## ACKNOWLEDGEMENT

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