

A FRAMEWORK TO ASSESS EFFECTIVENESS AND RISKS OF INTEGRATED RESERVOIR OPERATION FOR FLOOD MANAGEMENT CONSIDERING ENSEMBLE HYDROLOGICAL PREDICTION

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INTRODUCTION

Real-time reservoir operation

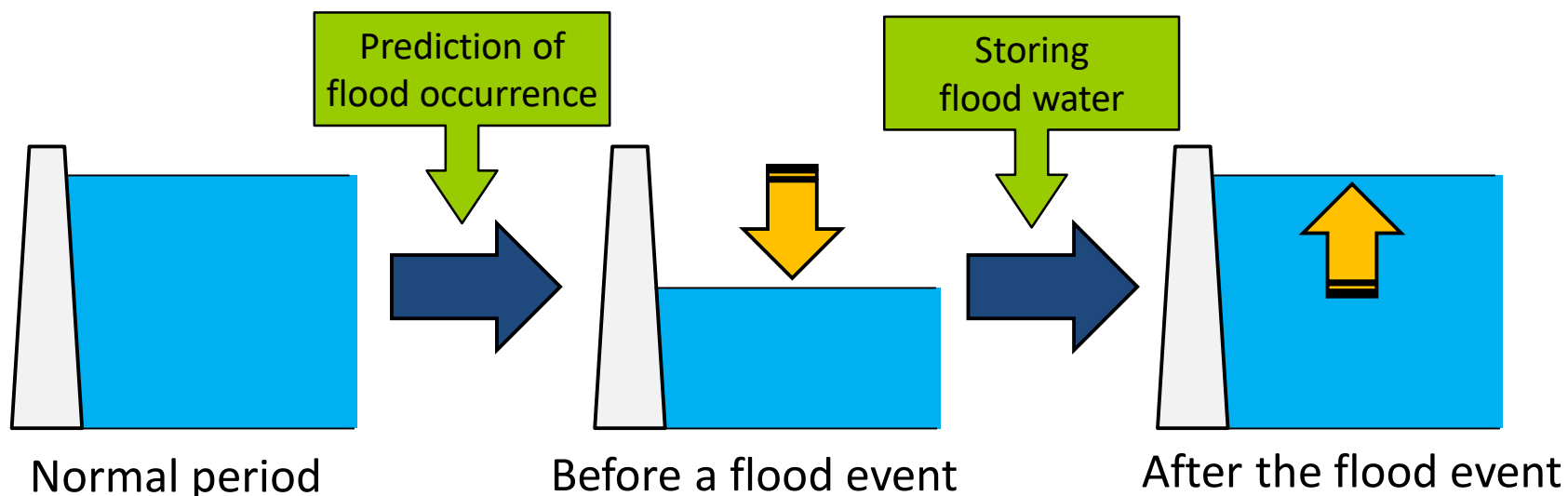
- Playing a significant role for effective water resources management including flood management by controlling fluctuation in river water flow
- More integrated reservoir operation considering the latest information on hydrological conditions in the target river basin is needed for more effective water resources management



INTRODUCTION

Preliminary release operation for flood management

Keeping water level as high as possible, at the same time as safely decreasing water level in advance of flood events so as to secure storage capacity for flood control (enables integrated management)

