

A Theoretical Study on Adjustment of Reservoir Operating Rules using Ensemble Streamflow Forecasts

Yoon, Hae Na, Seo, Seung Beom, Cho, Younghyun, and Kim, Young-Oh

Research Group for **C**limate **C**hange **A**daptation in **W**ater **R**esources

Dept. of Civil & Environmental Engineering

Seoul **N**ational **U**niversity, Korea

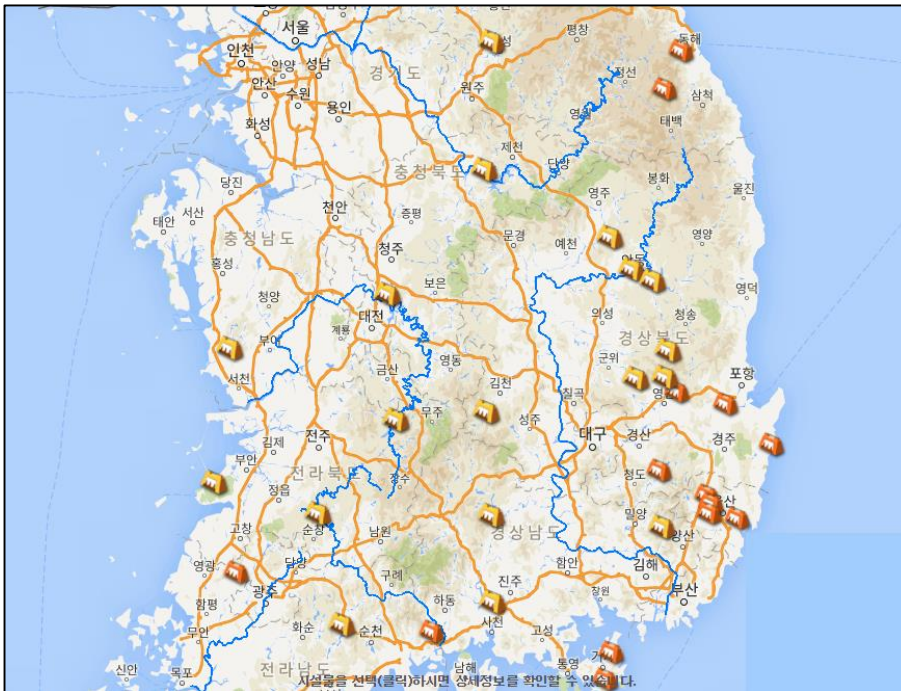


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Reservoir Operation in Korea

• Dams in Korea

- 20 multipurpose dams and 14 water storage dams are responsible for the water supply of the nearby watershed



Dams in Korea, K water

**If the dam
operation fails..**



Drought!

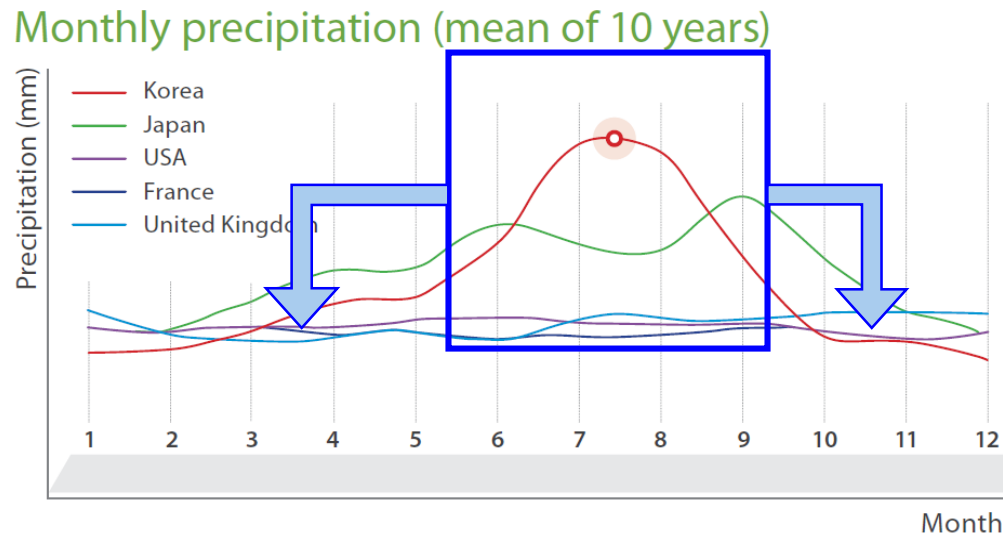


Flood !

