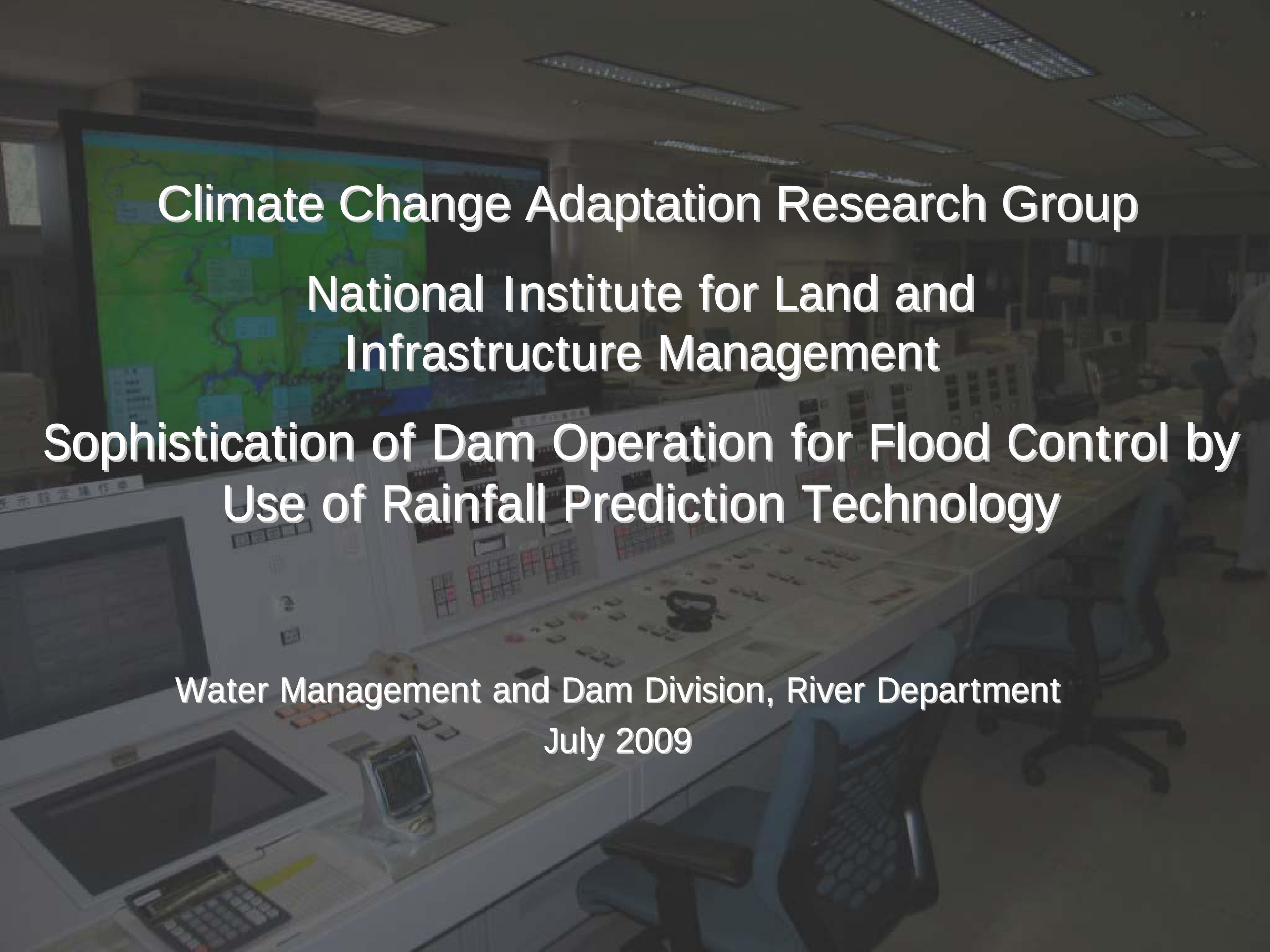


Climate Change Adaptation Research Group

National Institute for Land and Infrastructure Management

Sophistication of Dam Operation for Flood Control by Use of Rainfall Prediction Technology

Water Management and Dam Division, River Department

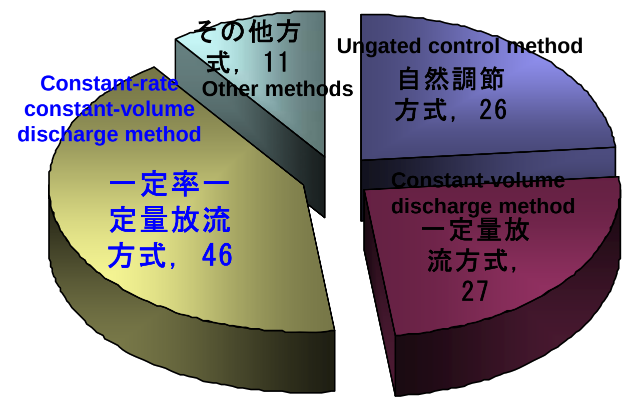
July 2009

Functions of multipurpose dam

Flood control methods

Flood control methods used at multipurpose dams can be broadly categorized into four types: ungated control method, constant volume discharge method, constant-rate constant-volume discharge method and others (e.g., bucket bottom cut method). The method most frequently used by the Ministry of Land, Infrastructure, Transport and Tourism and Japan Water Agency is the constant-rate constant-volume discharge method.

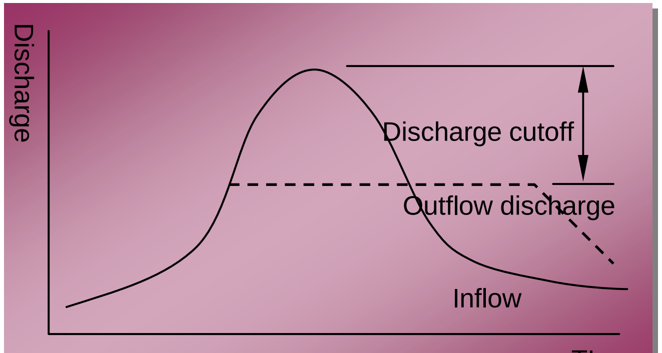
Flood control methods (MLIT and JWA dams)



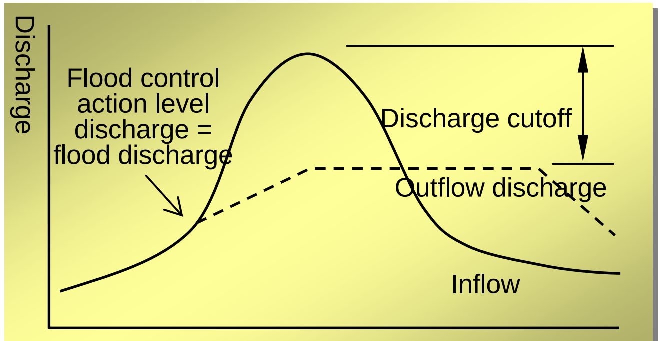
What is the "constant-rate constant-volume discharge method"?

