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 Climate Change Adaptation in Water Resources

Dept. of Civil & Environmental Engineering

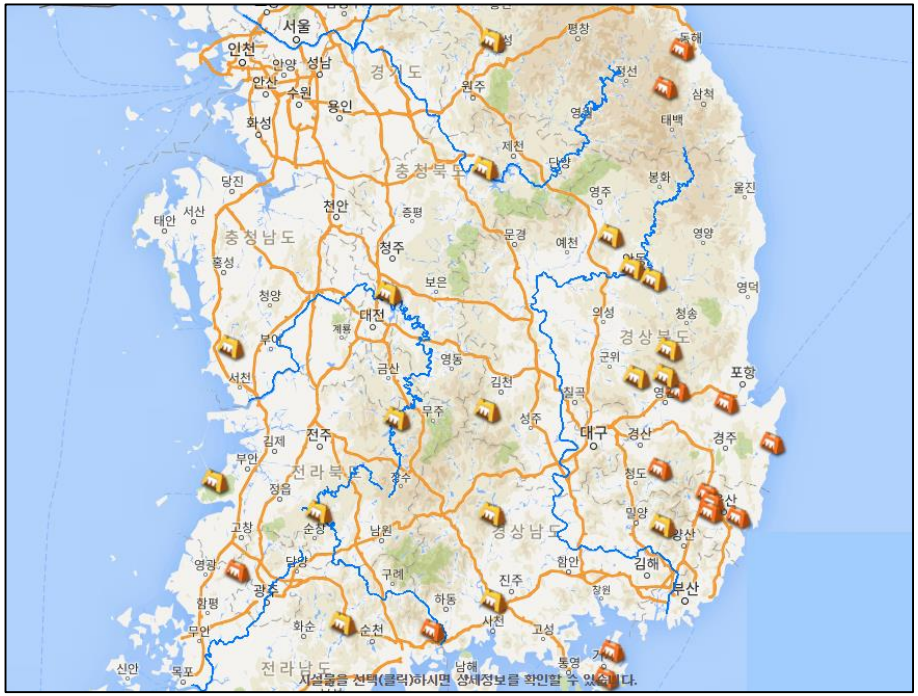
Seoul National University, Korea

K water

ENGINEERING
COLLEGE OF ENGINEERING
SEOUL NATIONAL UNIVERSITY

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

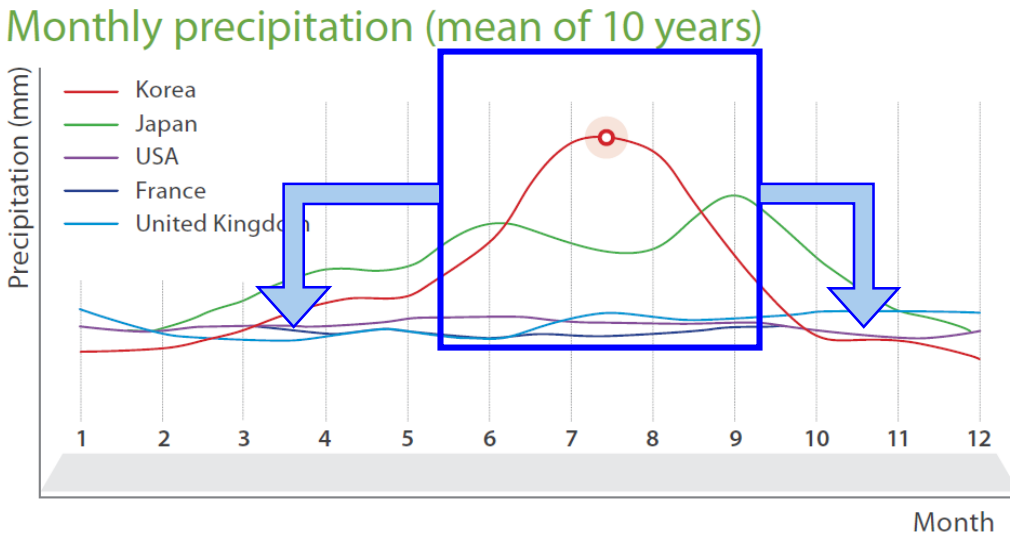
If the dam operation fails..