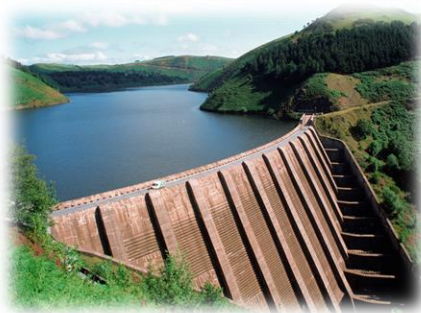
Introduction

• Characteristics of Water Resources in the Korean Peninsula

- 2/3 of annual precipitation (1300 mm) occurs in 3 month period (June to September)



- It is important to store water during summer and use it appropriately in drawdown period

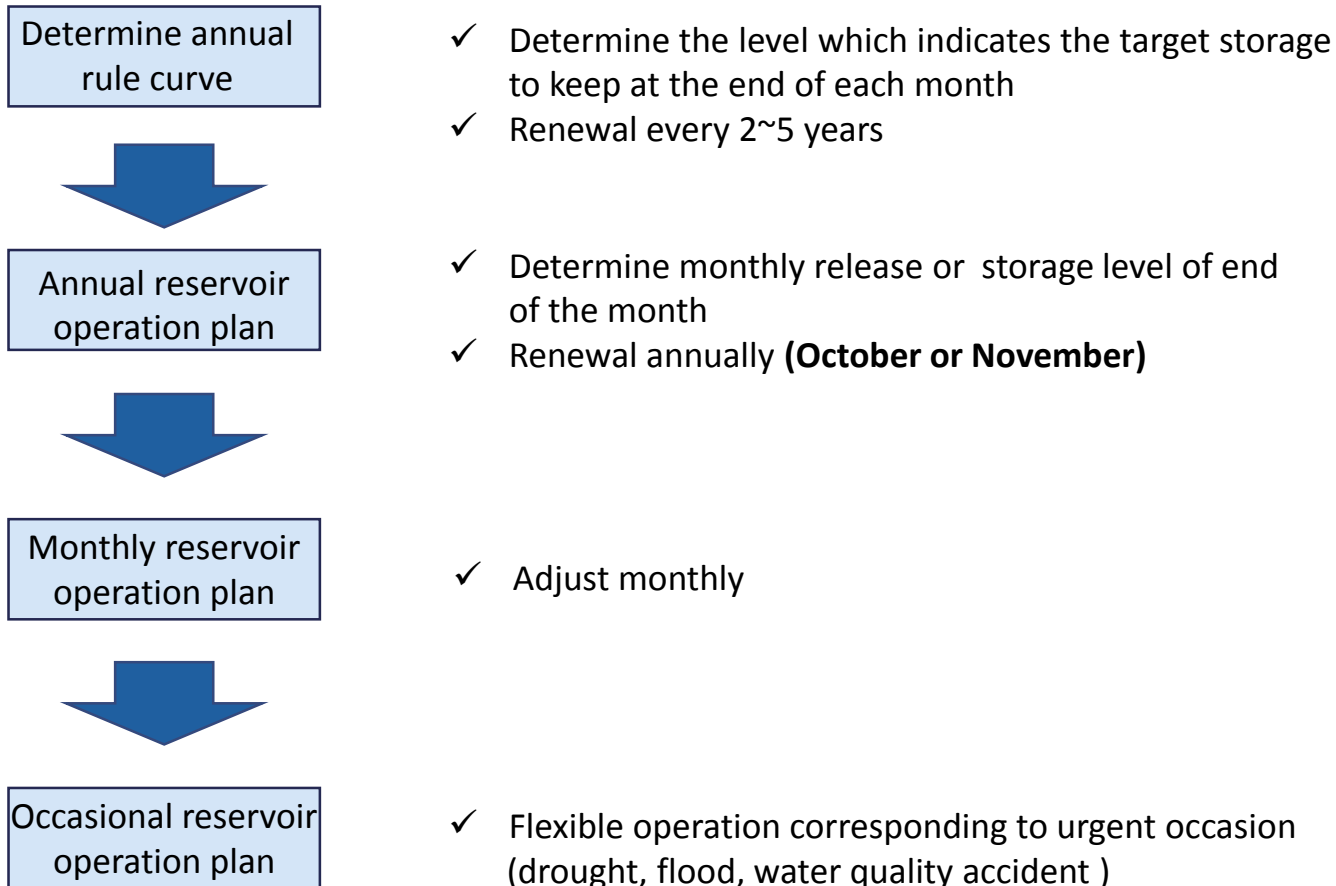


*Dam operates to store water
in the flood season (June ~ September)
and supply water during the
drawdown season (November ~ May)*

Reservoir Operation in Korea

- Current dam operation rule in Korea

- Operation rule based on the annual rule curve



Reservoir Operation in Korea

• Current dam operation rule in Korea

- Operation rule based on the **annual rule curve**

- Methods to determine annual rule curve

- ◆ Based on storage equation :

$$S_{t+1} = S_t + Q_t - R_t$$

Annual rule curve

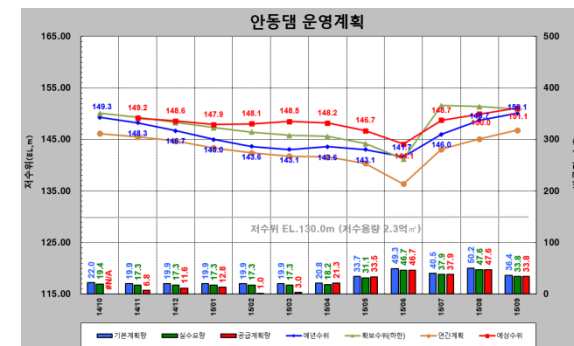
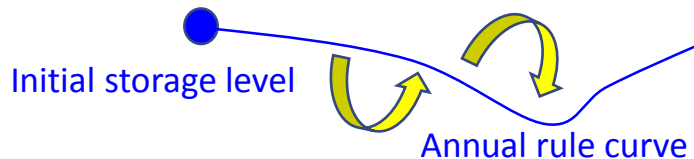
5% quantile of inflow

Annual planned release (water supply)