In the constant-rate constant-volume discharge method, when inflow has exceeded **the flood control action level discharge** (discharge below which downstream areas and facilities in river areas do not suffer major damage; the dam operating rules define refers to it as **"flood discharge";** also known as **"harmless discharge"**), **inflow is reduced at a constant rate until the peak inflow**. **After the peak inflow**, **water is released by constant volume**.

In this method, **the flood control effect of dams can be expected even in cases of medium or small flood**s. This method, therefore, is suitable for rivers whose downstream channels have not been improved substantially through river improvement projects. Compared with the constant-volume discharge method, however, this method requires a larger flood control reservoir capacity.



Constant-volume discharge method



Constant-rate constant-volume discharge method

Functions of multipurpose dam

Besides the flood control methods as mentioned earlier, methods for other purposes such as water supply are stipulated in the operating rules for each dam.

When the occurrence of a flood exceeding the design basis flood for the dam is expected, the following action is taken….

If the reservoir level is expected to exceed the surcharge level (upper limit level of flood control capacity) (i.e., if an extreme flood is expected), when the reservoir level has exceeded the 80% level of the reservoir capacity, dam operation procedures are taken so as to make the outflow discharge close to the inflow in order to prevent the reservoir level from exceeding the surcharge level.

= These are called particular operating

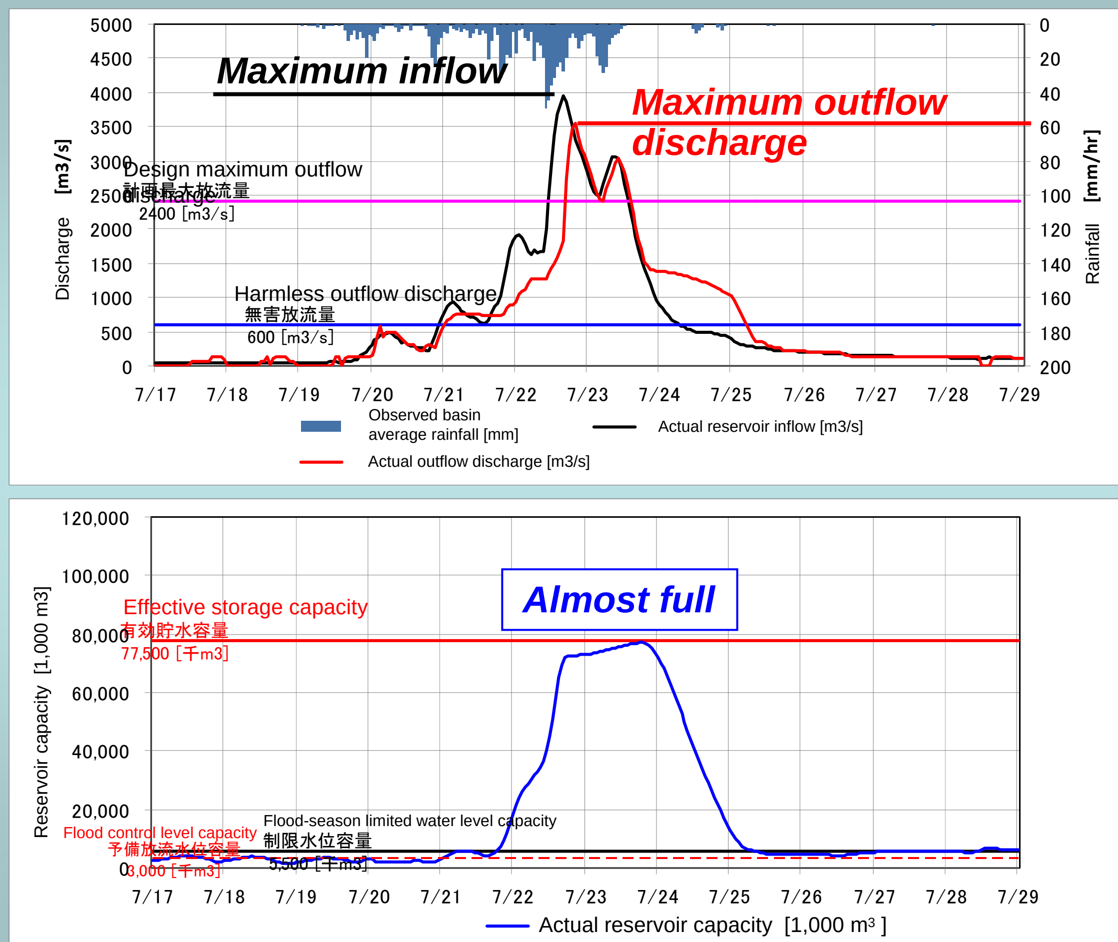
Note: In this case, the outflow discharge will never exceed the inflow.

Functions of multipurpose dam

Example of operation under the particular operating rules

If a great flood exceeding the design flood for the flood control plan occurs, the discharge-reducing effect of the dam decreases.

T Dam: Example during the July 2006 flood



Note: The outflow discharge will never exceed the inflow at or around the flood peak discharge.

Problems of current dam operating methods

(1) In the event of an extreme flood, a outflow discharge higher than the design maximum outflow discharge is needed under the so-called "particular operating rules." As a result, the damage-mitigating effect is reduced.

→ It is hoped that operation under the particular operating rules is avoided.

(2) Even if an extreme flood is expected, preliminary release is not necessarily carried out.

→ There are no established criteria based on rainfall prediction for deciding whether to carry out preliminary releases.

(3) In the constant-rate constant-volume discharge method (a method which is currently in use at many dams and which does not utilize rainfall prediction), even when a medium or small flood is expected and the reservoir has sufficient flood control capacity, downstream damage might be caused by a outflow discharge exceeding the harmless discharge.

→ If it can predicted that a medium or small flood is coming, flood control can be done by carrying out a outflow discharge within the limit of the harmless discharge.

(4) Since water supply capacity is not currently used for flood control, the effectiveness of the flood control function relying solely on flood control capacity is limited.

