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Impact of Future Climate Change on the Water Resources System of Chungju Multi-purpose Dam in South Korea

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Soil & Water Assessment Tool SWAT

Outline

1. **Introduction**
2. **Modeling Approach**
   - *LARS-WG model*
   - *SWAT hydrological model*
   - *HEC-ResSim reservoir simulation model*
3. **Study Area Description and Data for Model Evaluation**
4. **Climate Change Projections**
5. **Climate Change Impacts on Water Resources System**
   - *Watershed hydrology*
   - *Hydrological regimes*
   - *Water resources*
   - *Reservoir operation*
   - *Hydropower productions*
6. **Concluding Remarks**

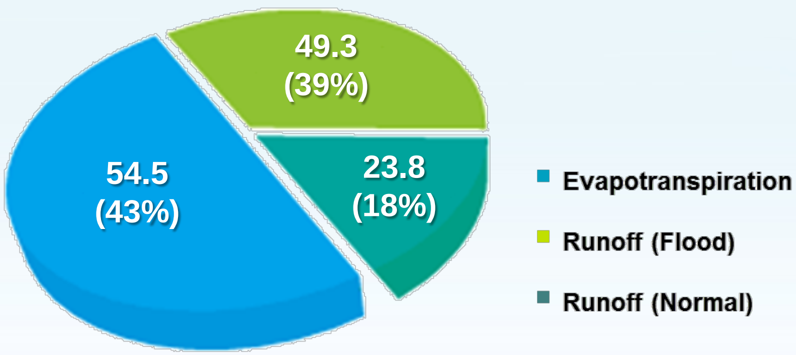
Water resources in South Korea

◆ Comparison of country precipitation

	Korea	Japan	USA	England	China	Canada	World average
mean annual precipitation(mm)	1,283	1,728	760	1,064	660	522	973

◆ Status of water use in South Korea (unit: billion m^3/year)

✓ **Total precipitation: 127.6 (100%)**



Seasonal precipitation: Two-thirds of the annual precipitation is concentrated in the rainy monsoon (flood) period from June to September.

Runoff characteristics: Of this amount, 49.3 billion is swept away by floods immediately, the remaining amount of water, 23.8 billion flows during normal periods.

✓ **The amount of stream runoff: 73.1 (57%)**

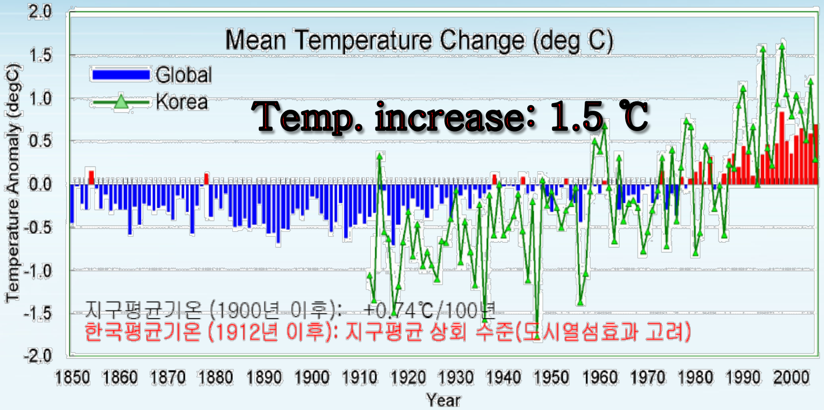
- used as ground water 3.7 (3%)
- dam usage 13.3 (10%)
- streamwater usage 16.1 (13%)
- lost to sea 40.0 (31%)

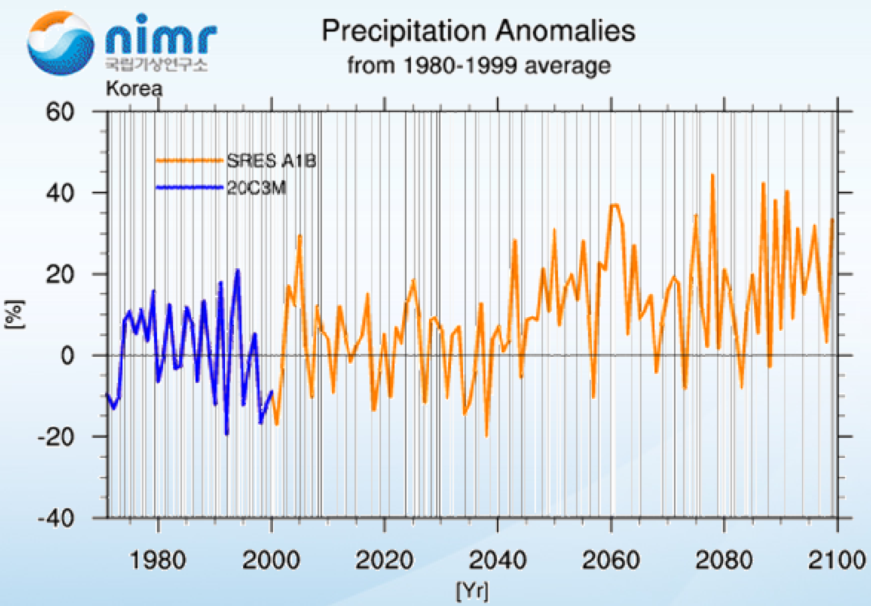
✓ **Total amount of water use: 33.1 (26%)**

- municipal use 7.3
- industrial use 2.9
- agricultural use 15.8
- environmental use 7.1

Source: Korea Water Resources Association (http://eng.kwra.or.kr)

Background



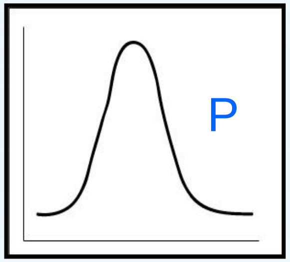


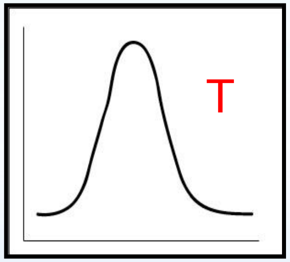
한반도 강수편차 (시계열)

A comprehensive
climate change impacts assessment
for South Korea

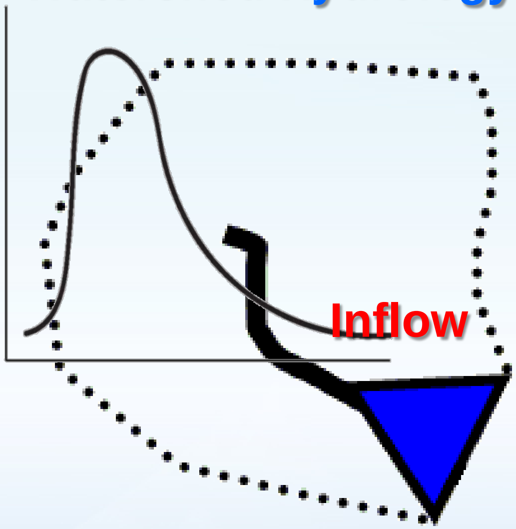
Purpose of this study

Probabilities of Climate Change	→	Probabilities of change in Hydrological Variables	→	Decisions on Adaptation Planning





Watershed Hydrology



Water Resources

The purpose of this study is…

to evaluate the future potential climate change impacts on hydrology and water resources system of Chungju multi-purpose dam in South Korea.