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)**

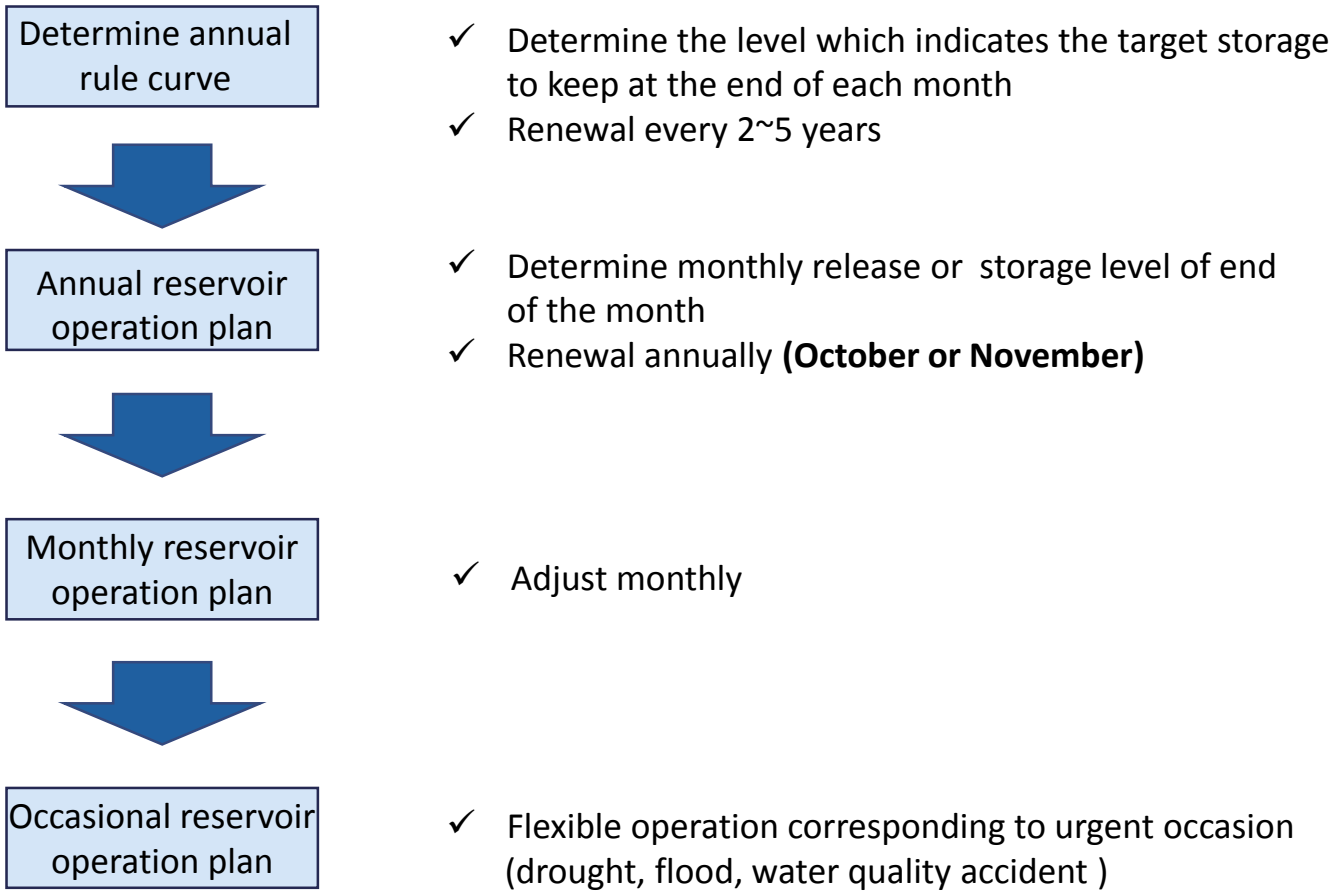


  - **It is important to store water during summer and use it appropriately in drawdown period**