→ Water supply capacity can also be utilized by making effective use of rainfall prediction.

(5) Information related to rainfall prediction is lacking, and rainfall predictions are not currently used for flood control operation.

→ The accuracy of rainfall prediction is not clearly known. Operating methods using rainfall predictions have not been clearly indicated.

Purpose of research

Furthermore . . .
The frequency of damaging floods has increased in recent years, and flood risk is expected to increase in the coming years under the influence of climate change. River channel improvement has not progressed as expected because of the reduced budget for public works projects. The construction of a new dam takes considerable time and funding.

Therefore . . .
It is hoped, in order to make effective use of existing dams, that a large quantity of water is stored in ordinary times and when a major flood is expected, the required capacity for flood control is created by making a preliminary release.

○ Social needs

- Mitigation of flood damage in the event of an extreme flood
- Flood damage prevention in the event of a medium or small flood
- Efficient flood control made possible by reconsidering conventional dam operation
- Rational dam operation in coordination with water supply

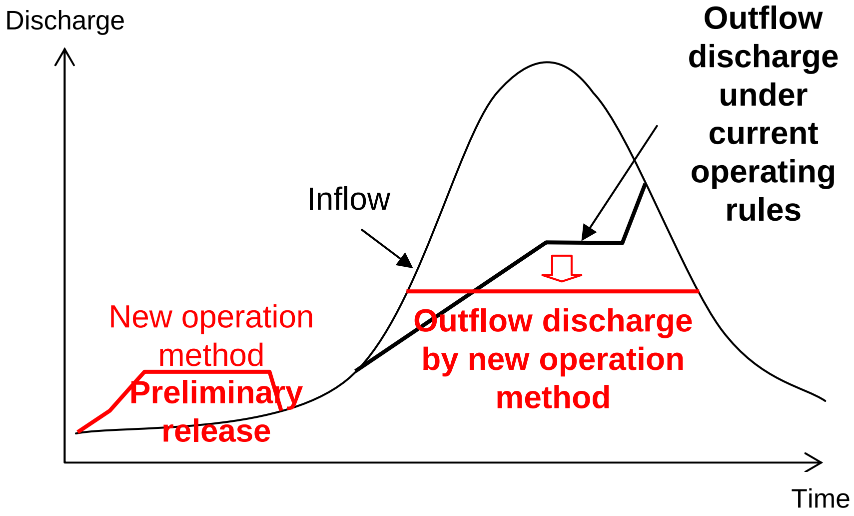
Merits of dam operation methods using rainfall prediction

Use of rainfall prediction makes the following possible:

In case of extreme flood

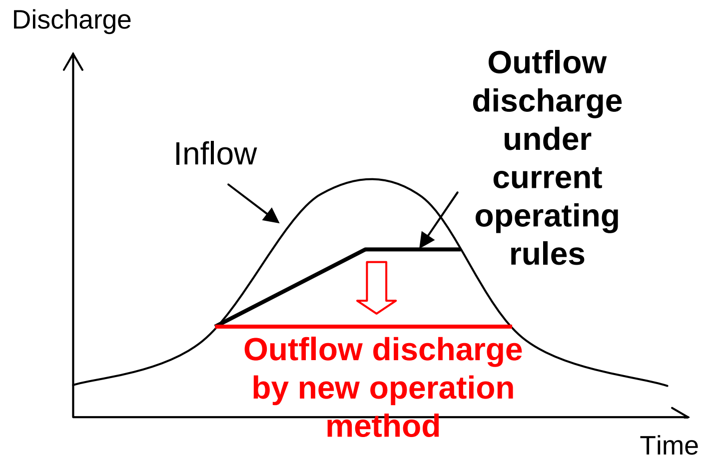
Flood control capacity is increased by making preliminary releases, and damage is minimized by reducing the maximum outflow discharge by the constant-volume discharge method.

If prediction is possible, water supply capacity can be used as part of flood control capacity.



In case of medium or small flood

If flood control capacity is thought to be larger than necessary for flood control, part of flood control capacity can be used to store flood water to eliminate downstream damage.



Previous study results and bottlenecks

・**Improvement of rainfall forecasting techniques (FY2007/2008)**

A prediction study has been conducted by using a new forecasting model (WRF) which uses JMA predictions as initial values and boundary values. The study has confirmed that rainfall forecasting accuracy can be enhanced.

→ There is still a certain degree of uncertainty because there are cases where accuracy is not improved. Quantitative evaluation of accuracy is needed.

・**Effective rainfall calculation method considering the water-holding capacity of soil (FY2007/2008)**

The relationship between the duration of dry weather and the recovery of the water-holding capacity of soil has been formulated, and a runoff prediction method considering the initial rainfall loss has been developed.

→ There are still uncertainty factors such as interception by trees and depressions

・**Establishing a dam operating method using rainfall prediction (FY2008)**

Up-to-48-hour rainfall predictions and the reservoir capacity at the time of prediction were compared, and a method for planning releases including preliminary releases has been established.

→ If rainfall prediction errors are large, there are cases where a large quantity of water is released even though there is still storage capacity or where because storage capacity is not large enough, the reservoir becomes full so that particular operating rules are applied. There is still need to consider actions to be taken when rainfall predictions have turned out to be inaccurate.

Rainfall forecasting technique (What is WRF?)

- WRF Weather Research and Forecasting Model

- Mesoscale weather model developed by NACR/NCEP (USA) for forecasting and research applications

  - Though developed from a single project, there are two types, one for forecasting applications and the other for research applications.

  - Based on the lessons learned from the emergence of many mesoscale models in the United States, the new model has been developed through a concerted effort.