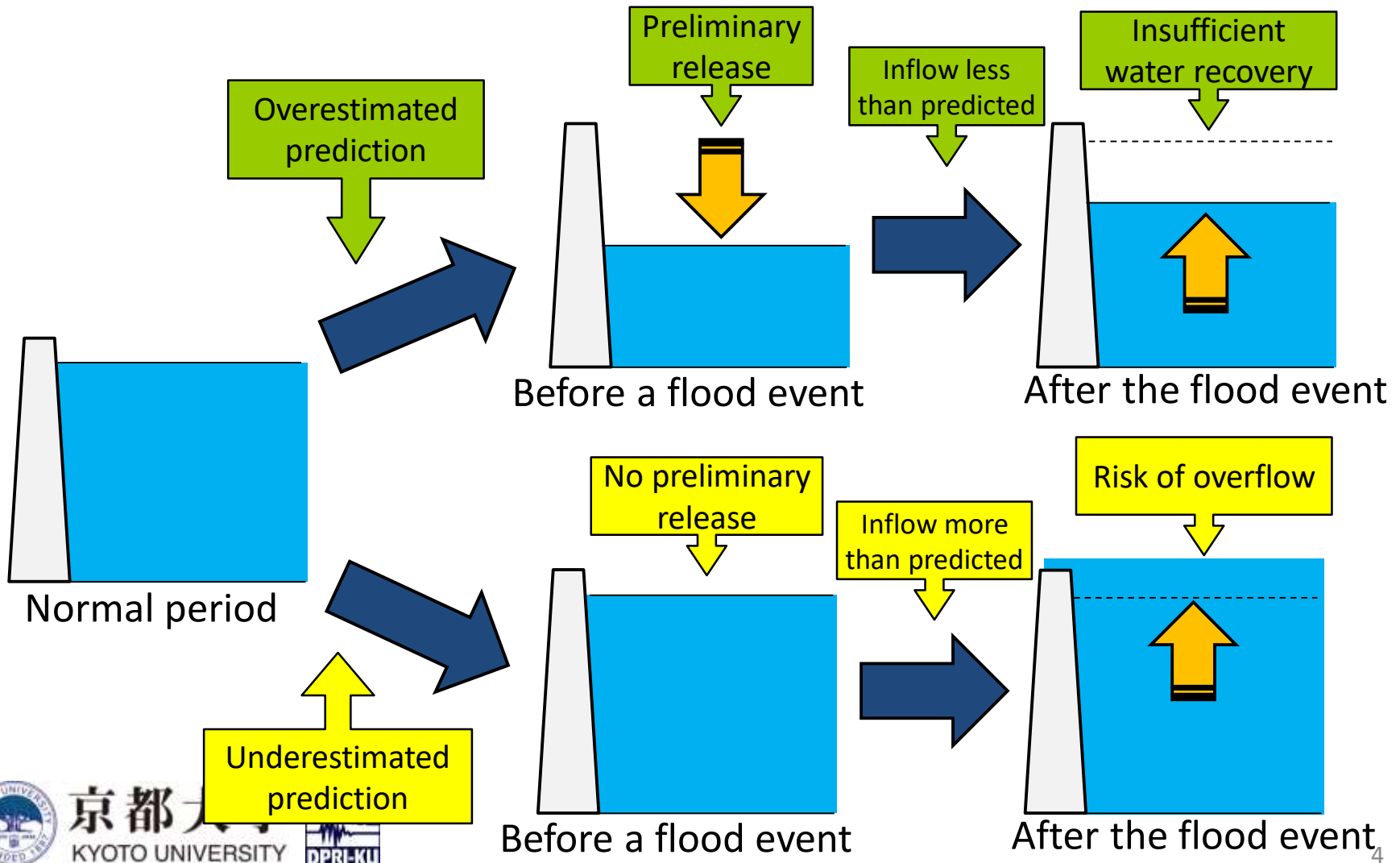


➡ Consideration of hydrological prediction is important.

INTRODUCTION

Effect of prediction uncertainty

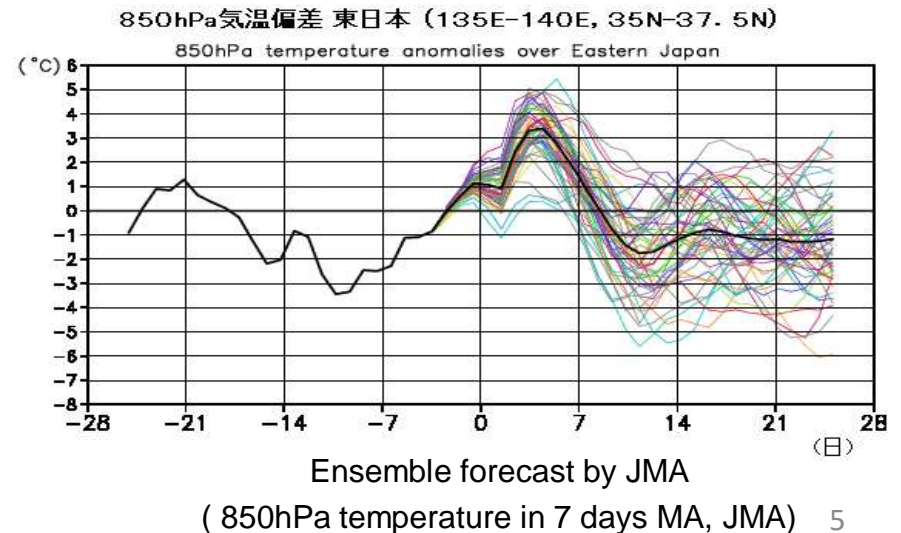
Handling uncertainty contained in the predictions has been issues



INTRODUCTION

Operational ensemble hydrological forecasts

- Various operational hydrological forecasts are provided by the authorities, including ensemble hydrological predictions (EHPs)
- EHP consists of multiple predicted sequences with different initial conditions to consider the effect of growth of initial errors in time horizon
- Including information on uncertainty, which can be estimated by considering spread of the predictions at each predicted time cross section
- Considered to bring more robust decision making in the reservoir operation by taking them into account



