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Water-Energy-Food Nexus Assessment in the Lower Mekong Basin

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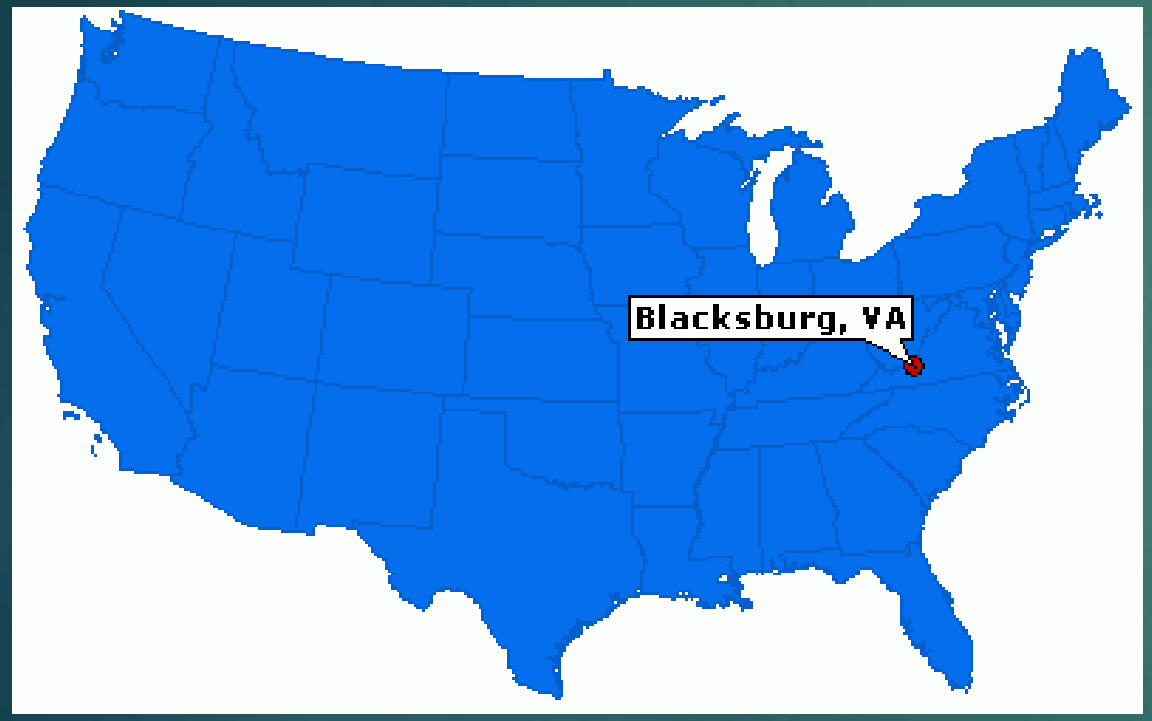


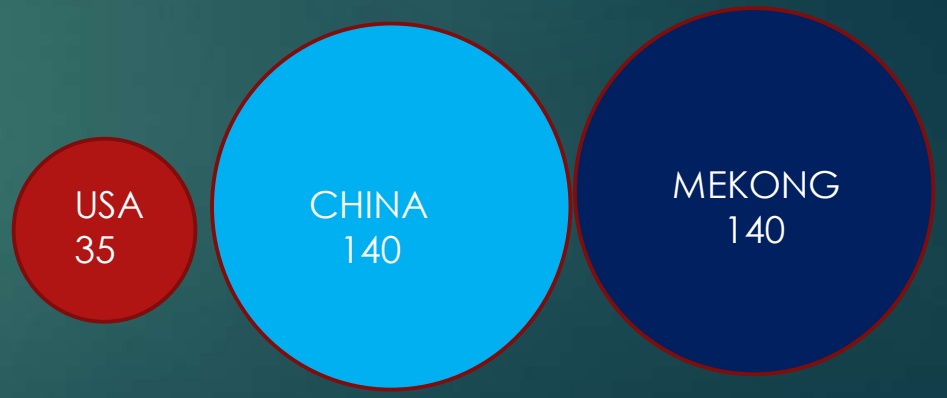
Source: Wikipedia

The Mekong Region

Source: **Basic Geographic Locations**

- Population: 186.5 M
- Area: 1,262,165 sq km
- Highest point: Mt Fansipan, Vietnam (3144 m)
- Biggest cities: Bangkok (9.3 Million); Ho Chi Minh City (7.4 Million)

- Population/sq km:

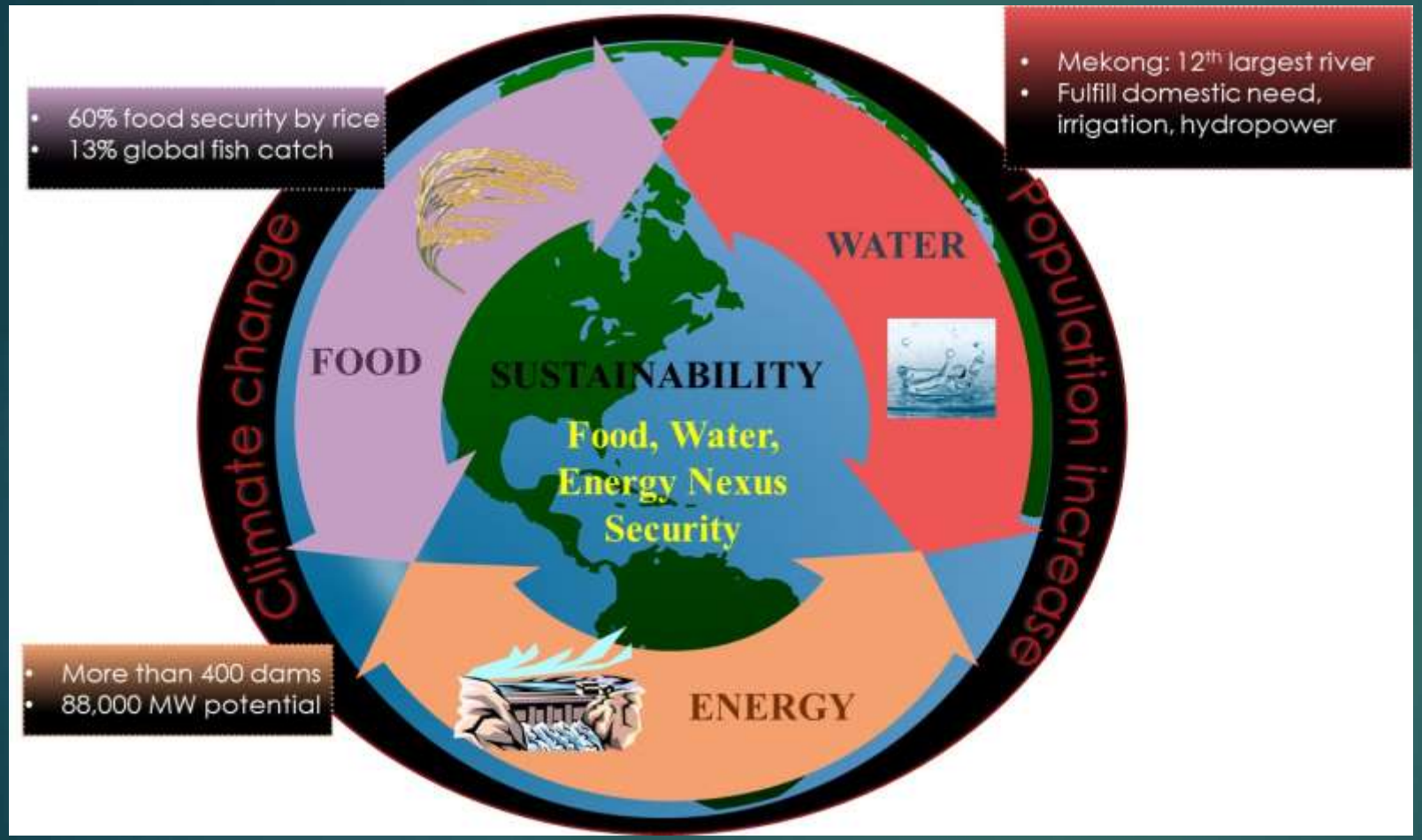


The Mekong River

- 12th largest in world & 7th largest in Asia
- 6 nations in southeast Asia
- Drainage area: ~765,000 sq.km.
- Annual mean flow: ~15,000 cu.km./yr
- Length: **UMRB**:~2200 km. + **LMRB**:~2600 km.
- Dams: Total 456 nos.

LCLUC has the potential to alter irrigation water demands which will have a direct impact on the water and energy fluxes.

Climate change is modifying the hydrologic responses of the basin.



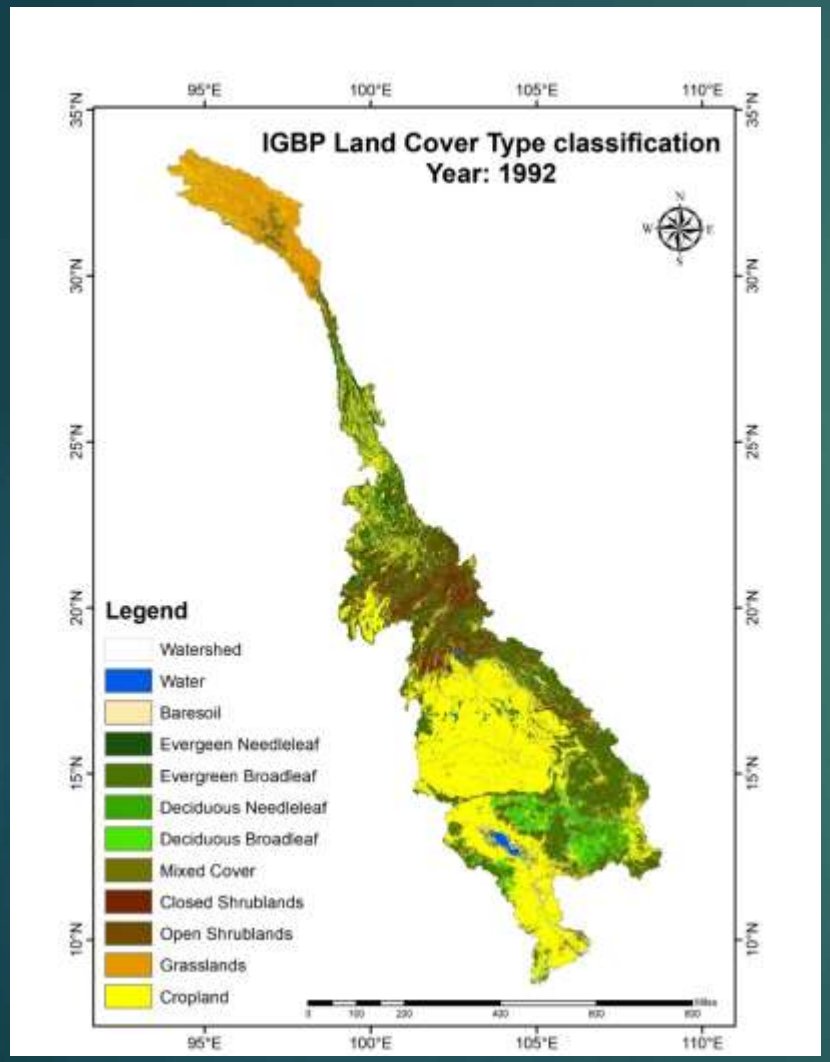
Required Understanding on:

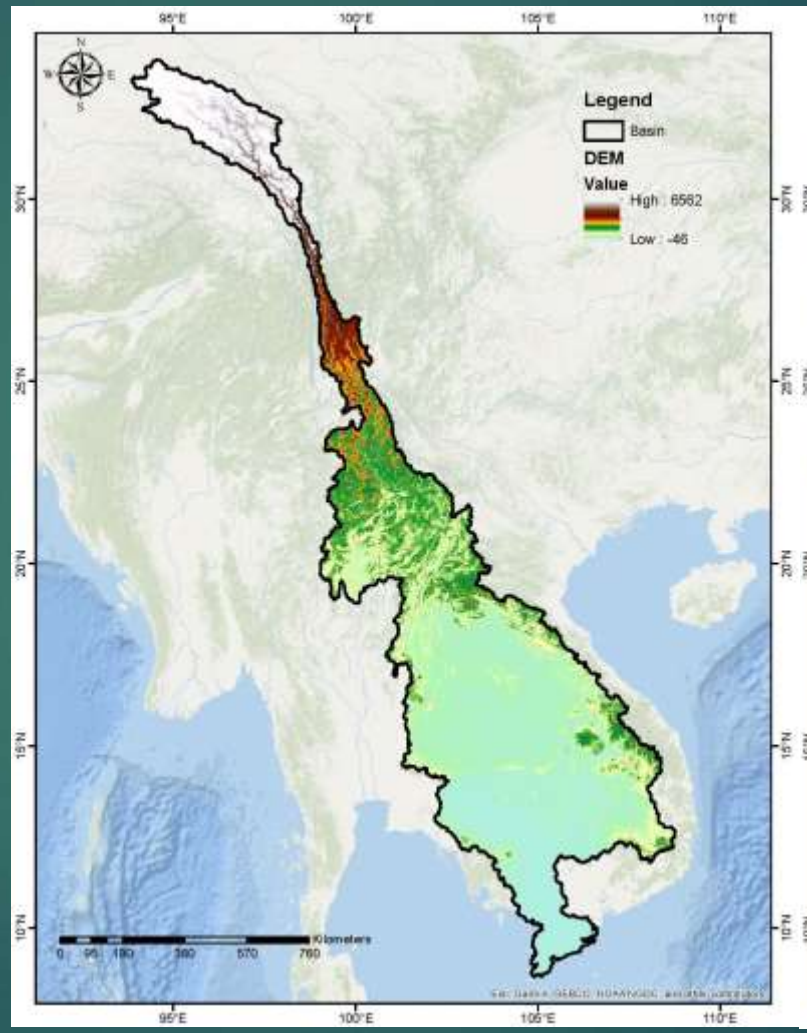
Basin hydrology using macroscale hydrological models

Changing precipitation, temperature and land-use patterns in LMB.

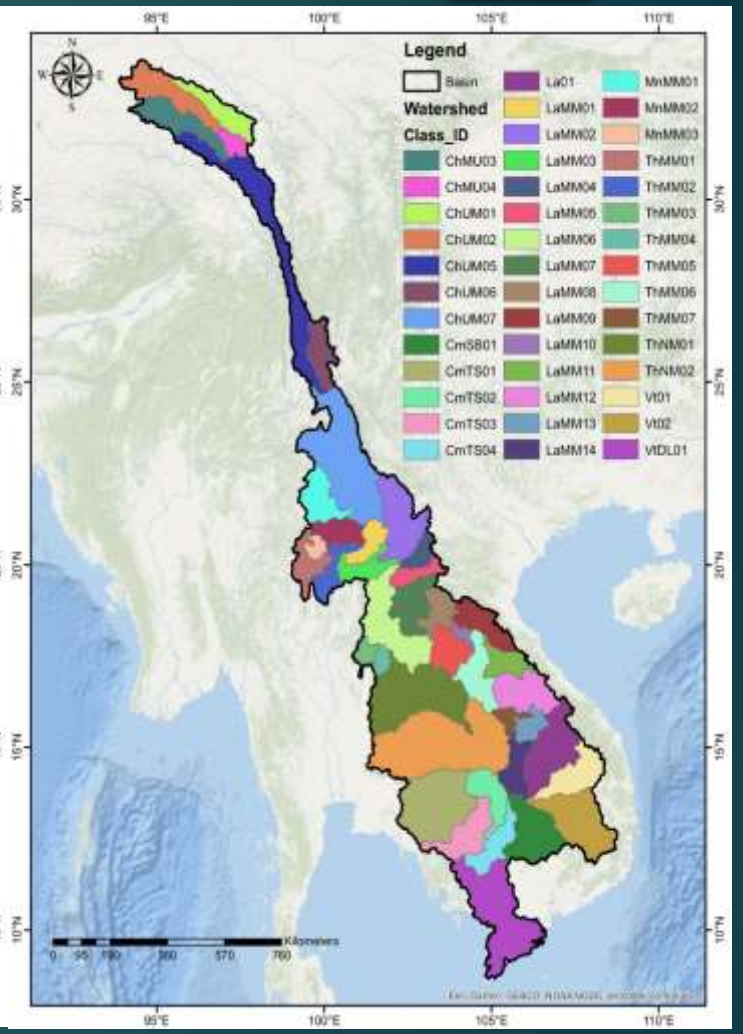
Baseline sub-basin scale water budget and storage using in-situ, remote sensing and modeling outputs