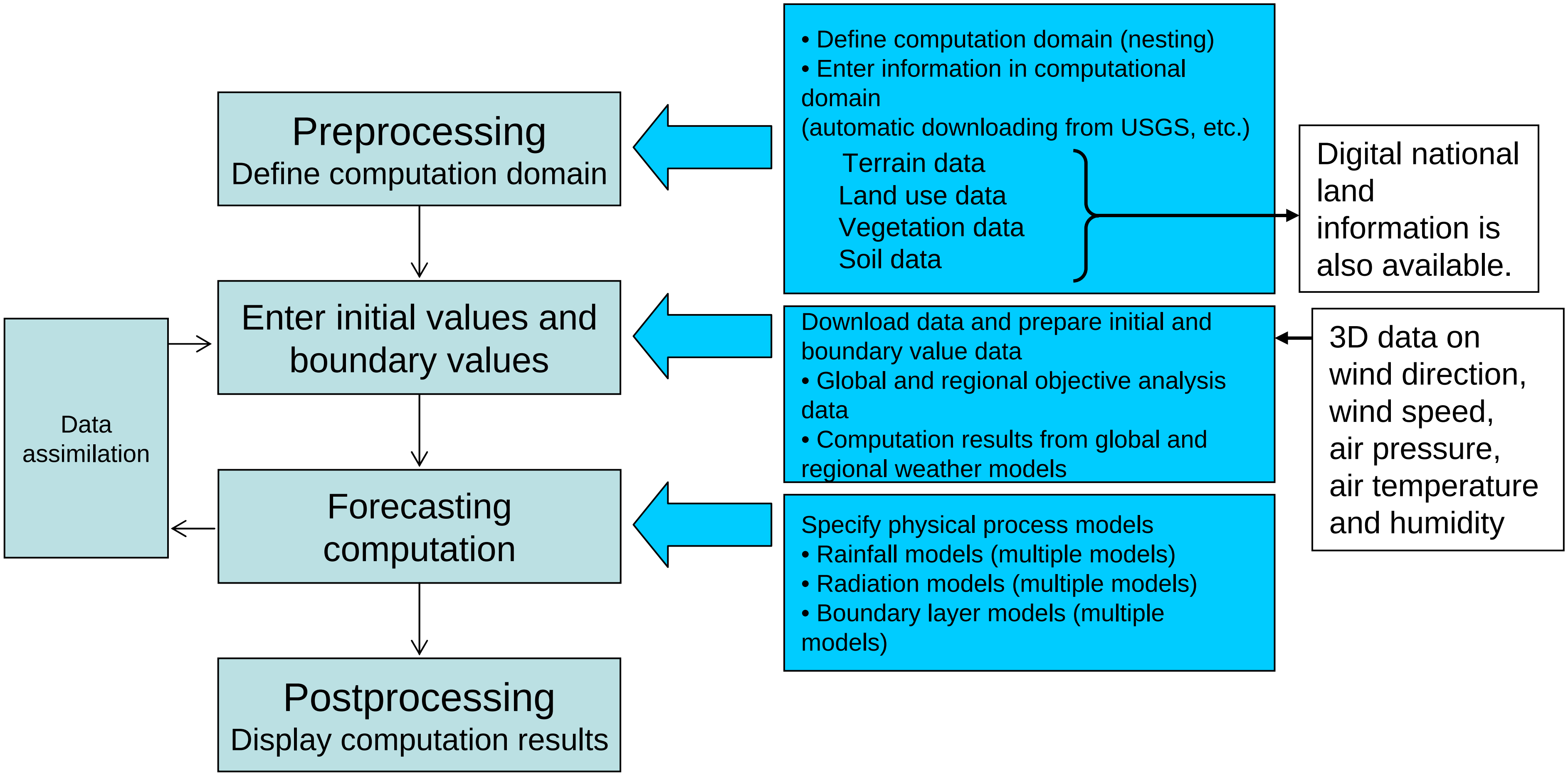
What is a mesoscale model?

- Non-hydrostatic model dealing with meteorological phenomena with horizontal scales ranging from 10 to 100 km, such as localized heavy rains and thunderstorms
  - Capable of 1-kilometer mesh computation

What kind of weather model is used for weather forecasting?

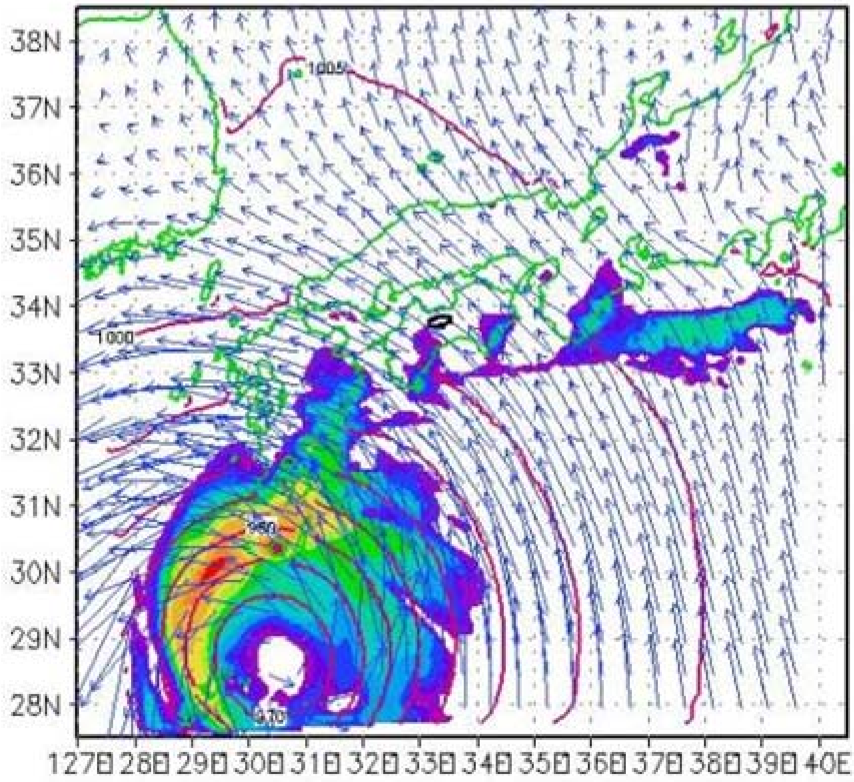
- Hydrostatic model dealing with global scale weather phenomena such as typhoons and Bai-u (rainy season) fronts
  - 10-km mesh is the limit because of hydrostatic approximation
  - Used for forecasting applications because computation can be done quickly

