Climate and Land Use/Cover Impacts on the Ecologically Relevant Flow Metrics in the Cahaba River

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Climate Change

- Earth's climate is changing in ways that affect our weather, oceans, snow, ice, society and ecosystems.

Indicators

Greenhouse Gases
- Atmospheric Concentrations of Greenhouse Gases

Weather and Climate
- Heavy Precipitation
- Drought
- Tropical Cyclone Activity

Oceans
- Ocean Heat
- Sea Surface
- Sea level
- Ocean Acidity

Snow and Ice
- Glaciers
- Lake Ice
- Snowfall
- Snow Cover

Health and Society
- Heat-related Deaths
- Length of Growing Seasons
- Pollen Seasons

Ecosystems
- Wildfires
- Streamflow
- Water Levels and Temperatures
- Bird Wintering Ranges
- Leaf and Bloom Dates

What is happening?

According the NASA (climate.nasa.gov)

Carbon Dioxide	Global Temperature	Sea Level	Land Ice	Arctic Ice Minimum	Forest Cover
• ↑ 400.57 parts per million	• ↑ 1.4 °F Since 1880	• ↑ 3.22 mm per year	• ↓ 287 billion metrics tons per year	• ↓ 13.3 percent per decade	• ↓ 1.5 million sq. km


Credit: www.ethicalconsumer.org/portals/0/images/oil%20sands/oil-sands-before&after800x2.jpg


©Mark Moran, U.S. National oceanic and atmospheric administration


Credit: Paul Souders/Corbis


Credit: texasstateaquarium.org

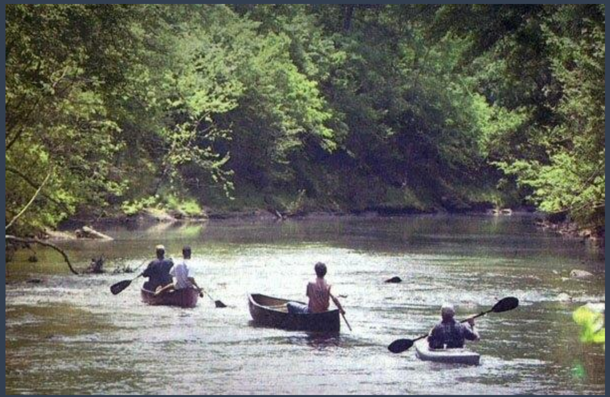
Impacts of LULC on the River Ecology

- Ecosystem and biodiversity are intrinsically dependent on the changes,
- Species and ecosystems are experiencing changes in:
  - ranges,
  - timing of biological activity,
  - growth rates,
  - cycling of water.

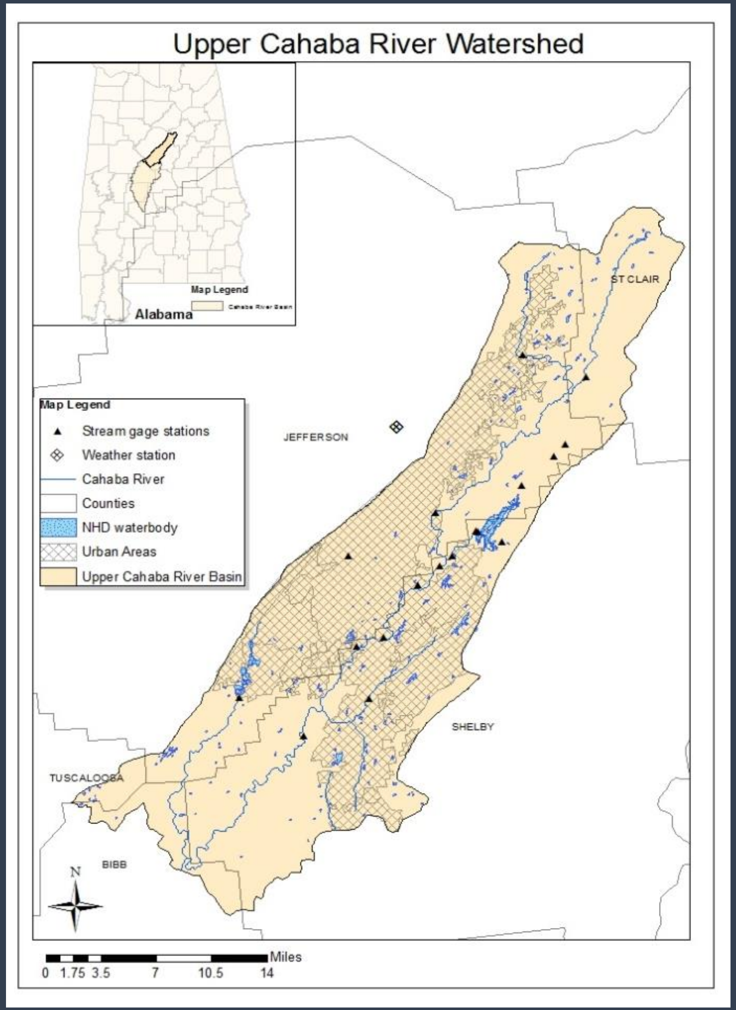
*Even small changes can have significant effects on living things.