Multi-model ensemble approach

GCM	ECHAM5-OM	HadCM3	MIROC3.2 HiRes
Center	MPI-M (Max-Planck-Institute for Meteorology)	UKMO (Meteorological Office)	NIES (National Institute for Environmental Studies)
Country	Germany	UK	Japan
Scenario	A2, A1B, B1	A2, A1B, B1	A1B, B1
Grid size	1.9° × 1.9°	3.7° × 2.5°	1.1° × 1.1°

Time Period

- *Baseline: 1990-2009*
- *2020s: 2010-2039*
- *2050s: 2040-2069*
- *2080s: 2070-2099*

↓ *bias correction*

Weather Generator (LARS-WG)

↓ *climate change projections (temperature and precipitation)*

Hydrologic Model (SWAT)

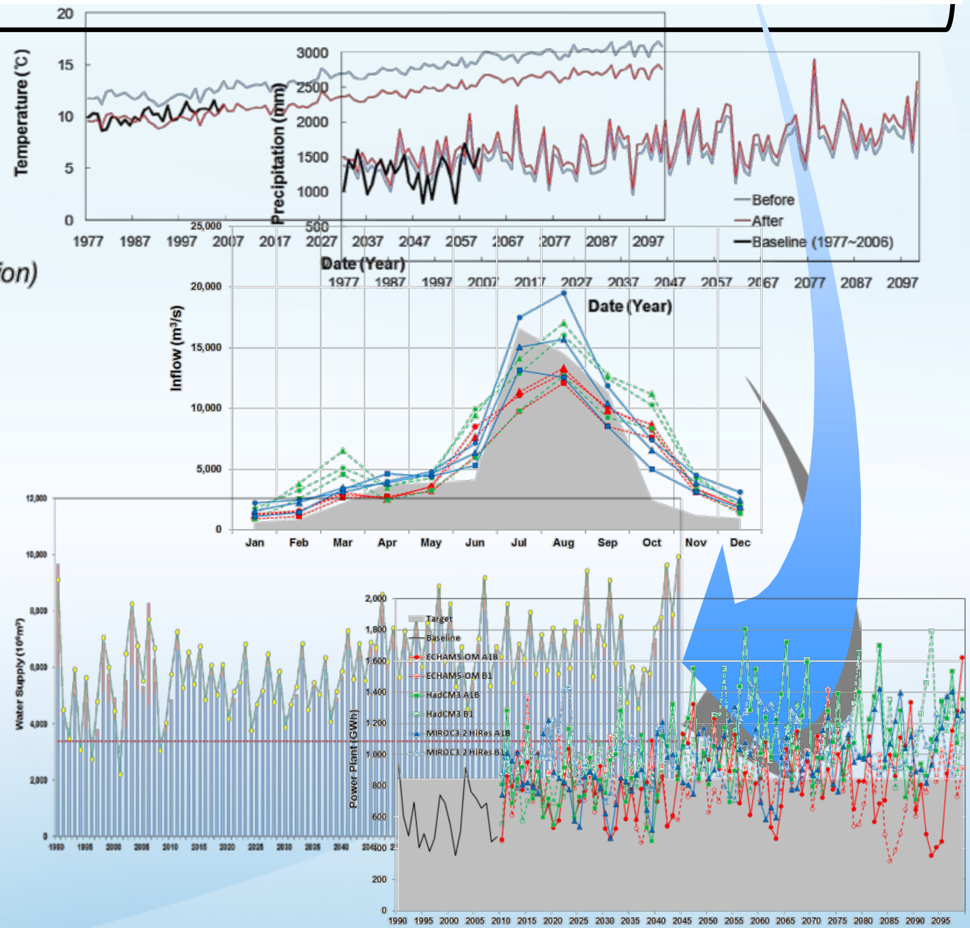
↓ *watershed hydrology (inflow sequences)*

Reservoir Model (HEC-ResSim)

↓ *reservoir operation*

Water Resources System

Water Supply Capacity | Hydropower Production



Models application

◆ **LARS-WG stochastic weather generator** (Semenov et al., 1998)

- ✓ Generation of synthetic series of daily weather data at a local site (daily precipitation, maximum and minimum temperature, and daily solar radiation)
- ✓ Procedure:
  - Use semi-empirical probability distributions to describe the state of a day (wet or dry)
  - Use semi-empirical distributions for precipitation amounts (parameters estimated for each month)
  - Use normal distributions for daily minimum and maximum temperatures
  - Use semi-empirical distribution for daily solar radiation

◆ **HEC-ResSim reservoir system analysis** (USACE, 2007)

- ✓ HEC-ResSim uses an original rule-based approach to mimic the actual decision-making process that reservoir operators must use to meet operating requirements for flood control, power generation, water supply, and environmental quality
- ✓ Procedure:
  - Simulates reservoir operations for flood management, low flow augmentation and water supply for planning studies, detailed reservoir regulation plan investigations, and real-time decision support
  - Simulates channel routing

Methods

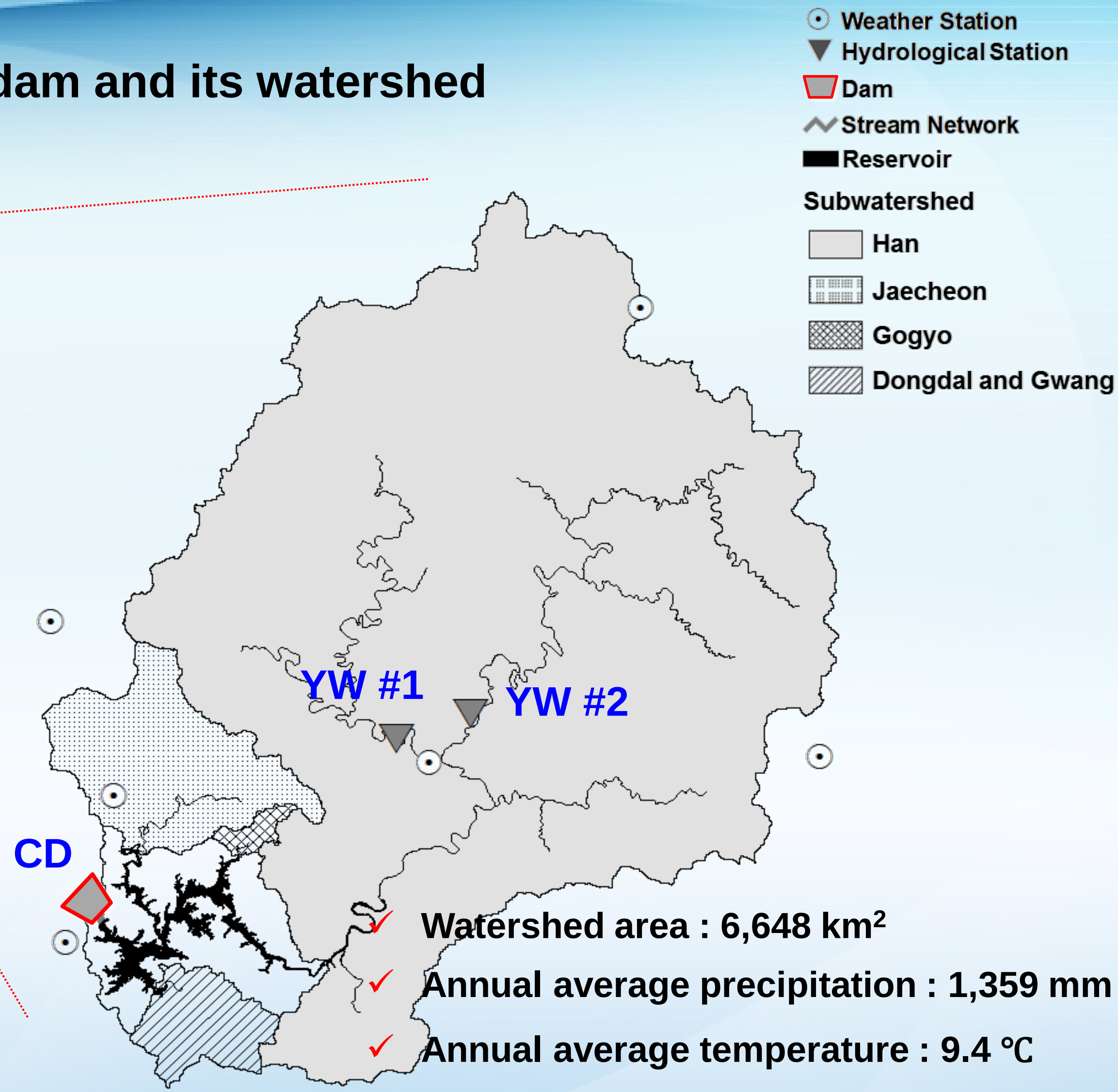
◆ Water resources assessment: performance measurement