Calculated with historical data

- Monthly adjustment

- ◆ Adjust the plan of monthly release to fit the rule curve

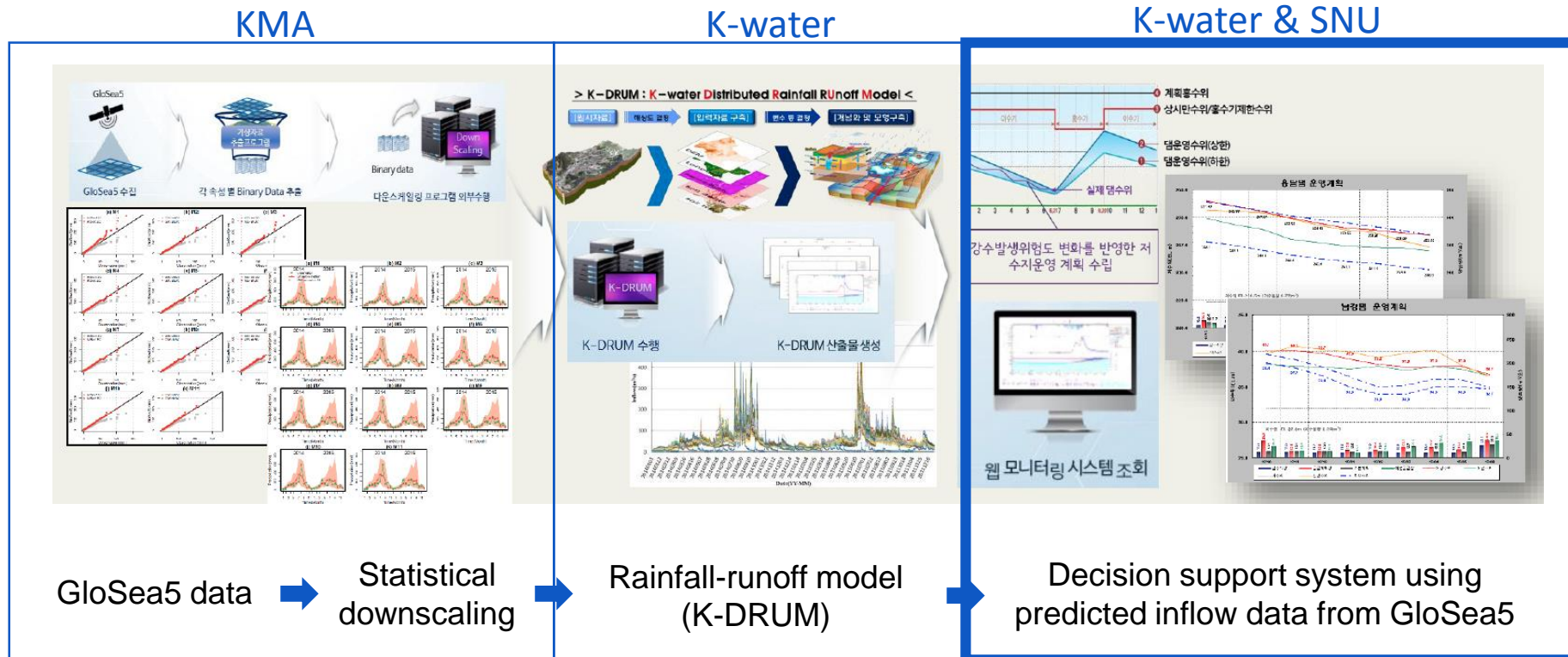


Andong dam's annual rule curve, K water (2015)

Reservoir operation using Glosea5

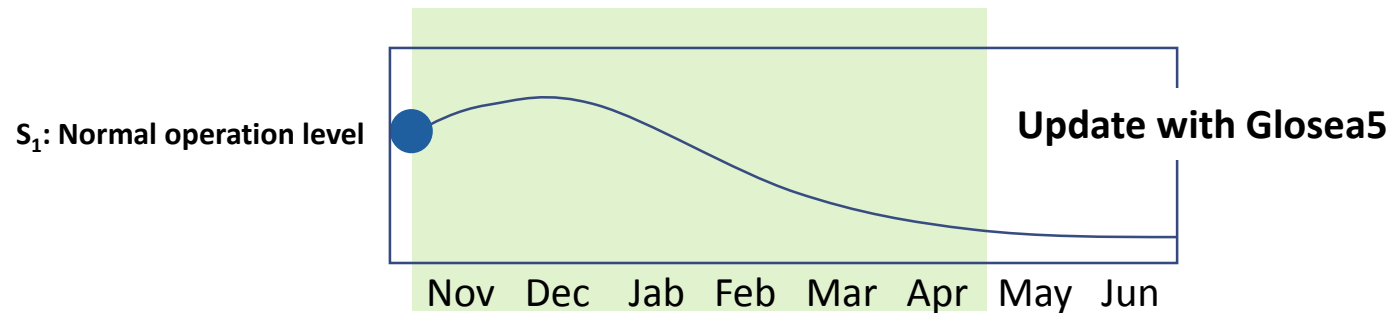
- **Glosea5 in Korea : forecasting system generates ensemble forecasts**

- In Korea, KMA has started to utilize GloSea5 for ensemble forecasts of climate forcing.
- Ensemble forecasts of dam inflow are driven by K-DRUM.
- K-water are going to propose decision support system using these data.



Reservoir operation using Glosea5

- Objective** Modify annual rule curve!



$$S_{t+1} = S_t + Q_t - R_t$$

5% quantile of inflow

Calculated with historical data

Update 5% quantile of inflow
with ensemble forecasts
of inflow (G)

$$q_t^{5\%} = F_{Q_t}^{-1}(0.05)$$

$$q_t^{*5\%} = F_{Q_t|G}^{-1}(0.05)$$

Reservoir operation using Glosea5

• How to modify 5% quantile of inflow

- The distribution of inflow estimated from past data is considered as prior information
- The 5% quantile of inflow is updated as the posterior distribution obtained by combining prior information and new information from ensemble forecasts

$$F_{Q_t|G_t \leq g_t}(q_t) = P(Q_t \leq q_t | G_t \leq g_t) = \frac{P(G_t \leq y_t | Q_t \leq q_t)P(Q_t \leq q_t)}{P(G_t \leq g_t)}$$