Cahaba River Watershed

- Alabama's longest free flowing river.
- Its headwaters are located within the Alabama Ridge and Valley physiographic region and eventually flow southwest into the East Gulf Coastal Plain.
- This is the only point within the 48 contiguous states where the geological landscape transitions abruptly from mountainous regions directly to a coastal plain.
- Most diverse aquatic ecosystems in the United States (Pierson et al., 1989).
- "Hotspot of Biodiversity" out of 2,111 watersheds in the contiguous United States (The Nature Conservancy).
- There are a variety of ways to enjoy the outdoors on the Cahaba River.



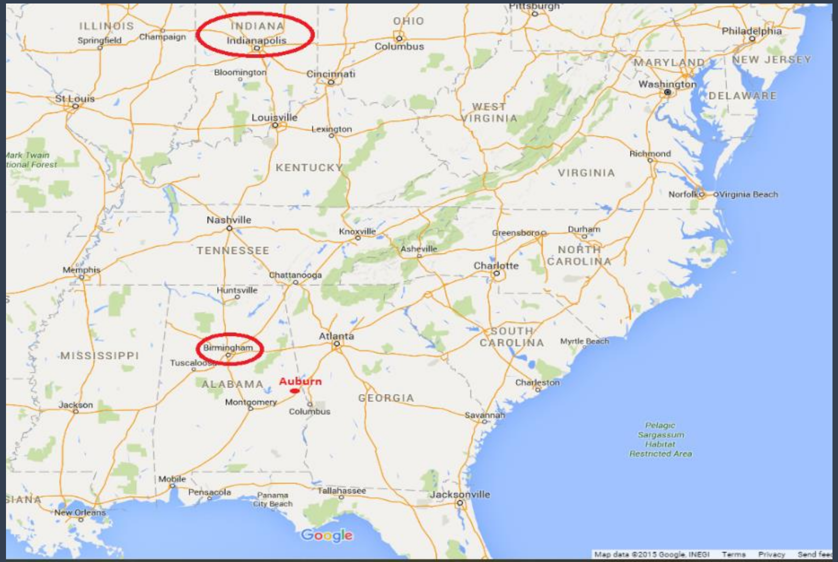
Cahaba River Watershed



- Highly developed urban area. Population expected to rise significantly within the watershed in the future.

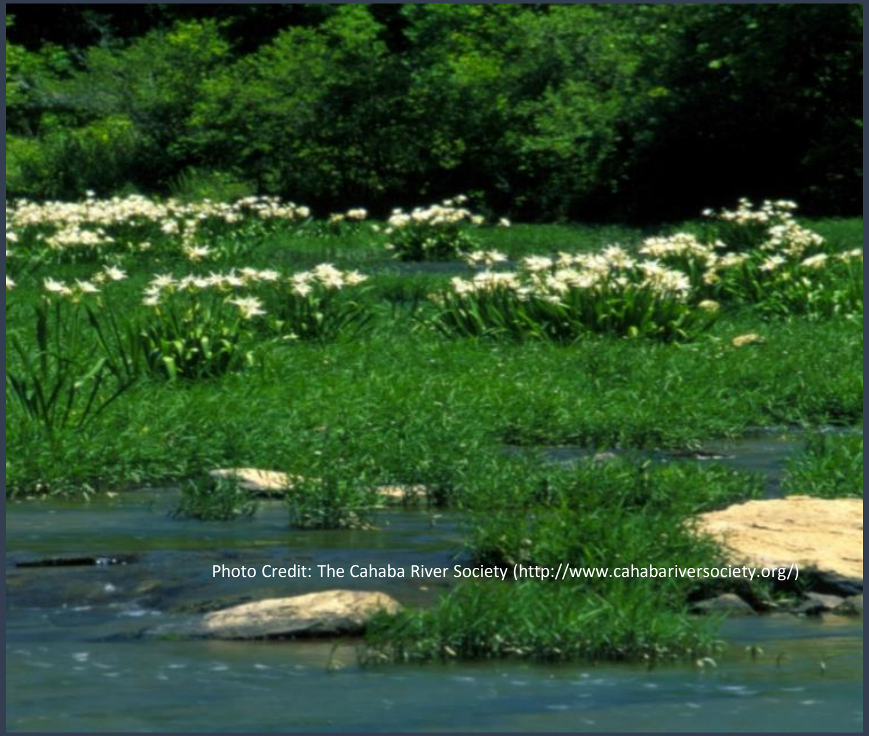
- Mainly humid with annual rainfall of 139.7 cm (55 inches). Mean monthly temperatures: 7.2°C (45°F) in January to 26.6°C (80°F) in July and August. (U.S Historical Climatology Network (USHCN)).