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**



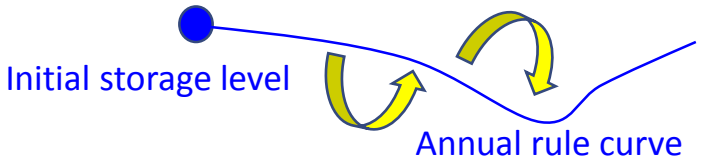
Reservoir Operation in Korea

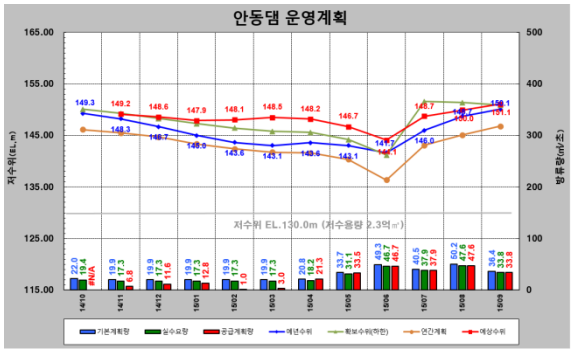
- **Current dam operation rule in Korea**
  - Operation rule based on the **annual rule curve**
    - Methods to determine annual rule curve
      - Based on storage equation : $S_{t+1} = S_t + Q_t - R_t$

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



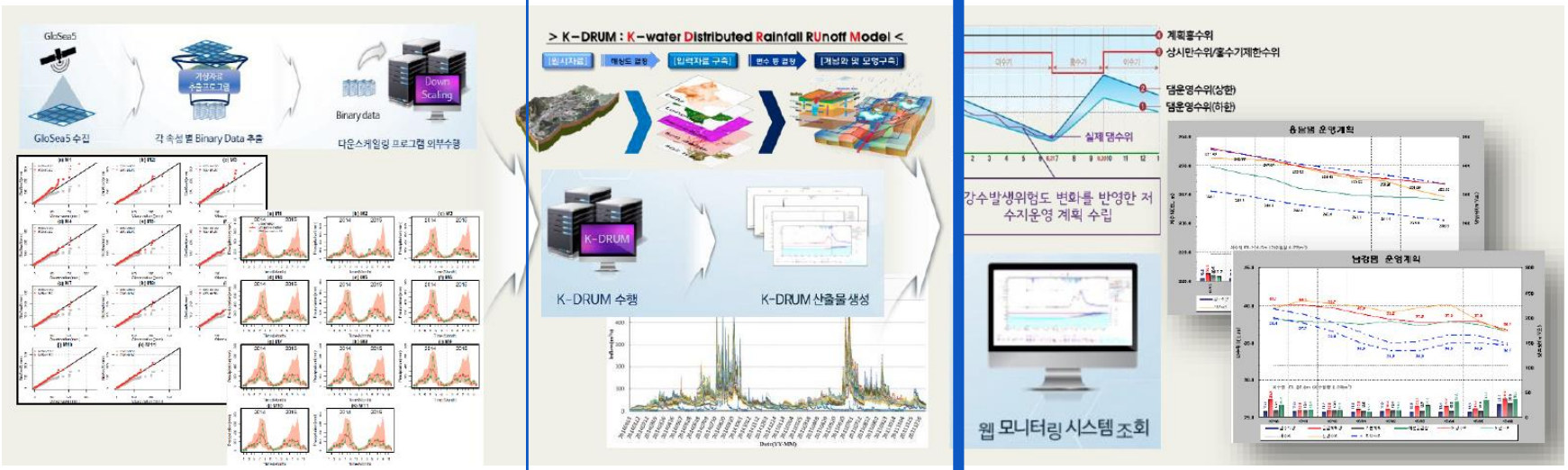


Andong dam's annual rule curve, K water (2015)

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.