The Mekong: Physiography



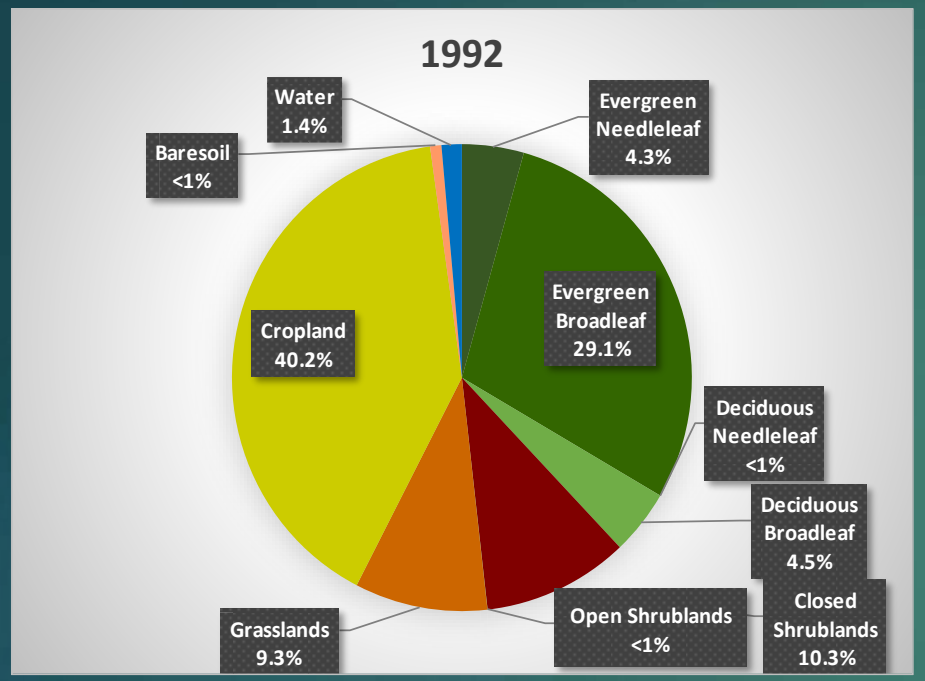


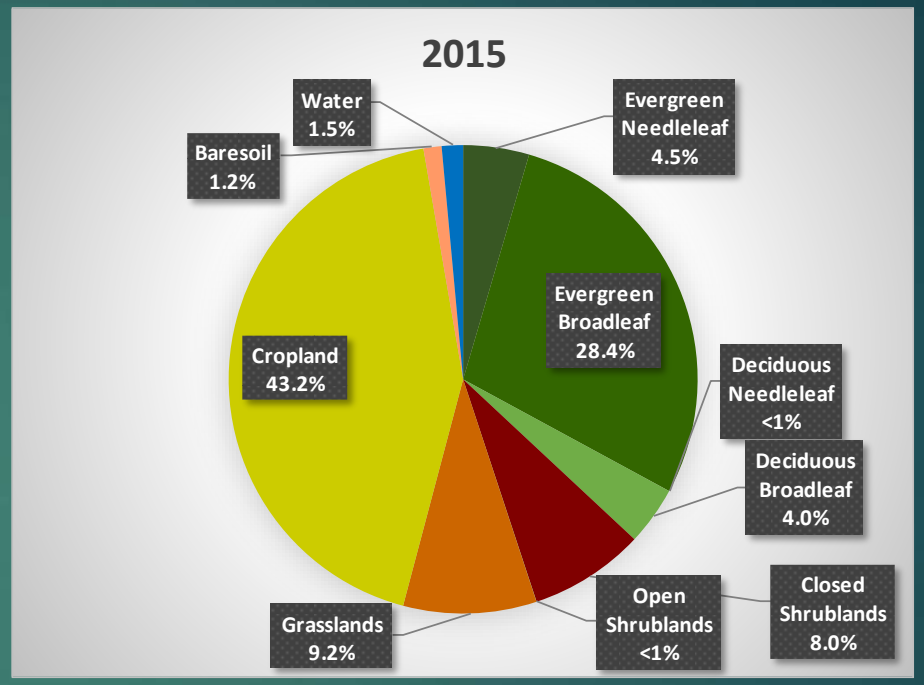
DEM



Watersheds

Land cover and Land use change





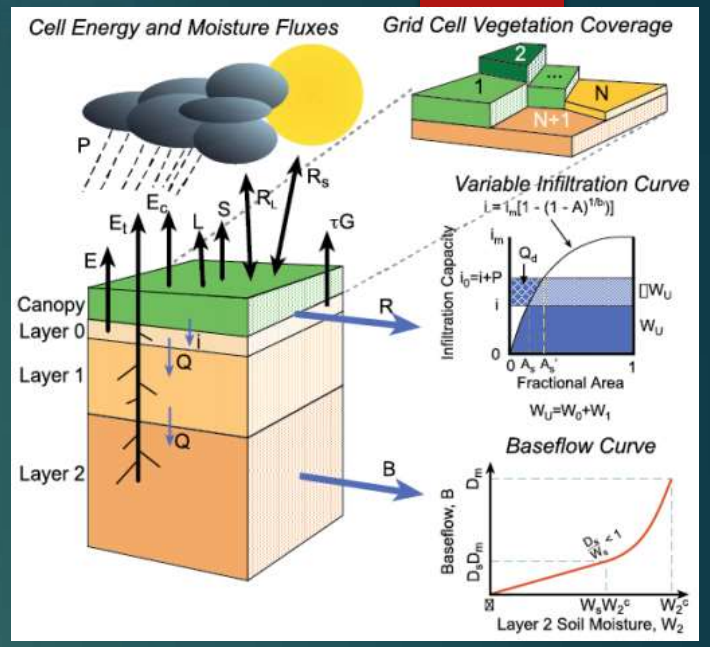
Vegetation: Landsat 8
Met data: Multiple
Fluxes: MODIS 16, GRACE, AMSR-E

Hydrology: Variable Infiltration Capacity (VIC) Model

- Semi-distributed physically based hydrological model.
- Solves water and energy balance for each grid-cell.
- Grid based land surface representation and each grid is independently simulated.
- Water enters only from atmosphere (precipitation).
- Multiple soil layer depths, (Generally 3 layers).
- Daily or sub-daily time steps.
- Sub-grid vegetation/land cover representation.
- Sub-grid elevation variability (snow band) representation.
- Developed by UW and Princeton Univ but has gone through substantial changes since its original implementation

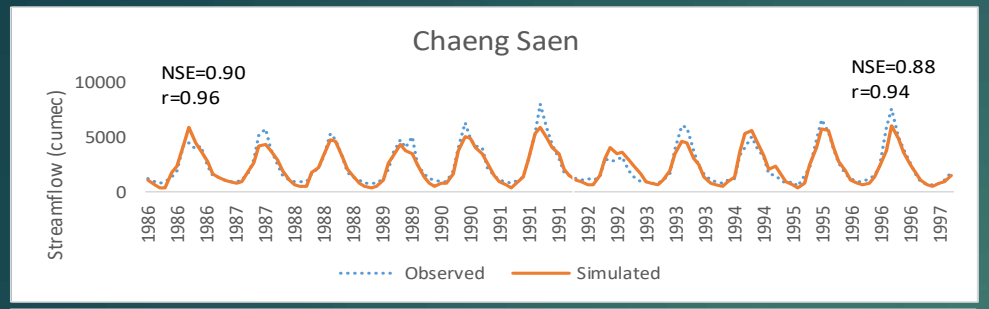
$P-ET-R-\Delta S=0$

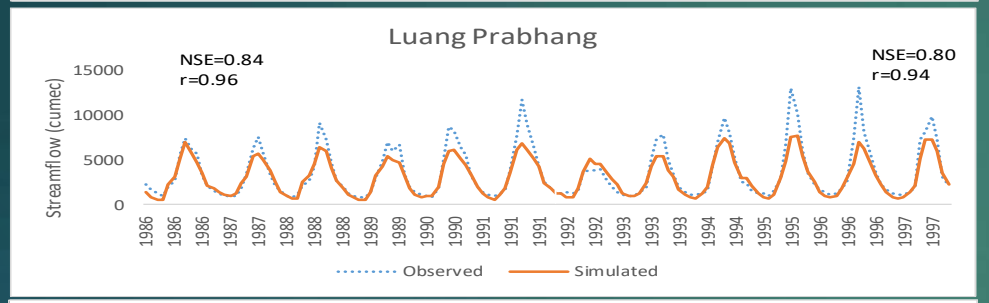
$Rnet-LH-SH+GH+\Delta Q/\Delta t=0$

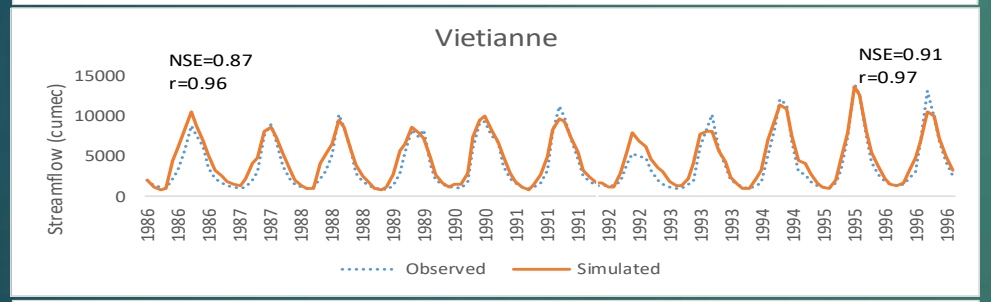


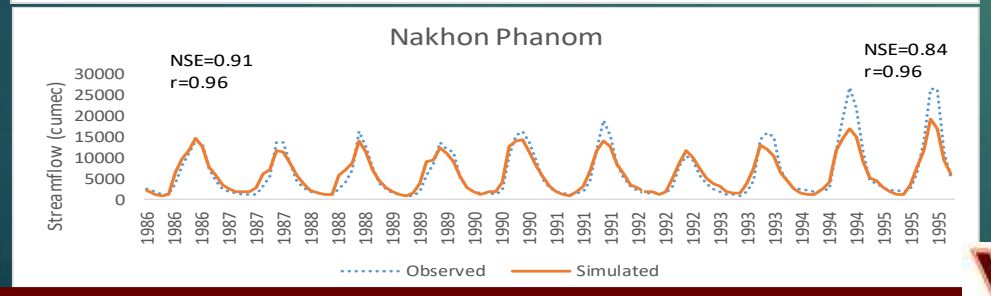
University of Washington, Princeton Univ