INTRODUCTION

- Analysis on **effects of prediction uncertainty** is important for designing an effective way to conduct prior release operation of reservoirs
- **Stochastic approach** is needed to thoroughly investigate effects of prediction uncertainty on prior release operation
- However, amount of actual prediction data provided under flood conditions is not much enough to carry on statistical analysis
- **Simulated generation of prediction with various degrees of uncertainty** is considered to be effective for such an analysis

OBJECTIVE

Analysis on effects of real-time ensemble hydrological prediction and its uncertainty on preliminary release operation of a multi-purpose reservoir

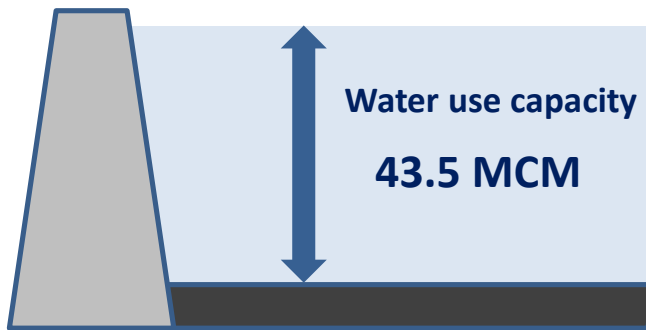
- For hourly operation of a single multi-purpose reservoir in Japan before and under flood conditions
- Coupled with a **simulated generation process of ensemble inflow prediction (EIP) with various degrees of errors**
- **Monte Carlo simulation (MCS)** of preliminary release operation with generated EIPs to analyze effects of prediction uncertainty on preliminary release operation in terms of flood control and water recovery

NAGAYASUGUCHI RESERVOIR

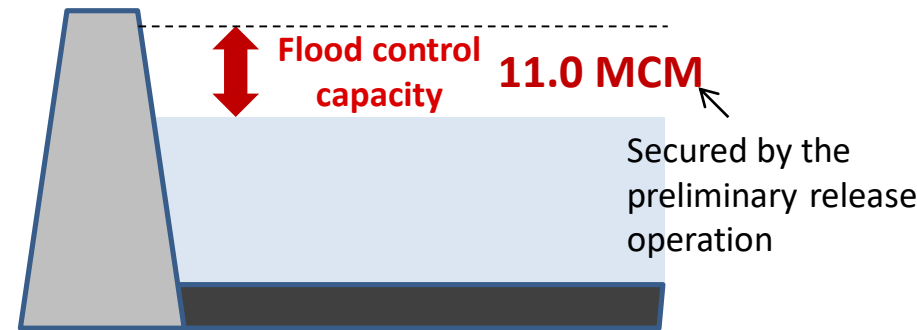
A multi-purpose reservoir for flood control, water supply and power generation in the Naka River Basin, Japan