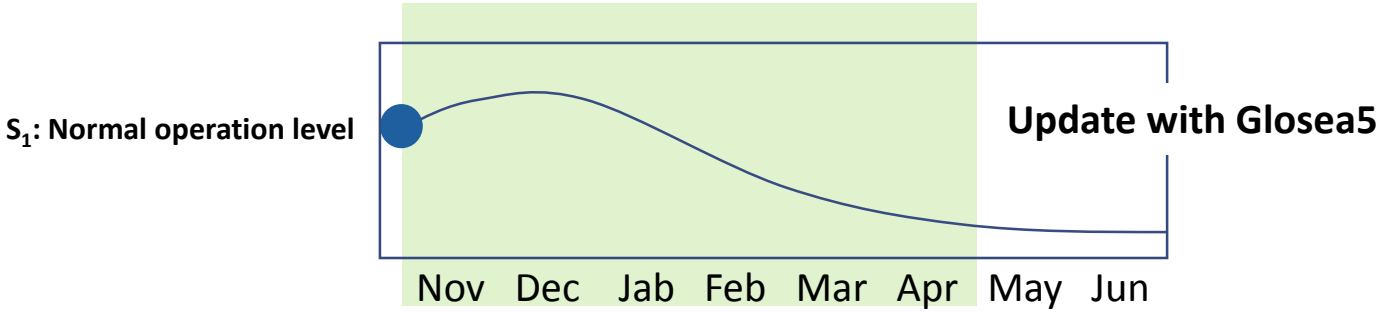
KMA | K-water | K-water & SNU



GloSea5 data → Statistical downscaling → Rainfall-runoff model (K-DRUM) → Decision support system using predicted inflow data from GloSea5

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 esnsemble forecasts

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

$P(Y_t \le y_t \mid Q_t \le q_t)$: Cumulative probability of esnsemble forecasts conditioned by observed inflow

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

$P(G_t \le g_t)$: Cumulative probability of esnsemble forecasts

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

Find $q_t^{*\,5\%}$

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

Reservoir operation using Glosea5

- **How to modify 5% quantile of inflow**

$$Find \quad q_t^{*5\%}$$

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

Calculate from historical data

Calculate from Glosea5 inflow data

- Distribution of "G|Q"
  - From Stedinger and Kim (2010)