- Elevations in the watershed range from 82meters (269 feet) to 335 meters (1,100 feet).



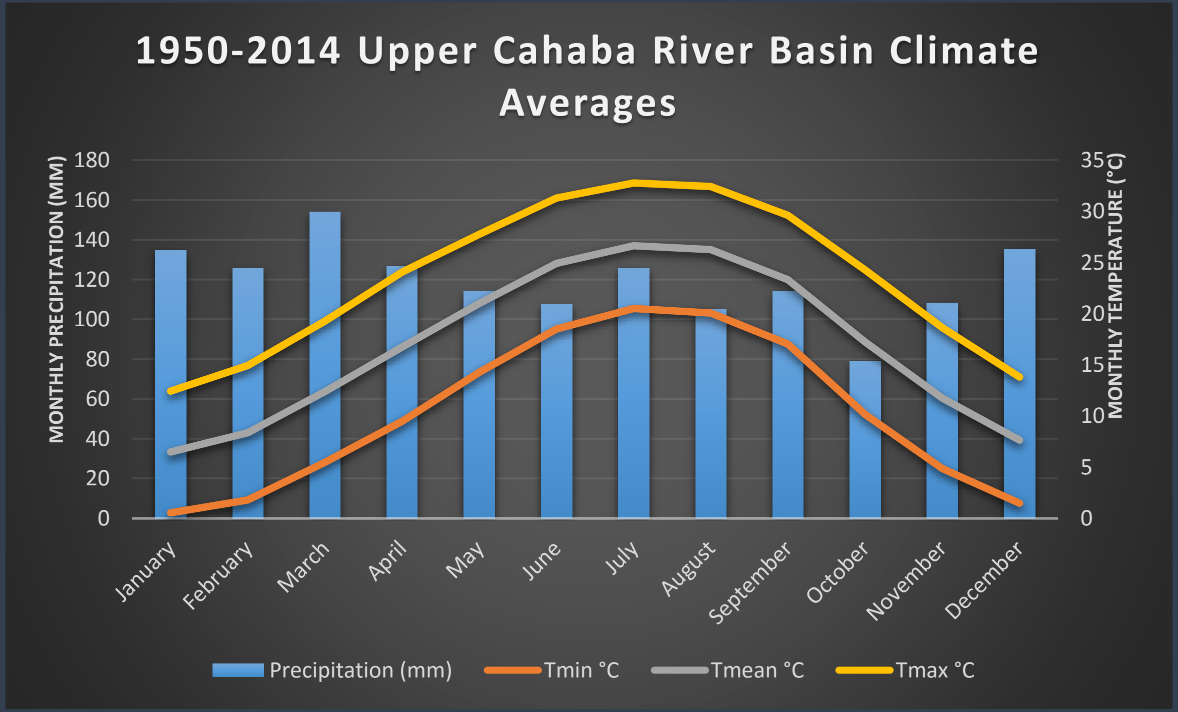
Cahaba River - Cahaba lilies(*Hymenocallis coronaria)*

- Cahaba River supports 69 rare and imperiled species (The Nature Conservancy).
- One of the most well-known is Cahaba lilies (*H. coronaria*)



Climate Averages and Land Use/Cover Changes in the upper Cahaba River Basin

Climate



Land Use

	1992 (%) NLCD	2011(%) NLCD	2040(%) USGS-EROS A1B
WATER	0.92	1.13	1.44
URBAN	9.15	32.5	49.59
FOREST	75.6	52.27	31.2
RNGB	5.42	7.39	11.1
AGRN	2.58	0.4	2.1
WETF	0.04	1.16	1.54
OTHERS	6.29	5.15	3.03

Objectives

1- What are the hydrological responses to land use/cover (LULC) and climate changes in rapidly urbanizing upper Cahaba River Basin in north-central Alabama?

2- How changes in flow in the Cahaba River system will affect Environmental Flow Components (EFCs)?