Non flood situation

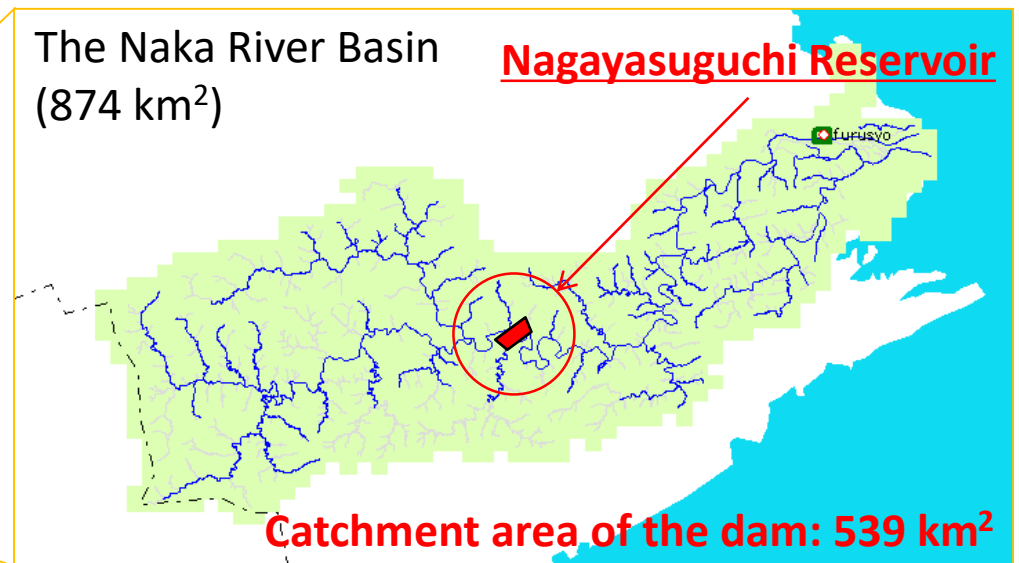


Flood situation



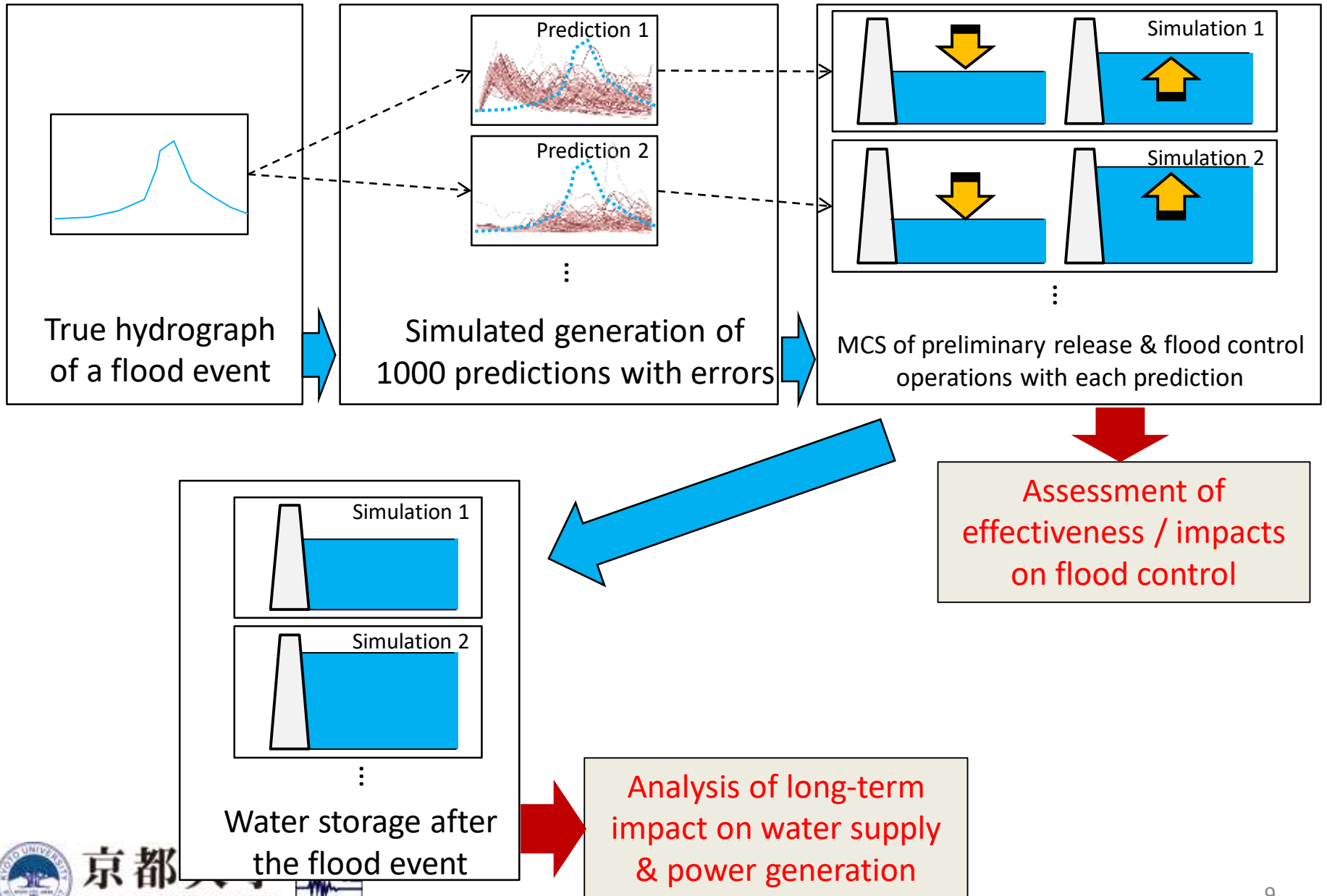
The Naka River Basin
(874 km²)

Nagayasuguchi Reservoir



Catchment area of the dam: 539 km²

FRAMEWORK OF ANALYSIS



GENERATION OF ENSEMBLE INFLOW PREDICTION

- Synthetic generation of **ensemble inflow predictions for the coming 8 days**
- Generation of predictions so that they have a certain degree of uncertainty by changing values for the following indices:

