# Assessment of Anti-Drought Capacity by Future Dry Climate for Boryeong Dam using SWAT

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SWAT Soil & Water Assessment Tool

KU KONKUK UNIVERSITY

# Introduction

- Climate change is one of the major challenges of our time and adds considerable stress to our societies and also to the environment.
- Without drastic action today, adapting to climate change impacts in the future will be more difficult and will need more cost.
- Drought in South Korea became a frequent phenomenon since 2000 and recently we suffered extreme droughts for three continuous years (2014, 2015, 2016).
- In particular, Boryeong Dam water storage dropped to below 30% and the residents had suffered restricted water uses.
- It is helpful to evaluate the risk of extreme drought like 2014~2016 in advance through long-term prediction by using available climate change scenarios for a target dam watershed.

# Flowchart

## *SWAT Modeling*

### *Observed Data*

- *Weather data (1980-2017) (Precipitation, Solar Radiation, Temperature, Wind Speed, Radiation Hour)*
- *Multipurpose water supply dam (1980-2017)*
    - *Dam sources*

### *GIS Data*

- *DEM*
- *Land Use*
- *Soil*

## *GCM Climate Change Scenario*

- *RCP 4.5*
- *RCP 8.5*
- *Precipitation, Temperature*

### *SPI Index*

- *Precipitation(2000-2099)*
- *Extreme drought scenario determination*

### *Verification*

- *Calibration and validation*
- *Dam inflow (2007-2016)*
- *Dam storage*
- *Dam operation (2007-2016)*

### *Future dam release*

- *Multiple Linear Regression Analysis*
- *Based on observed data*

### *Extreme Drought Scenario*

- *Magnitude*
- *Duration*
- *Longest dry period*
- *Driest Scenario among RCP 4.5 and RCP 8.5*

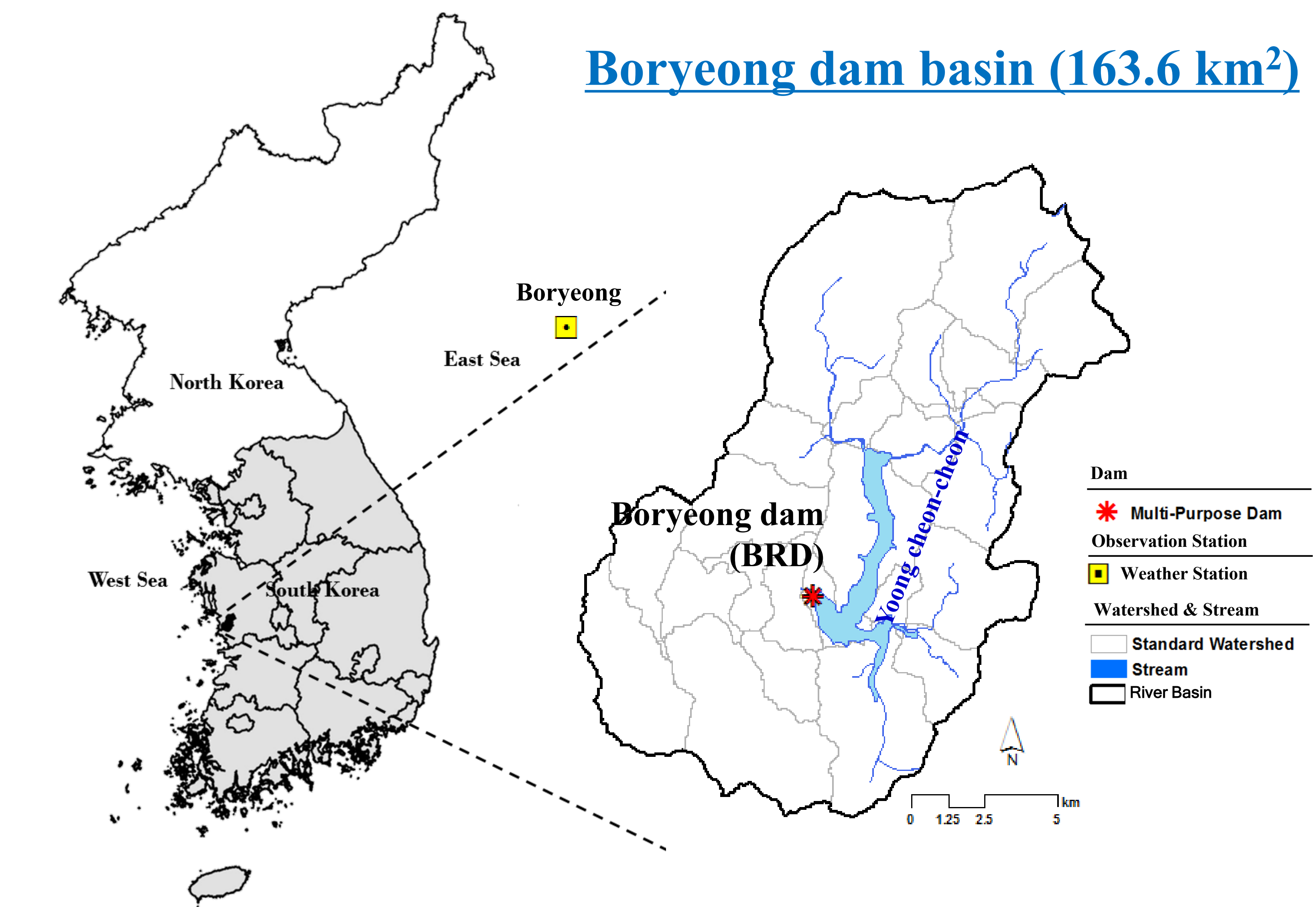
## *SWAT Model Generation*

- *Model run (2007-2046)*
- *Calibrated and Validated Parameters*
- *Future Dam Release*
- *Extreme Drought Scenario*