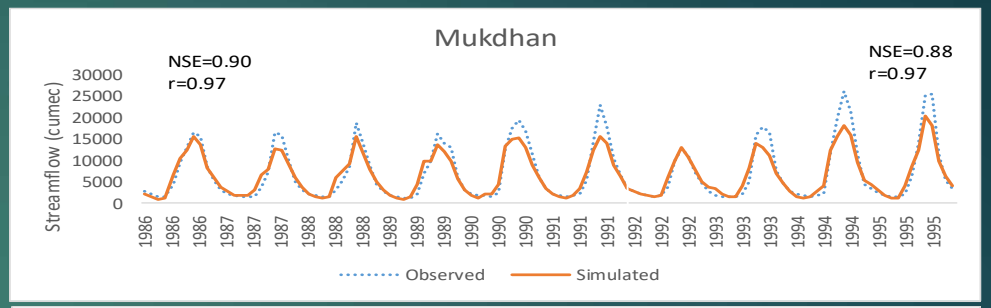
Calibration/Validation

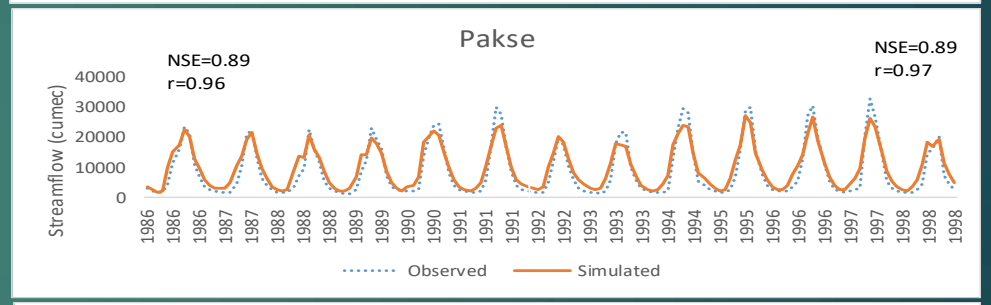


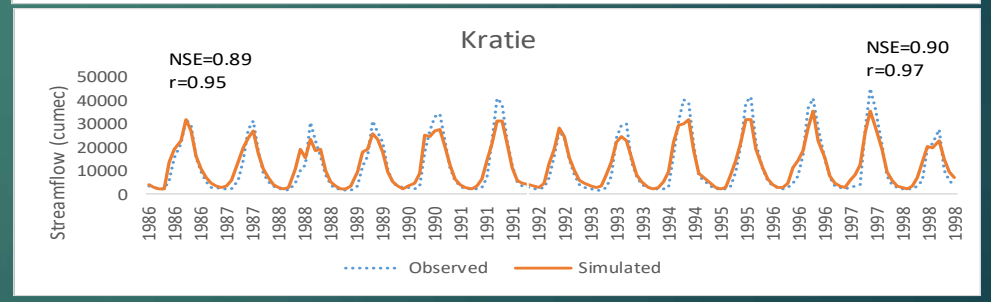




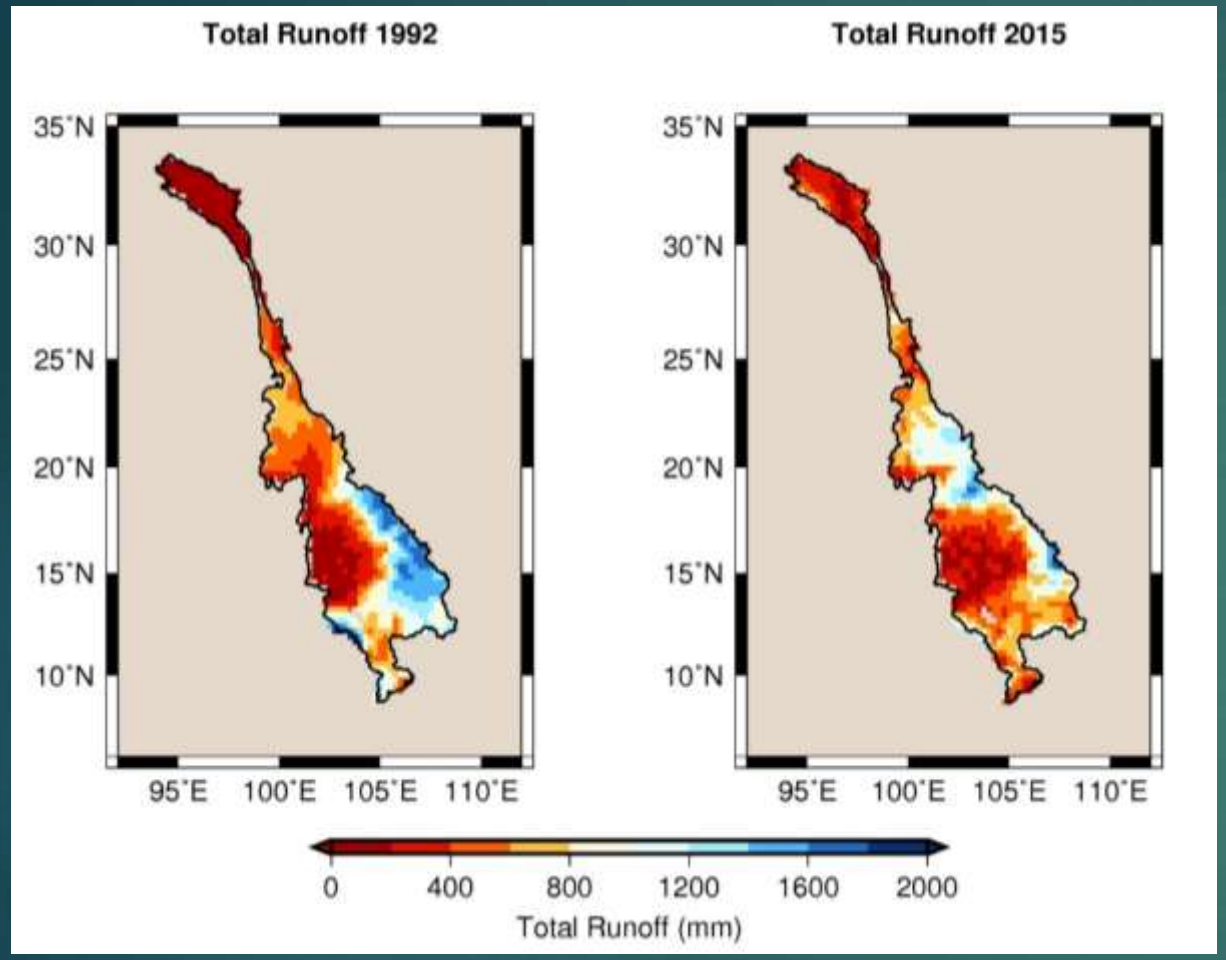


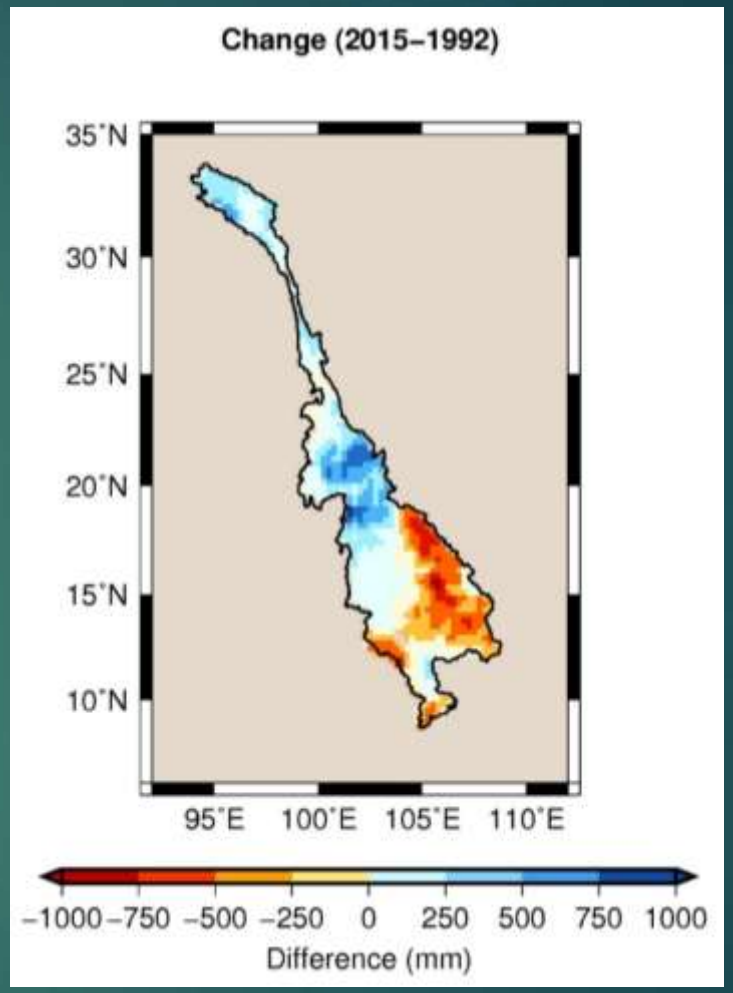




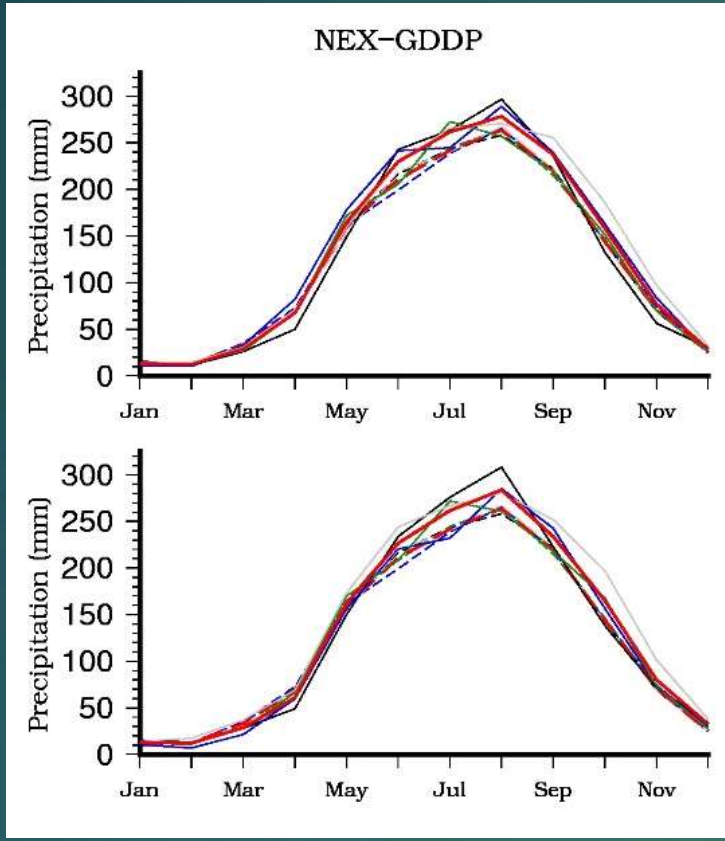


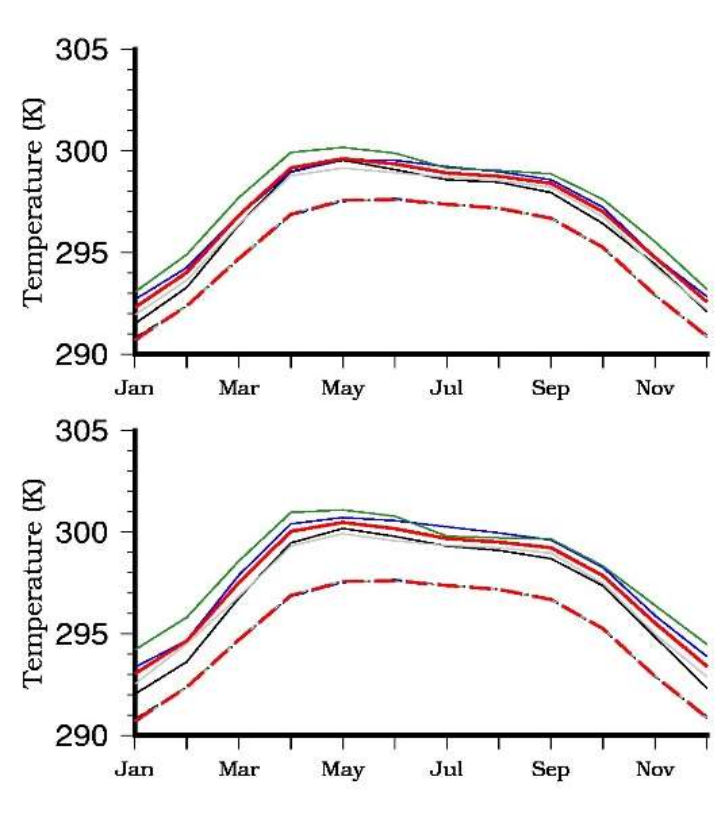
Change in total runoff





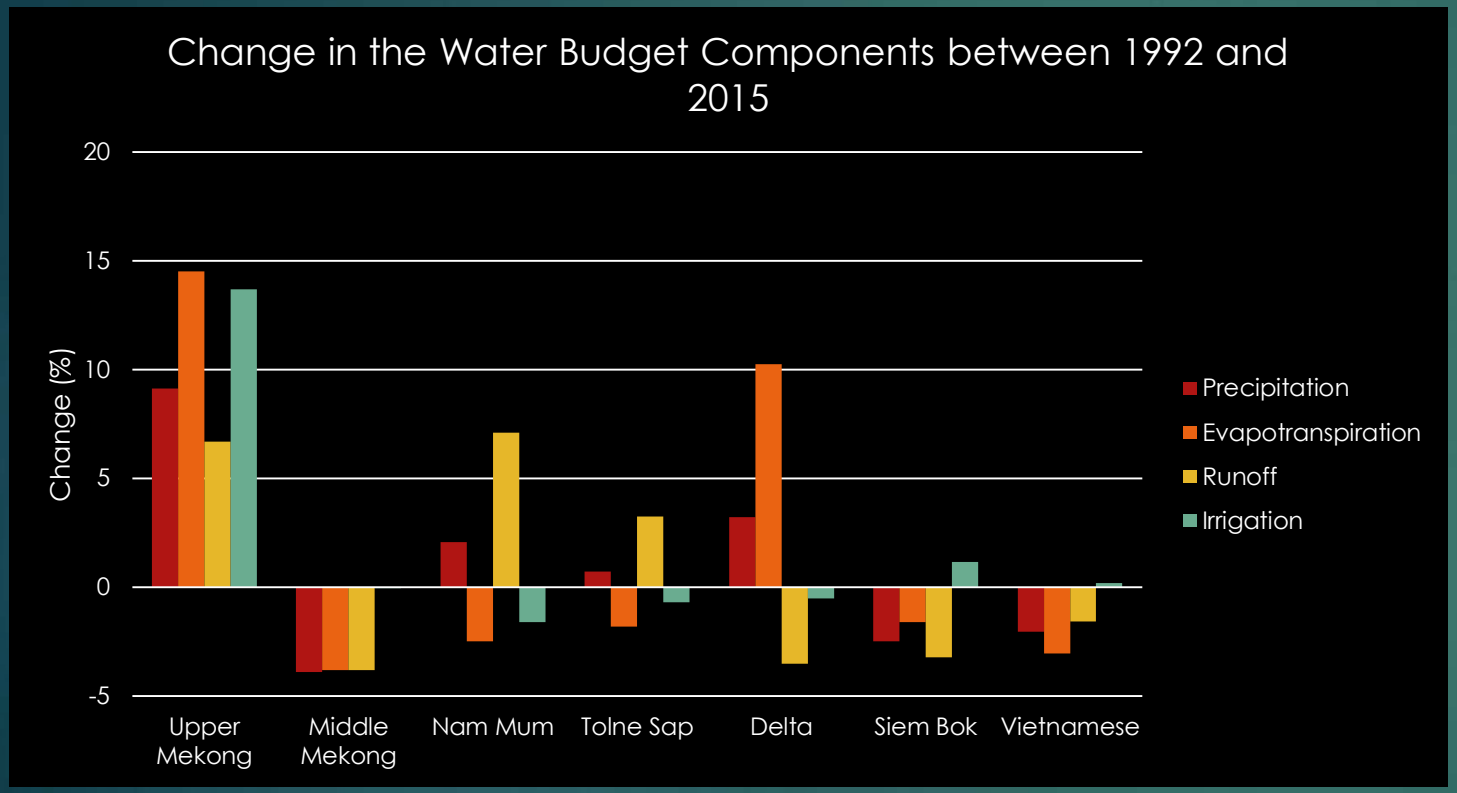
Seasonal change in the precipitation and temperature

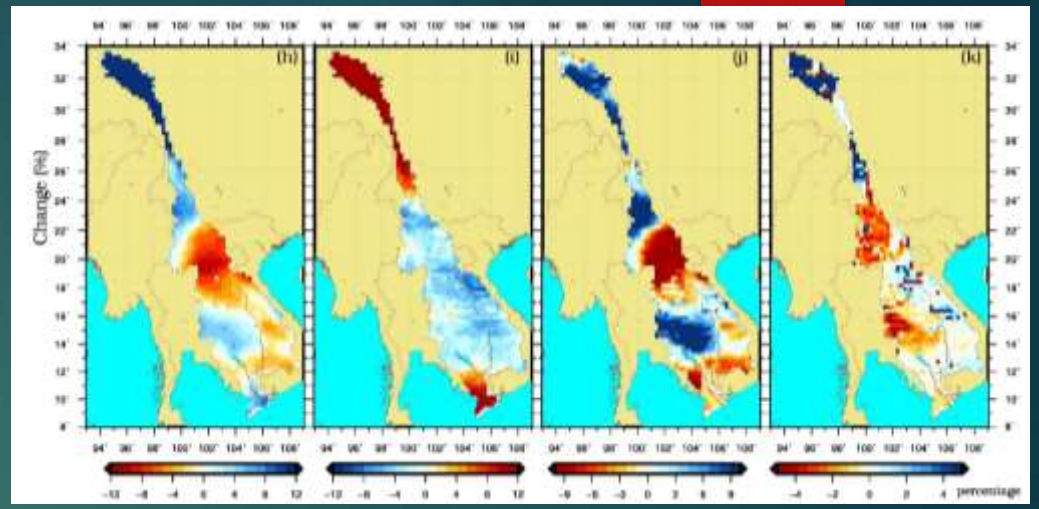


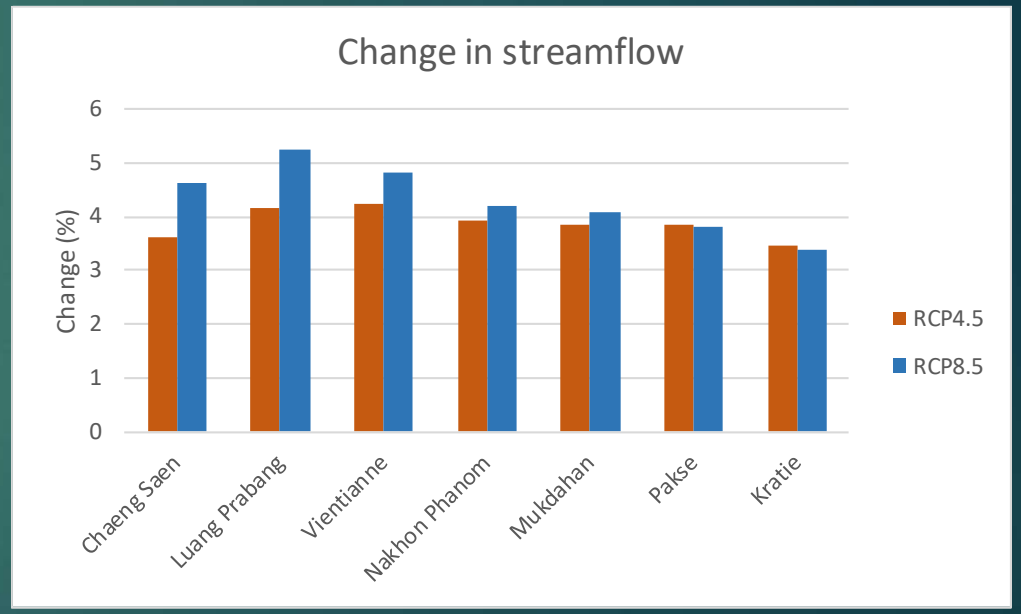


- Highest precipitation occurs in the months, June to September.
- Lowest precipitation occurs during November to March.
- Increases in precipitation for future period is plausible.
- Increases in temperature is higher during the period April-September
- Increases in temperature is higher for RCP8.5 as compared to RCP4.5.

Water Budget Estimation



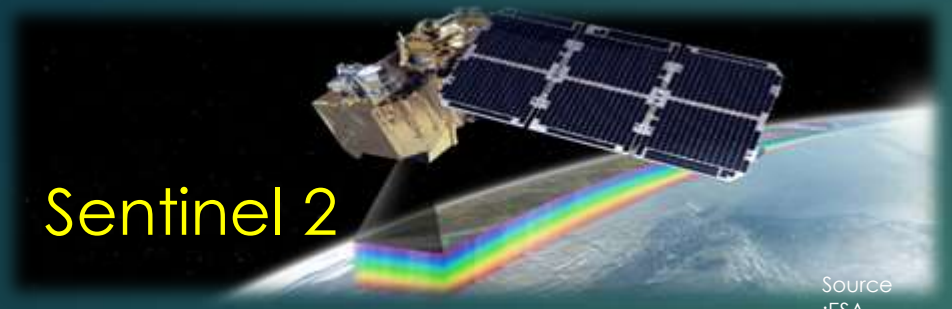




February 11, 2013 - present

Source :landsat.usgs.gov

The Landsat 8 mission objective is to provide timely, high quality visible and infrared images of all landmass and near-coastal areas on the Earth, continually refreshing an existing Landsat database.



Source :ESA

7 March, 2017 - present

Sentinel-2 is an Earth observation mission developed by ESA as part of the Copernicus Programme to perform terrestrial observations in support of services such as forest monitoring, land cover changes detection, and natural disaster management.

Source : ESA

Source

1 March, 2002 – 8 April, 2012

Envisat ("**Environmental Satellite**") is a large inactive Earth-observing satellite which is still in orbit. Operated by the European Space Agency (ESA), it was the world's largest civilian Earth observation satellite.