- **Ensemble mean error:** Averaged error (or goodness) of predictions

$$e_M = \frac{1}{M} \sum_m (x_m^* - x_o)$$

M : Number of ensemble members

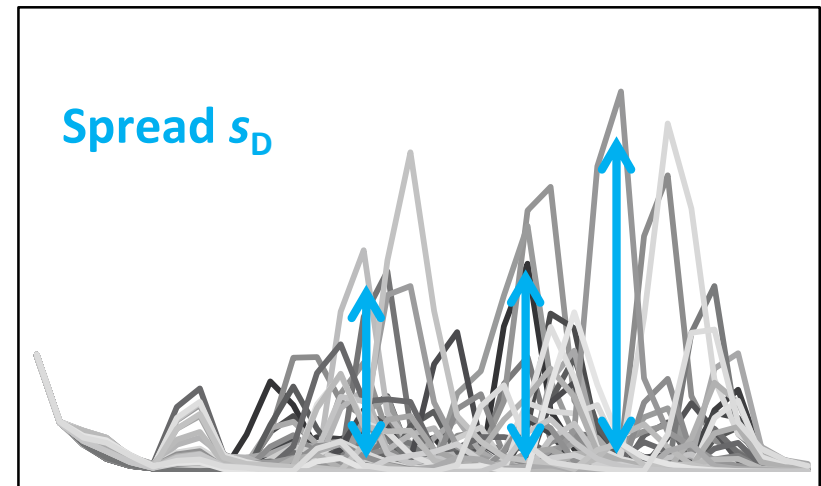
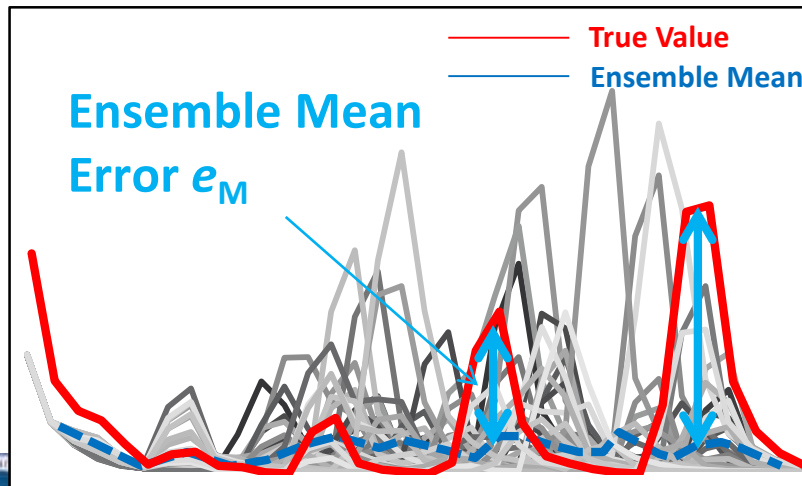
x_m^* : Prediction by member m

x_o : True value of inflow

- **Spread:** Degree of uncertainty contained in an ensemble prediction

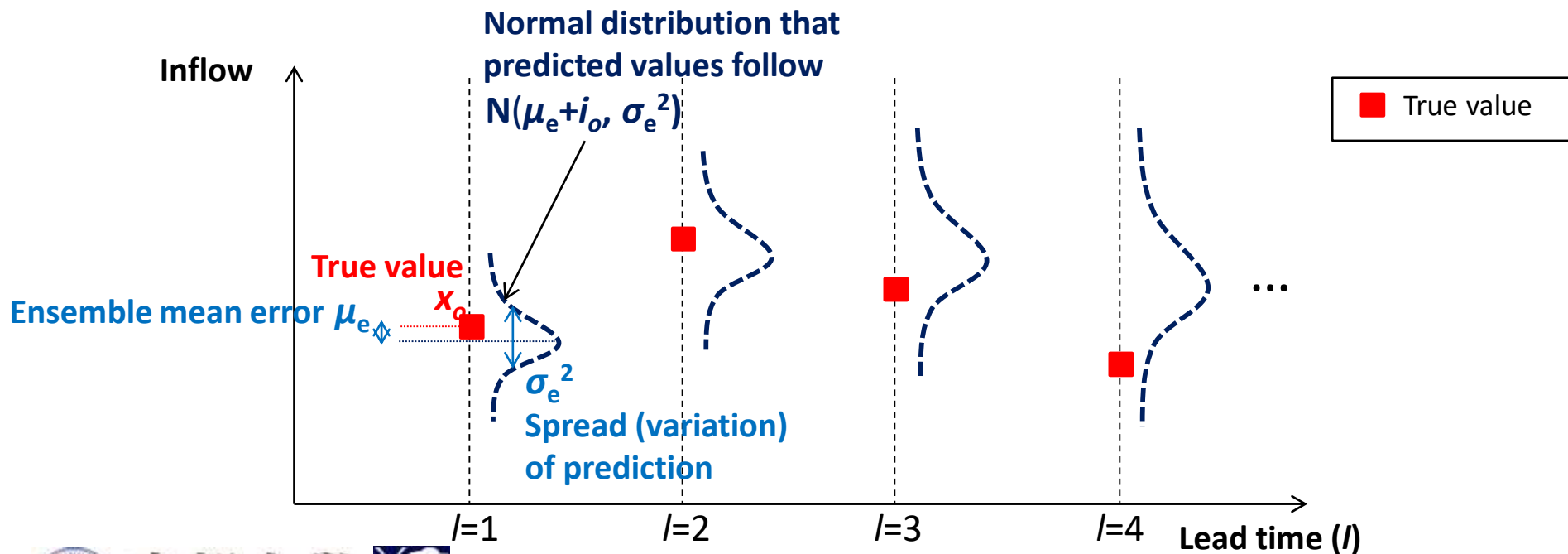
$$s_D = \frac{1}{M} \sum_m (x_m^* - \bar{x})^2$$