## *Anti-drought Capacity Assessment*

- *Runs Theory*
- *Frequency Analysis*
- *Hydrology evaluation*

# Study area

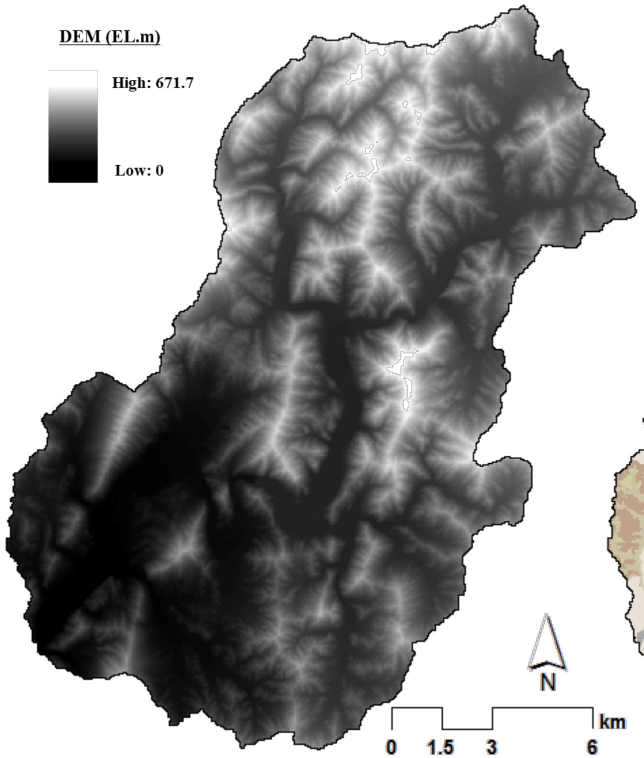

Boryeong dam basin (163.6 km²)
Boryeong
East Sea
North Korea
West Sea
South Korea
Boryeong dam
(BRD)
Yoong cheon-cheon
Dam
Multi-Purpose Dam
Observation Station
Weather Station
Watershed & Stream
Standard Watershed
Stream
River Basin
N
km
0
1.25
2.5
5

# SWAT model

## GIS Data

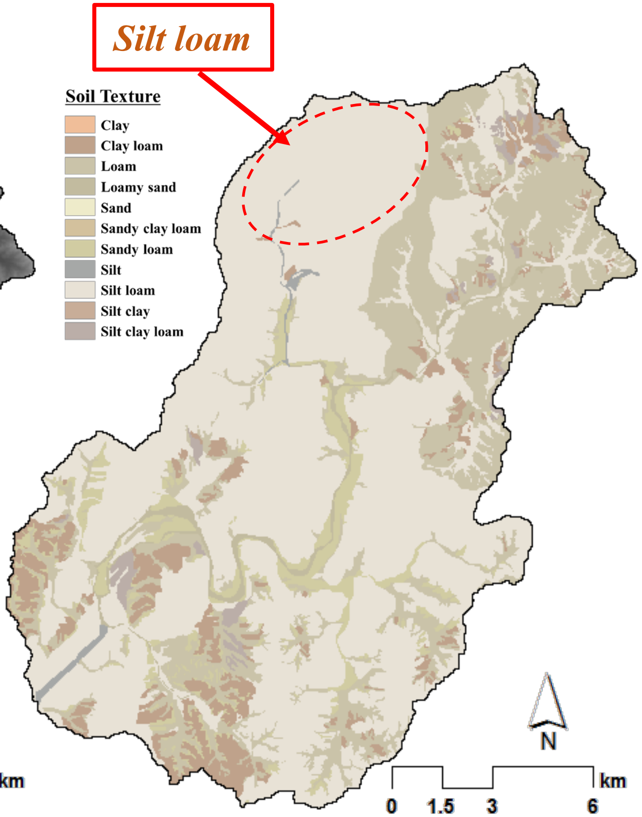
(a) DEM

Elevation : 0 – 671.7m
(30m grid size)



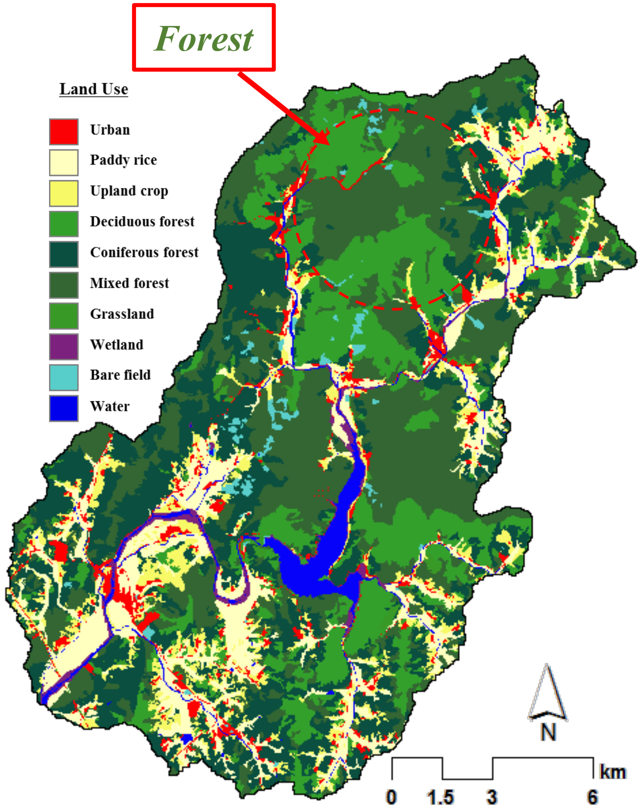

(b) Soil

Soil : Silt loam (62%) and
loam (22%)




(c) Land Use

Land Use (2008) : Forest (71%)
and paddy rice (12%)