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

where

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

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

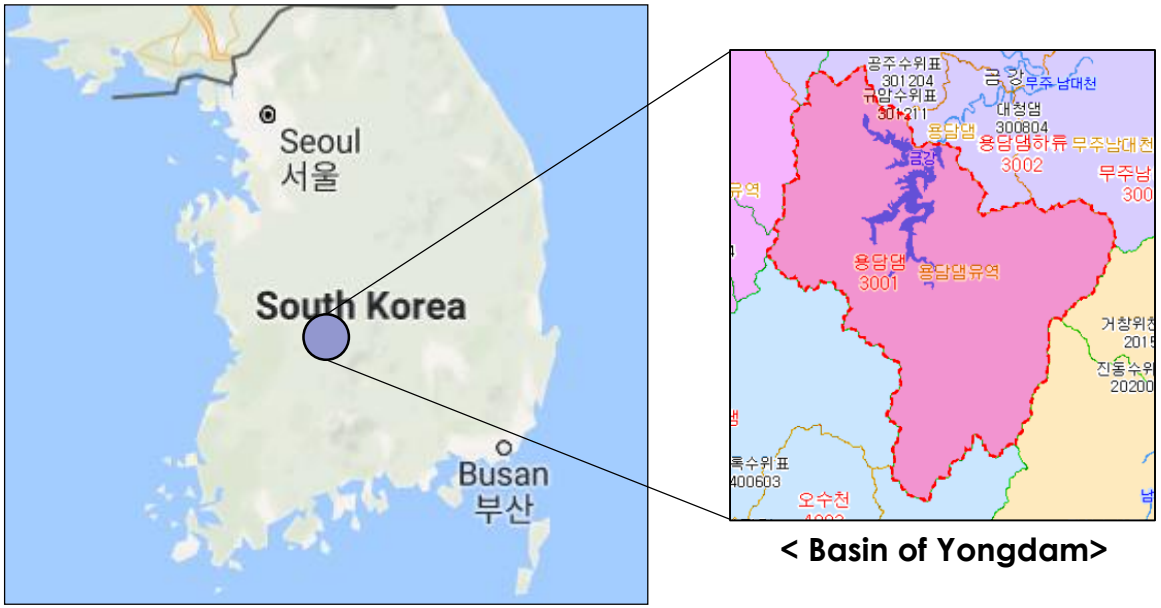
$$G \sim (\mu_G, \sigma_G^2)$$

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

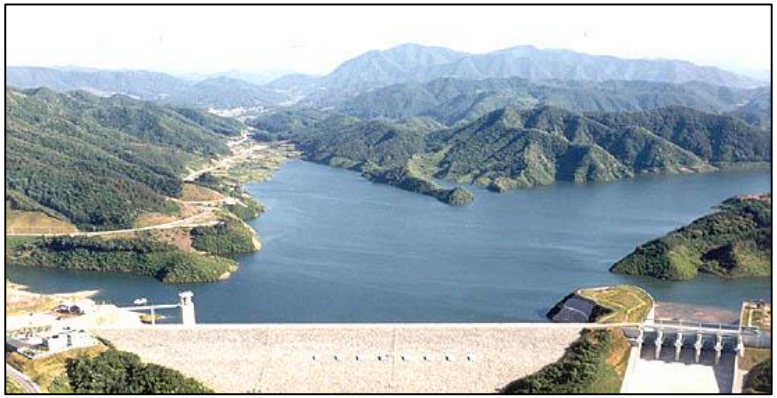
$$Q = G + \varepsilon, \ \varepsilon \sim N(\mu_Q - \mu_G, \sigma_\varepsilon^2)$$