- ✓ A set of relevant indicators is used to compare the future climate change scenarios with the baseline period
- ✓ There are two types of indicators used:
  - a set of quantitative criteria evaluating the total annual water supply and hydropower production and its seasonal distribution
  - a set of qualitative criteria evaluating the performance of the reservoir in terms of reliability, resilience, and vulnerability (RRV) criteria, based on the methodology presented by Hashimoto et al. (1982)

Indicator name	Signification	Measurement method
Reliability (%)	Frequency of failure states	(1 - sum of failure states) / total number of simulated time periods
Resilience (%)	Speed of recovery	Sum of restoration states / sum of failure states
Vulnerability (%)	Extent of system failure	Sum of water deficit / sum of water demand during failure states
Efficiency (%)	Water use efficiency	Sum of water released through the turbines / sum of water inflow in to the reservoir over entire simulation period
Production (GWh)	Mean annual production	Sum of produced electricity / number of simulated years
Summer Production (%)	Mean summer production	Sum of electricity produced during summer / total electricity produc tion over the whole simulation period
Winter Production (%)	Mean winter production	Sum of electricity produced during winter / total electricity productio n over the whole simulation period
Spill	Spillway activation index	Sum of months with spillway activation / length of simulation period

Study area

◆ **Chungju multi-purpose dam and its watershed**

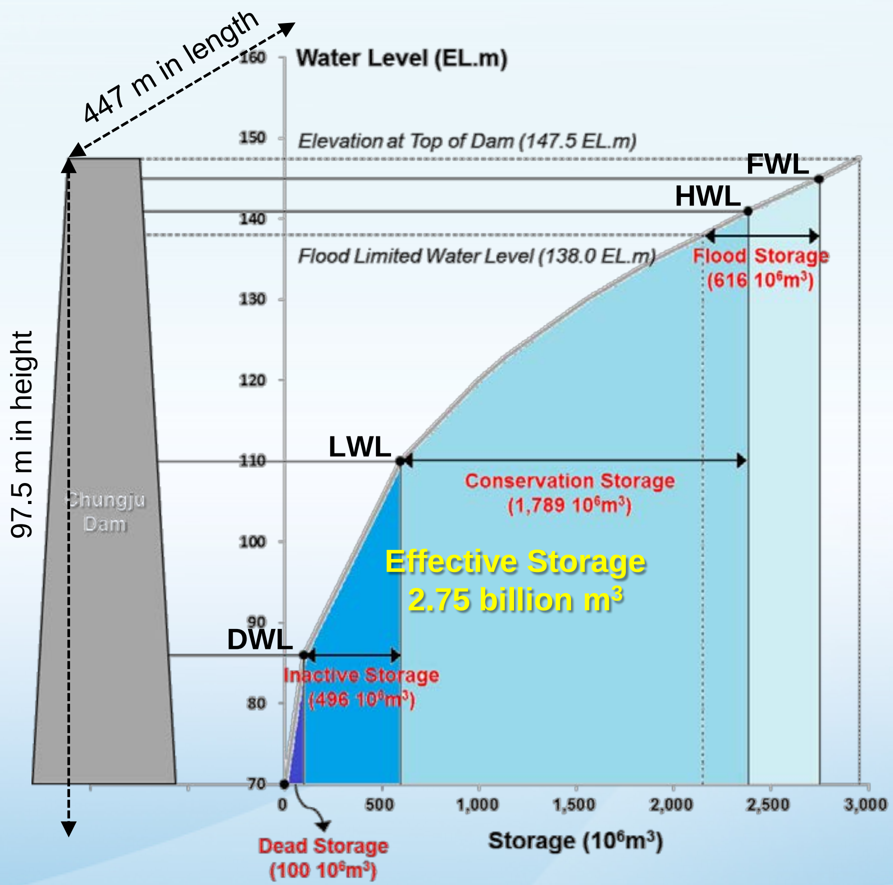


- ✓ **Watershed area : 6,648 km^2**
- ✓ **Annual average precipitation : 1,359 mm**
- ✓ **Annual average temperature : 9.4 ℃**
- ✓ **Forest area : 84.6 % (5573.1 km^2)**

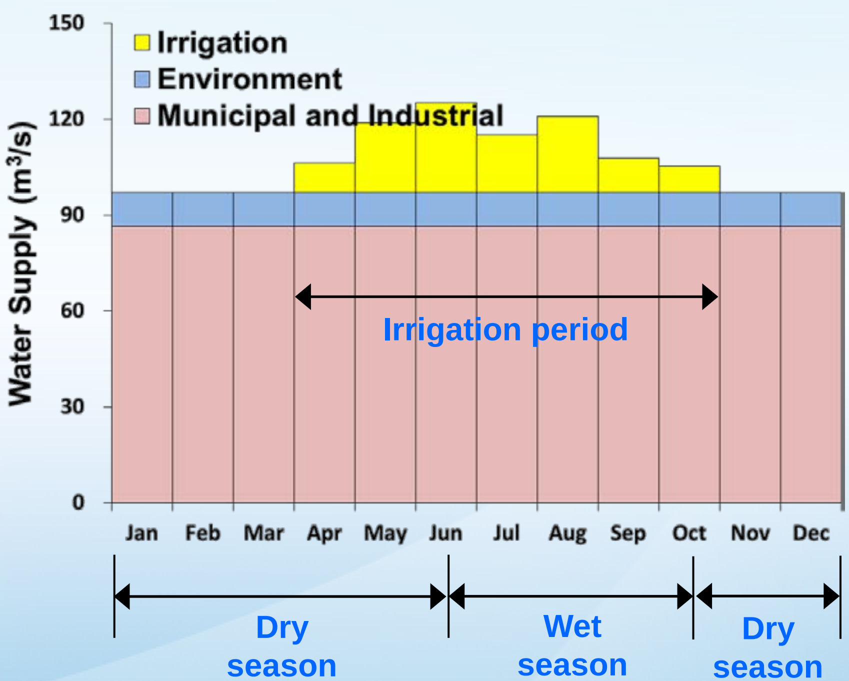
Study area

◆ Multi-purpose dam operating rules

- ✓ Comprehensive benefits of the Chungju multi-purpose dam include flood control, water supply, power generation, and recreation, etc.
- ✓ The future water demand is assumed as same with the baseline period.