Computational flow of mesoscale weather model

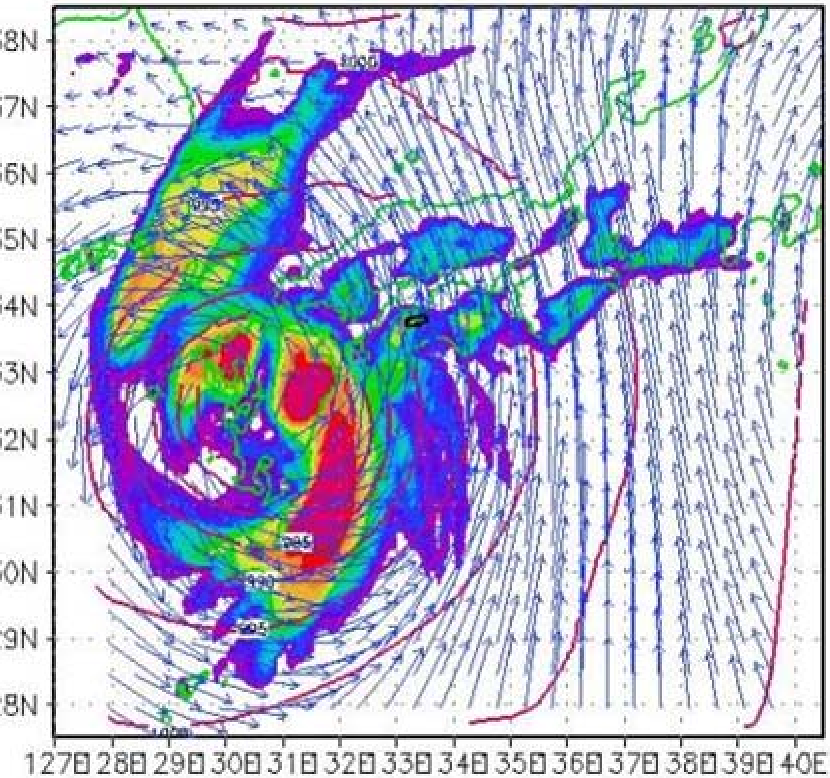


- Although rainfall forecasting accuracy is dependent on the kind of physical process models used, but it is determined mainly by the degree of closeness of the initial values and boundary values to the realities.

Displayed computation results (examples)



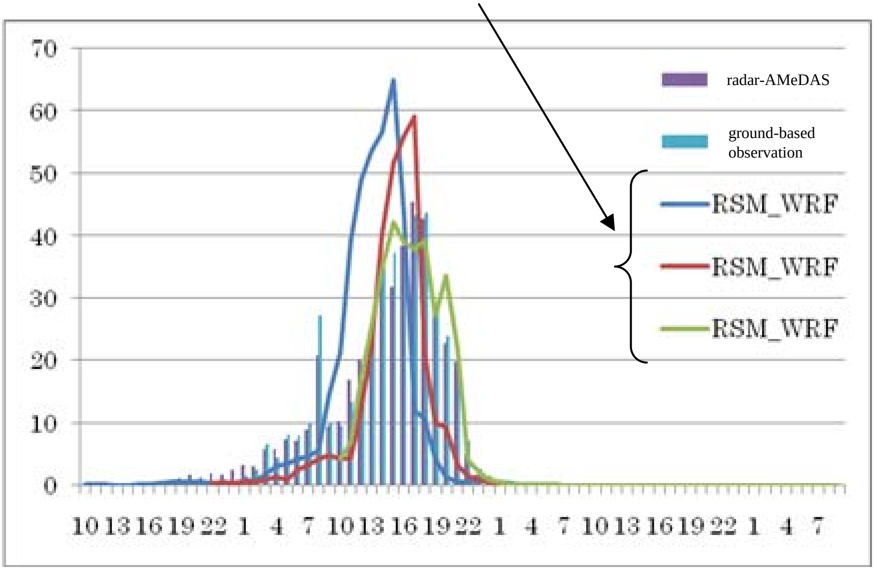
3-hour forecasting



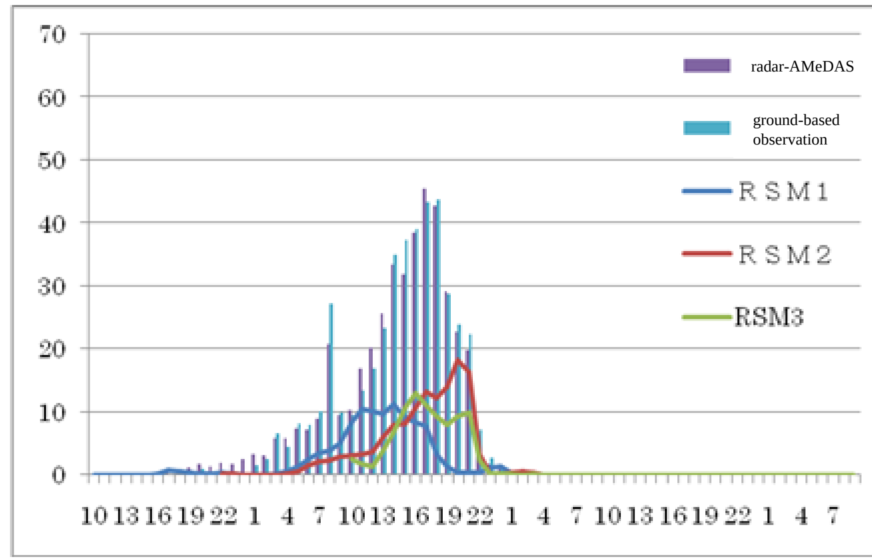
12-hour forecasting

Computation results obtained by using RSM data as initial and boundary values (a case in which accuracy is improved)

Calculation start time differs.