Application

- **Application cite : Yongdam Dam**



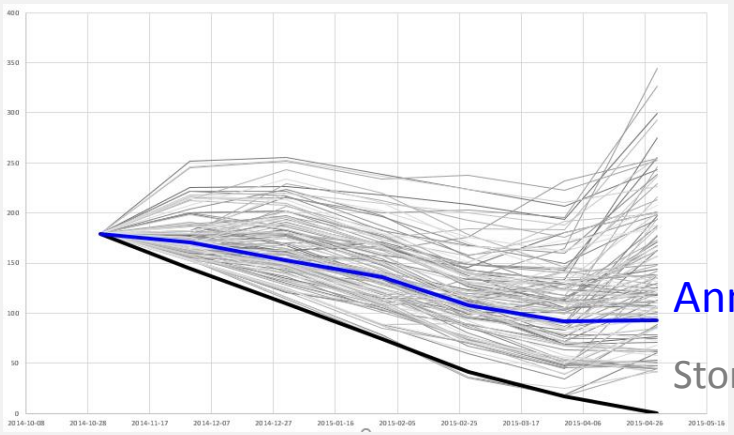
< Basin of Yongdam>



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%

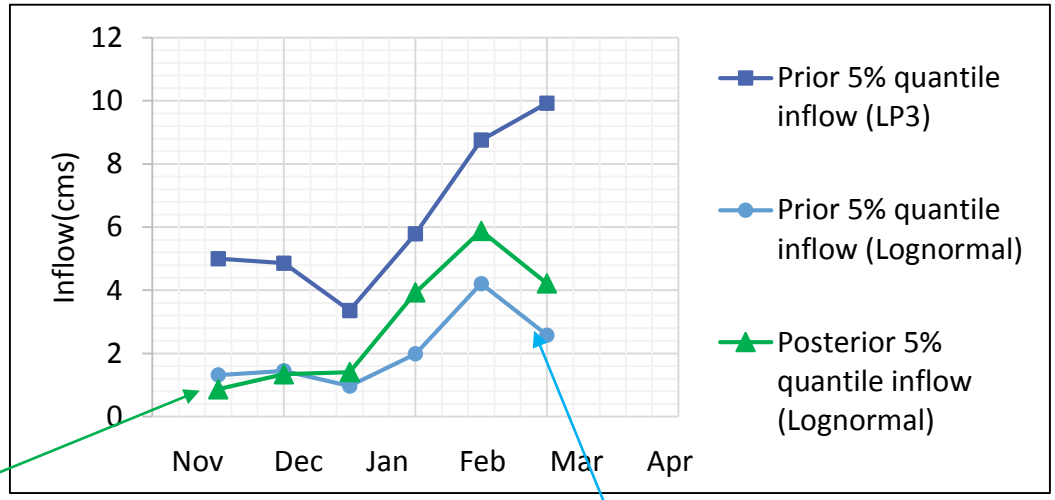


Annual rule curve calculated from $q^{5\%}$

Storage curves calculated from GloSea5 inflow forecasts

Results

- **Adjusting 5% quantile inflow using GloSea5 inflow data**

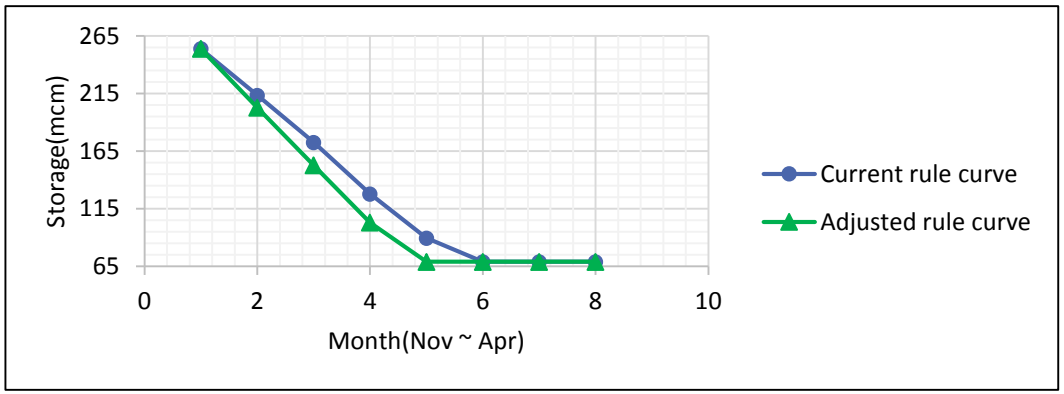


Find $q_t^{*5\%}$

where $5\% = F_{Q_t|G_t \le g_t}(q_t^{*5\%}) = P(Q_t \le q_t^{*5\%} \mid G_t \le g_t = q_t^{5\%}) = \dfrac{P(G_t \le q_t^{5\%} \mid Q_t \le q_t^{*5\%})P(Q_t \le q_t^{*5\%})}{P(G_t \le q_t^{5\%})}$

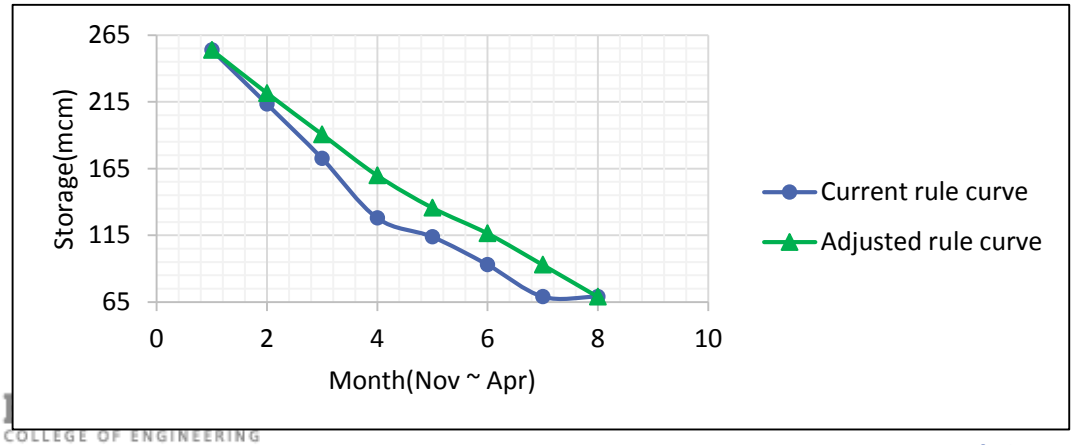
Results

- **Adjusting annual rule curve**
  - Simply calculate with storage equation.