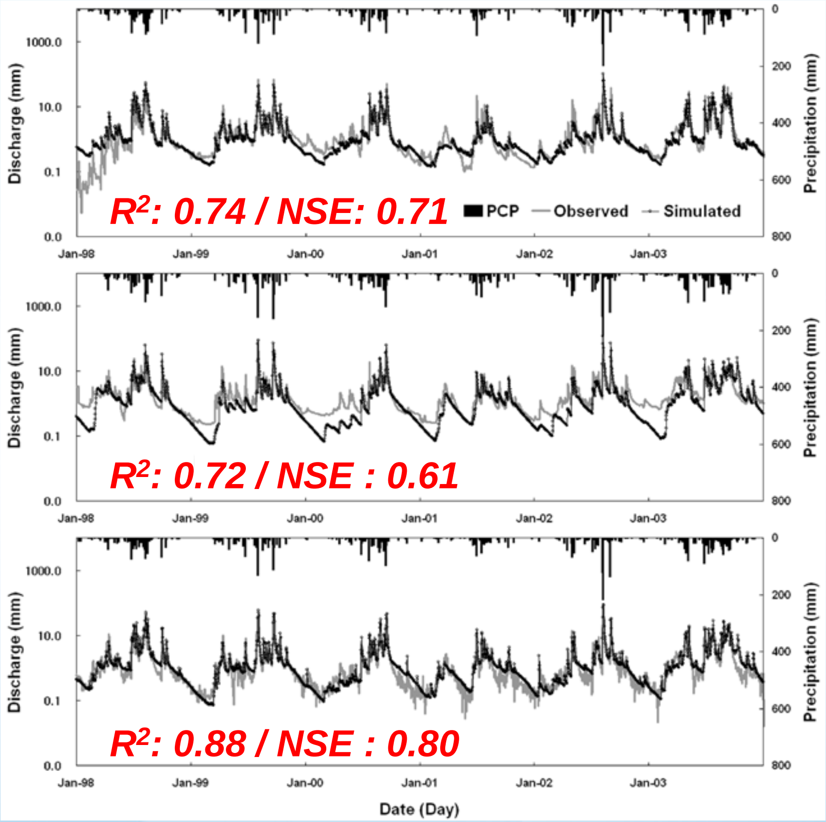
The impounded water is released through the turbine to generate electricity

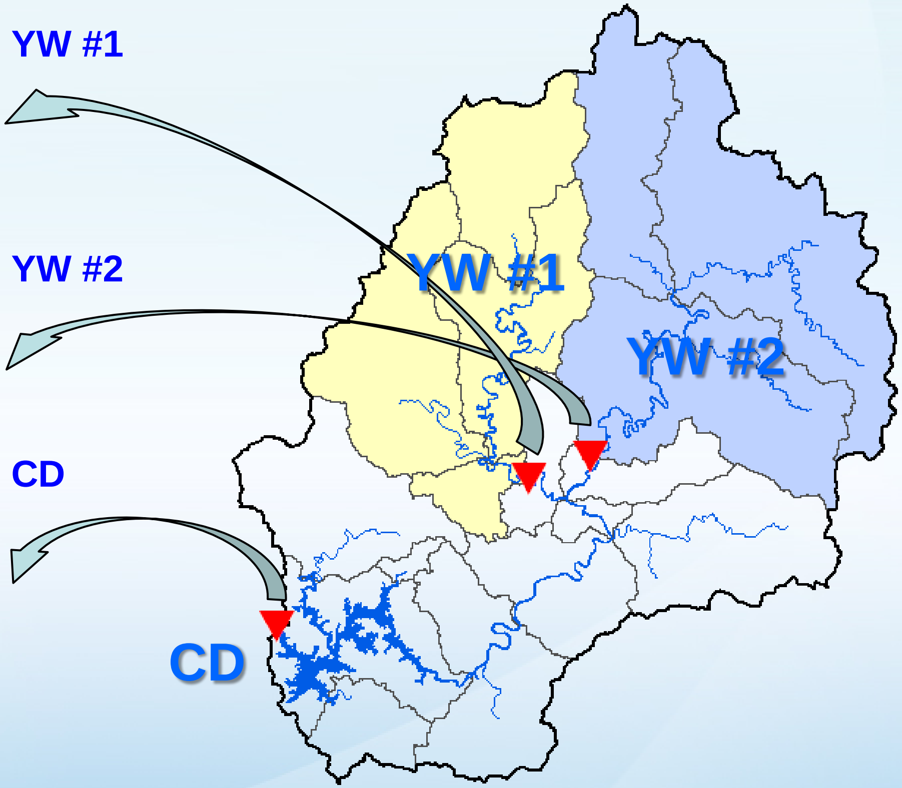


Model calibration (SWAT)

◆ **SWAT – streamflow (Park et al., 2011)**

- ✓ Calibration period : 1998-2000 / Validation period : 2001-2003
- ✓ Using daily discharge records at three calibration points

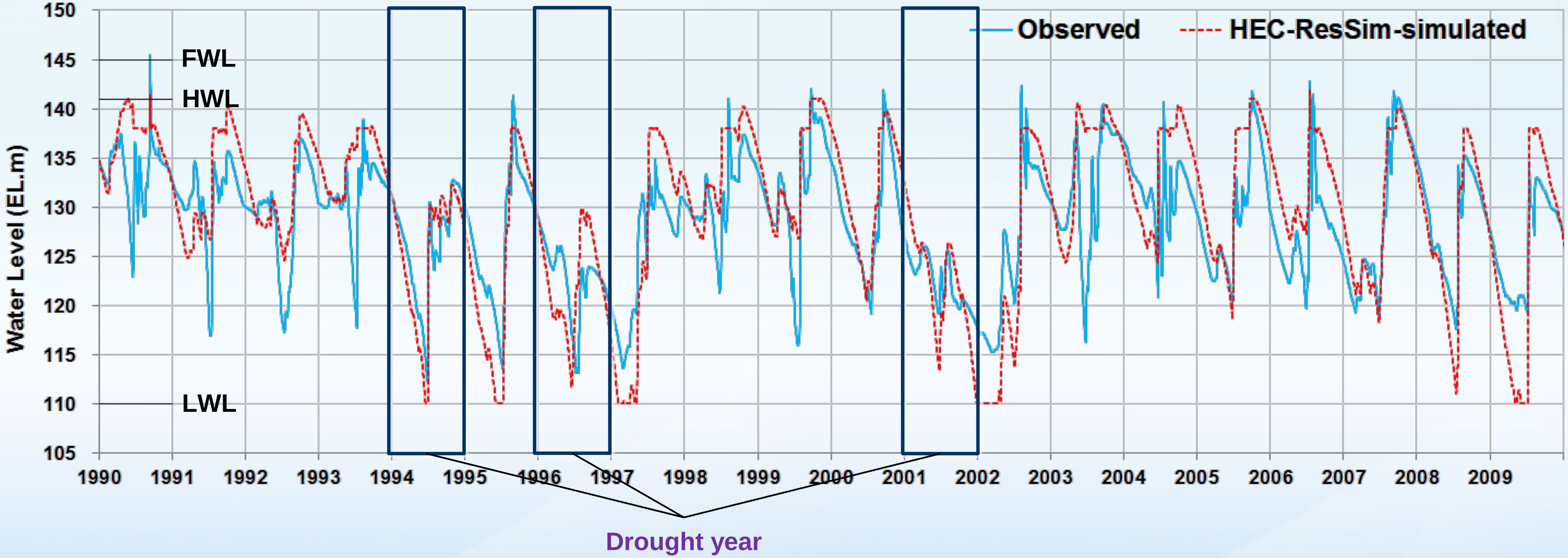




Model calibration (HEC-ResSim)