$P(Y_t \leq y_t | Q_t \leq q_t)$: Cumulative probability of ensemble forecasts conditioned by observed inflow

$P(Q_t \leq q_t)$: Cumulative probability of observed inflow

$P(G_t \leq g_t)$: Cumulative probability of ensemble forecasts

- Adjustment 5% quantiles of inflow : $q_t^{5\%} \rightarrow q_t^{*5\%}$

Find $q_t^{*5\%}$

$$\text{where } 5\% = F_{Q_t|G_t \leq g_t}(q_t^{*5\%}) = P(Q_t \leq q_t^{*5\%} | G_t \leq g_t = q_t^{5\%}) = \frac{P(G_t \leq q_t^{5\%} | Q_t \leq q_t^{*5\%})P(Q_t \leq q_t^{*5\%})}{P(G_t \leq q_t^{5\%})}$$

Reservoir operation using Glosea5

• How to modify 5% quantile of inflow

Find $q_t^{*5\%}$

$$\text{where } 5\% = F_{Q_t | G_t \leq g_t}(q_t^{*5\%}) = P(Q_t \leq q_t^{*5\%} | G_t \leq g_t = q_t^{*5\%}) = \frac{P(G_t \leq q_t^{*5\%} | Q_t \leq q_t^{*5\%}) P(Q_t \leq q_t^{*5\%})}{P(G_t \leq q_t^{*5\%})}$$

Calculate from
historical data

Calculate from
Glosea5 inflow data

▫ Distribution of “G|Q”

- From Stedinger and Kim (2010)

$$[G | Q = q] \sim N[\mu_G + \sigma_p^2 / \sigma_\varepsilon^2 (q - \mu_Q), \sigma_p^2]$$