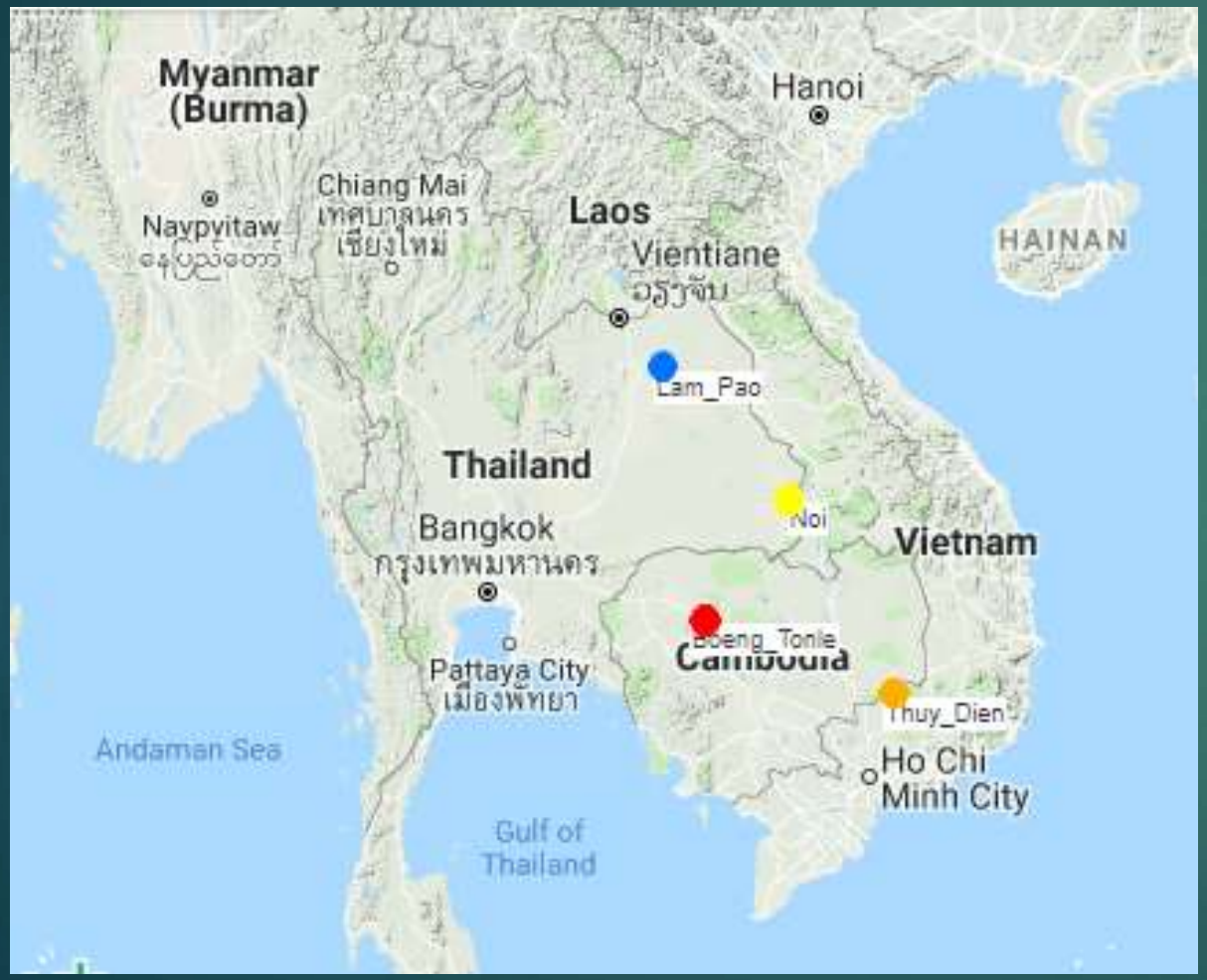
Source : ESA

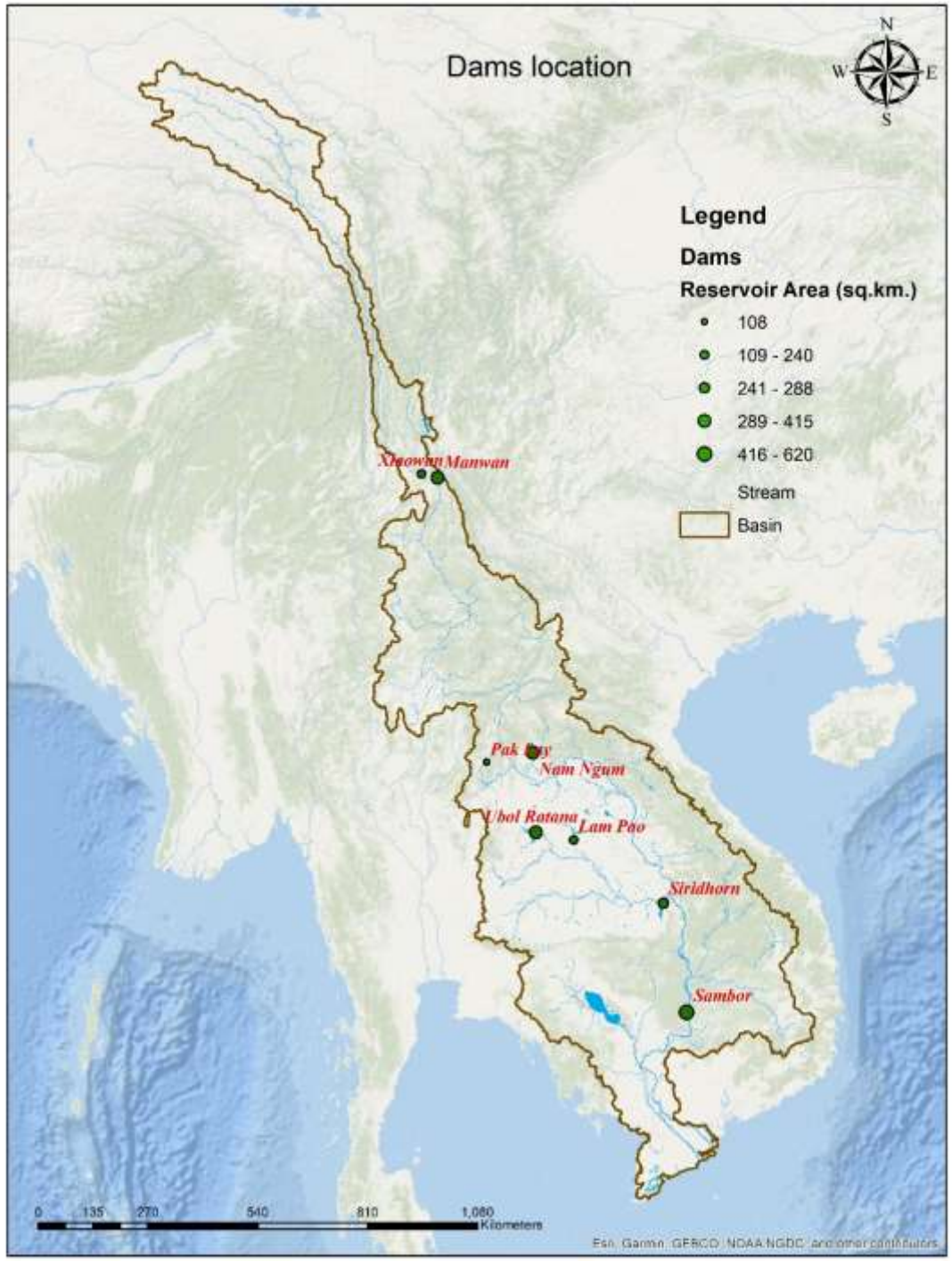
Jason-3

17 January, 2017 - present

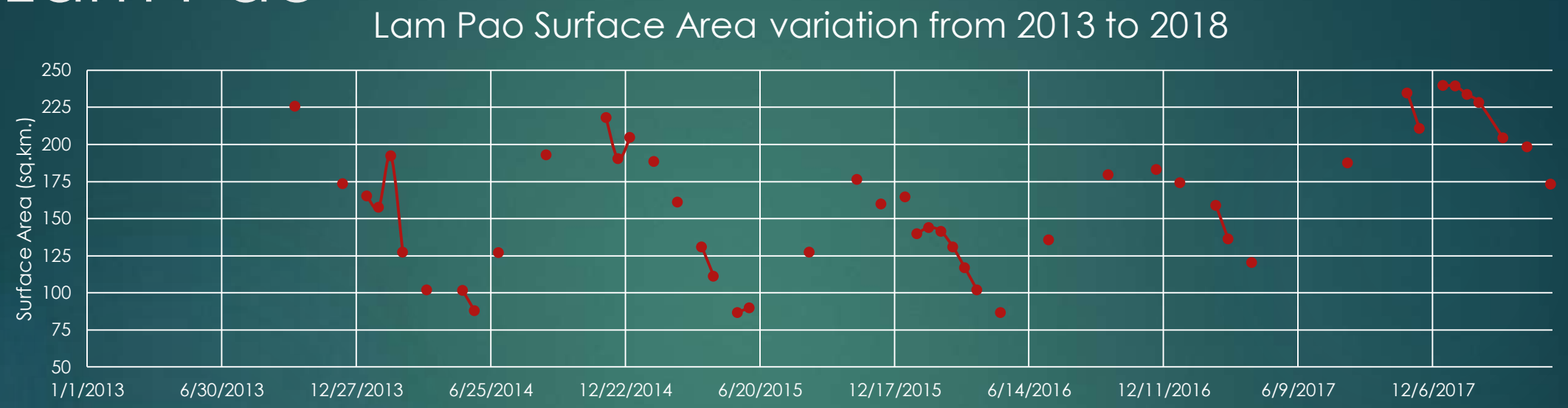
Jason-3 is the fourth mission in U.S.-European series of satellite missions that measure the height of the ocean surface. Launched on January 17, 2016, the mission will extend the time series of ocean surface topography begun by the TOPEX/Poseidon satellite mission in 1992 and continuing through the Jason-1 (launched in 2001) and the currently operating OSTM/Jason-2 (launched in 2008) missions.

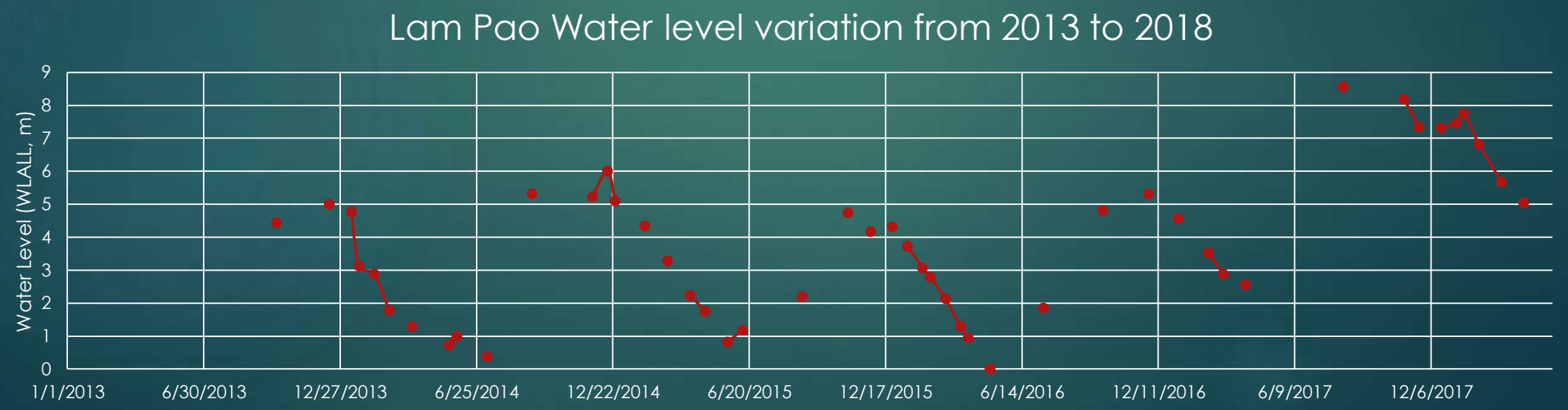
Lam Pao


Myanmar
(Burma)
Hanoi
Chiang Mai
Naypyitaw
Laos
Vientiane
HAINAN
Lam_Pao
Thailand
Noi
Bangkok
Vietnam
Pattaya City
Cambodia
Thuy_Dien
Andaman Sea
Ho Chi
Minh City
Gulf of
Thailand


Dams location
N
W
E
S
Legend
Dams
Reservoir Area (sq.km.)
108
109 - 240
241 - 288
289 - 415
416 - 620
Stream
Basin
Xiaowan
Manwan
Pak Mun
Nam Ngum
Ubol Ratana
Lam Pao
Sirindhorn
Sambor
0
135
270
540
810
1,080
Kilometers

Surface Area and Water Level variation of Lam Pao



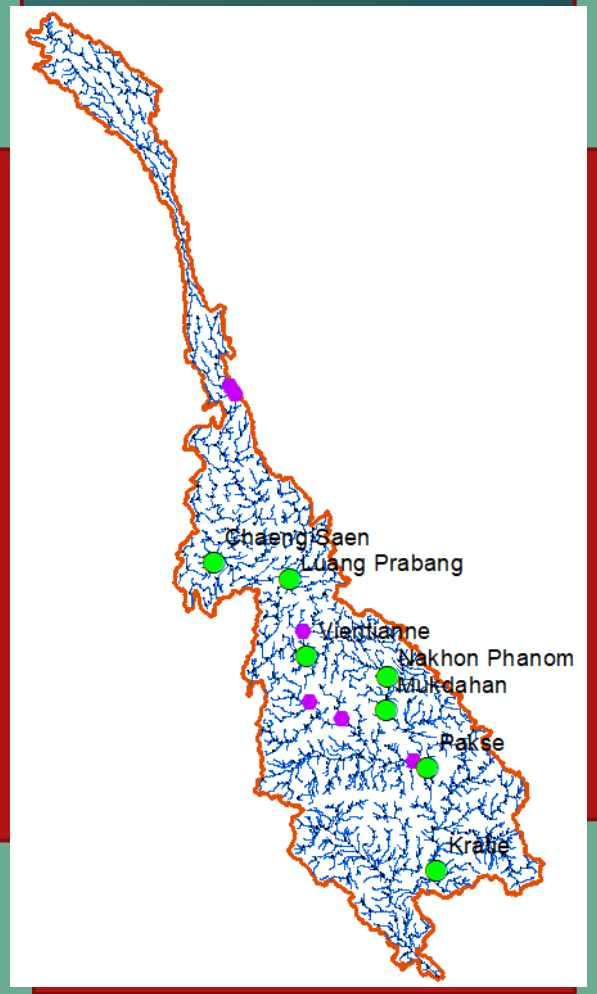


Streamflow simulation for Mekong river basin (SWAT)

- Forcing: 1948 to 2016 from Sheffield's data
- 0.25 X 0.25 degree resolution
- 6 existing dams

Latitude: 33.625
Longitude: 94.125

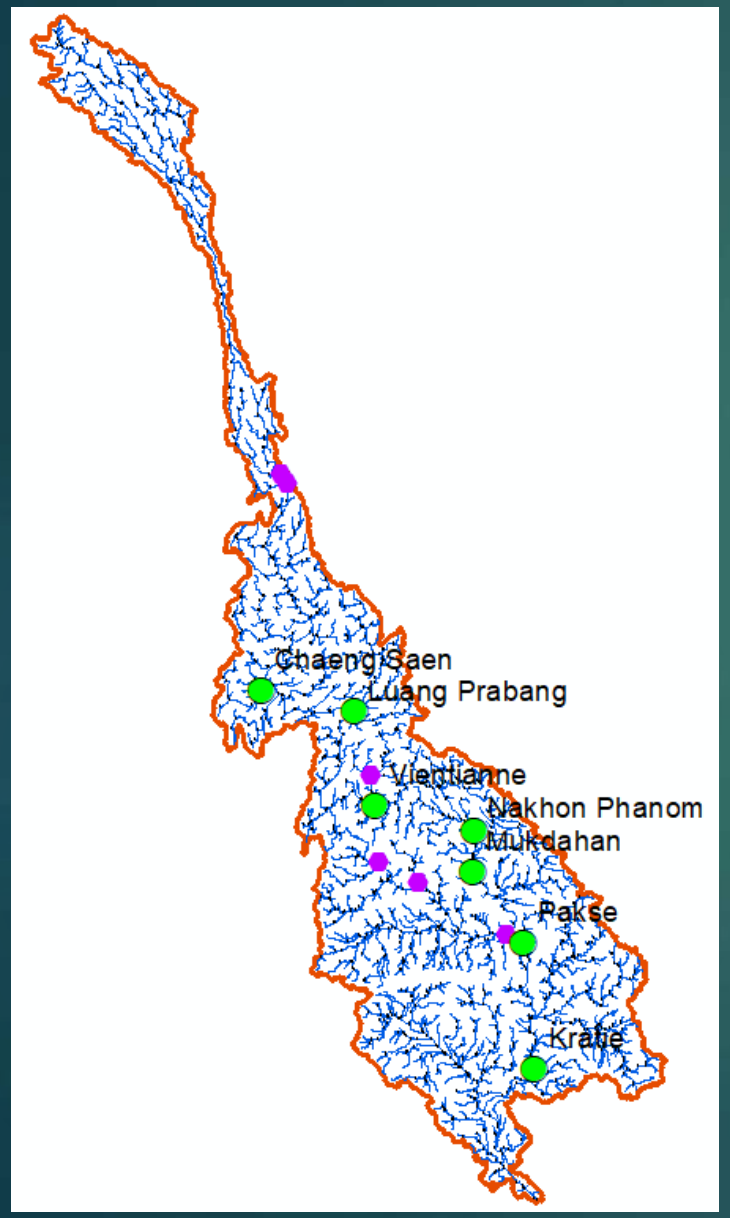
Latitude: 33.625
Longitude: 108.625



Latitude: 8.875
Longitude: 94.125

Latitude: 8.875
Longitude: 108.625

Sub-watershed and dams (Six dam application)