◆ HEC-ResSim – water level

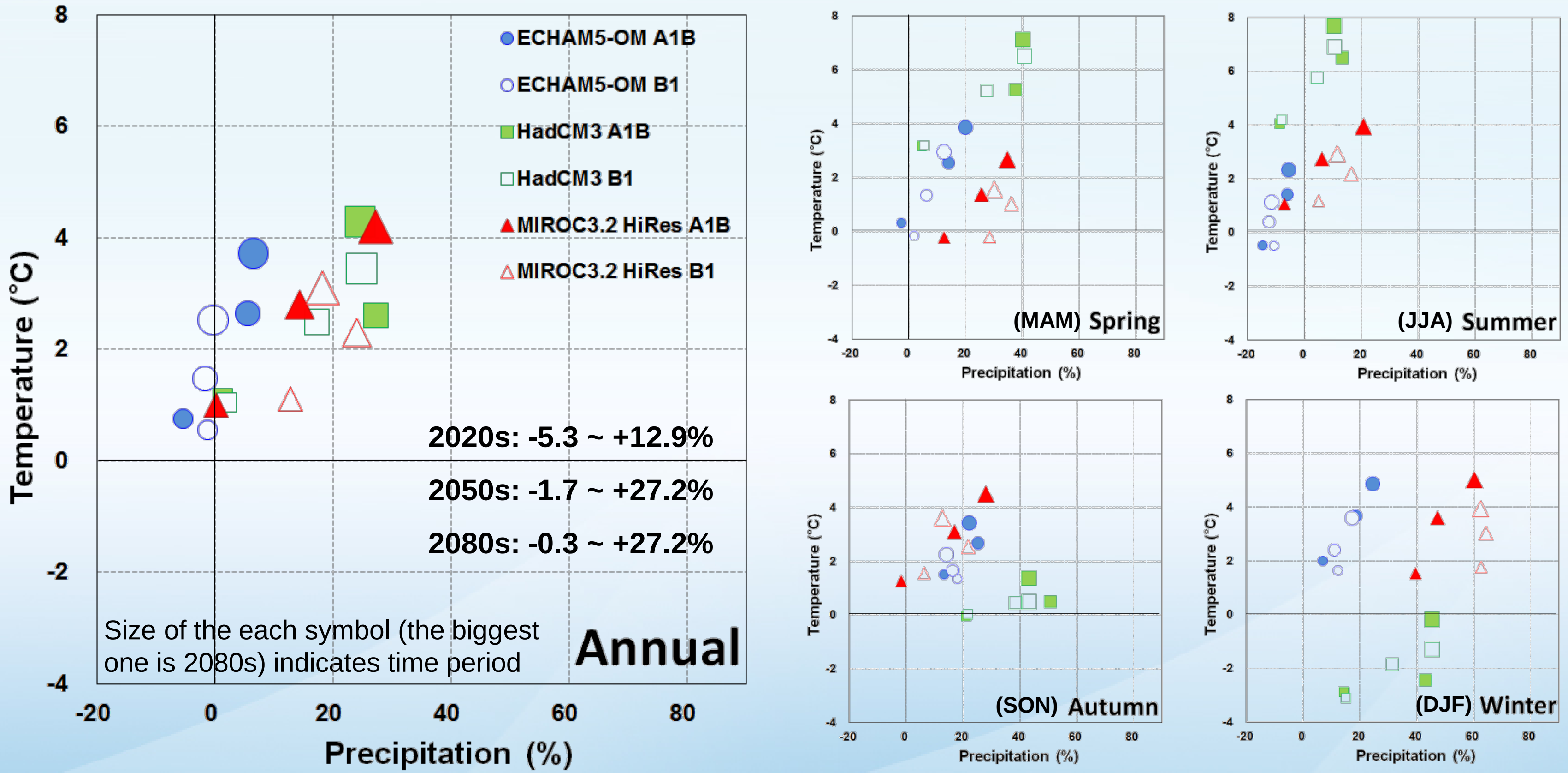
- ✓ Calibration period : 1990-2009
- ✓ The daily inflow data include losses of pool seepage and reservoir evaporation
- ✓ The model was modified to adjust the references to the specified release, and the model was allowed to make the release determination for each period



➡ Several factors (human element, uncertainty of inflow data, and pool elevation-storage curve) led to the errors

Climate change projections

- ✓ The three GCM data were downscaled using the LARS-WG stochastic weather generator
- ✓ The uncertainty of future temperature and precipitation causes evaluation difficulties for prediction of the future watershed hydrology
- ✓ Two emission scenarios from the three GCM models adequately reproduced the temperature and precipitation distribution during the whole monsoon season



Watershed hydrology

◆ Climate change impacts on watershed hydrology

✓ By applying the future downscaled climate change scenarios, SWAT was run to evaluate the future impacts of climate change on watershed hydrology (specifically evapotranspiration, surface runoff, subsurface later flow, groundwater recharge, and streamflow)