Forecasting computation by WRF

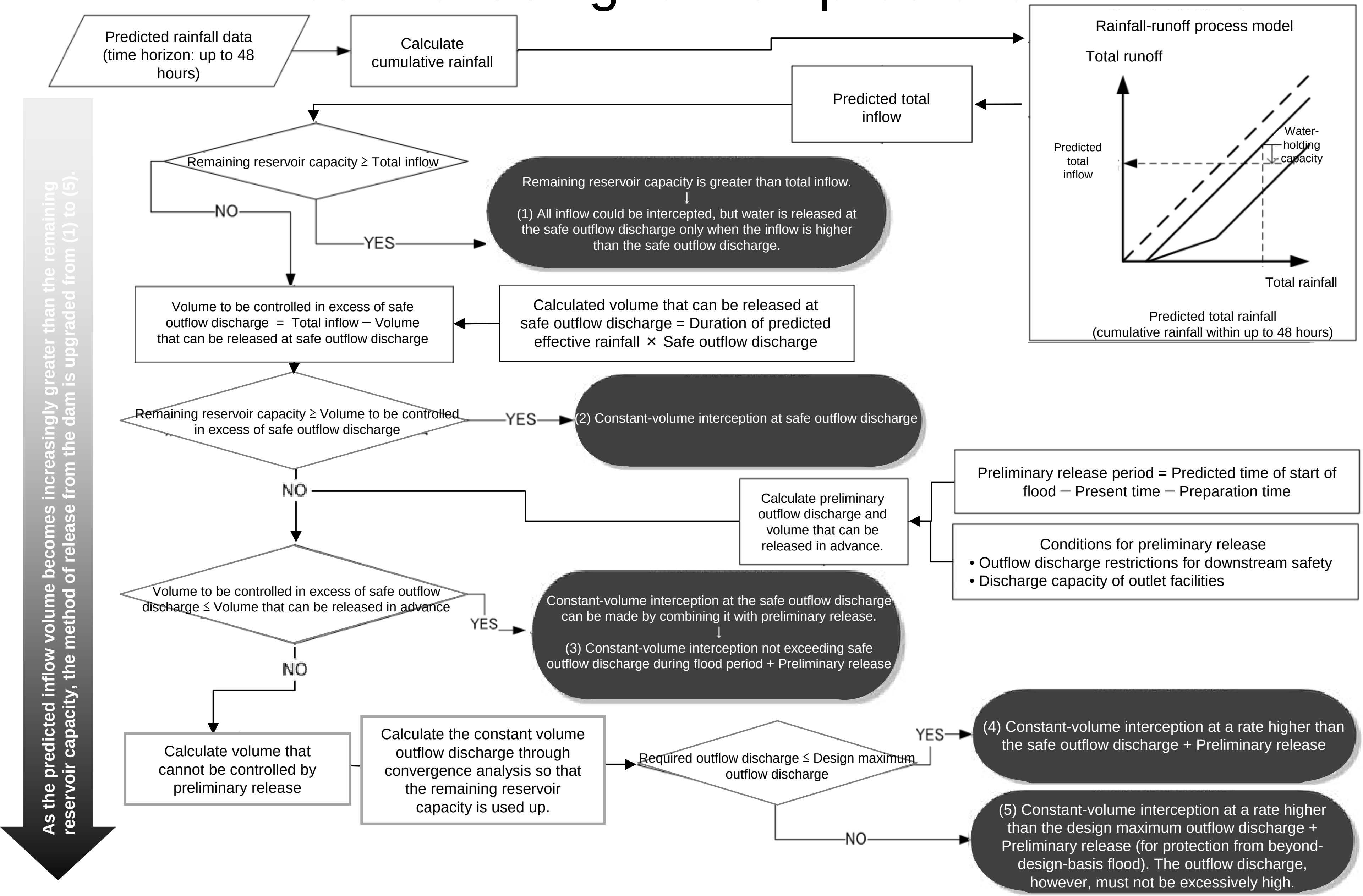


Forecasting computation by JMA's RSM

Basin of Sameura Dam (August 30, 2004)

- Forecasting accuracy of RSM has been improved by using WRF
- RSM was fairly accurate in predicting the start and end of rainfall although the predictions were not accurate quantitatively.

Flowchart for simulation of dam-based flood control using rainfall prediction



Evaluating rainfall prediction errors in simulation

The prediction accuracy of JMA's VSRF, MSM and RSM at 214 rain gauge stations in the catchments of dams in 7 river systems in Japan has been evaluated.

Study on usability of weather forecast data (NILIM)

Regression coefficient = Predicted rainfall / Measured rainfall

Expectable maximum measured rainfall = Predicted rainfall / 0.7 = 1.43 ∗ Predicted rainfall

Expectable minimum measured rainfall = Predicted rainfall / 1.4 = 0.71 ∗ Predicted rainfall

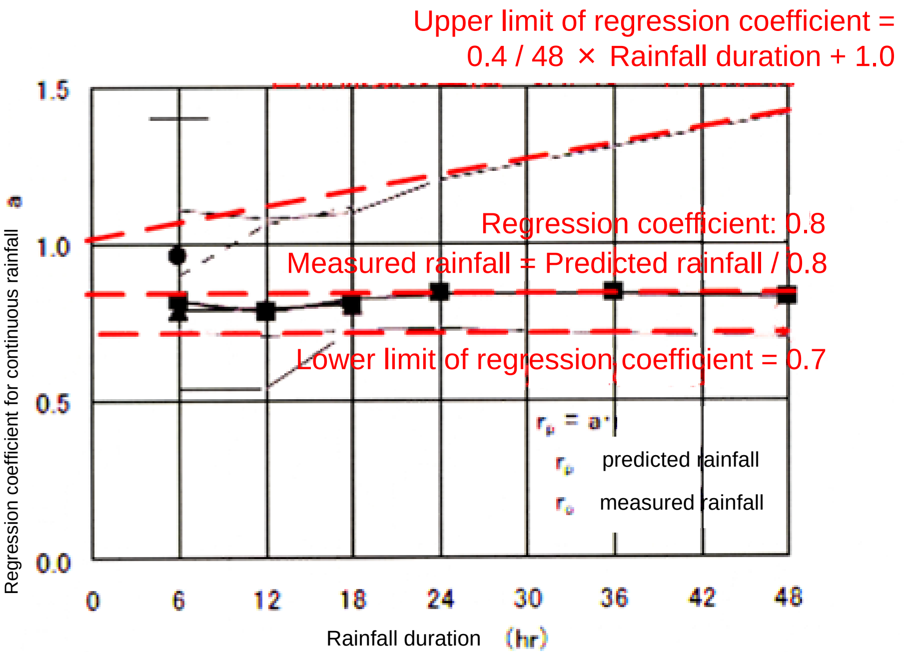


Fig. 1 Upper and lower limits of the regression coefficient for cumulative rainfall determined from past study results

Use of past study research (analysis using JMA forecasts)
It is necessary to make forecasting by using the newly developed WRF to accumulate data and evaluate accuracy.

Calculating effective rainfall

Initial rainfall loss, primary runoff ratio, saturation rainfall and maximum rainfall loss are determined on the basis of total runoff and total rainfall data for single rainfall events at each dam.

The recovery of the maximum water-holding capacity is determined, by assuming it to be an exponential function, from the discharge reduction condition after the second inflection point during the discharge reduction period during a flood.