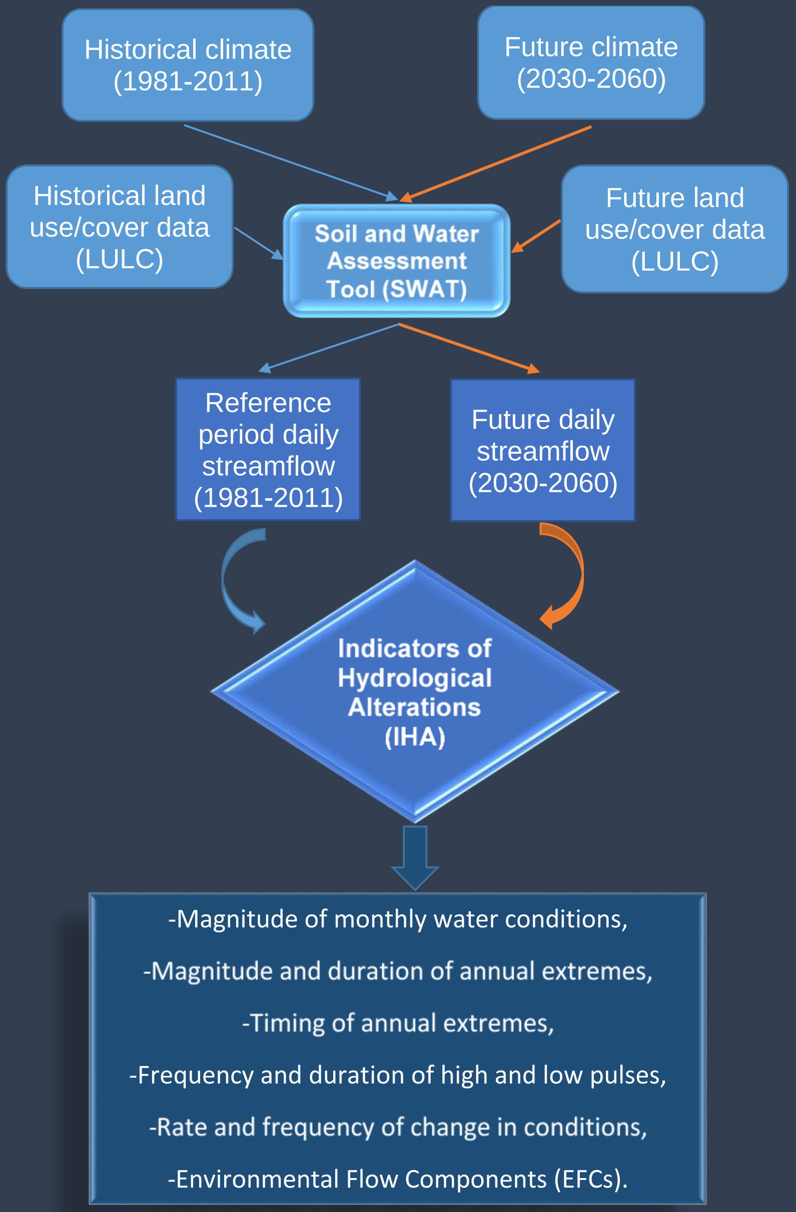
Ecologically Relevant Flow Metrics

- Indicators of Hydrologic Alterations software (IHA)
- The Nature Conservancy has identified 32 key flow metrics that captures low, median, high flow as well as flashiness having significant impact on the flora and fauna.

IHA group	Hydrologic parameters	Ecosystem influences
Magnitude of monthly water conditions	Mean value for each calendar month (12 parameters)	1. Availability of habitat for aquatic organisms 2. Availability of soil moisture for plants 3. Availability of water 4. Reliability of water supplies for wildlife 5. Effects of water temperature and dissolved oxygen
Magnitude and duration of annual extreme water conditions (mean daily flow)	1. Annual 1-day minima 2. Annual 3-day minima 3. Annual 7-day minima 4. Annual 30-day minima 5. Annual 90-day minima 6. Annual 1-day maxima 7. Annual 3-day maxima 8. Annual 7-day maxima 9. Annual 30-day maxima 10. Annual 90-day maxima 11. Number of zero-flow days 12. 7-day minima/mean for year	1. Balance of competitive and stress-tolerant organisms 2. Creation of sites for plant colonization 3. Structure of river channel morphology and physical habitat conditions 4. Soil moisture stress in plants 5. Dehydration in wildlife 6. Duration of stressful conditions 7. Distribution of plant communities
Timing of annual extreme water conditions	1. Julian date of each annual 1-day maxima 2. Julian date of each annual 1-day minima	1. Predictability and avoidability of stress for organisms 2. Spawning cues for migratory fish
Frequency and duration of high and low pulses	1. Number of low pulses within each year 2. Mean duration of low pulses each year 3. Number of high pulses within each year 4. Mean duration of high pulses each year	1. Frequency and magnitude of soil moisture stress for plants 2. Availability of floodplain habitat for aquatic organisms 3. Effects of bedload transport and channel sediment distribution, and duration of substrate disturbance
Rate and frequency of water condition changes	1. Means of all positive differences between consecutive daily values 2. Means of all negative differences between consecutive daily values 3. Number of hydrologic reversals	1. Drought stress on plants 2. Desiccation stress on low-mobility streamedge organisms