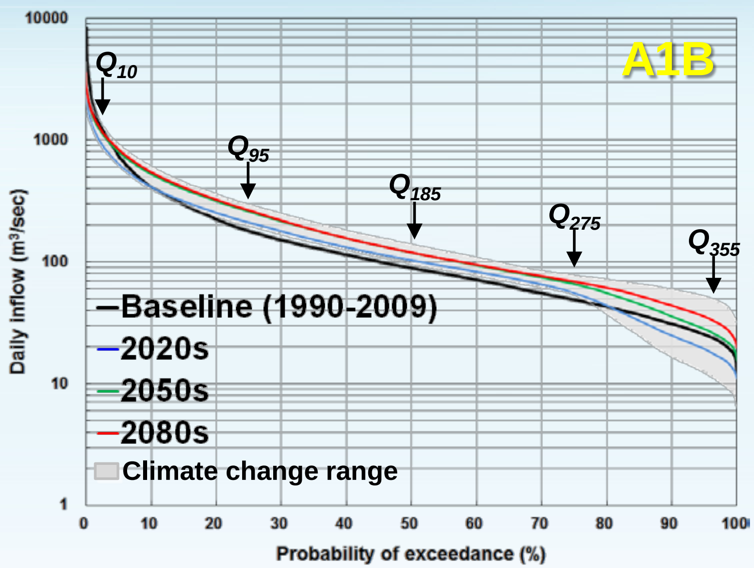
Unit: mm/year

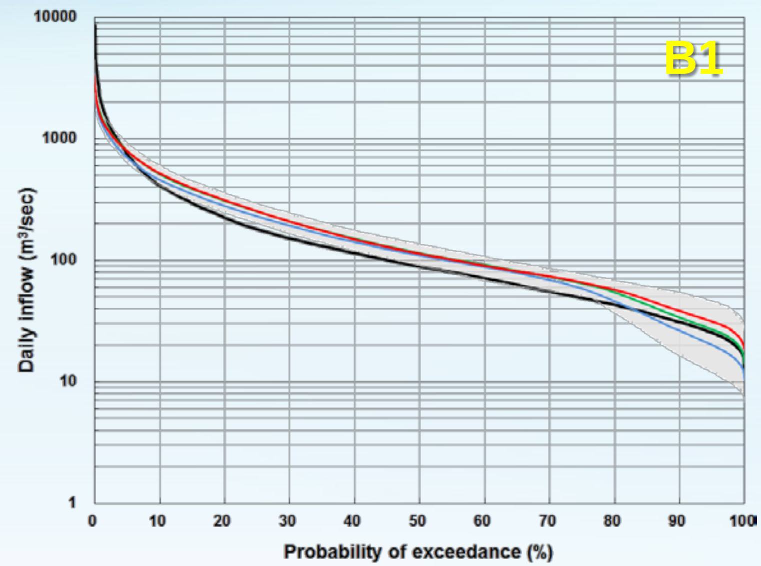
Scenario		P	ET	SR	LAT	GW	ST
Baseline (1990-2009)		1474	462	593	46	305	941
ECHAM5-OM (A1B)	2020s	1396 (-5.3)	488 (+5.6)	486 (-18.1)	45 (-3.7)	318 (+4.1)	845 (-10.2)
	2050s	1556 (+5.6)	528 (+14.2)	577 (-2.7)	48 (+3.9)	336 (+10.1)	958 (+1.7)
	2080s	1569 (+6.5)	542 (+17.4)	565 (-4.6)	50 (+8.6)	340 (+11.4)	953 (+1.2)
ECHAM5-OM (B1)	2020s	1458 (-1.1)	489 (+5.8)	538 (-9.3)	45 (-4.3)	326 (+6.8)	905 (-3.9)
	2050s	1449 (-1.7)	520 (+12.5)	498 (-16.0)	43 (-7.4)	324 (+6.3)	862 (-8.4)
	2080s	1470 (-0.3)	542 (+17.3)	491 (-17.2)	44 (-4.6)	326 (+7.0)	858 (-8.8)
HadCM3 (A1B)	2020s	1494 (+1.4)	516 (+11.7)	521 (-12.2)	47 (+1.6)	329 (+7.8)	894 (-5.1)
	2050s	1875 (+27.2)	547 (+18.4)	793 (+33.8)	52 (+12.4)	379 (+24.1)	1220 (+29.6)
	2080s	1836 (+24.6)	563 (+21.9)	738 (+24.6)	55 (+17.6)	379 (+24.1)	1168 (+24.1)
HadCM3 (B1)	2020s	1505 (+2.1)	519 (+12.3)	525 (-11.4)	48 (+3.4)	331 (+8.6)	901 (-4.3)
	2050s	1727 (+17.2)	535 (+15.8)	682 (+15.1)	51 (+9.8)	362 (+18.7)	1092 (+16.0)
	2080s	1839 (+24.8)	548 (+18.5)	759 (+28.0)	54 (+15.6)	377 (+23.6)	1186 (+26.0)
MIROC3.2 HiRes (A1B)	2020s	1478 (+0.3)	509 (+10.2)	509 (-14.1)	46 (-0.2)	343 (+12.4)	895 (-4.9)
	2050s	1685 (+14.3)	533 (+15.3)	654 (+10.4)	51 (+10.6)	372 (+22.0)	1074 (+14.1)
	2080s	1874 (+27.2)	556 (+20.4)	793 (+33.7)	55 (+17.4)	393 (+28.9)	1236 (+31.3)
MIROC3.2 HiRes (B1)	2020s	1664 (+12.9)	524 (+13.4)	656 (+10.7)	46 (-0.3)	358 (+17.3)	1057 (+12.3)
	2050s	1828 (+24.0)	533 (+15.3)	785 (+32.5)	50 (+6.7)	380 (+24.5)	1211 (+28.6)
	2080s	1742 (+18.2)	534 (+15.7)	697 (+17.7)	51 (+9.2)	379 (+24.3)	1123 (+19.4)

(values in parentheses are percent change in hydrologic components based on the baseline)

Hydrological regimes

- **Future flow duration**



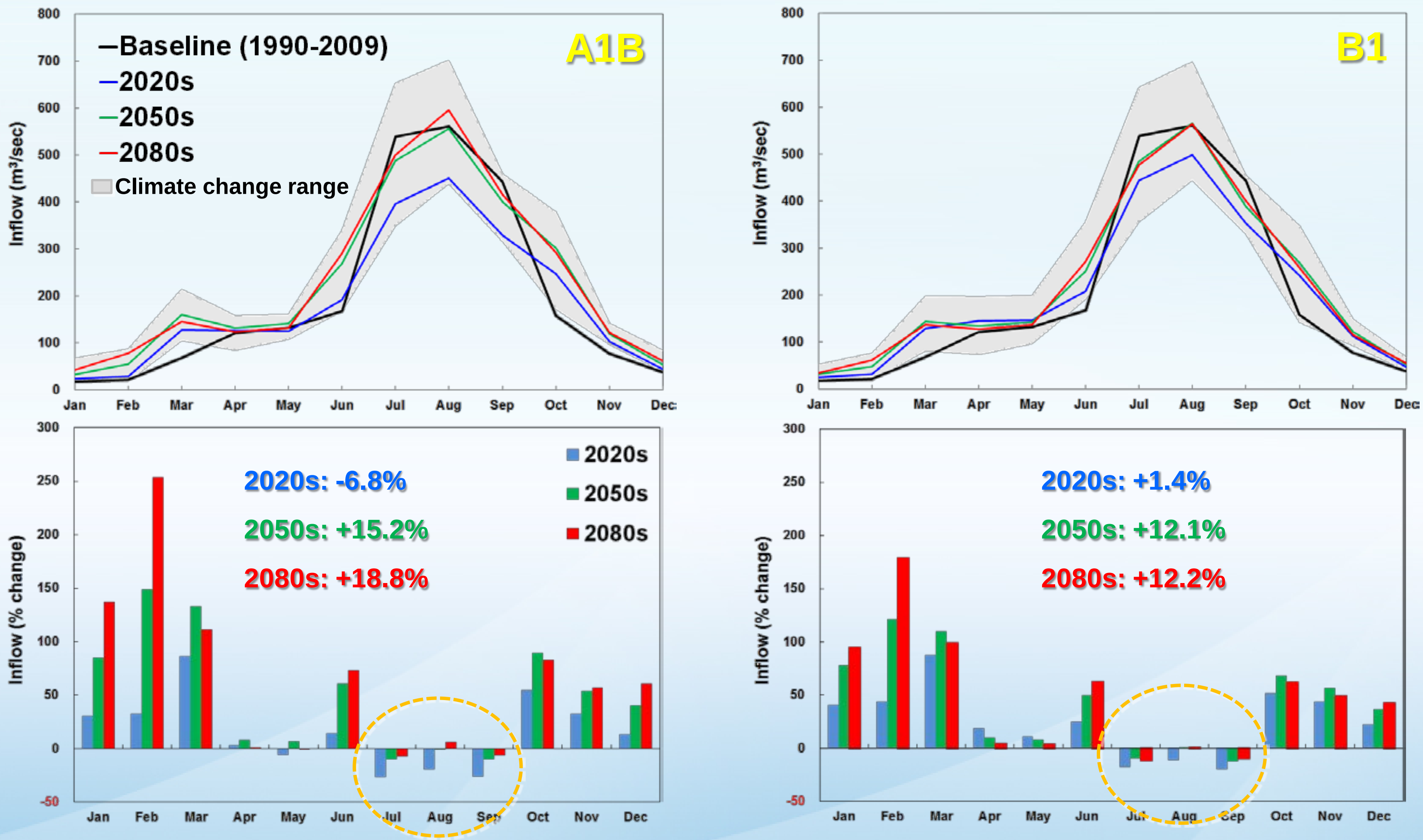


	Baseline	A1B			B1		
		2020s	2050s	2080s	2020s	2050s	2080s
Mean (m^3/s)	203.0	184.0	227.2	234.5	200.0	221.2	221.3
SD	412.7	242.6	305.0	312.1	263.2	295.6	290.1
Flow Index (m^3/s)							
Q_{10}	1171.0	872.7	1090.0	1123.0	965.6	1073.1	1055.1
Q_{95}	173.4	204.4	249.0	255.2	221.4	242.5	243.0
Q_{185}	87.5	101.4	117.0	117.3	107.9	112.6	111.3
Q_{275}	48.5	54.7	65.0	68.3	57.7	63.8	65.0
Q_{355}	22.3	16.5	24.4	31.0	17.3	65.0	28.0
Coefficient (Q_{10}/Q_{355})	52.5	52.9	44.7	36.2	55.8	16.5	37.7