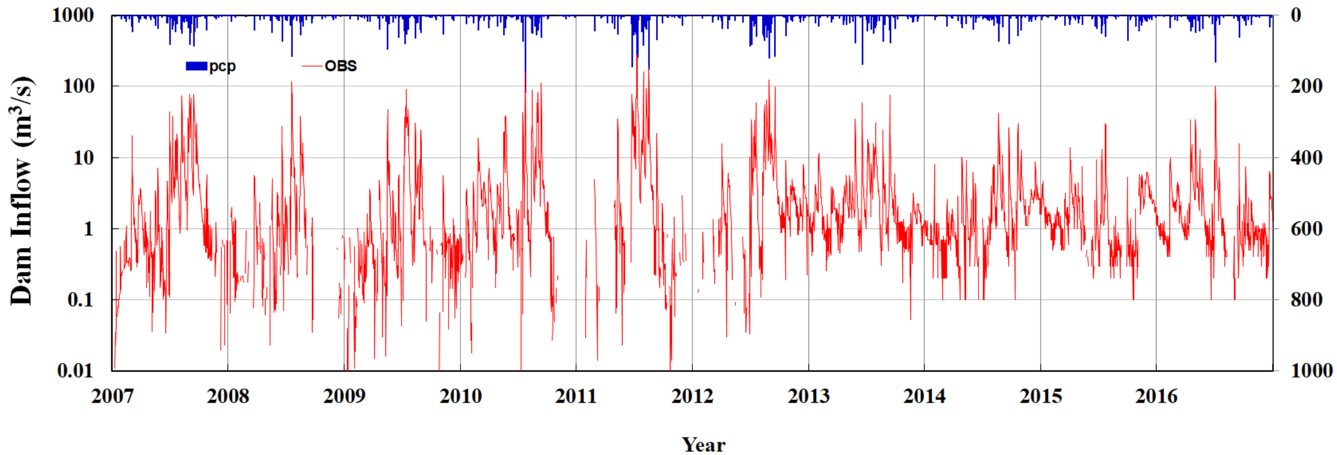


# SWAT model

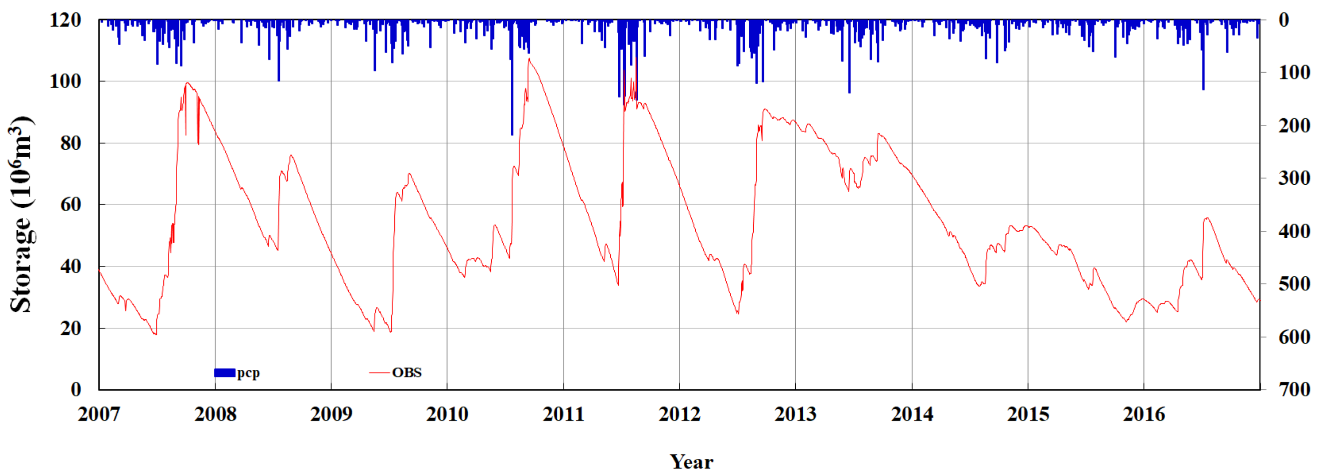
## Observed Data

www.wamis.go.kr
Water Management Information System

### Dam inflow data (2007-2016)




### Dam storage data (2007-2016)



# SWAT model

## Calibration and Validation

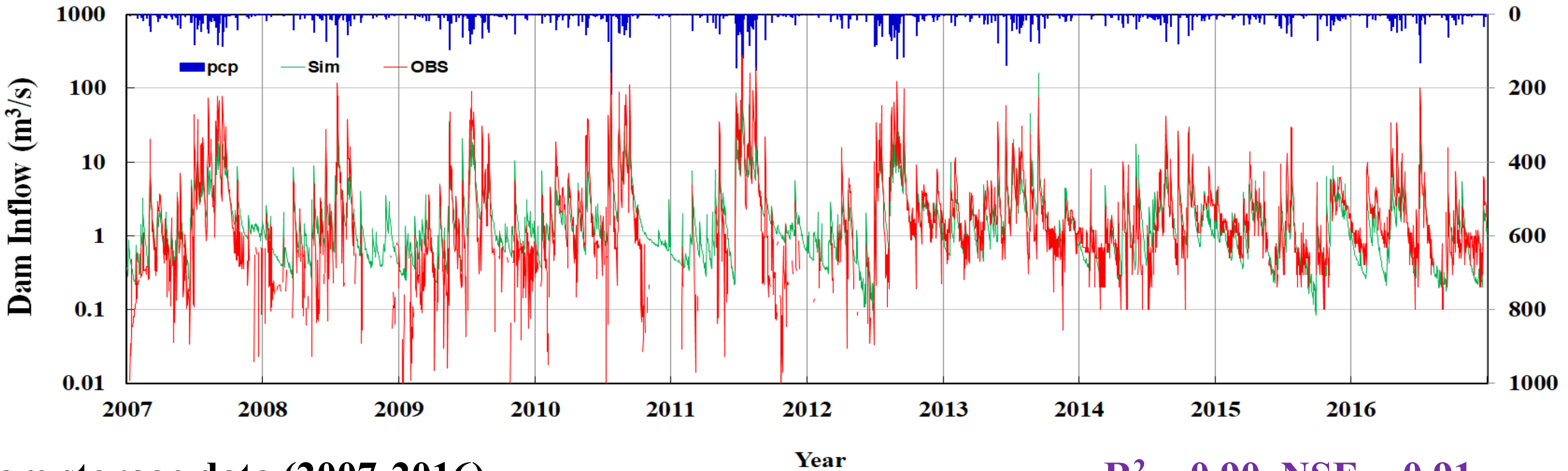
| Parameters | Definition | Range | Adjusted value |
|---|---|---|---|
| **Surface runoff** | | | |
| **CN2** | SCS curve number for moisture condition | 35 to 98 | +10 |
| **Evapotranspiration** | | | |
| **ESCO** | Soil evaporation compensation coefficient | 0 to 1 | 0.4 |
| **CANMX** | Maximum canopy storage | 0 to 100 | 11 |
| **Lateral flow** | | | |
| **SLOIL** | Slope length of lateral subsurface flow (m) | 0 to 150 | 0 |
| **LAT_TIME** | Lateral flow travel time (days) | 0 to 180 | 7 |
| **Groundwater** | | | |
| **GW_DELAY** | Delay time for aquifer recharge (days) | 0 to 500 | 100 |
| **ALPHA_BF** | Base flow recession constant | 0 to 1 | 0.6 |
| **Reservoir** | | | |
| **RES_ESA** | Reservoir surface area when the reservoir is filled to the emergency spillway (ha) | - | 690 |