Effective rainfall at K Dam

Initial rainfall loss (R_{SL})	40 [mm]
Primary runoff ratio (f_1)	0,4
Saturation rainfall	210 [mm]
Maximum water-holding capacity of surface soil	102 [mm]

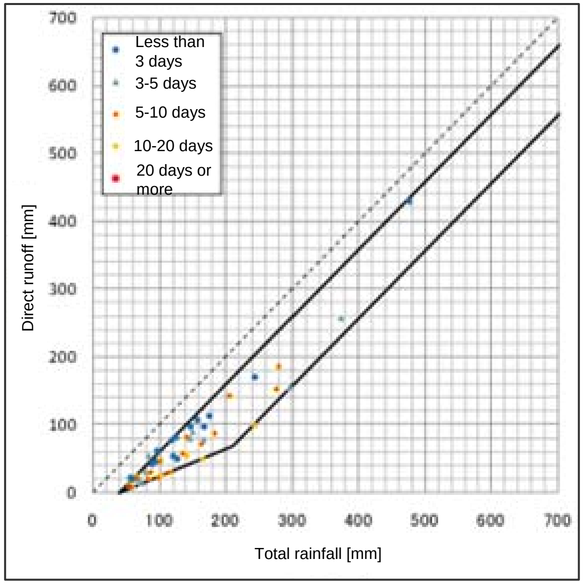


Fig. 2 Total rainfall and direct runoff at K Dam

(colored according to time from initial stage of rainfall)

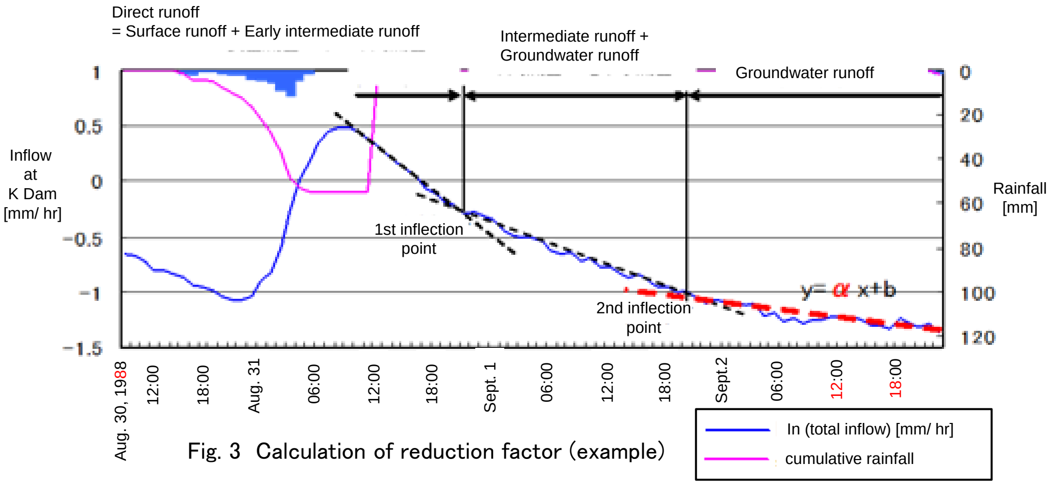


Fig. 3 Calculation of reduction factor (example)

Surface soil moisture condition RG = Maximum water-holding capacity ∗ $\exp^{\alpha T}$

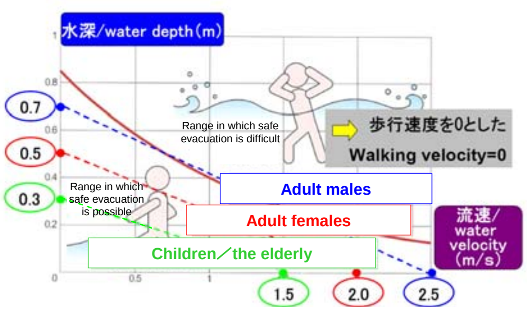
Water-holding capacity during the rainfall = Maximum water-holding capacity − R_G

Proposed procedure for safety checks for preliminary release -draft-

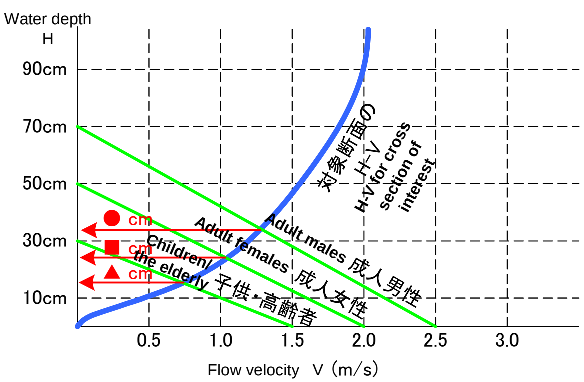
< Important considerations>

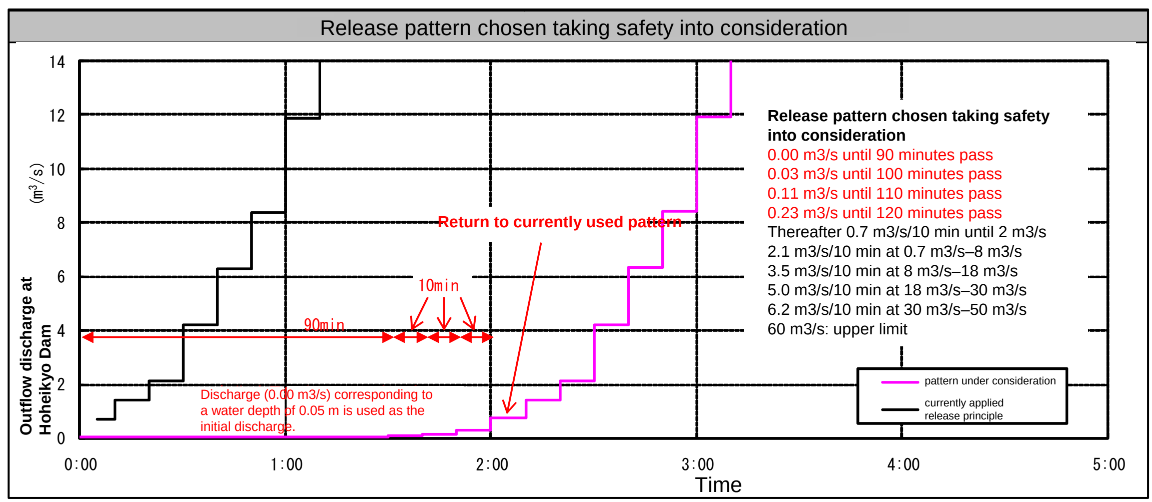
- River use downstream and the rate of water level rise
- Time required for river patrol and the scope of patrol
- Determination of release pattern taking into consideration river users' ability to escape

	Critical depth	Critical flow velocity	Maximum velocity
Adult males	0.7(m)	2.5(m/s)	1.5(m/s)
Adult females	0.5(m)	2.0(m/s)	1.3(m/s)
Children/ the elderly	0.3(m)	1.5(m/s)	1.2(m/s)