where

$$\sigma_p^2 = \sigma_\varepsilon^2 (1 - \sigma_\varepsilon^2 / \sigma_Q^2)$$

$$\sigma_\varepsilon^2 = \sigma_Q^2 - \sigma_G^2$$

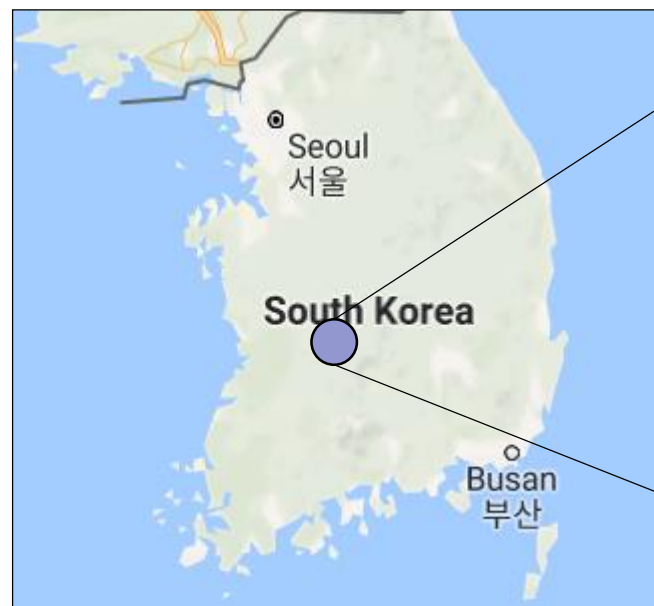
$$G \sim (\mu_G, \sigma_G^2)$$

$$Q \sim (\mu_Q, \sigma_Q^2)$$

$$Q = G + \varepsilon, \varepsilon \sim N(\mu_Q - \mu_G, \sigma_\varepsilon^2)$$

Application

- Application cite : Yongdam Dam



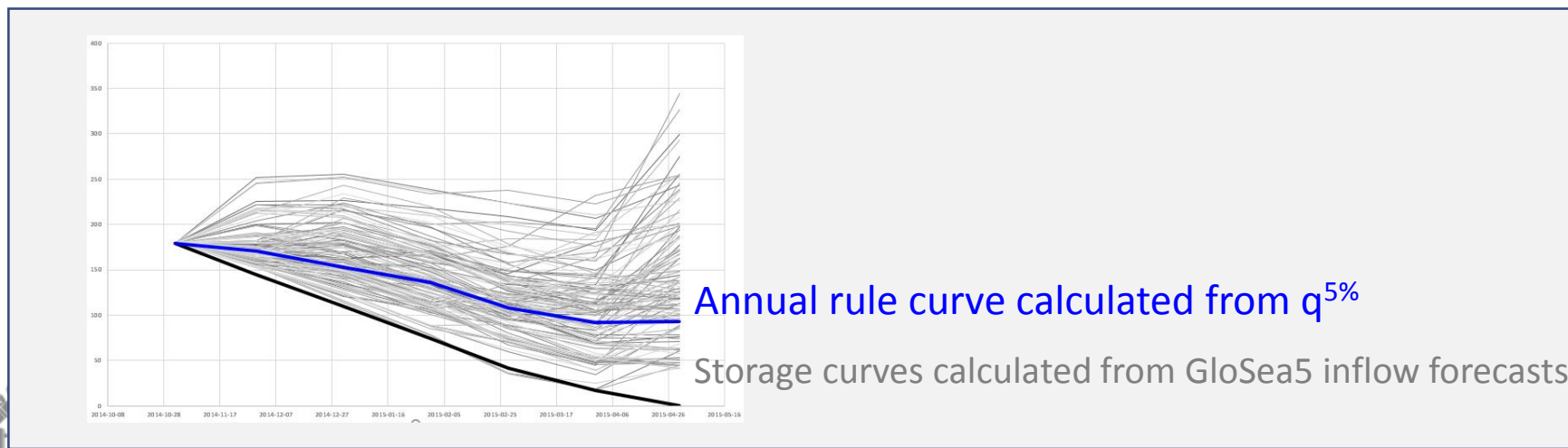
< Basin of Yongdam >



Application