Hydrological regimes

◆ The future dam inflow scenarios

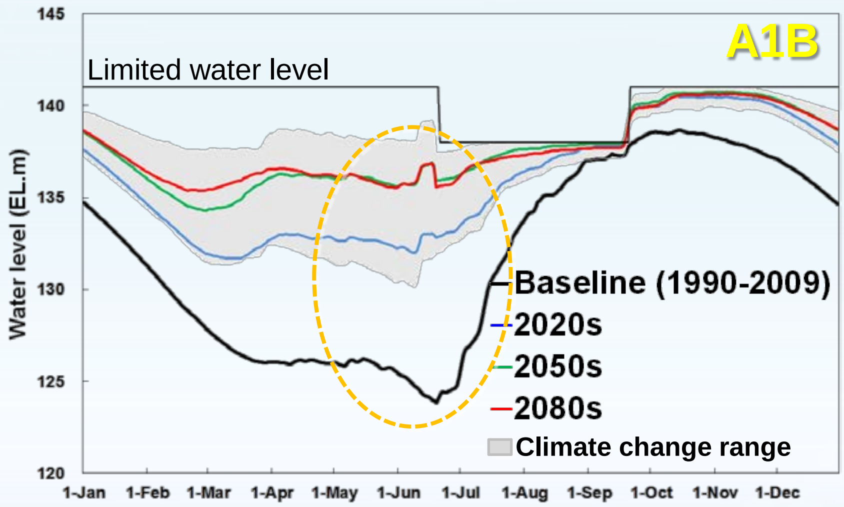
- ✓ The timing and magnitude of dam inflow (streamflow at the watershed outlet), forest-dominated dam watershed such as Chungju dam watershed is strongly influenced by climate change

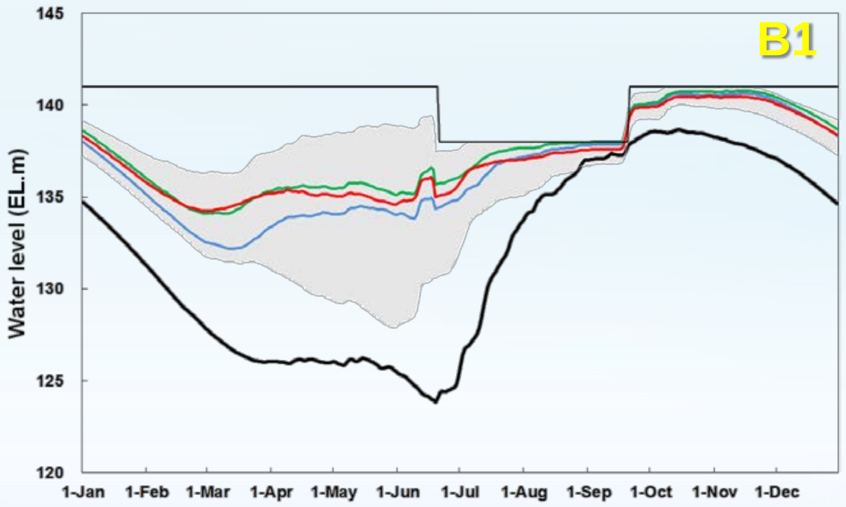


Water resources

◆ The assessment of water resources

- ✓ Daily inflow (1990-2099) from the SWAT simulations was used as input to reservoir simulation model (HEC-ResSim) that simulate the operations of Chungju reservoir systems
- ✓ HEC-ResSim was run to evaluate the future impacts of climate change on the water resources system (specifically water system indicators, water supply capacity, and hydropower plant)

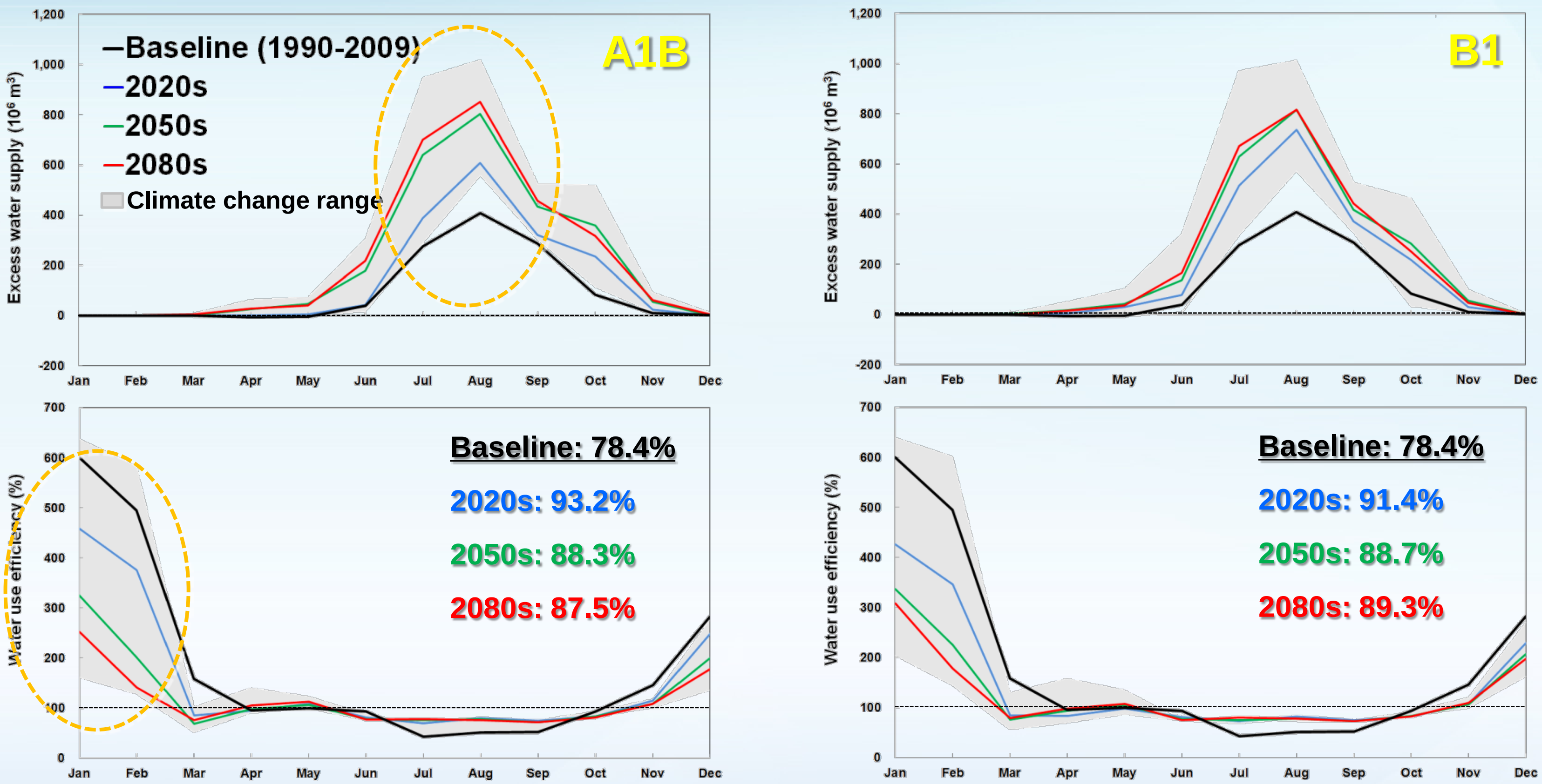




	Baseline	A1B			B1		
		2020s	2050s	2080s	2020s	2050s	2080s
Average annual inflow (10^6m^3)	6,226	5,806 (-6.8)	7,170 (+15.2)	7,399 (+18.8)	6,312 (+1.4)	6,981 (+12.1)	6,984 (+12.2)
Total average annual release (10^6m^3)	6,238	5,790 (-7.2)	7,168 (+14.9)	7,396 (+18.6)	6,294 (+0.9)	6,980 (+11.9)	6,983 (+11.9)
Average annual release to water supply	4,884	5,413	6,333	6,474	5,772	6,192	6,234
Average annual spills	1,354	377	835	922	522	788	549