| **RES_EVOL** | Volume of water needed to fill the reservoir to the emergency spillway (104 m3) | - | 11335.5 |
| **RES_PSA** | Reservoir surface area when the reservoir is filled to the principal spillway (ha) | - | 672 |
| **RES_PVOL** | Volume of water needed to fill the reservoir to the principal spillway (104 m3) | - | 10693.3 |
| **RES_VOL** | Initial reservoir volume(104 m3) | - | 8997.8 |
| **RES_K** | Hydraulic conductivity of the reservoir bottom (mm/hr) | 0 to 1 | 0.7 |
| **EVRSV** | Lake evaporation coefficient | 0 to 1 | 0.7 |

# SWAT model

## Calibration and Validation

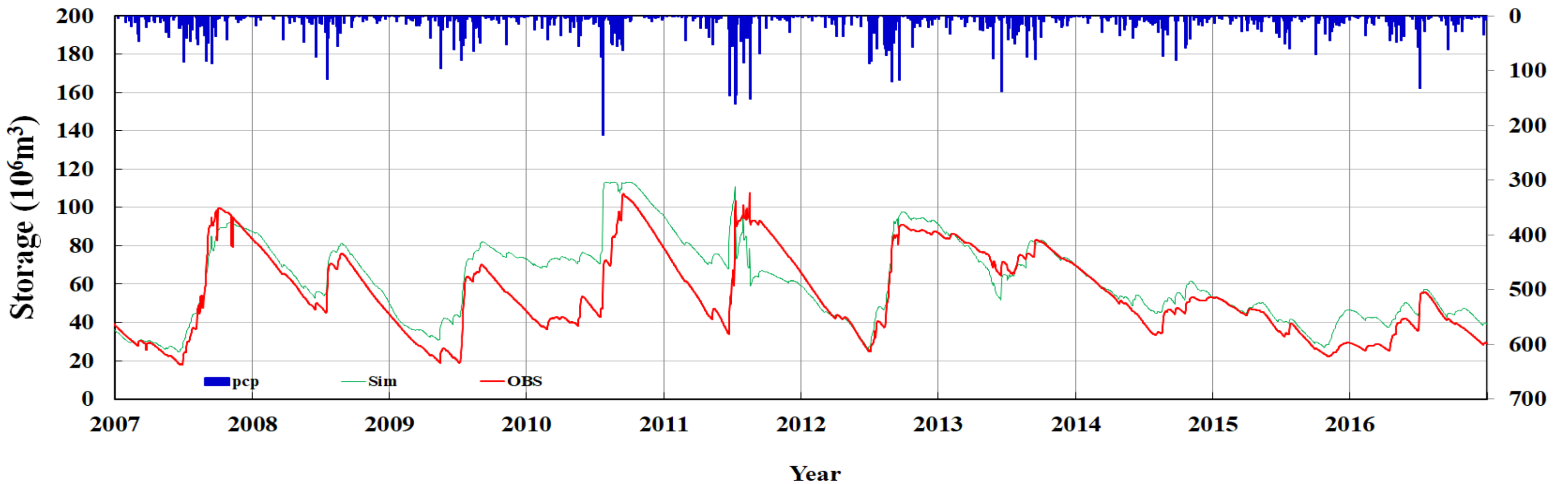
### Dam inflow data (2007-2016)

$R^2 = 0.82$, NSE = 0.59




### Dam storage data (2007-2016)

$R^2 = 0.90$, NSE = 0.91



# Extreme drought scenario

## Select among Climate Change Scenarios

- APCC CMIP5 GCM(General Circulation Model)
- 27 RCP(Representative Concentration Pathway) 4.5 Scenarios and 26 RCP 8.5 Scenarios
- Precipitation, Maximum & Minimum Temperature
- Study Period Classification