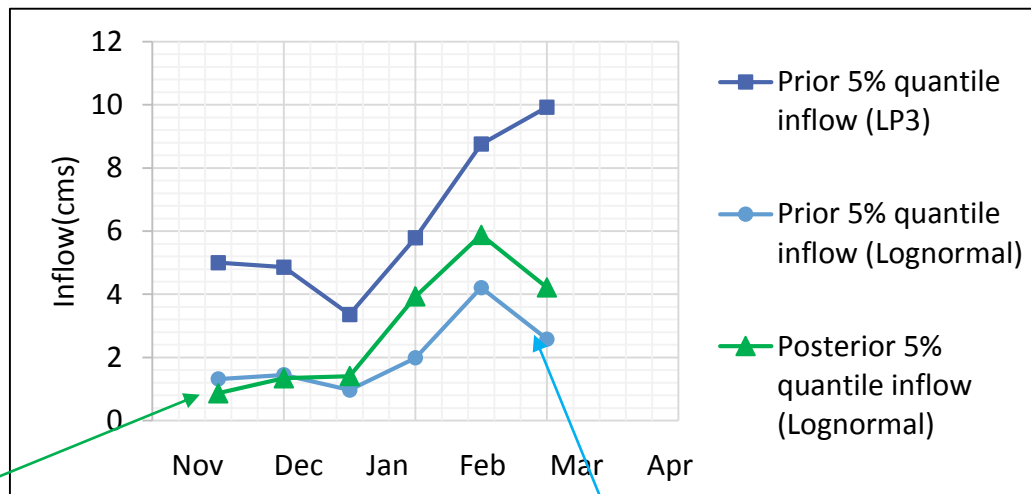
- **Forecast period : November, 2014 ~ April, 2015**
 - Observed Data : 2002~ 2013 (12 years)
 - GloSea5 Data : November, 2014 ~ April, 2015
- **Current 5% quantile of inflow vs GloSea5 inflow forecasts**

Month	November	December	January	February	March	April
5% quantile inflow ($q^{5\%}$) (cms)	5	4.86	3.36	5.79	8.75	9.92
Non-exceedance probability of GloSea5 inflow forecasts below $q^{5\%}$	0.50%	2.80%	6.36%	38.94%	24.51%	0.67%