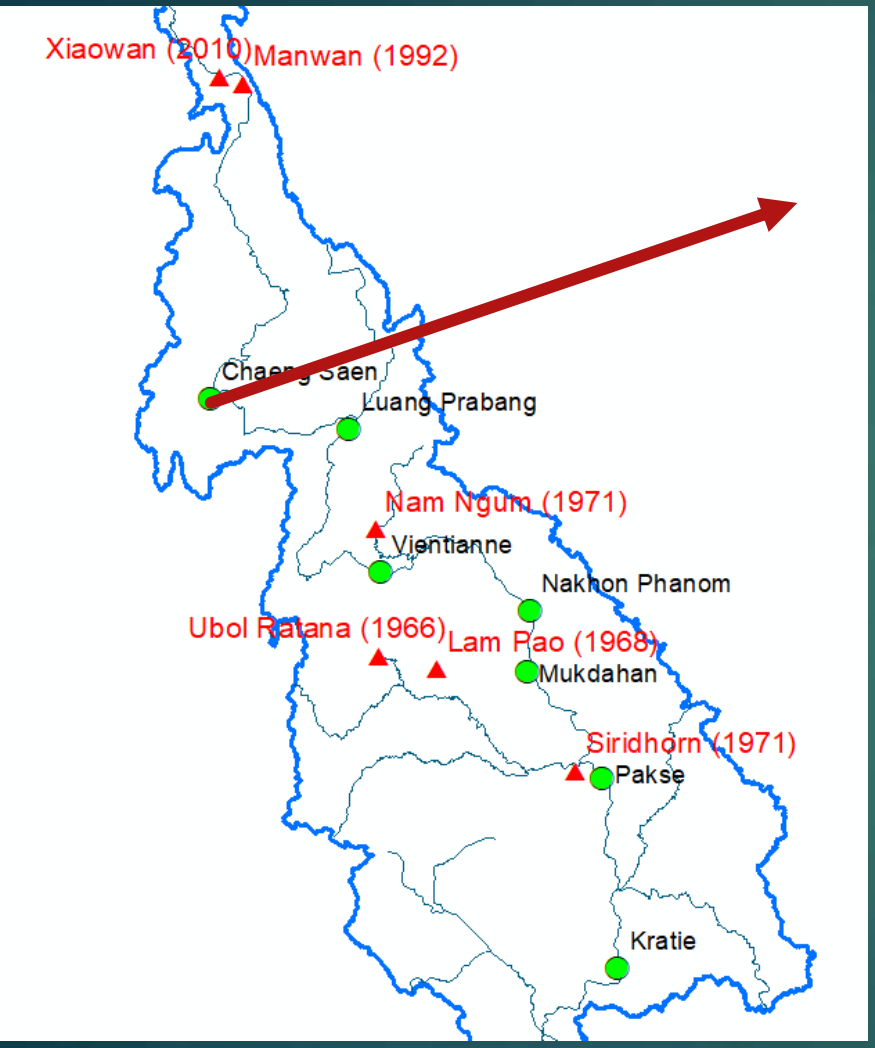
2141 Sub-watersheds
1147 climate grids (0.25 X 0.25 degree)
1948-2016 forcing (Sheffield's)

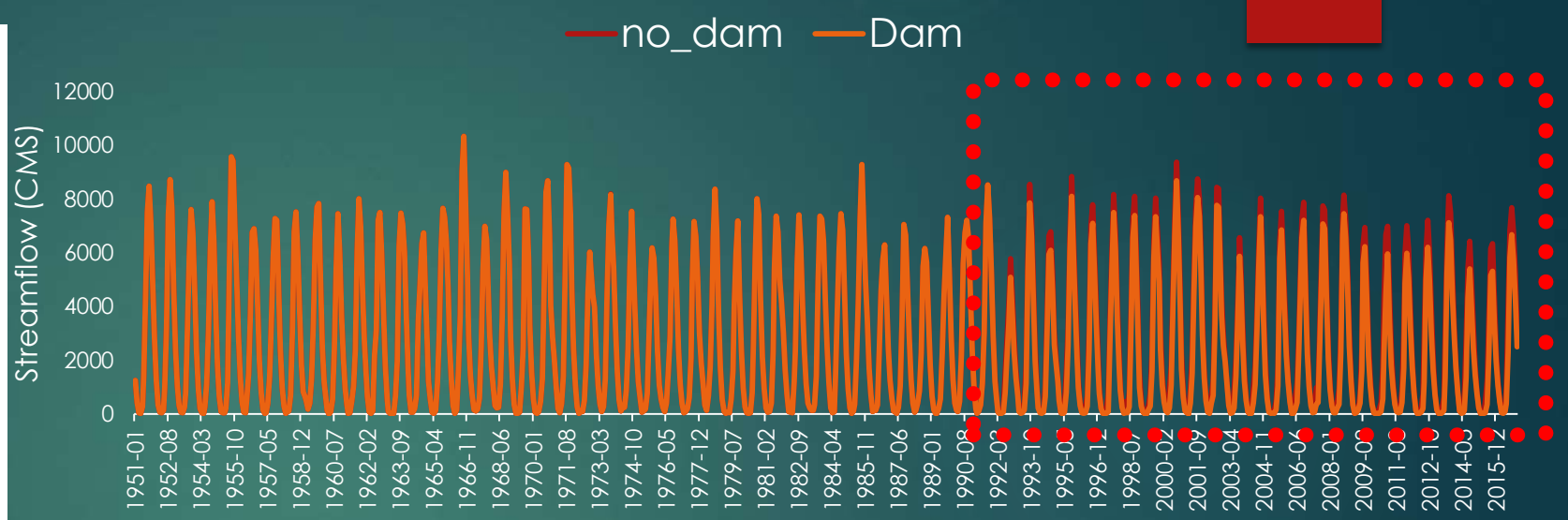
Mekong_stations
Dams

Name	Country	sub	RES_ESA	RES_EVOL	RES_PSA	RES_PVOL	RES_VOL
Manwan	CHN	249	41500	92000	24900	55200	18400
Ubol Ratana	THA	1111	41000	255900	24600	153540	51180
Nam Ngum	LAO	773	37000	470000	22200	282000	94000
Siridhorn	THA	1481	28800	196700	17280	118020	39340
Lam Pao	THA	1175	24000	134000	14400	80400	26800
Xiaowan	CHN	248	19400	1456000	11640	873600	291200

RES_ESA : Reservoir surface area when the reservoir is filled to the emergency spillway [ha]
RES_EVOL : Volume of water needed to fill the reservoir to the emergency spillway (10^4 m^3)
RES_PSA : Reservoir surface area when the reservoir is filled to the principal spillway [ha]
RES_PVOL : Volume of water needed to fill the reservoir to the principal spillway [10^4 m^3]
RES_VOL : Initial reservoir volume [10^4 m^3]

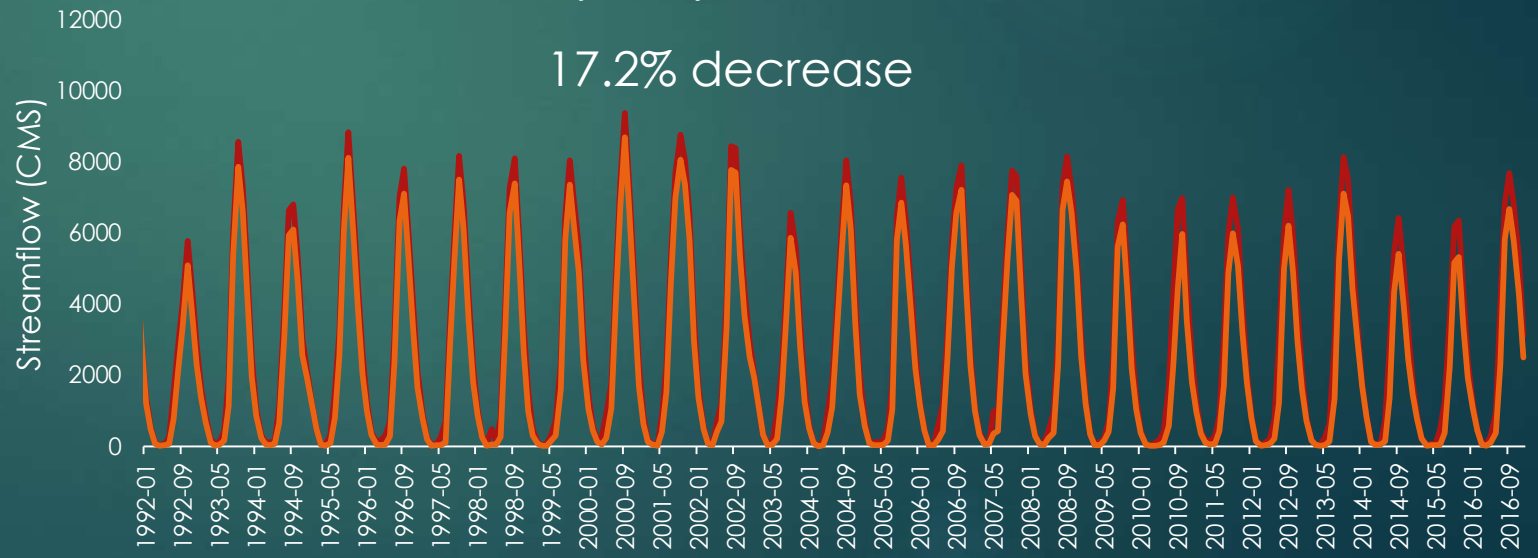
Dam and streamflow



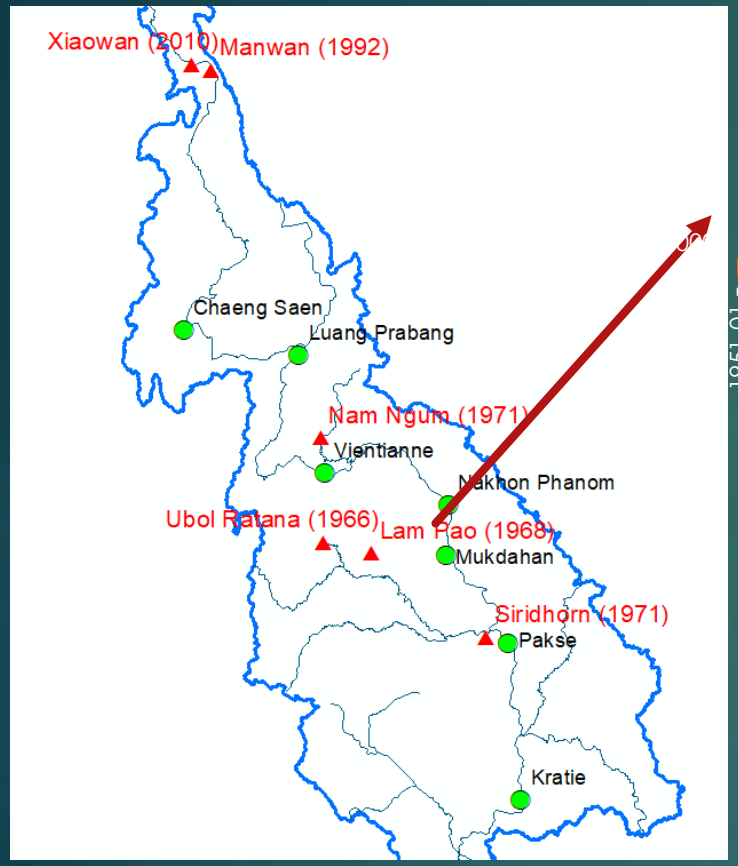


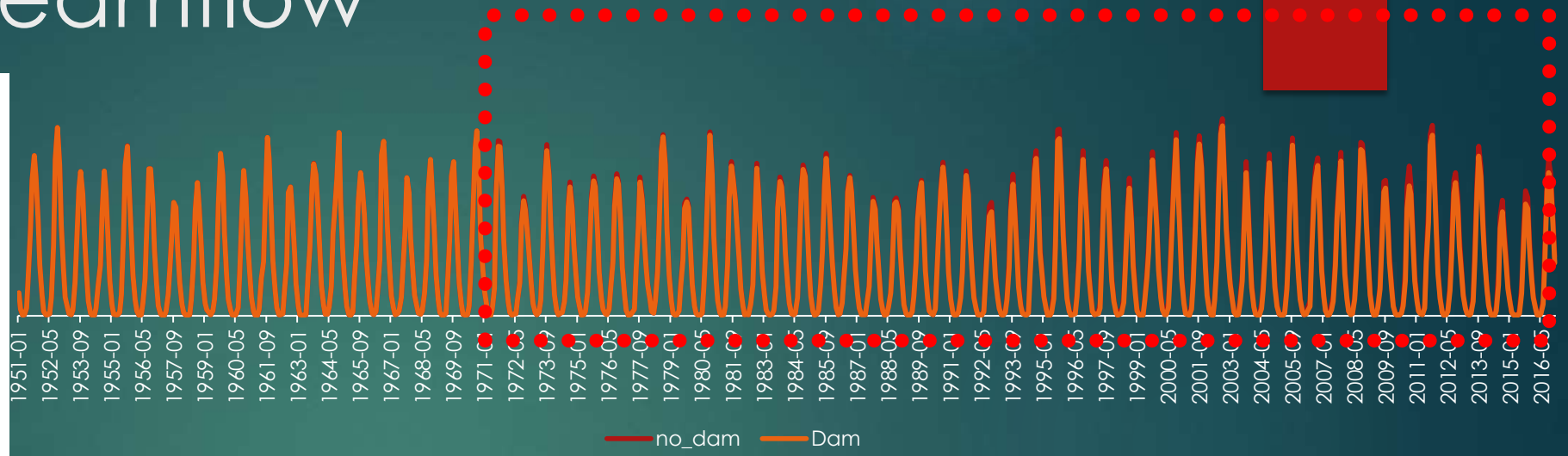
After dam construction….(1992)