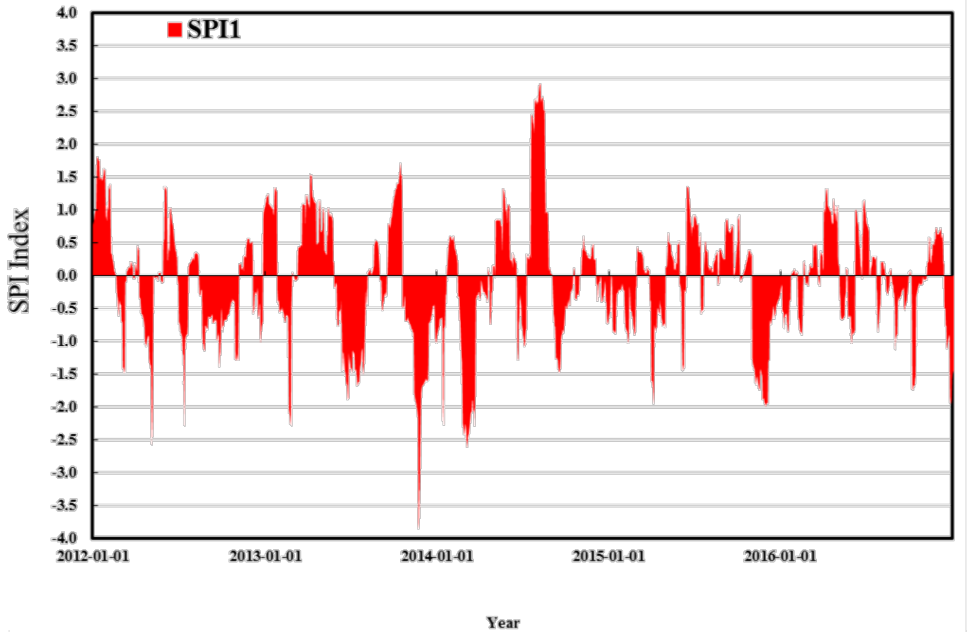
S0: 2007-2016, S1: 2017-2026, S2: 2027-2036, S3: 2037-2046

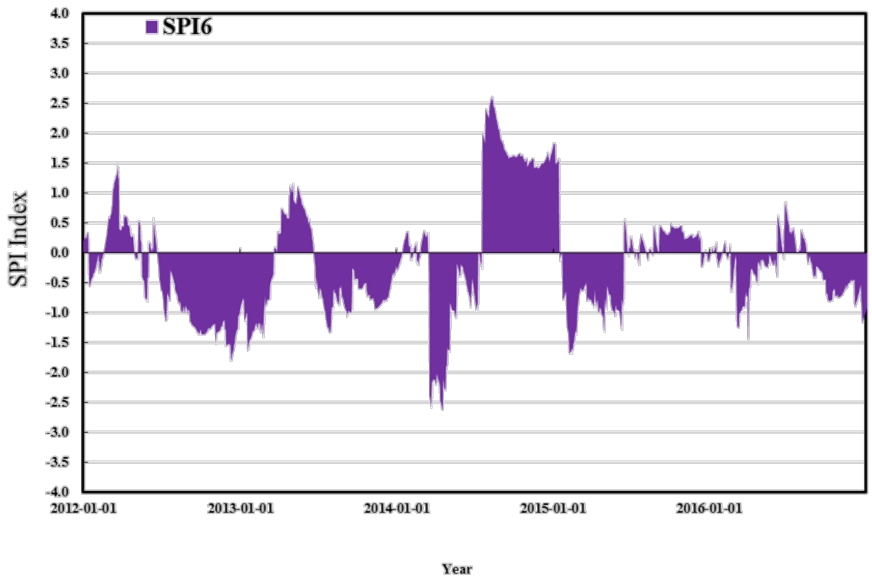
| | Priority | 2020s | 2050s | 2080s | | Priority | 2020s | 2050s | 2080s |
|---|---|---|---|---|---|---|---|---|---|
| **RCP 4.5** | 1 | HadGEM2-AO | FGOALS-s2 | CanESM2 | **RCP 8.5** | 1 | CESM1-BGC | NorESM1-M | MIROC5 |
| | 2 | CMCC-CMS | CMCC-CMS | CMCC-CMS | | 2 | MRI-CGCM3 | INM-CM4 | INM-CM4 |
| | 3 | HadGEM2-ES | HadGEM2-ES | INM-CM4 | | 3 | HadGEM2-AO | GFDL-ESM2G | CanESM2 |
| | 4 | IPSL-CM5A-LR | INM-CM4 | HadGEM2-ES | | 4 | GFDL-ESM2G | HadGEM2-ES | CNRM-CM5 |
| | 5 | GFDL-ESM2G | CNRM-CM5 | CCSM4 | | 5 | IPSL-CM5A-MR | IPSL-CM5A-MR | IPSL-CM5A-MR |
| | 6 | FGOALS-s2 | CESM1-BGC | MRI-CGCM3 | | 6 | INM-CM4 | CMCC-CM | HadGEM2-ES |
| | 7 | INM-CM4 | GFDL-ESM2M | FGOALS-s2 | | 7 | HadGEM2-ES | CNRM-CM5 | CMCC-CM |
| | 8 | CESM1-CAM5 | CMCC-CM | IPSL-CM5A-LR | | 8 | MPI-ESM-LR | CCSM4 | FGOALS-s2 |
| | 9 | CanESM2 | CanESM2 | MPI-ESM-MR | | 9 | FGOALS-s2 | FGOALS-s2 | CESM1-BGC |
| | 10 | | GFDL-ESM2G | | | 10 | MPI-ESM-MR | | MPI-ESM-MR |
| | 11 | | MRI-CGCM3 | | | 11 | | | MRI-CGCM3 |