The Nature Conservancy©, Indicators of Hydrologic Alteration.

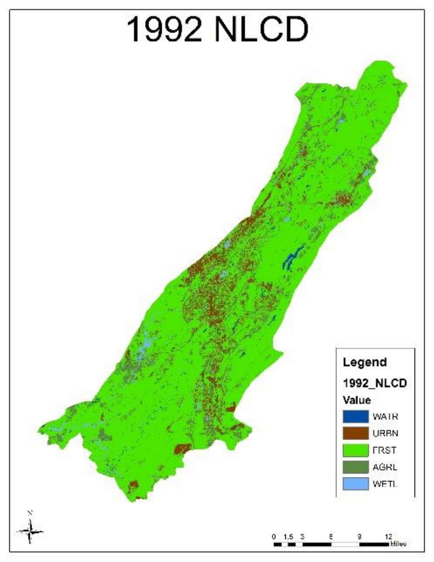
Methodology



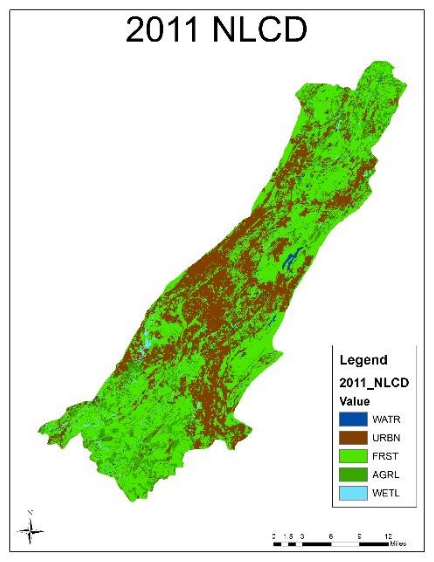
- **Model and Calibration:** Soil and Water Assessment Tool (SWAT) and SWAT-CUP
- **Weather Data:** PRISM Climate Group Climate Data and Coupled Model Intercomparison Project Phase 5 (CMIP5)
- **Land Use/Cover Data:** NLCD (1992-2011) and USGS EROS Center FORE-SCE (2040 A1B)
- **For understanding Hydrologic Changes in Ecologically-Relevant Terms:** Indicators of Hydrological Alterations (IHA)

Input Data and Scenarios

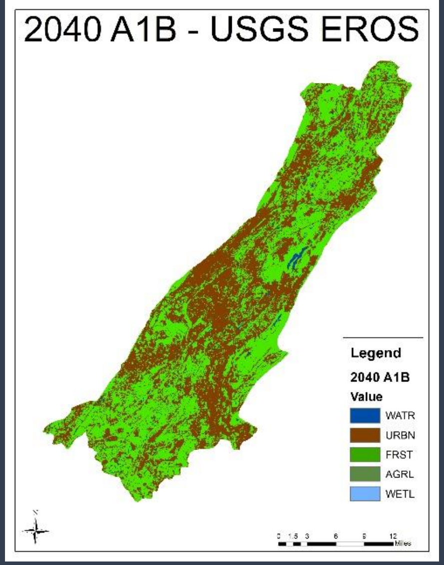
Topography Map	Land Use/Cover Map		Soil Data	Weather	
USGS Digital Elevation Map 10m	USGS - NLCD (1992-2011)	USGS-EROS (2040)	SSURGO	PRISM (daily present)	CMIP5 (daily future projection)



1992 NLCD



2011 NLCD



2040 A1B - USGS EROS

	1- R'92	2- R'11	3- R'45	4- Fw'11	5- Fd'11	6- Fw'45	7- Fd'45
Land Use/Cover	1992	2011	2040(A1B)	2011	2011	2040(A1B)	2040(A1B)
Weather	1981-2011	1981-2011	1981-2011	2030-2060 (W)	2030-2060 (D)	2030-2060 (W)	2030-2060 (D)