17.2% decrease



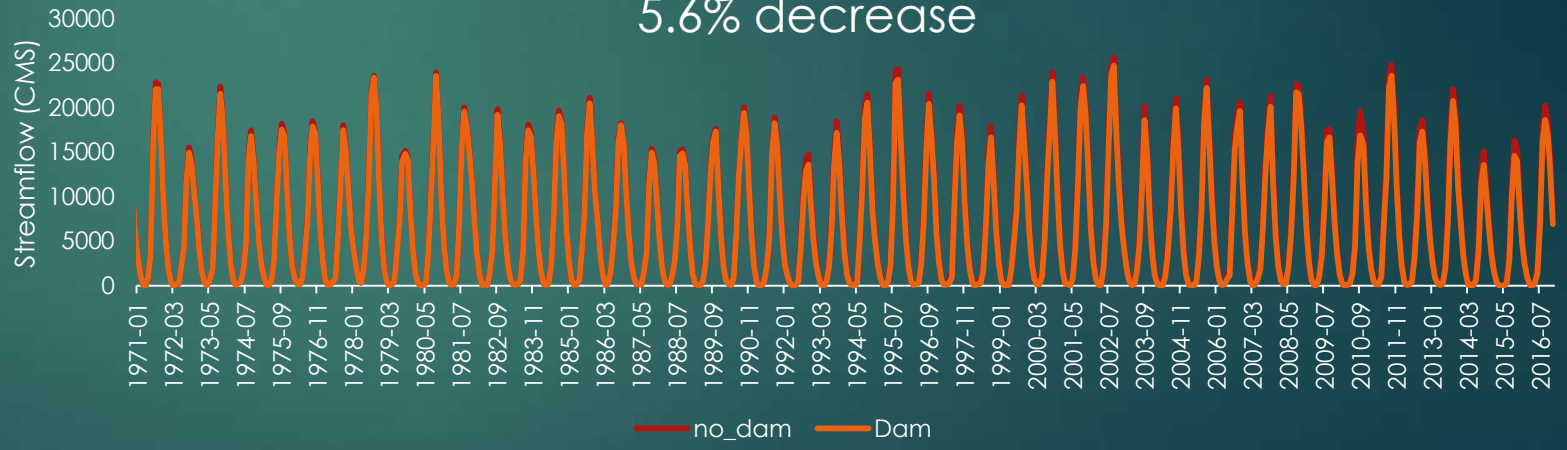
Dam and streamflow



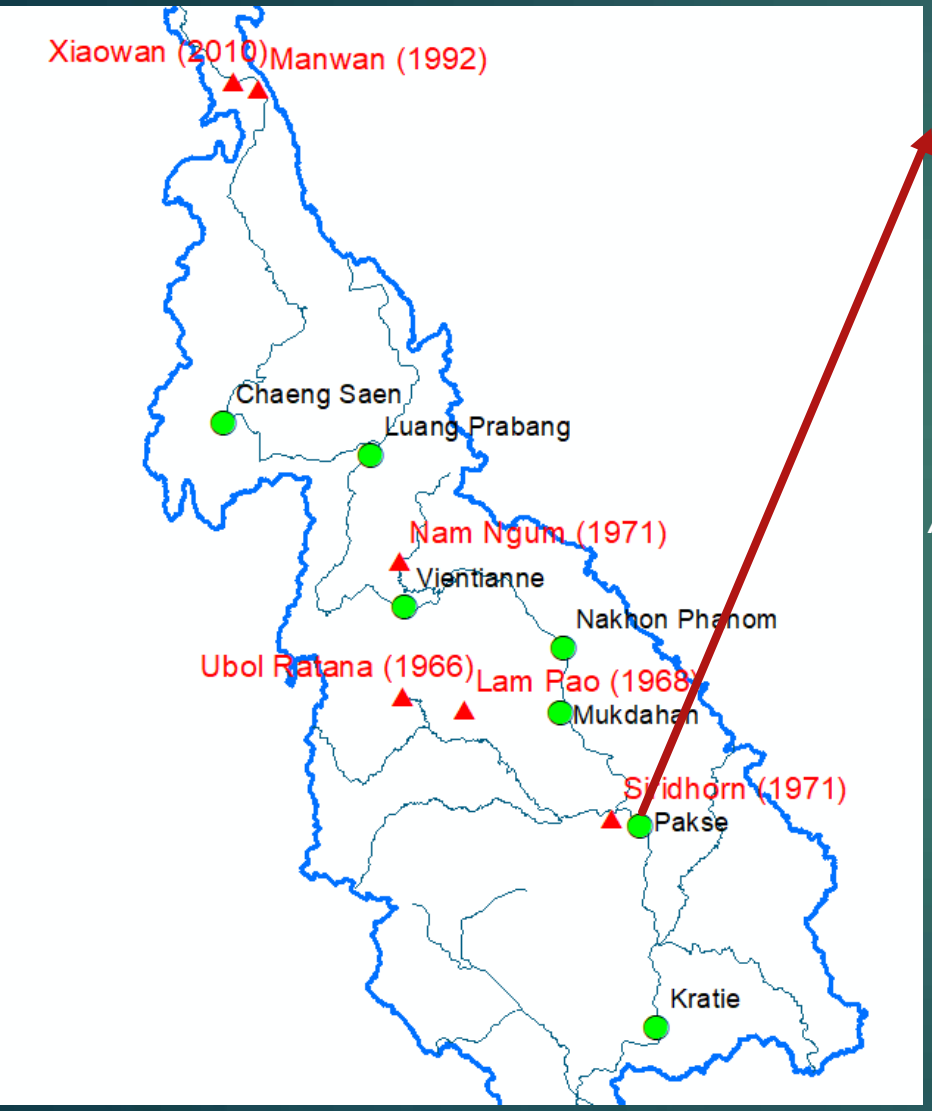


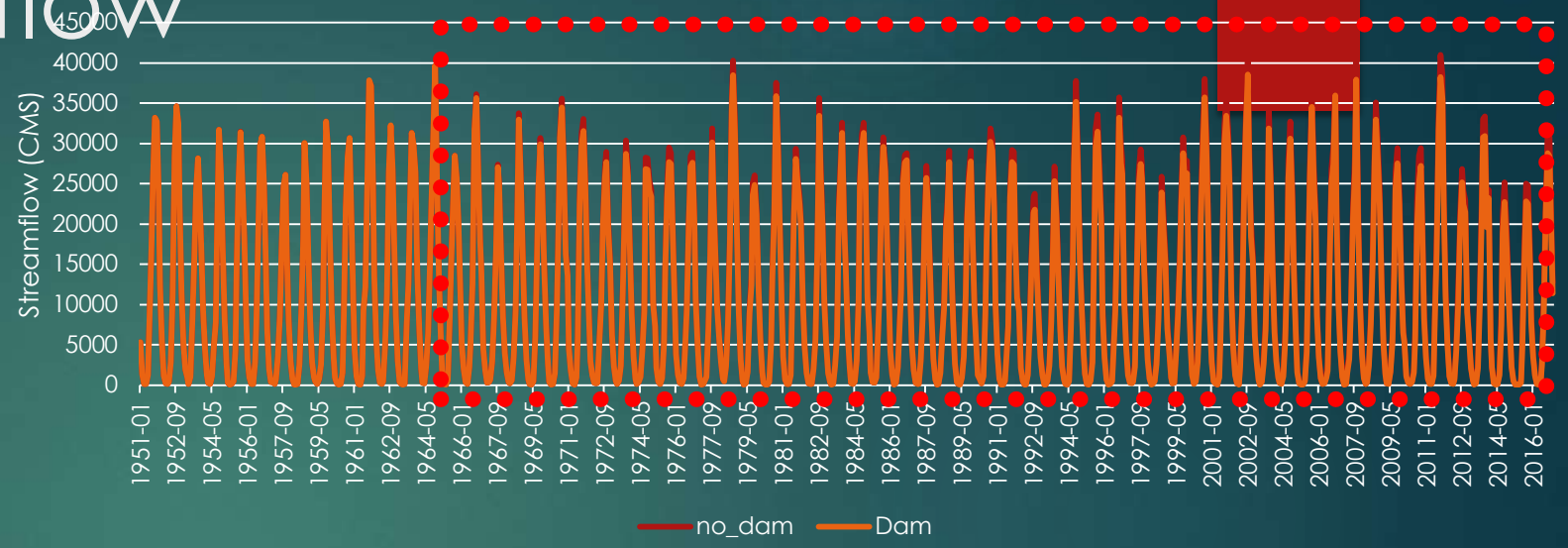
After dam construction….(1971)

5.6% decrease



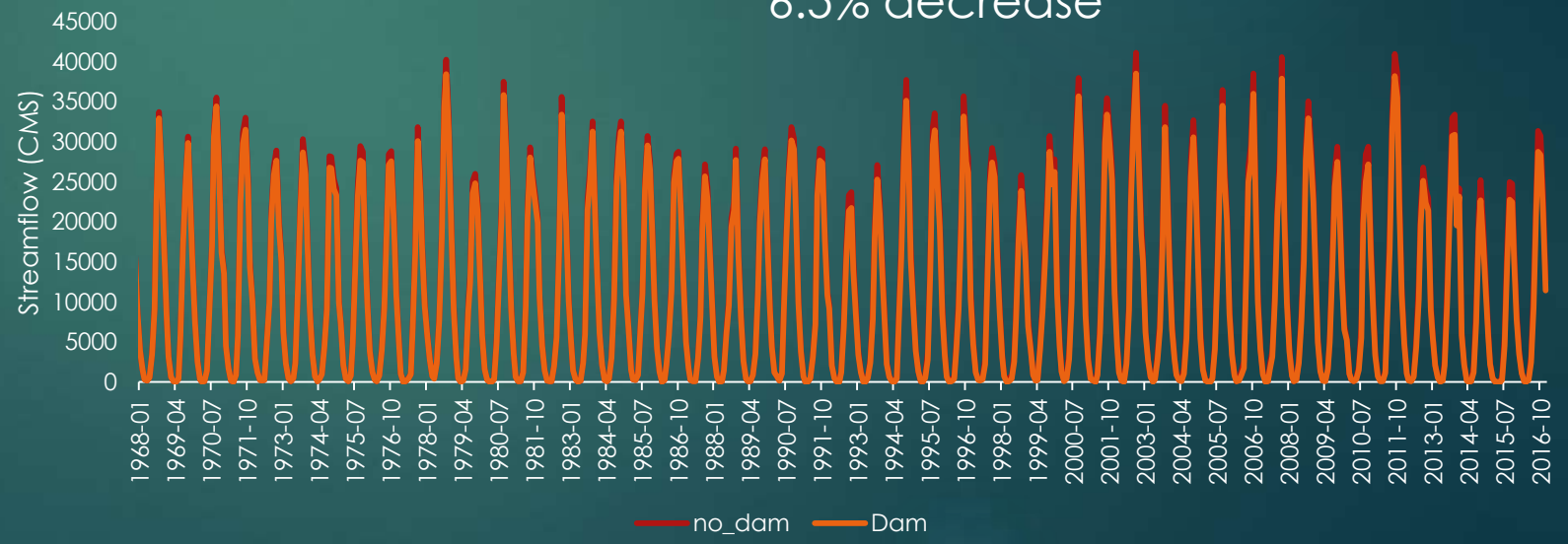
Dam and streamflow





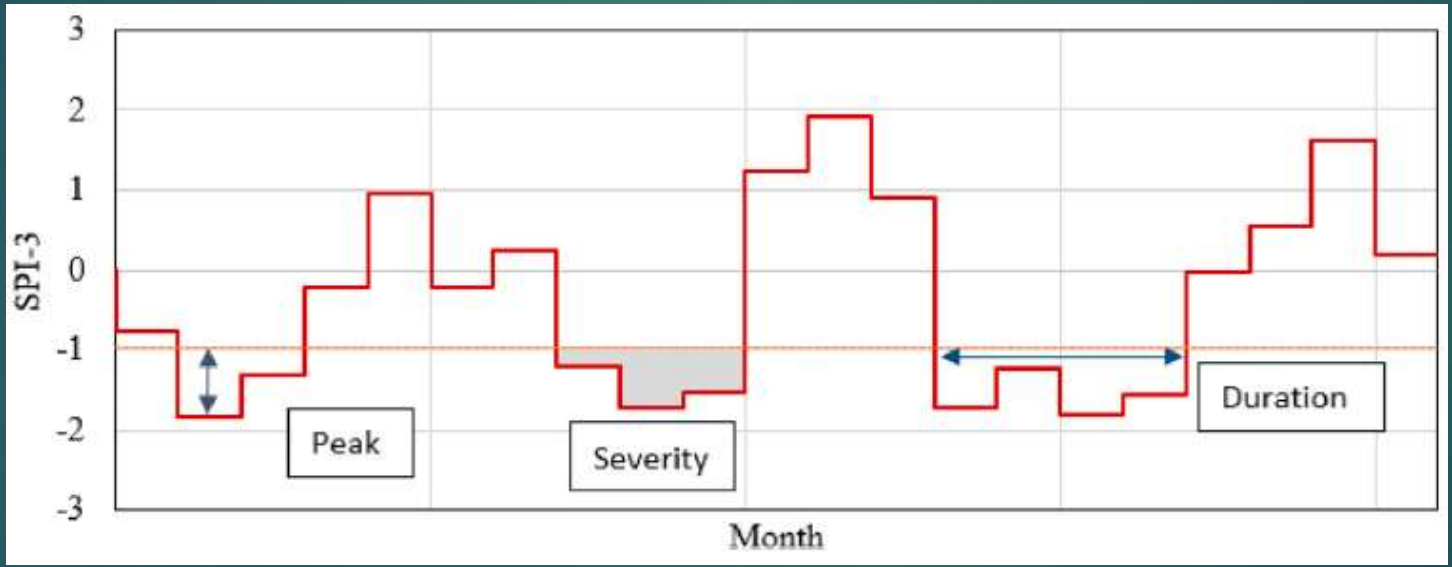
After dam construction….(1968)

6.5% decrease



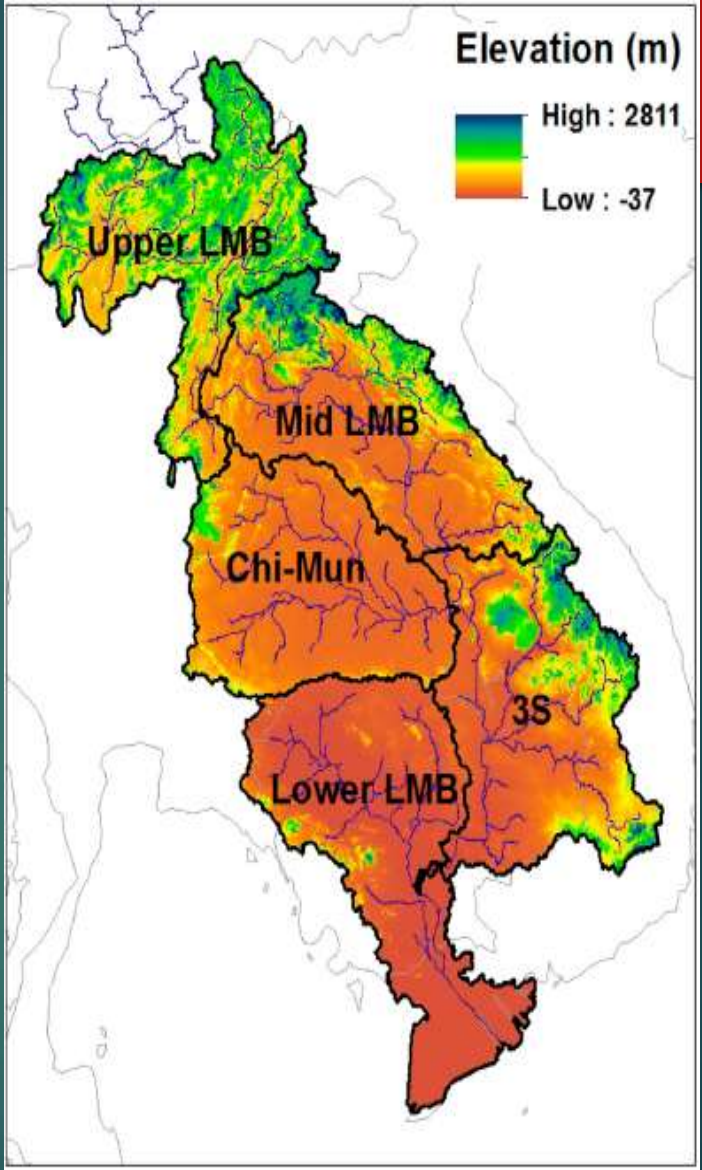
Drought

- A drought is characterized by severity, duration, and intensity.
- Drought occur with deficit rainfall and increased temperature and identified by climatological drought indices.
- Climate change is expected to intensify drought.



- Drought incidents:
  - Thailand – 1992, 1997-98, and 2004
  - Vietnam – 1997-98
  - Cambodia – 2002

- 15 GCMs data from NEX-GDDP: Future – 2016-2057 RCP 4.5
  2058-2099 RCP 4.5
  2016-2057 RCP 8.5
  2058-2099 RCP 8.5



Methods

- Characteristics of droughts
  - SPI-3 months with truncation level for drought as -1.
  - Long-term record of monthly precipitation was fitted to a gamma distribution, which was then transformed to a normal distribution.