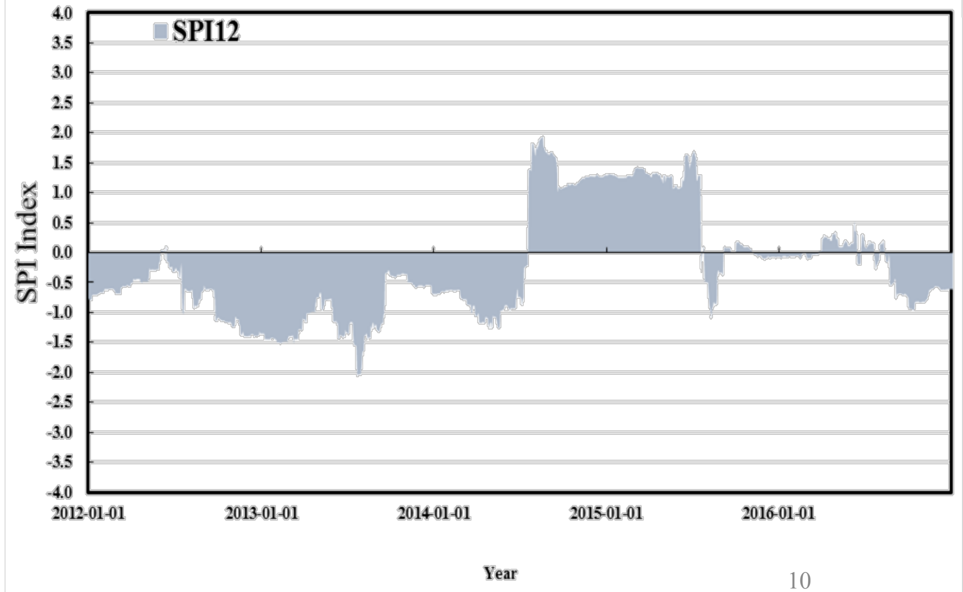
# Extreme drought scenario

## SPI(Standardized Precipitation Index)

- SPI enables rainfall conditions to be quantified over different time scales
- SPI-1 expressed short-term drought
- SPI-12 expressed long-term drought
- The most appropriate SPI expressing both short-term and long-term drought is SPI-6



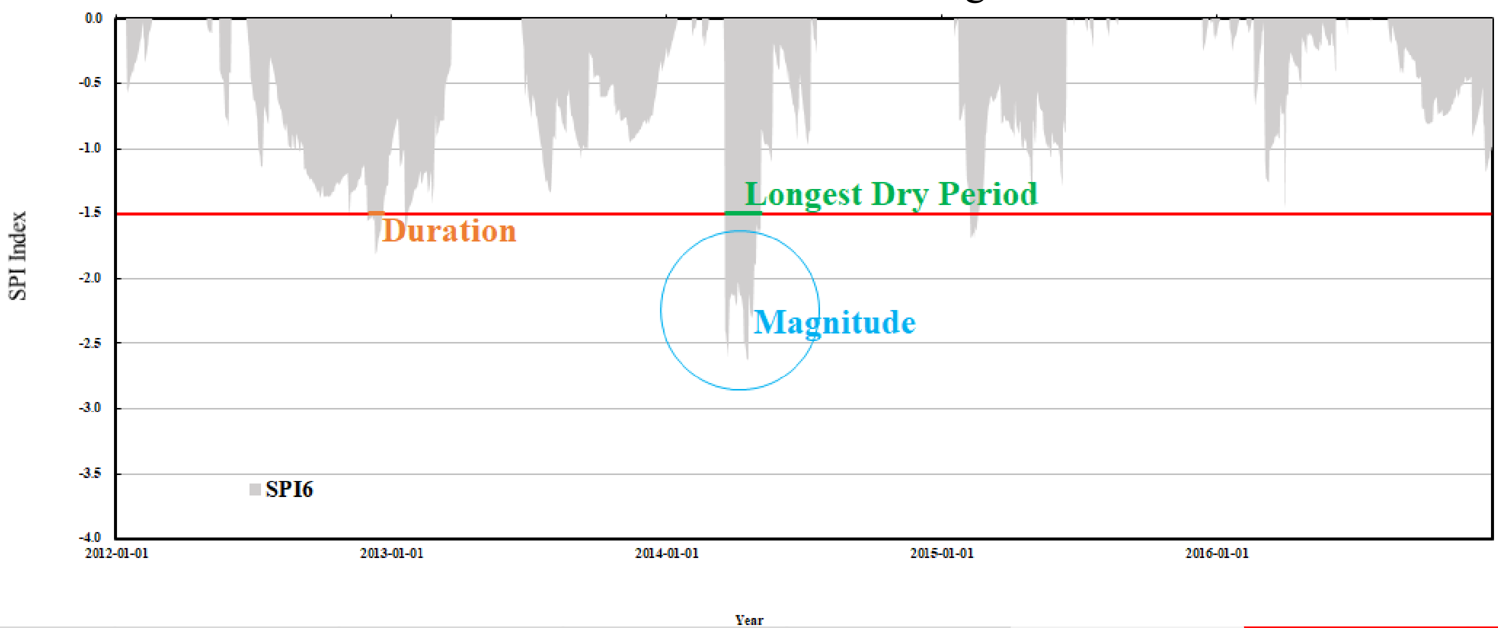



# Extreme drought scenario

## Extreme drought index

- Three drought indices; Magnitude, Duration, Longest Dry Period
- McKee et al (1993) classified Dry/Wet Condition by SPI Range
- Determined the Standard of Severe drought under -1.5
- Assume three indices have same weight for the dryness
- RCP 8.5 BCC-CSM1-1-M is selected for the extreme drought scenario




| SPI | 2.0 | 1.5 | 1.0 | 0.0 | -1.0 | -1.5 | -2.0 |
|---|---|---|---|---|---|---|---|
| Condition | Extremely Wet | Severely Wet | Moderately Wet | Normal | Moderately Dry | Severely Dry | Extremely Dry |

# Future Dam Release

## Multiple Linear Regression Analysis

| Multiple Linear Regression Analysis | | | |
|---|---|---|---|
| $$Y = B_1x_1 + B_2x_2 + B_3x_3 + B_4x_4 + B_5x_5$$ | | | |
| Y | Dam release | $x_2$ | Precipitation weight term |
| $\beta_n$ | Increment coefficient of Y for increment of $x_n$ | $x_3$ | Average Storage |
| $x_1$ | Precipitation | $x_4$ | Inflow |
| $x_5$ | Inflow weight term | | |