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

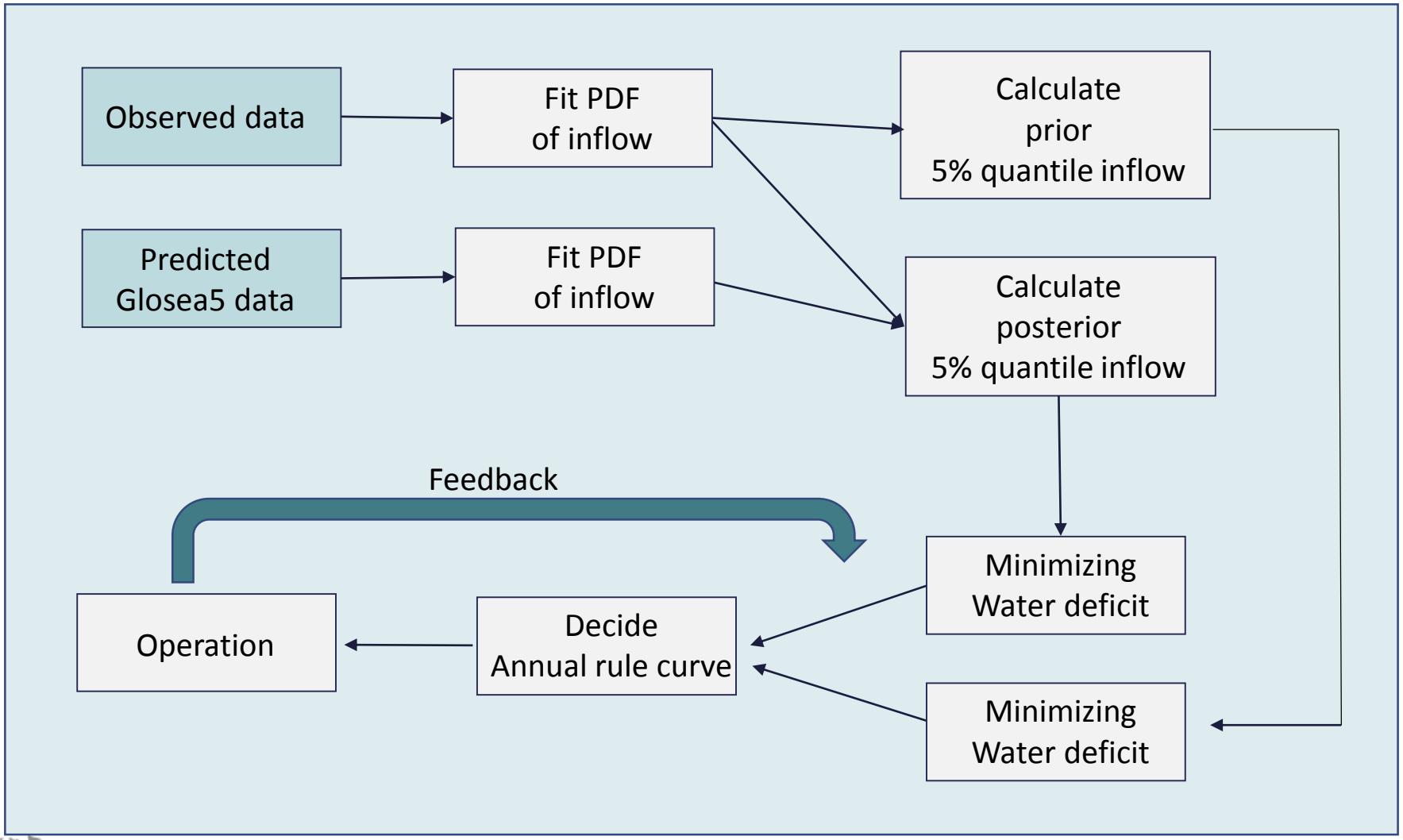
  - Optimize storage curve to minimize water deficit in drawdown period.



$$\underset{S_t^{*}}{Minimize} \left| Demand_t - R_t \right|^2$$

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 water 물관리 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