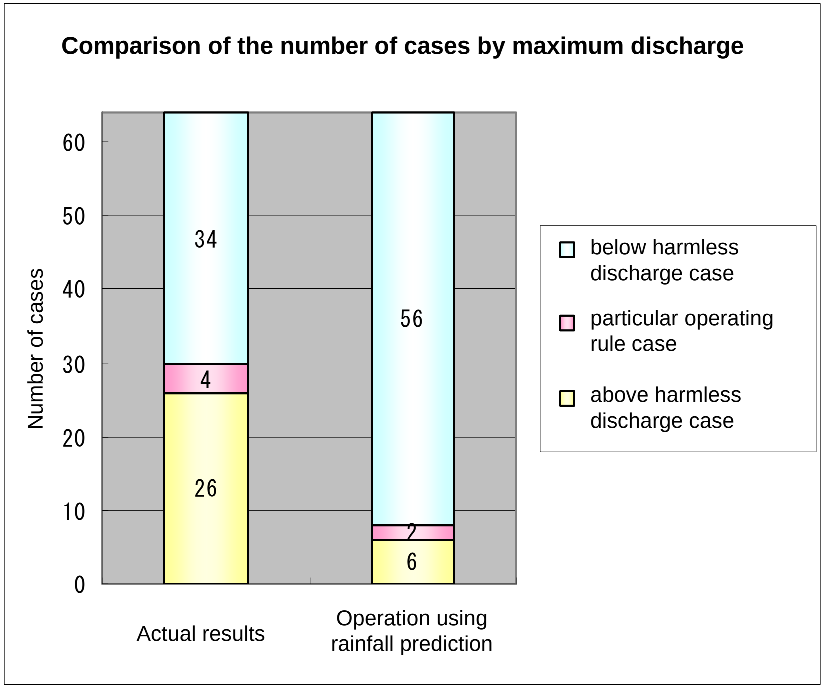
Source: Suga et al.: Experiment on safe evacuation behavior (wading through water) in case of flood

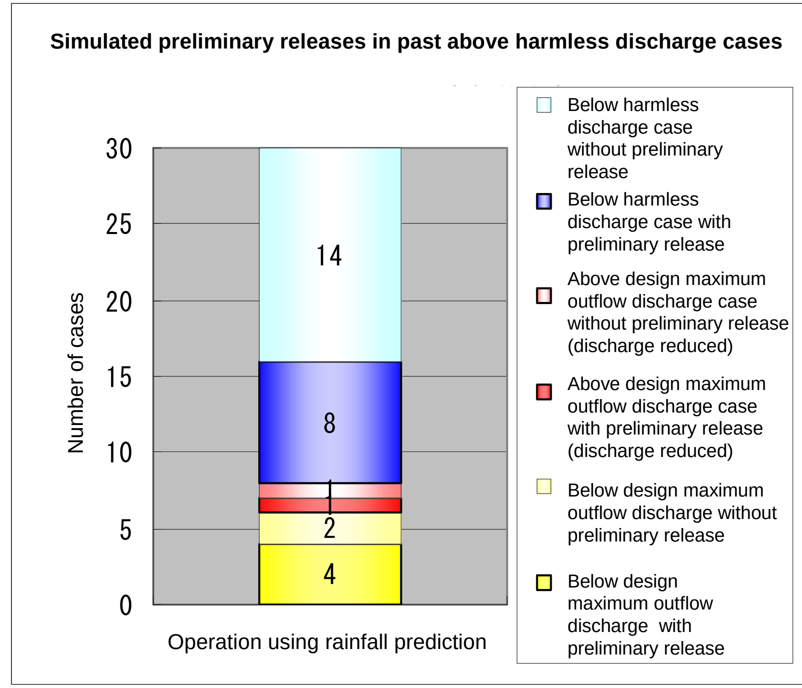




Result of simulation of new operation method

Results obtained in 64 flood cases at 7 dams





- In 22 out of the 30 flood cases in which water was actually released at out higher than harmless discharge, it would be possible to reduce water at outflow discharge lower than harmless discharge.
- In 13 out of the 30 flood cases in which water was actually released at outflow discharge higher than harmless discharge, preliminary releases would be carried out.
- In 8 out of these cases, it would be possible to release water outflow discharge lower than harmless discharge. In the remaining 5 cases, peak discharge would be reduced.

Evaluation Dam operation using WRF

- It has been confirmed that preliminary releasing is effective to a certain degree against an extreme flood. A preliminary release, however, should be carried out in view of such factors as prediction errors and the possibility of the recovery of water supply capacity and the exceeding of flood control capacity.

- At a dam where the constant-rate constant-volume discharge method is used, the decision to narrow down options to constant-volume discharge at the harmless discharge, which uses the flood control capacity more, should be made carefully. → The relationship between forecasting accuracy and flood control needs to be determined.

- In predicting reservoir inflow, it is desirable to use a high-accuracy runoff analysis model, such as a distributed runoff model.

- There are dams incapable of carrying out effective preliminary releases because of the lack of capacity of outlet facilities where preliminary releases would in theory be effective. → There is a need to reconsider existing reservoir outlet facilities.

Problems to be addressed

< Improving operating methods>

- Determining outflow discharges in cases where flood control capacity is not large enough even after a preliminary release is carried out
- Policies needs to be determined as to how to use reservoir capacity in view of WRF errors

< Improving forecasting techniques>

- Confirming WRF errors in order to optimize flood control so that downstream damage is minimized
- Conducting runoff analyses using distributed runoff models, etc., to forecast reservoir inflow more accurately and perform more appropriate flood control operation taking into consideration the safety of downstream areas

< Redesigning institutional systems>

- It is necessary to develop operating rules or operating manuals for new flood control methods and conduct studies on where the responsibility for operation lies and on actions to be taken dealing with risks.

Research schedule

FY2008	**Establishing a concept for dam operation methods taking rainfall prediction into consideration**	**Improving WRF by using GSM20, precipitable water, etc.**
FY2009	**Verifying the accuracy of WRF-based rainfall forecasting applied to historical floods and evaluating its usefulness in flood control**	**Predicting rainfall by using an improved WRF (accumulation of data)**
	Studies on criteria for carrying out preliminary releases taking into consideration the magnitudes of rainfall events, forecasting errors and characteristics of dams	
FY2010	**Forecasting reservoir inflow by making combined use of a distributed runoff model and rainfall forecasting, and evaluating the accuracy of forecasting**	**Verifying prediction accuracy**
	Studies on the type and accuracy of rainfall prediction information necessary for dam operation	
	Studies on risk management using rainfall prediction and studies on dam operating rules using rainfall prediction by WRF	
FY2011	Validating dam operation methods using rainfall prediction	