- Multiple Linear Regression Analysis on the hydrological variables influencing dam release
- Monthly equations for dam release estimation
- Five variables were used

Precipitation, Average storage, Inflow, and Weight terms for precipitation and inflow

- Precipitation, Average storage and Inflow were used in the first place, but showed bad result
- Weight term for factors having large deviation as a resolution

# Future Dam Release

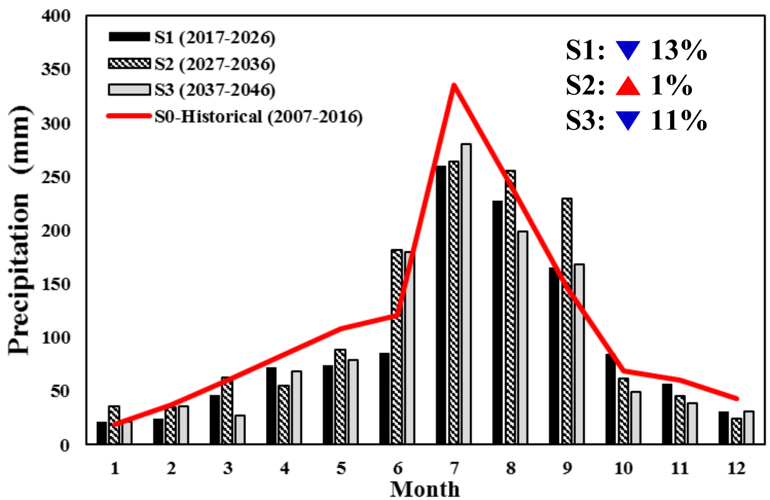
## Results

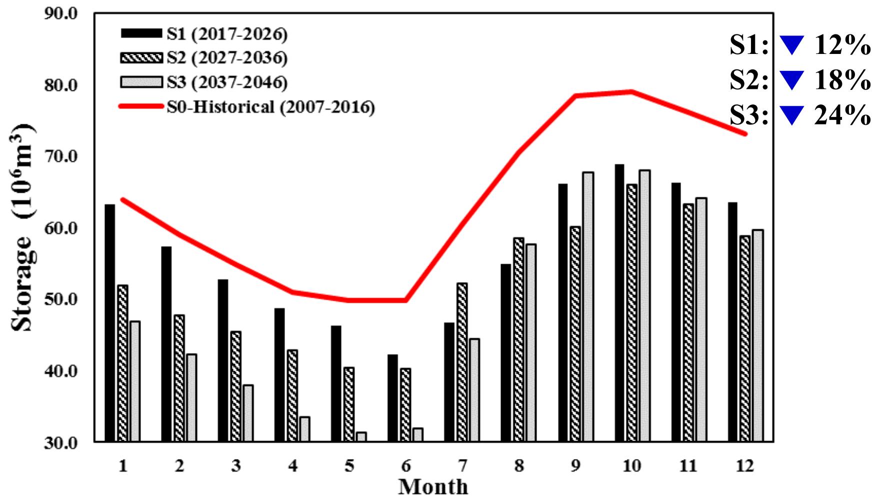
| month | | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| Coefficient | $x_1$=pcp | 8.67E-05 | 0.003786 | 0.006962 | 0.000882 | 0.000509 | 0.000229 |
| | $x_2$=p_bin | 0.143248 | 0.034508 | -0.2027 | 0.041779 | -0.18782 | -0.22642 |
| | $x_3$=storage | 0.051108 | 0.05687 | 0.05793 | 0.064774 | 0.074406 | 0.083391 |
| | $x_4$=inflow | 0.071528 | 0.001969 | 0.011472 | -0.01756 | 0.046154 | 0.004878 |
| | $x_5$=i_bin | -0.41955 | -0.43429 | -0.28378 | -0.18422 | 0.166 | 0.039211 |
| $R^2$ | | 0.98 | 0.98 | 0.97 | 0.97 | 0.84 | 0.92 |
| **month** | | **7** | **8** | **9** | **10** | **11** | **12** |
| Coefficient | $x_1$=pcp | 0.024391 | -0.16451 | 0.072566 | -0.03573 | -0.00068 | -0.00506 |
| | $x_2$=p_bin | -3.36807 | 0.091712 | 0.668881 | 0.187445 | 0.007683 | 0.064485 |
| | $x_3$=storage | 0.080352 | 0.054399 | 0.03971 | 0.038432 | 0.042312 | 0.047005 |
| | $x_4$=inflow | 0.506205 | 0.616625 | 0.208253 | 0.466362 | -0.08956 | -0.06811 |
| | $x_5$=i_bin | -2.69637 | -1.68663 | 0.156315 | -0.64031 | -0.00294 | -0.18038 |
| $R^2$ | | **0.57** | **0.57** | **0.54** | 0.70 | 0.98 | 0.98 |