Results

- Adjusting 5% quantile inflow using GloSea5 inflow data



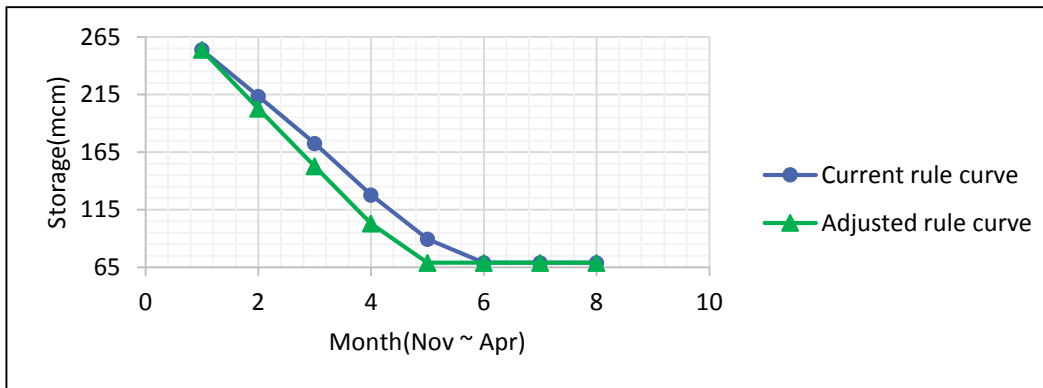
Find $q_t^{*5\%}$

$$\text{where } 5\% = F_{Q_t | G_t \leq g_t}(q_t^{*5\%}) = P(Q_t \leq q_t^{*5\%} | G_t \leq g_t = q_t^{5\%}) = \frac{P(G_t \leq q_t^{5\%} | Q_t \leq q_t^{*5\%})P(Q_t \leq q_t^{*5\%})}{P(G_t \leq q_t^{5\%})}$$

Results

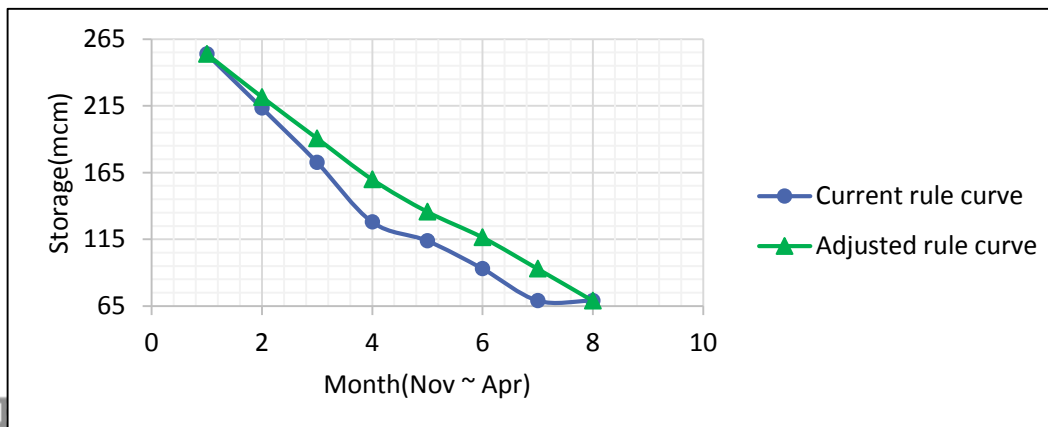
• Adjusting annual rule curve

- Simply calculate with storage equation.