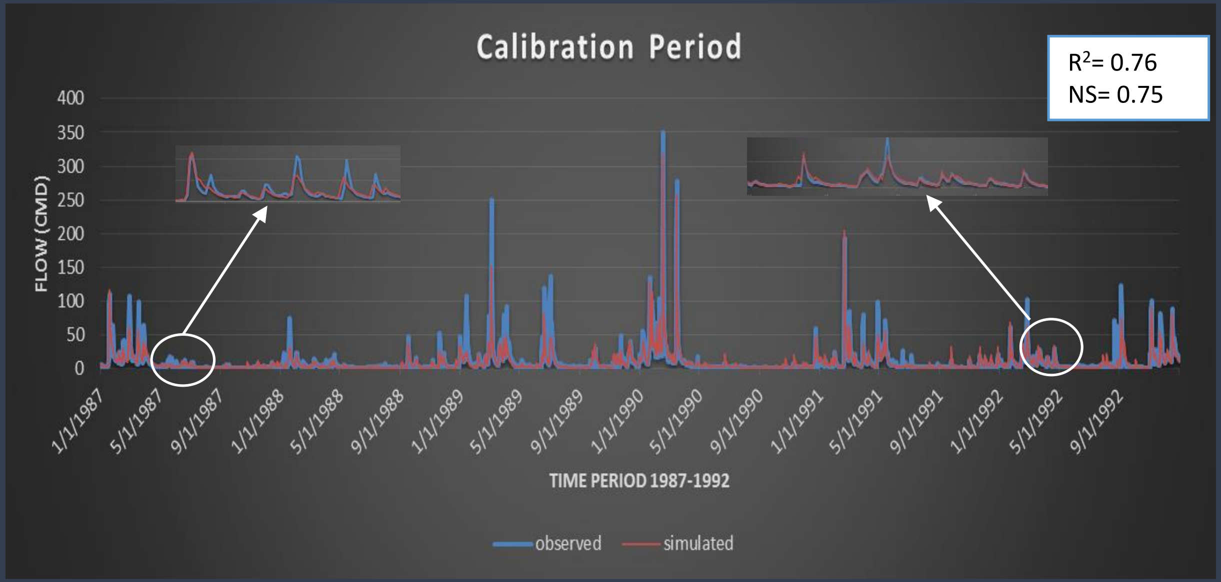
R: Reference, **Fw**: Future wet, **Fd**: Future dry