- Average $R^2$ is 0.83
- Showed lower $R^2$ during rainy season

# SWAT Model Generation

## Hydrology Evaluation

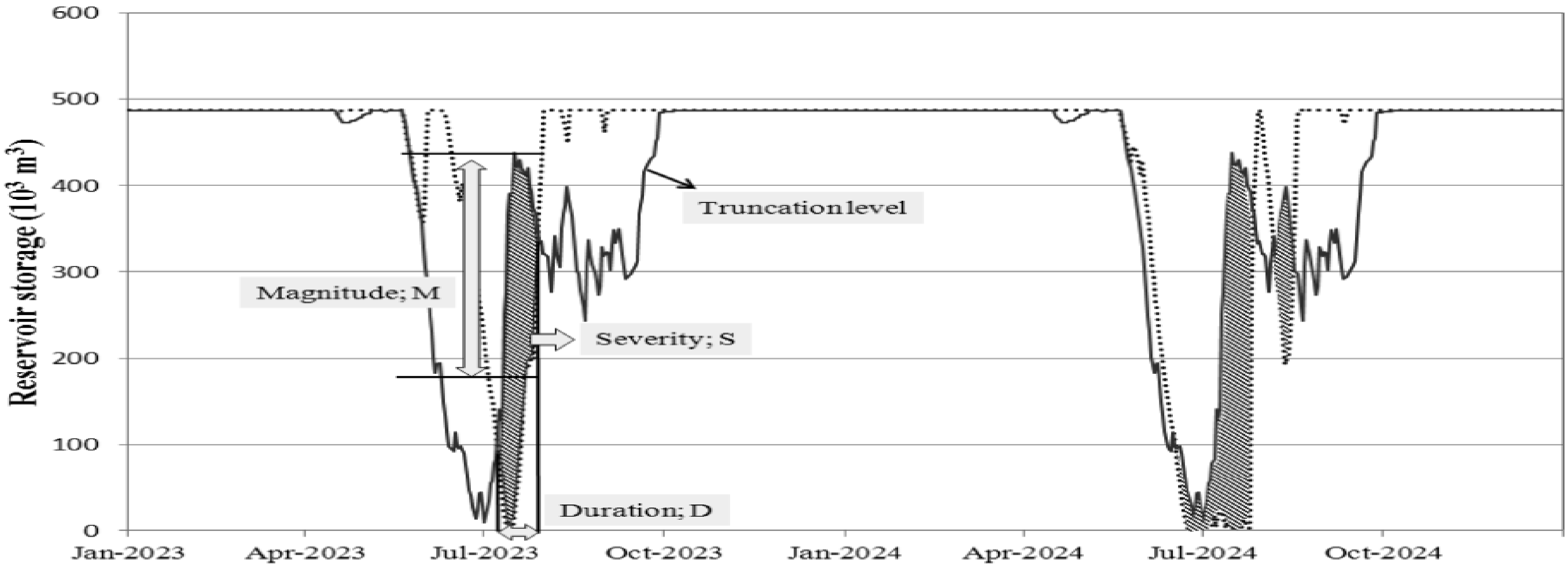



| Seasons | Precipitation (mm) | | | | Storage ($10^6m^3$) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2007-2016 | 2017 - 2026 | 2027 - 2036 | 2037 - 2046 | 2007-2016 | 2017 - 2026 | 2027 - 2036 | 2037 - 2046 |
| Total | 1,324.8 | 1,149.7 (-13.2 %) | 1,338.7 (+ 1.0%) | 1,176.7 (-11.2 %) | 63.9 | 56.4 (-11.6 %) | 52.3 (-18.1 %) | **48.8 (-23.6 %)** |
| Spring (3-5) | 251.9 | 192.8 (-23.5 %) | 205.7 (-18.3 %) | **175.1 (-30.5 %)** | 51.9 | 49.3 (-5.0 %) | 42.9 (-17.3 %) | **34.2 (-34.0 %)** |
| Summer (6-8) | 697.6 | 573.7 (-17.8 %) | 700.6 (+0.4 %) | 658.6 (-5.6 %) | 60.3 | 48.0 (-20.4 %) | 50.3 (-16.5 %) | 44.7 (-25.9 %) |
| Autumn (9-11) | 275.6 | 306.1 (+11.0 %) | 337.7 (+22.5 %) | 255.2 (-7.4 %) | 77.9 | 67.1 (-13.9 %) | 63.1 (-19.0 %) | 66.7 (-14.5 %) |
| Winter (12-2) | 99.7 | 77.2 (-22.5 %) | 94.7 (-5.0 %) | 87.8 (-12.0 %) | 65.4 | 61.4 (-6.1 %) | 52.8 (-19.2 %) | 49.6 (24.1 %) |

# Anti-drought capacity

## Runs theory




- Method to calculate drought severity
- Severity is the total sum of reservoir storage shortage for one drought
- The storage deficiency is estimated from truncation level
- Measured all set of drought severity during the standard period S0 (2007~2016)
- And used them in frequency analysis

# Anti-drought capacity

## Frequency analysis

| | 2-year | 3-year | 5-year | 10-year |
|---|---|---|---|---|
| **Severity ($10^6 m^3$ day)** | 3,721.4 | 4,729.7 | 5,852.6 | 7,283.7 |
| | | **5-10 year frequency drought** | | |
| **Frequency** | S0 (2007~2016) | S1 (2017~2026) | S2 (2027~2036) | S3 (2037~2046) |
| | 3 | 4 | 4 | **5** |

- Drought Severity with return period of 2, 3, 5, and 10 years are estimated
- Drought with the intensity of 5-10 year return period
- 4 times in S1 and S2, 5 times in S3.
- For S3 (2037~2046) period, the drought of 5 to 10 year return period occurred nearly two times compared to the standard period S0 (2007~2016).

# Summary and Findings

- For Boryeong Dam where issued an administrative order for municipal water supply restriction by 2014~2016 consecutive extreme drought, the future anti-drought capacity of the dam was evaluated using SWAT watershed hydrology, climate change scenarios and multiple linear regression derived dam release scenarios.
- <u>SWAT analysis results</u>
  - For S3 (2037~2046) CMIP5 RCP8.5 scenarios, the spring precipitation was projected to decrease 30.5% and the dam storage of the period decreased 23.6%. In particular, the storage of spring, summer and winter season decreased 34.0%, 25.9% and 24.1% respectively. This requires a new dam operation rule by controlling dam releases from the autumn Typhoons and heavy rains of the previous year.
- <u>Frequency analysis results</u>
  - For S3 (2037~2046) period, the drought of 5 to 10 year return period occurred nearly twice times compared to the standard period S0 (2007~2016).
- It is believed that SWAT model is available for predicting future drought prediction.