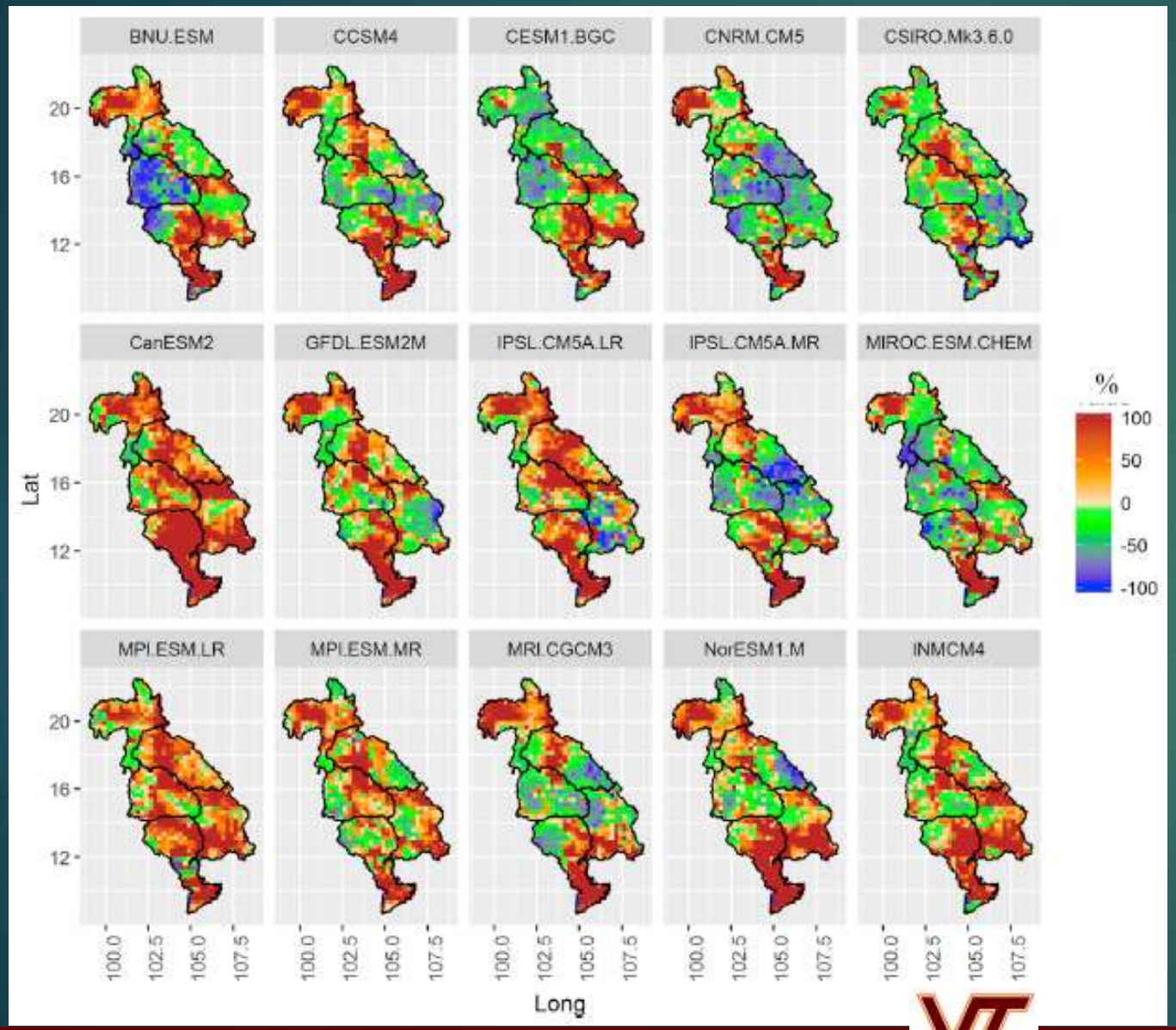
- Univariate and multivariate analysis
  - Return period is the average interval between occurrence of an event with a particular magnitude or greater.
  - Univariate return period:

$$T = \frac{E(L)}{1-F(s)} \qquad T = \frac{E(L)}{1-F(s)} \qquad T = \frac{E(L)}{1-F(s)}$$

  - Trivariate joint occurrence probability:

$$P(S \geq s \text{ or } D \geq d \text{ or } PK \geq pk) = 1 - F(s) - F(d) - F(pk) + C[F(s), F(d)] + C[F(s), F(pk)] + C[F(d), F(pk)] - C[F(s), F(d), F(pk)]$$

Drought characteristics of future scenarios

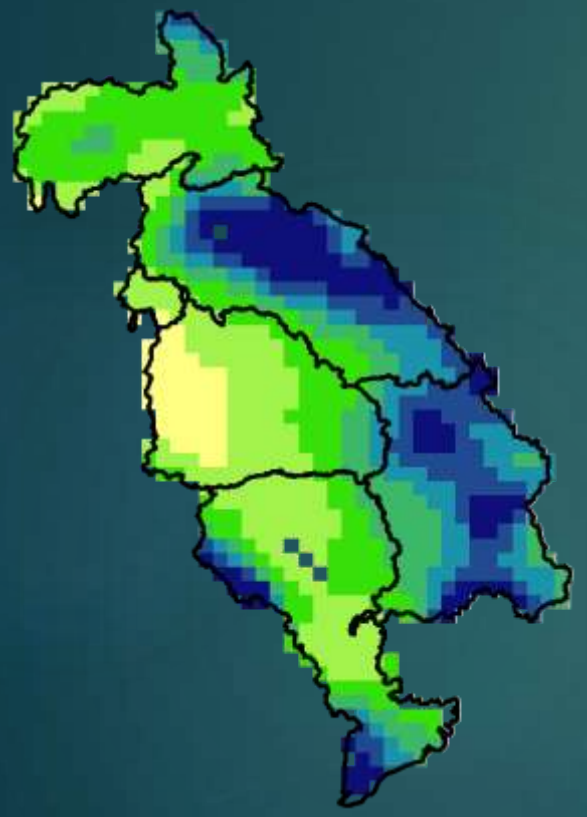


- The identified threshold were 3.13 for severity, 4 months for duration and 1.47 for the peak (95th percentile).
- 14 of the 15 GCMs indicated increased probabilities of drought in the Mekong Delta.
- Increased probability of drought in the most part of the Upper LMB estimated by atleast 11 of the 15 GCMs.
- 6 of 15 GCMs projected a reduction in drought magnitudes in Chi-Mun in all future scenarios.

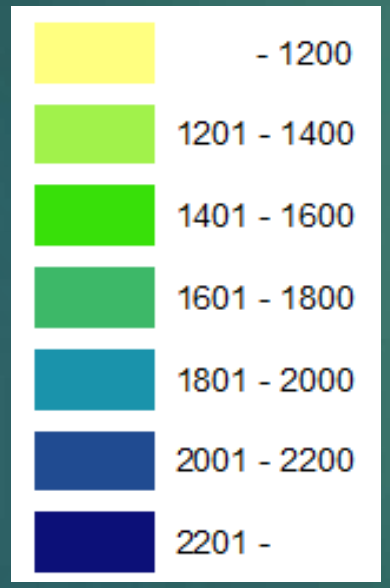
Thilakarathne, M., V. Sridhar (2017) Characterization of future drought conditions in the Lower Mekong Basin, *Weather and Climate Extremes*, 17, 47-58, DOI: 10.1016/j.wace.2017.07.004.

MIROC-ESM-CHEM (RCP4.5) – Precipitation

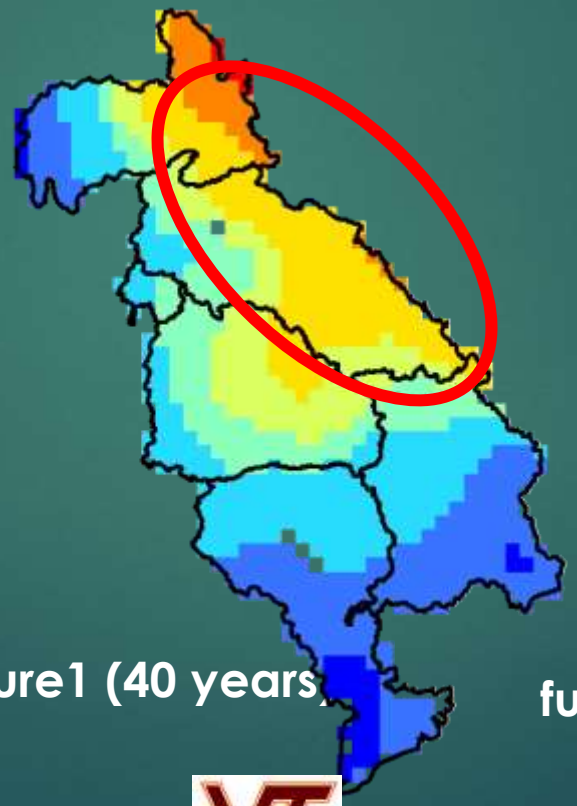
1966-2005: historic (40 years)
2020-2059: future1 (40 years)
2060-2099: future2 (40 years)



Historic annual Precipitation (mm)

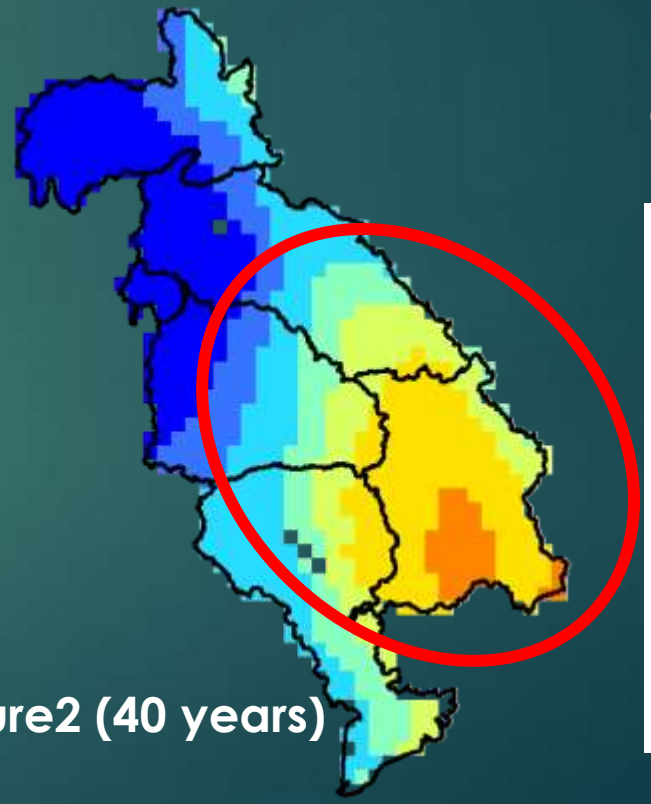


Change in Precipitation (f1)



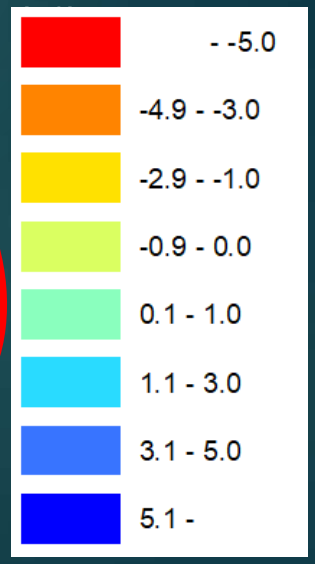
future1 (40 years)

Change in Precipitation (f2)



future2 (40 years)

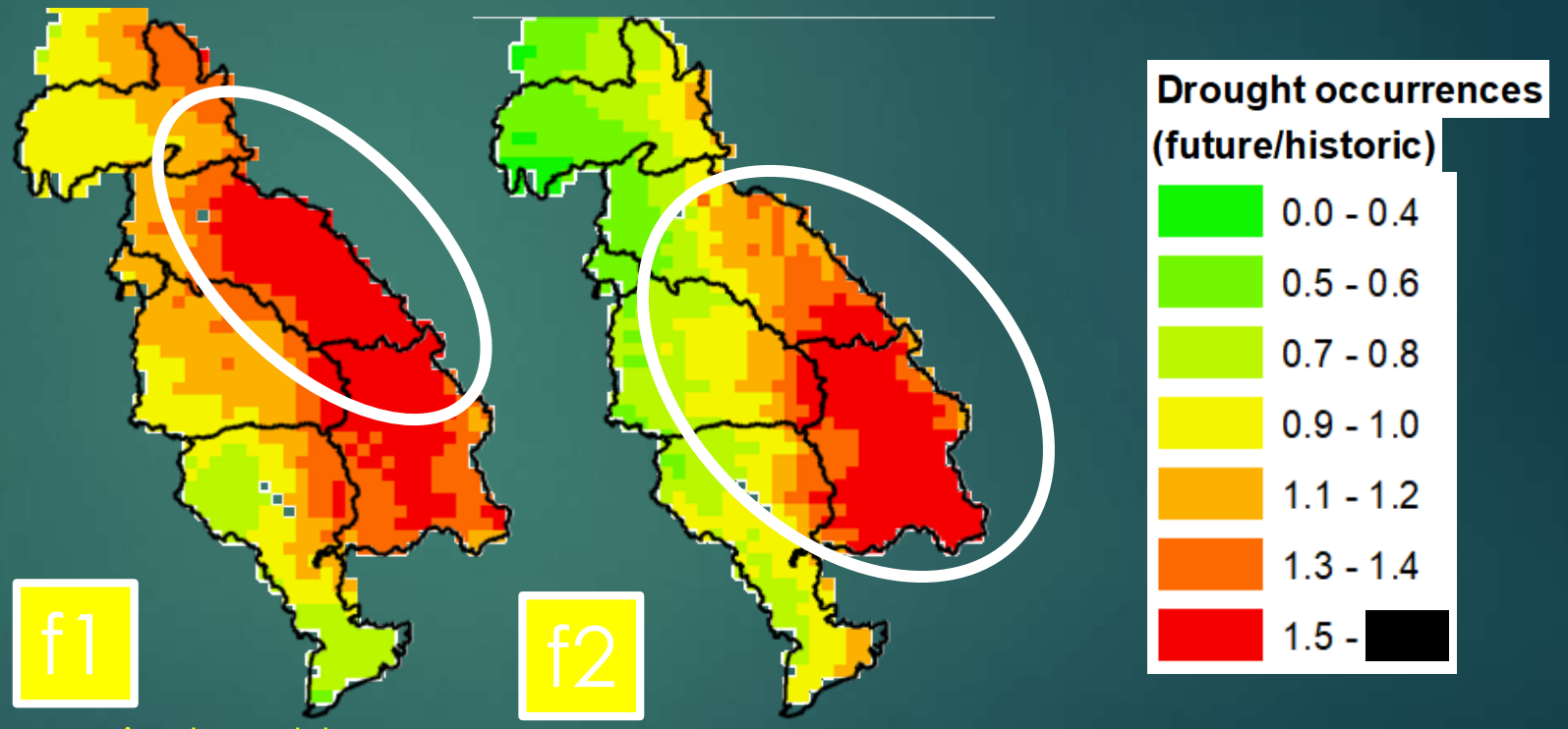
Change in Precipitation



1966-2005: historic (40 years)

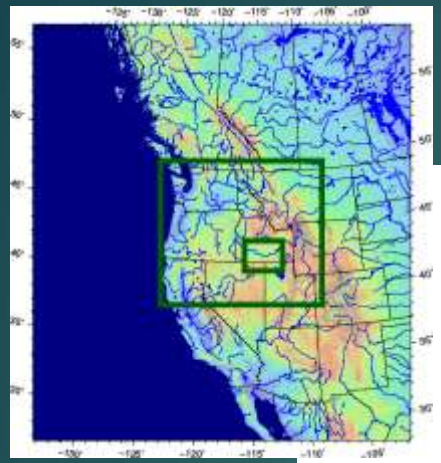
Drought occurrences based on the MSDI estimations - MIROC-ESM-CHEM (RCP4.5)

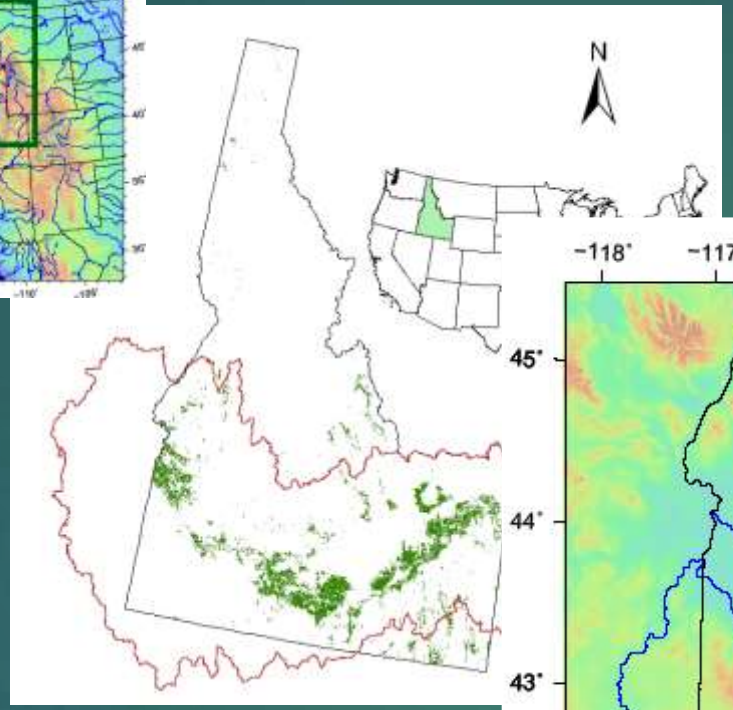
1966-2005: historic (40 years)
2020-2059: future1 (40 years)
2060-2099: future2 (40 years)

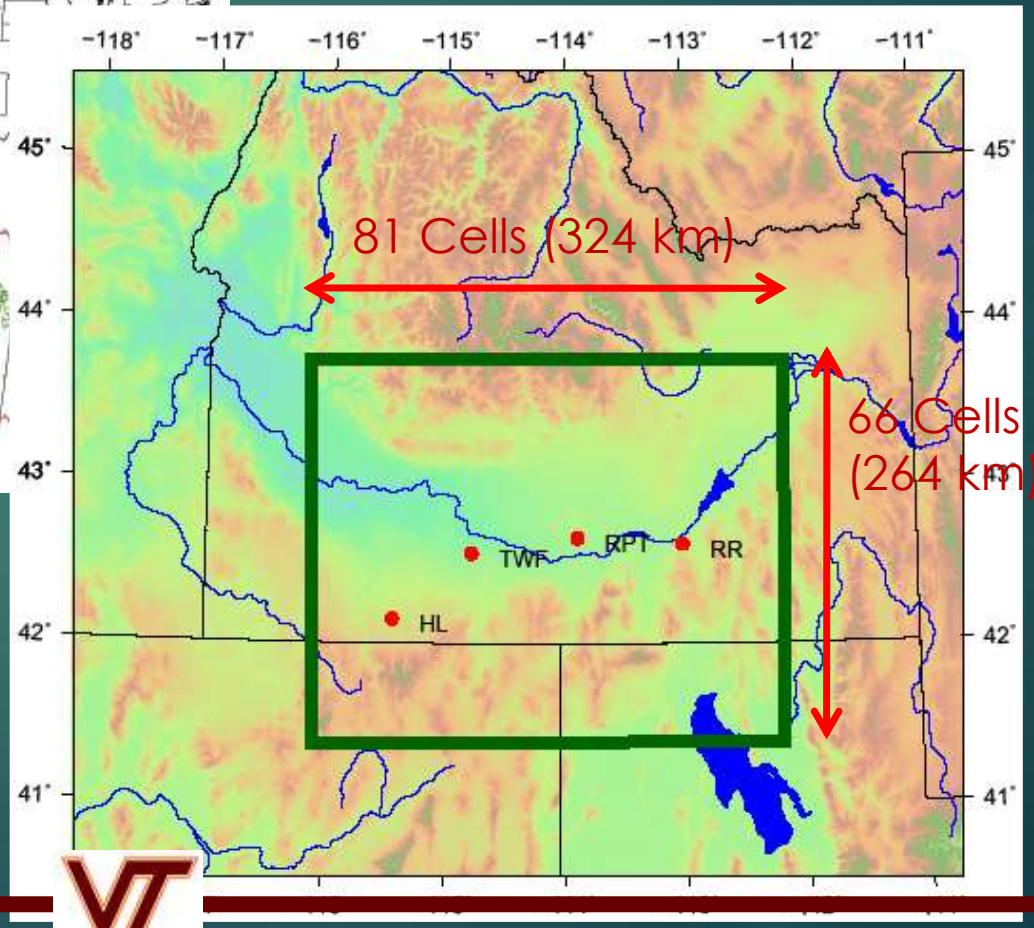


Decrease in precipitation led to increases in drought occurrences,
but temperature should be considered for the MSDI estimations.
MSDI is based on the joint probability of precipitation and temperature.