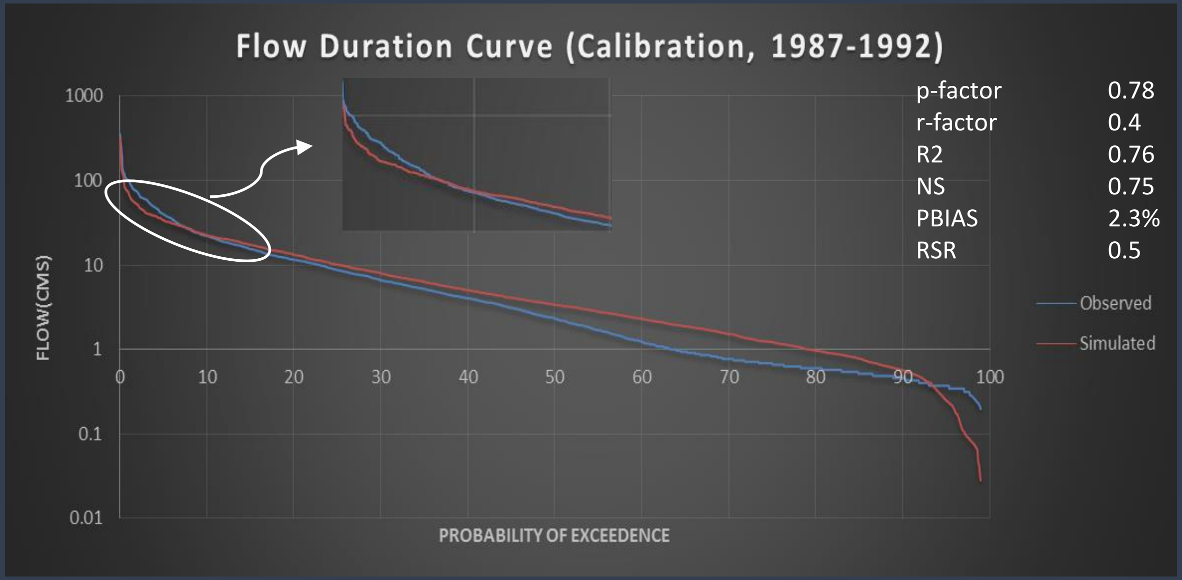
SWAT Model

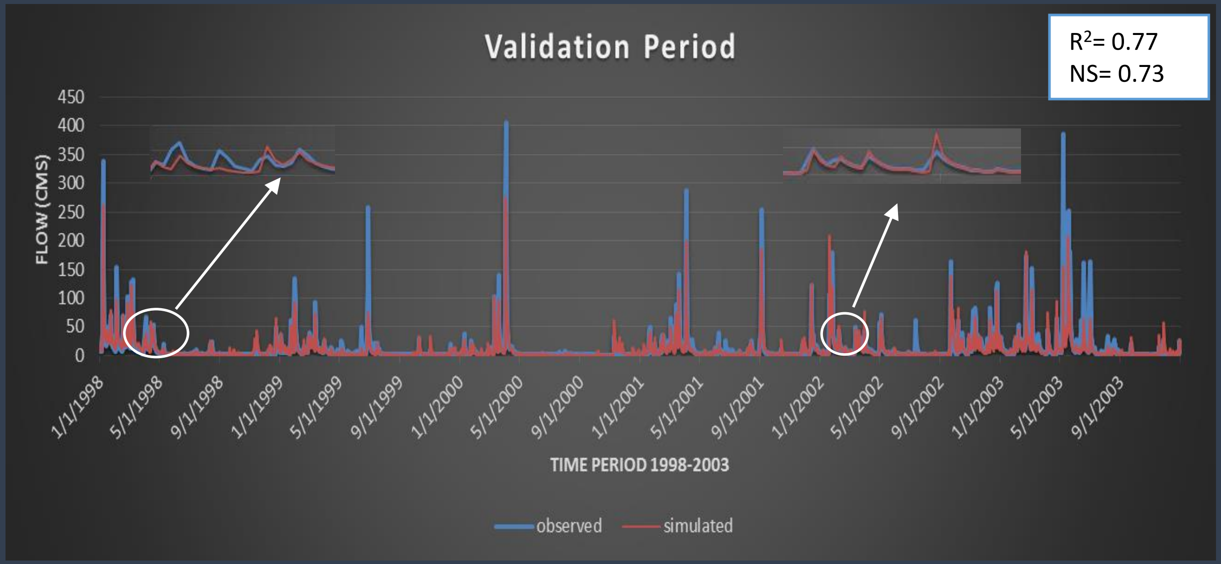
- The model was calibrated (1987-1992) and validated (1998-2003)
- For different scenarios daily streamflow data was produced from;

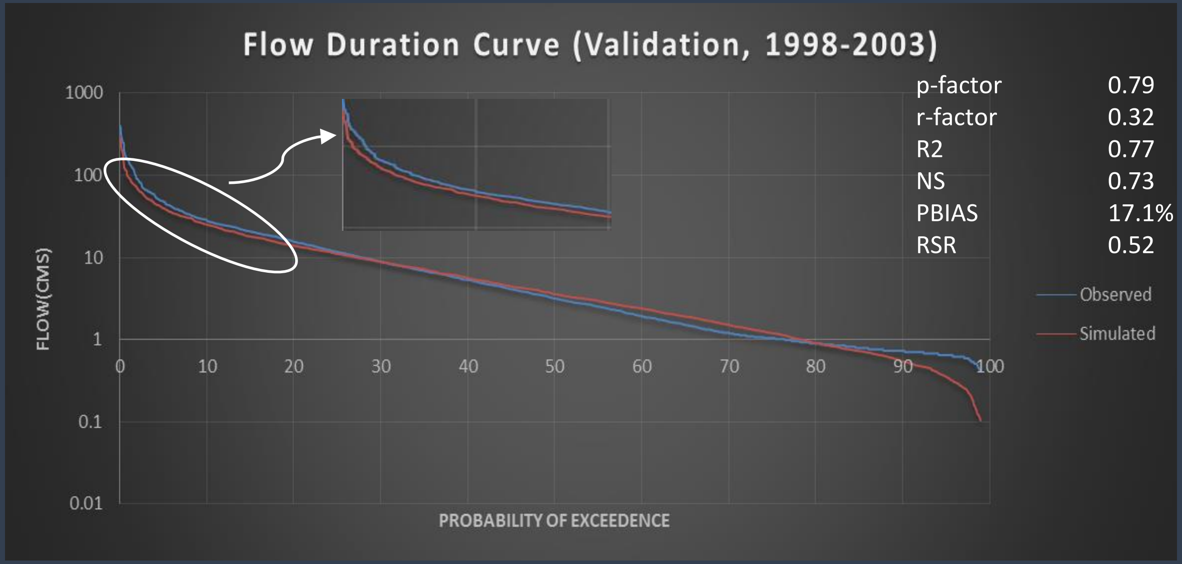
  1) 1981 to 2011

  2) 2030 to 2060


Calibration Period
R²= 0.76
NS= 0.75
FLOW (CMD)
TIME PERIOD 1987-1992
observed
simulated