$$S_{t+1}^* = S_t^* + (q_t^{*5\%}) - R_t$$

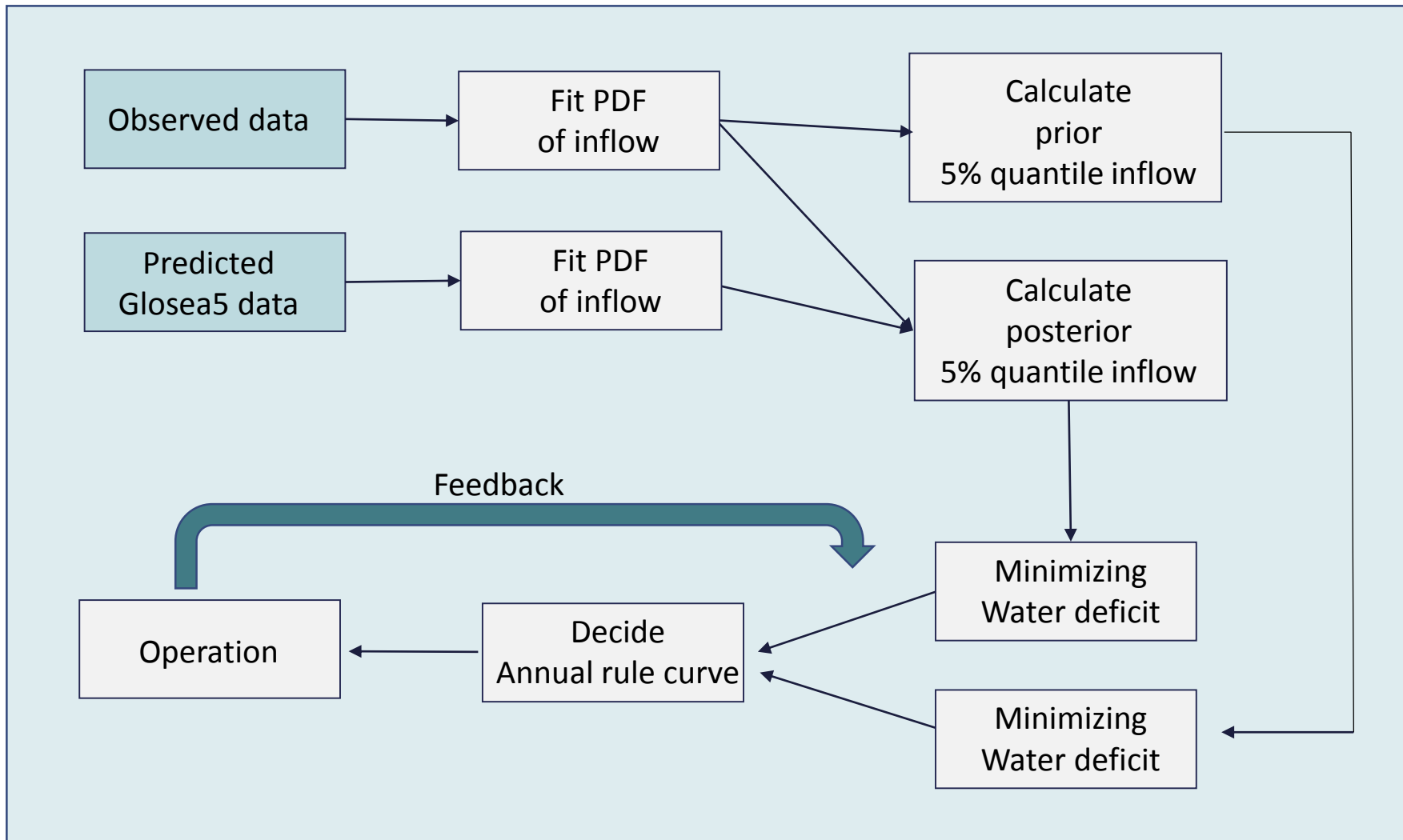
- Optimize storage curve to minimize water deficit in drawdown period.



$$\text{Minimize } | \text{Demand}_t - R_t |^2$$

Results

- Decision support system



Conclusion

- **Conclusion**

- Using the Bayesian concept, we proposed a method to modify the historical 5% quantile of inflow with 1 year forecast data.
- We provide guidelines that can be applied to the dam (reservoir) operation using forecast data.

- **Future works**

- Verification of this methodology with more of data.

References

- Croley, T. E. "Using meteorology probability forecasts in operational hydrology." *American Society of Civil Engineers*, 2000.
- Day, G. N. "Extended streamflow forecasting using NWSRFS." *Journal of Water Resources Planning and Management* 111.2 (1985): 157-170.
- Faber, B. A., and Stedinger, J. R. "Reservoir optimization using sampling SDP with ensemble streamflow prediction (ESP) forecasts." *Journal of Hydrology* 249.1 (2001): 113-133.
- K water물관리 센터. "댐 운영기준 및 대응절차 개선방안" (2014)
- Stedinger, J. R., and Kim, Y. O. "Probabilities for ensemble forecasts reflecting climate information." *Journal of hydrology* 391.1 (2010): 9-23.
- Kim, Y. O., Jeong, D. I., and Kim, H. S. "Improving water supply outlook in Korea with ensemble streamflow prediction." *Water international* 26.4 (2001): 563-568.

Thank you