\bar{x} : Average of predictions (ensemble mean)



GENERATION OF ENSEMBLE INFLOW PREDICTION

- Generation of prediction errors
 $x^*[prediction] = x_o[true\ value] + e[error]$
- Assuming that prediction errors follows a normal distribution $N(\mu_e, \sigma_e^2)$
- Values of prediction therefore follows the normal distribution $N(\mu_e + x_o, \sigma_e^2)$, where μ_e and σ_e^2 respectively correspond to the ensemble mean error and spread.
- If one considers $\sigma_e^2 = C_e(l) \cdot \sigma_o^2$ and assume an error growth function like $C_e(l) = \alpha l + \beta$, it can be modelled that error variance becomes greater as lead time of prediction becomes long (where σ_o^2 is the variance of true values of inflow).



GENERATION OF A SERIES OF ENSEMBLE INFLOW PREDICTION

- Randomly sample m values from a normal distribution which prediction errors follow and respectively add them to a true value to get an ensemble prediction with m members for each time step
- Generation of a series of prediction errors for each ensemble member using the following AR(1) model

$$\hat{e}(m, l) = \hat{e}(m, l - 1) \cdot \rho_L(1) + \gamma(m, l) \sqrt{1 - [\rho_L(1)]^2}$$

$$e(m, l) = \hat{e}(m, l) \cdot \sigma_e(l) + \mu_e(l)$$

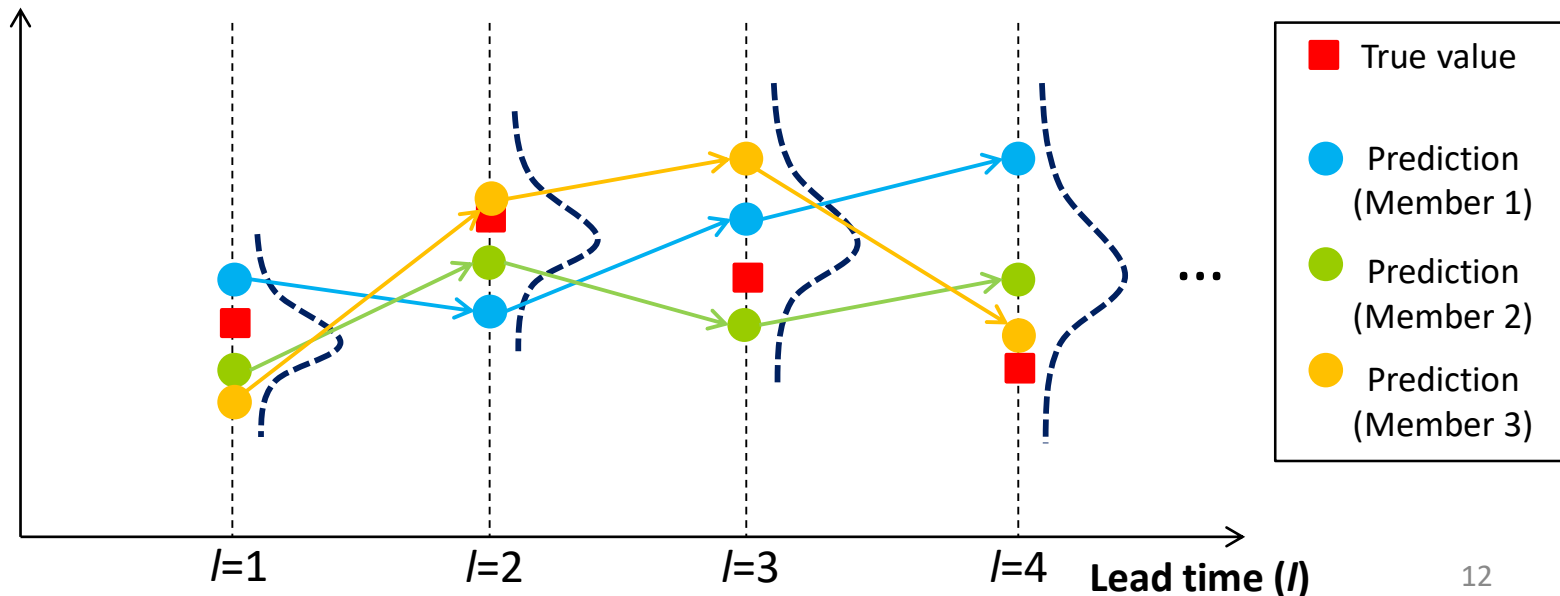
$$x^*(m, l) = x_o(m, l) + e(m, l)$$

$\hat{e}(m, l)$: Standardized prediction errors

$\rho_L(1)$: Serial correlation

$\gamma(m, l)$: A random value following $N(0, 1)$

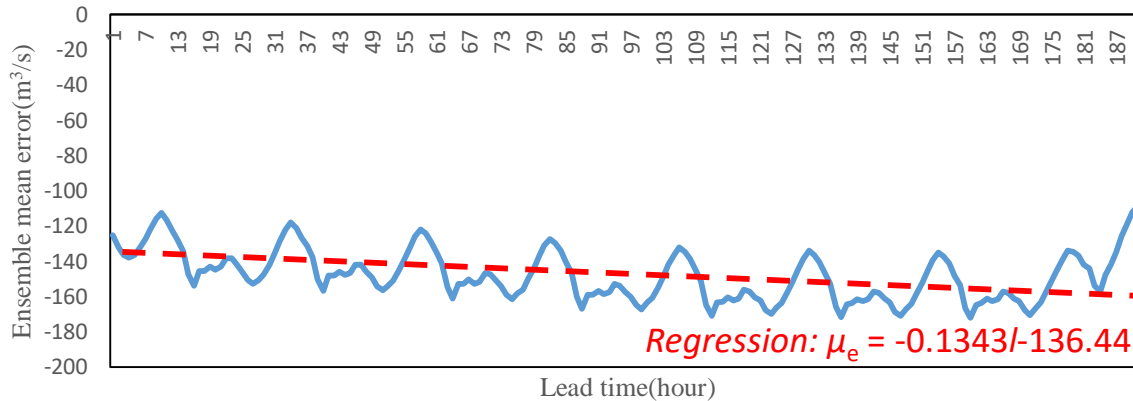
Inflow



ERROR PARAMETERS ESTIMATED FROM OPERATIONAL ENSEMBLE PREDICTION

Ensemble inflow prediction estimated from JMA's One-week Ensemble Forecast (JMA-EPSW) of precipitation with temporal range of 192 hours (8 days)

Averaged Ensemble Mean Errors of Ensemble Inflow Predictions

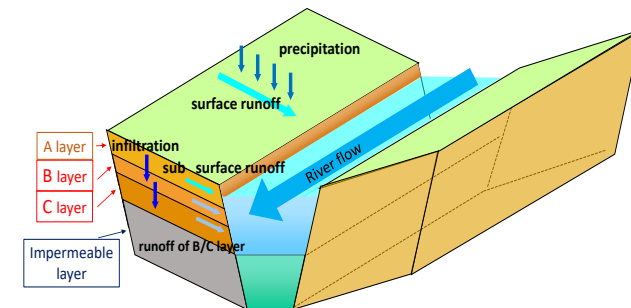
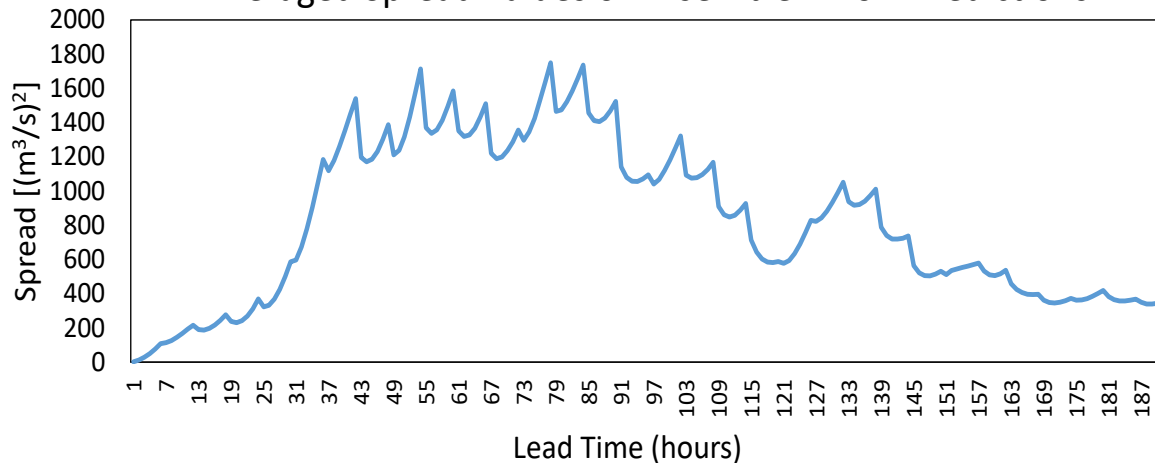