Snake River Basin, Idaho, USA

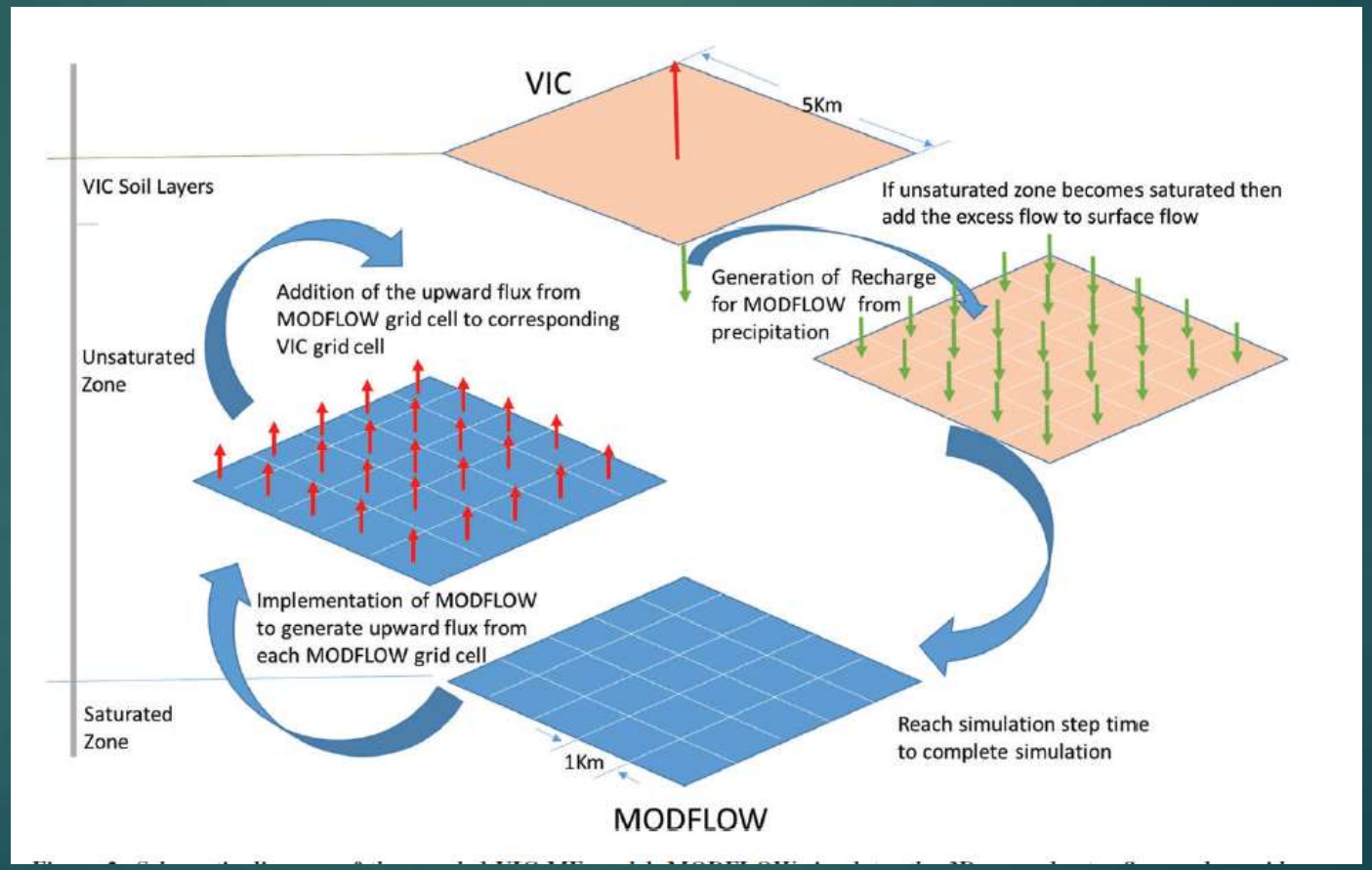


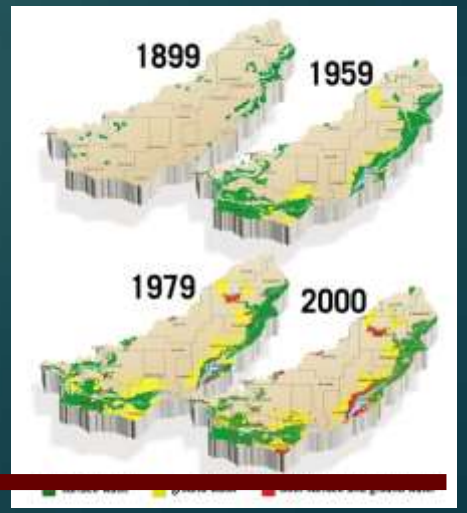




Basin irrigated area = 13, 468 km^2

Groundwater-Surface water Exchanges (MODFLOW-VIC)





Groundwater Level

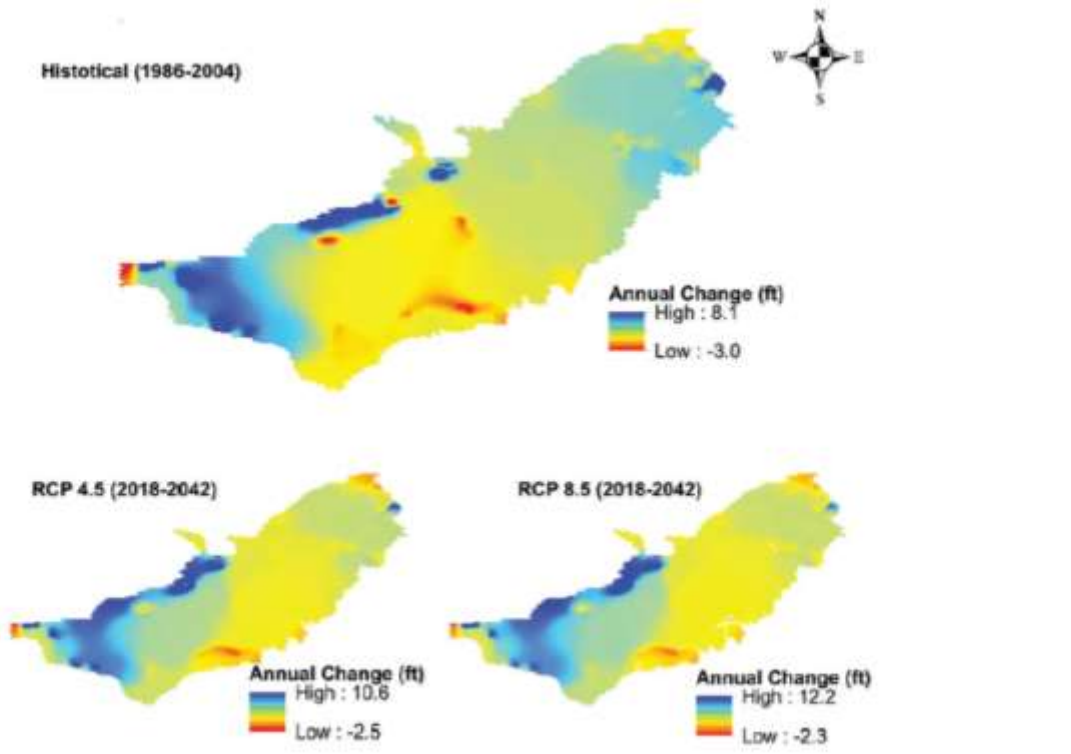


Figure 10. Change in the annual groundwater level when using gridded historical data (1986 to 2004) and future (2018 to 2042) scenarios. The future scenarios are based on the averages of climate models (CanESM2 and GFDL-ESM2M) for both the RCP 4.5 and RCP 8.5 scenarios.

Sridhar, V., M. M. Billah, J. Hildreth (2017) Development of a coupled surface and groundwater hydrological model (VIC-MODFLOW) and evaluation in the Snake River Basin, *Groundwater*, DOI:10.1111/gwat.12610.

Development of System Dynamics Model

The Snake River Planning Modeling is developed

1. Parallel structure
   - Natural flow river (theoretical)
   - Regulated flow river (actual)
2. Response Functions
   - Groundwater entities (GWSIM)
   - Surface Entities (SD-SRPM)
3. Flood control operations
   - Flood control curves (MODSIM)

A System Dynamics Model for Conjunctive Management of Water Resources in the Snake River Basin

TABLE 1. Irrigation Entities in System Dynamics-Snake River Planning Model and Location of the Enhanced Snake Plain Aquifer Model (ESPAM) Grid Cell/Centroid Used to Generate the Response Functions for Each Entity.

Entity	ESPAM Row	ESPAM Column	Irrigated Area (acres)	% Mixed Source	Diversions
Surface water entities					
S1 Henrys Fork	57	189	46,722	0.05	30, 35, 40, 60, 80, 90, 91, 100, 110
S2 Egin Bench	52	187	27,157	0.05	45, 50, 51, 70
S3 Rexburg	59	180	5,968	0.30	120
S4 Reid	63	178	20,410	0.30	160, 165
S5 Harrison	72	169	70,803	0.30	135, 175
S6 Burgess	63	170	56,470	0.30	145
S7 Butte & Market	57	163	12,132	0.95	170
S8 New Sweden	72	155	37,500	0.30	175, 180
S9 Idaho	80	153	49,370	0.30	190, 220
S10 Aberdeen	82	119	42,700	0.70	230, 240, 242
S11 Blackfoot	87	131	49,260	0.30	248, 249, 255
S12 Burley	88	51	52,583	0.16	260
S13 Minidoka	82	57	73,905	0.03	270, 271
S14 A&B	78	48	28,789	0.95	285
S15 Milner	80	36	12,600	0.96	310
S16 Northside1	72	36	36,544	0.3	300
S17 Northside2	54	26	99,440	0.3	300
S18 Northside3	67	39	26,516	0.35	300
S19 Milner-Gooding1	80	36	14,066	0.6	290
S20 Milner-Gooding2	50	42	12,383	0.5	290
S21 Milner-Gooding3	41	53	20,708	0.05	290
S22 Milner-Gooding4	37	38	25,826	0.05	290
S23 Milner-Gooding5	35	25	32,970	0.05	290
Groundwater entities					
G1 Upper Teton	65	187	67,175		
G2 NW Idaho Falls	62	155	67,619		
G3 Upper Springfield	74	131	109,976		
G4 Upper Aberdeen	85	99	92,016		
G5 Upper Minidoka	73	60	171,338		
G6 Declo	88	42	13,429		
G7 Southwest	86	41	76,376		
G8 Northside1	75	37	10,170		
G9 Mud Lake	36	164	51,444		
G10 Northside2	63	34	6,503		
G11 Northside3	57	30	6,806		
G12 Northside4	51	33	8,803		
G13 Northside5	48	18	40,290		
G14 Northside6	36	19	10,571		

Hoekema and Sridhar, 2013 (J. American Water Resources Association);
Hoekema and Sridhar, 2011 (Water Resources Research)

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Article

Improved Drought Prediction Using Nea Climate Forecasts and Simulated Hydrologic Conditions

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Abstract: Short-term drought forecasting is helpful for establishing drou for managing risks that often ensue in water resource systems. Addition using high-resolution spatial and temporal data is used to simulate th energy fluxes, including runoff, baseflow, and soil moisture, which are use In this study, the Soil and Water Assessment Tool (SWAT) and Variable I models are used for short-term drought forecasting in the contiguous as many areas in this region are frequently affected by varying drought inter meteorological inputs are provided by the Climate Prediction Center (C period (January 2012 to July 2017) and Climate Forecasting System v forecasting period (August 2017 to April 2018), and these inputs are use and groundwater drought conditions. For drought assessment, three drought indices, namely

WATER RESOURCES RESEARCH, VOL. 47, W07536, doi:10.1029/2010WR009697, 2011

Relating climatic attributes and water resources allocation: A study using surface water supply and soil moisture indices in the Snake River basin, Idaho

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Received 28 June 2010; revised 15 April 2011; accepted 5 May 2011; published 20 July 2011.

[1] Climate change forced by anthropogenic activities has been ongoing since at least the beginning of the industrial revolution. Part of the recent warming in the western United States has been attributed to anthropogenic climate change. This research seeks to answer the basic question of how declining streamflow, increasing temperatures, and fluctuation in precipitation have impacted water resource allocation in the Snake River Plain over the past 35 years (1971–2005). Understanding how changes in climatic attributes have historically impacted water allocation should help water managers better understand how projected climate change may influence allocation. Annual and monthly diversion trends from 62 locations in the Snake River Plain were compared to temperature and precipitation trends at 10 climate stations across the basin. We found a strong trend of declining annual surface water diversions across the study area. Of the 62 diversion points examined, 45 have highly significant decreasing annual diversion trends, while an additional 8 have significant decreasing trends. Despite the annual decline in surface water diversions, April diversions have increased at more than half of the diversion points, with 15 locations showing highly significant trends and an additional 17 showing significant increasing diversion trends. A comparison of diversions to the Surface Water Supply Index indicates that the decline in midseason and late season diversions is mostly caused by decreasing supply in the study period, while a comparison of diversions to Palmer's Z index and the Standardized Precipitation Index indicates that early season diversions are highly correlated to early season moisture anomalies.

s, soil moisture, and
e, large-aperture scintillometer, and
emiarid climate

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iversity, Blacksburg, Virginia 24061, USA

al and interannual energy partition and flux analyses were conducted to differentiate ing sagebrush, cheatgrass, and lodgepole pine in the Snake River Plain of Idaho. The eddy covariance (EC) and large aperture scintillometer (LAS) flux measurements to l processes that control the surface energy partitioning. A comparison of sensible heat nd LAS (H_{LAS}) showed H_{EC} was slightly underestimated due to wind turbulence and issues. The Noah Land Surface Model (LSM) was configured with NCEP-NARR or meteorological observation from the EC tower ($NOAH_{Obs}$ simulation). $NOAH_{NARR}$ ficantly more RMSE compared to $NOAH_{Obs}$ due to biases in downwelling shortwave and precipitation (P) in the NARR data. Higher leaf area index (LAI) and moderate stomatal ole pine resulted in increased evapotranspiration (ET) (472–535 mm/year) compared to 78 mm/year) and sagebrush (229–353 mm/year). The Budyko ET analysis showed that ter deficient and the evaporative ratio was less for the lodgepole pine ecosystem (0.80) brush (0.94) and cheatgrass (0.93). The residual (attributed to deep percolation and udget was higher (15–16%) in the lodgepole pine compared to that of cheatgrass (2–5%) hur results indicate the field-scale distinguishing features of heterogeneous ecosystems in ent and emphasize the need for intercomparison of flux measurements for better un- udget partitioning and improving the accuracy of simulated fluxes.

Summary

- Hydrology and water resources in the Mekong basin needs a careful review on a regular basis
- Obtaining reliable precipitation for drought and floods in the future is critical for water supply and demand management.
- Monitoring, modeling (physically-based and stochastic) is required.
- Taking examples of managed basins can be helpful to minimize the unintended consequences

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