Reservoir operation

◆ **Performance measurement for the future water supply**

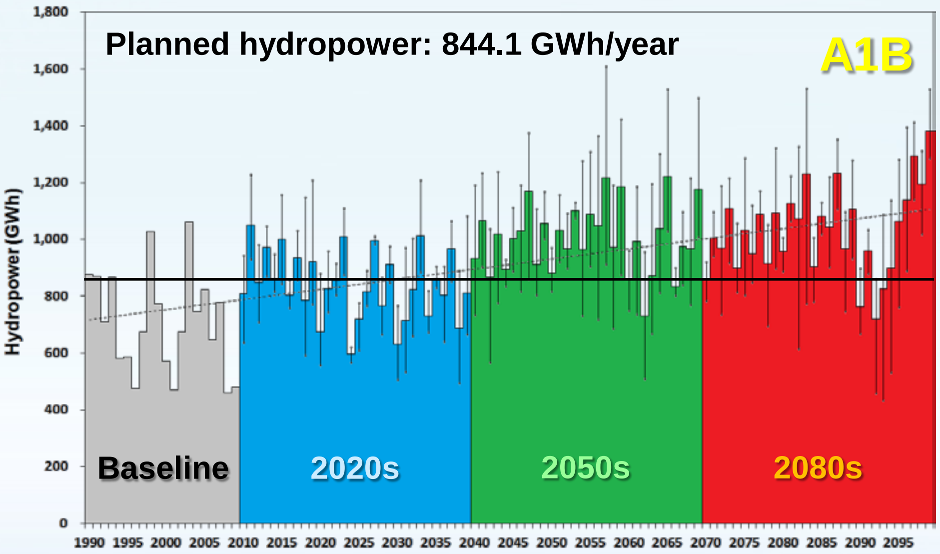


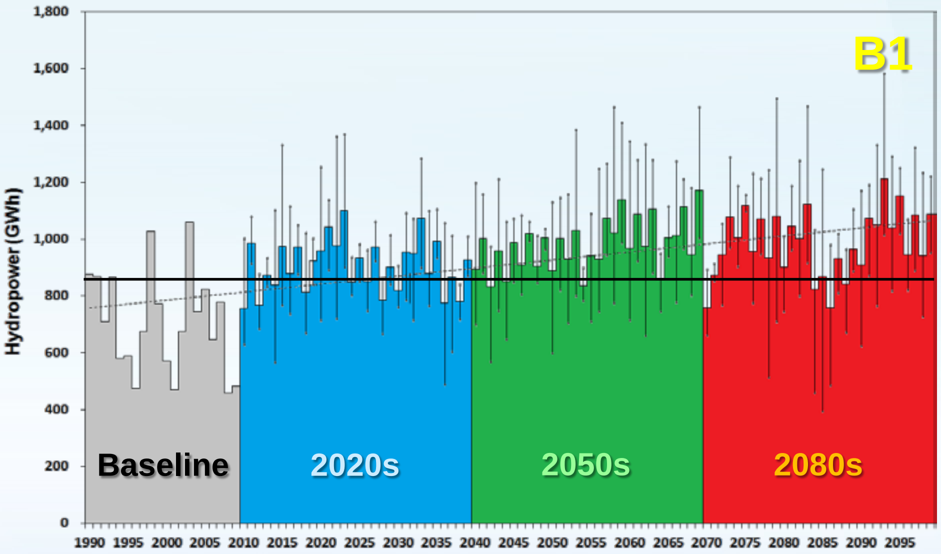
Performance indicator	Baseline	A1B			B1		
		2020s	2050s	2080s	2020s	2050s	2080s
Reliability (%)	92.9	97.7	98.9	98.4	98.2	98.9	98.1
Resilience (%)	52.9	91.7	100.0	84.8	92.6	100.0	84.6
Vulnerability (%)	13.8	0.2	0.2	5.6	0.2	0.2	6.2

Hydropower productions

◆ Climate change impact on hydropower production

- ✓ In South Korea, most energy use usually takes place in the summer and winter
- ✓ Record-breaking winter and summer temperatures have spurred increased use of heating and cooling equipment. Heating is mostly fuelled by oil and gas, whereas cooling is mostly used by electricity





Performance indicator	Baseline	A1B			B1		
		2020s	2050s	2080s	2020s	2050s	2080s
Average annual temperature (˚C)	10.3	11.3	13.0	14.4	11.2	12.4	13.3
Average annual production (GWh)	702	840 (+18.8)	1,002 (+41.7)	1,029 (+45.5)	906 (+28.0)	980 (+38.5)	986 (+39.4)
Summer Production (%)	40.5	42.8	45.1	46.2	45.0	45.6	46.4
Winter Production (%)	16.7	14.8	13.2	13.1	14.0	13.5	13.2

Summary

Performance indicator	Baseline	A1B			B1		
		2020s	2050s	2080s	2020s	2050s	2080s
Average annual temperature (˚C)	10.3	11.3	13.0	14.4	11.2	12.4	13.3
Average annual precipitation (mm)	1,474	1,456 (-1.2)	1,705 (+15.7)	1,760 (+19.4)	1,542 (+4.6)	1,668 (+13.2)	1,684 (+14.2)
Average annual inflow ($10^6 m^3$)	6,226	5,806 (-6.8)	7,170 (+15.2)	7,399 (+18.8)	6,312 (+1.4)	6,981 (+12.1)	6,984 (+12.2)
Average inflow during wet season	4,535	3,619	4,531	4,767	3,984	4,479	4,537
Average inflow during dry season	1,691	2,187	2,639	2,632	2,328	2,502	2,447
Total average annual release ($10^6 m^3$)	6,238	5,790 (-7.2)	7,168 (+14.9)	7,396 (+18.6)	6,294 (+0.9)	6,980 (+11.9)	6,983 (+11.9)
Average annual release to water supply	4,884	5,413	6,333	6,474	5,772	6,192	6,234
Average annual spills	1,354	377	835	922	522	788	549
Efficiency (%)	78.4	93.2	88.3	87.5	91.4	88.7	89.3
Spill	0.18	0.21	0.31	0.33	0.25	0.29	0.30
Reliability (%)	92.9	97.7	98.9	98.4	98.2	98.9	98.1
Resilience (%)	52.9	91.7	100.0	84.8	92.6	100.0	84.6
Vulnerability (%)	13.8	0.2	0.2	5.6	0.2	0.2	6.2
Average annual production (GWh)	702	840 (+18.8)	1,002 (+41.7)	1,029 (+45.5)	906 (+28.0)	980 (+38.5)	986 (+39.4)
Average annual surplus production	95.5	99.1	174.1	213.9	97.2	146.0	161.5
Average annual deficit production	214.3	88.5	61.9	73.9	52.4	10.3	49.1
Summer Production (%)	40.5	42.8	45.1	46.2	45.0	45.6	46.4
Winter Production (%)	16.7	14.8	13.2	13.1	14.0	13.5	13.2

Concluding remarks

- **Climate change will affect the regional water supply and water security (e.g., flood and drought) in the study area**
  - ✓ Hydrology output from the SWAT by downscaled climate change scenarios suggests a significant increase in the amount of dam inflow due to precipitation increase
  - ✓ To mitigate negative hydrologic impacts and utilize positive impacts, climate change should be considered in water resource planning for the multi-purpose dam watersheds
- **The dam inflow change gave us the clue for the future adjustment of dam operation rule for both efficient water use and flood control**
  - ✓ Assuming current operation rule, these changes in system performance may result in increases in economic value of water supply and hydropower production
  - ✓ We need to evaluate the monthly water supply for profit maximization based evaluation of optimal reliability of dam operation system
  - ✓ The prediction of water demand is essential to assess future water resource system
- **To enable adaptation due to climate change as a widely accepted future occurrence, watershed decision makers require quantitative results for the establishment of adaptation strategies**

Thank you