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(Valid Time: 01.29.12UTC)



Japan Meteorological Agency
JMA-EPSW

Averaged Spread Values of Ensemble Inflow Predictions



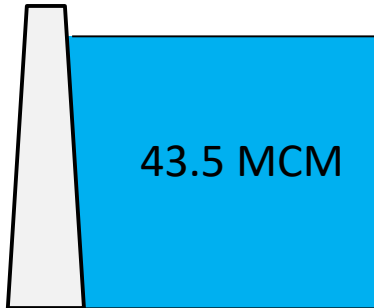
Hydro-BEAM
(Rainfall-runoff Model)

PRELIMINARY RELEASE OPERATION

Preliminary release operation rules of the Nagayasuguchi Reservoir

- **1st stage:** Water storage is decreased to **38.1 MCM** when inflow exceeds **70 m³/s**.
- **2nd stage:** Water storage is decreased to **32.5 MCM** when inflow is expected to exceed **500 m³/s**.

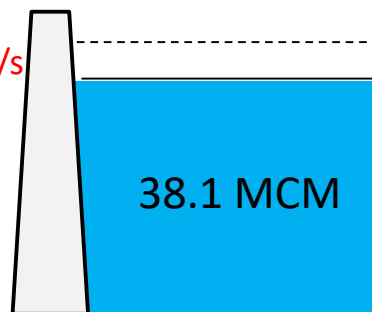
Keep high water level for water use (**Policy 1**)



$Q_{in} > 70 \text{ m}^3/\text{s}$



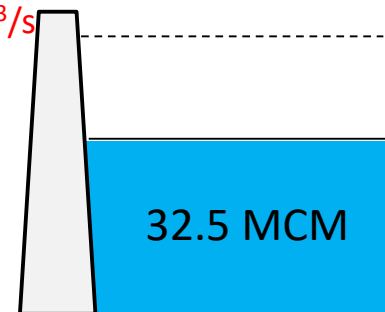
Preliminary release of 1st stage (**Policy 2**)



$Q_{in} > 500 \text{ m}^3/\text{s}$



Preliminary release of 2nd stage (**Policy 3**)



ASSESSMENT ON PRELIMINARY RELEASE OPERATION CONSIDERING ENSEMBLE INFLOW PREDICTION

Results of Monte Carlo simulation of reservoir operation with 1000 simulations to analyze impacts and risks of preliminary release operation considering ensemble inflow prediction

Results of simulations on preliminary release operation **when ensemble mean predictions were considered**

Events	Rate of simulations where preliminary release was conducted (%)	Rate of simulations where water storage recovered (%)	Storage rate after flood averaged over the simulations (%)
Flood 1	0.0	100.0	100.0
Flood 2	100.0	100.0	100.0

Results of simulations on preliminary release operation **when the ensemble member with the maximum value of prediction was considered**

Events	Rate of simulations where preliminary release was conducted (%)	Rate of simulations where water storage recovered (%)	Storage rate after flood averaged over the simulations (%)
Flood 1	99.7	96.7	99.9
Flood 2	100.0	100.0	100.0

CONCLUDING REMARKS

- A method to quantitatively analyze effects and risks of preliminary release operation of a multi-purpose reservoir considering ensemble inflow prediction was developed.
- A method of synthetic generation of ensemble hydrological predictions with a certain error characteristics was applied.
- Potential effects of preliminary release operation considering ensemble hydrological predictions on flood management or risk on water utilization can be quantified by using the proposed method employing error parameters derived from operational predictions
- Future tasks include:
 - Estimation of more realistic probabilistic distribution of prediction errors;
 - More case studies changing flood situations, target areas, or error parameter settings;
 - Providing information how good predictions should be to be successfully applied to preliminary release operation

**THANK YOU FOR YOUR ATTENTION !
ANY QUESTIONS?**