Flow Duration Curve (Calibration, 1987-1992)
p-factor 0.78
r-factor 0.4
R2 0.76
NS 0.75
PBIAS 2.3%
RSR 0.5
Observed
Simulated
FLOW(CMS)
PROBABILITY OF EXCEEDENCE


Validation Period
R²= 0.77
NS= 0.73
FLOW (CMS)
TIME PERIOD 1998-2003
observed
simulated


Flow Duration Curve (Validation, 1998-2003)
p-factor 0.79
r-factor 0.32
R2 0.77
NS 0.73
PBIAS 17.1%
RSR 0.52
Observed
Simulated
FLOW(CMS)
PROBABILITY OF EXCEEDENCE

Future Climate Projections (Emission Scenarios and Climate Models)

- Future daily streamflow was generated using daily CMIP5 climate data (P, Tmin, Tmax) up to year 2060 with two climate models under two different emissions scenarios (RCP6.0, and RCP8.5).

	Description	Publication
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m2 (~1370 ppm CO2 eq) by 2100.	Riahi et al. 2007
RCP6	Stabilization without overshoot pathway to 6W/m2 (~850 ppm C)2 eq) at stabilization after 2100	Fujino et al. 2006; Hijioka et al. 2008
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m2 (~650 ppm CO2 eq) at stabilization after 2100	Clarket et al. 2007; Smith and Wigley 2006; Wise et al. 2009
RCP2.6	Peak in radiative forcing at ~3 W/m2 (~490 ppm CO2 eq) before 2100 and then decline (the selected pathway declines 2.6 W/m2 by 2100)	Van Vuuren et al. 2007a; van Vuurent et al. 2006

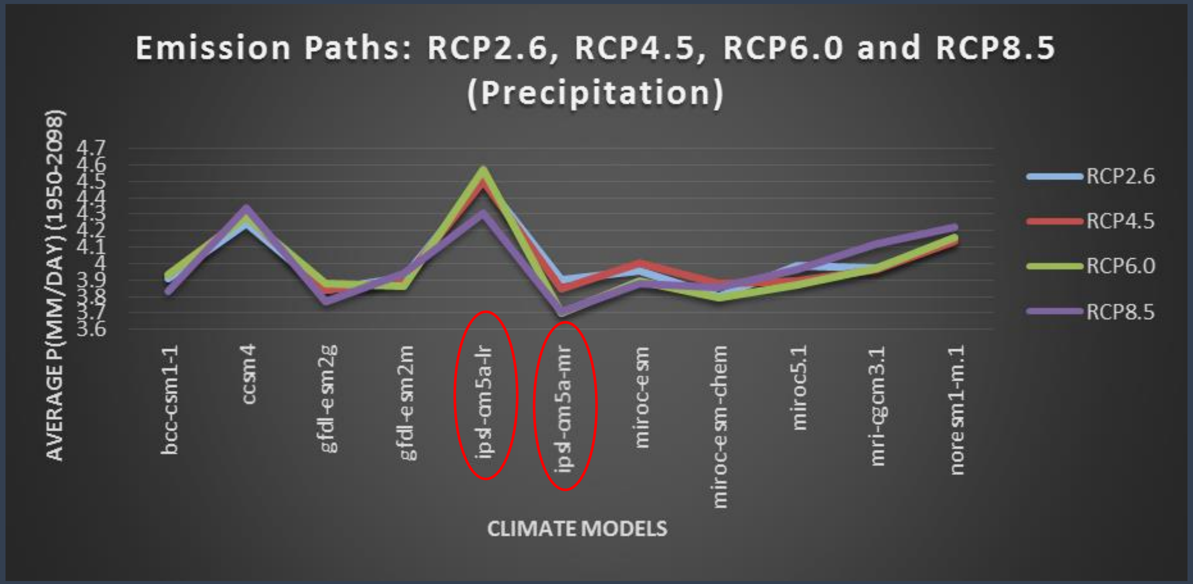
HIGH (RCP8.5, RCP6)

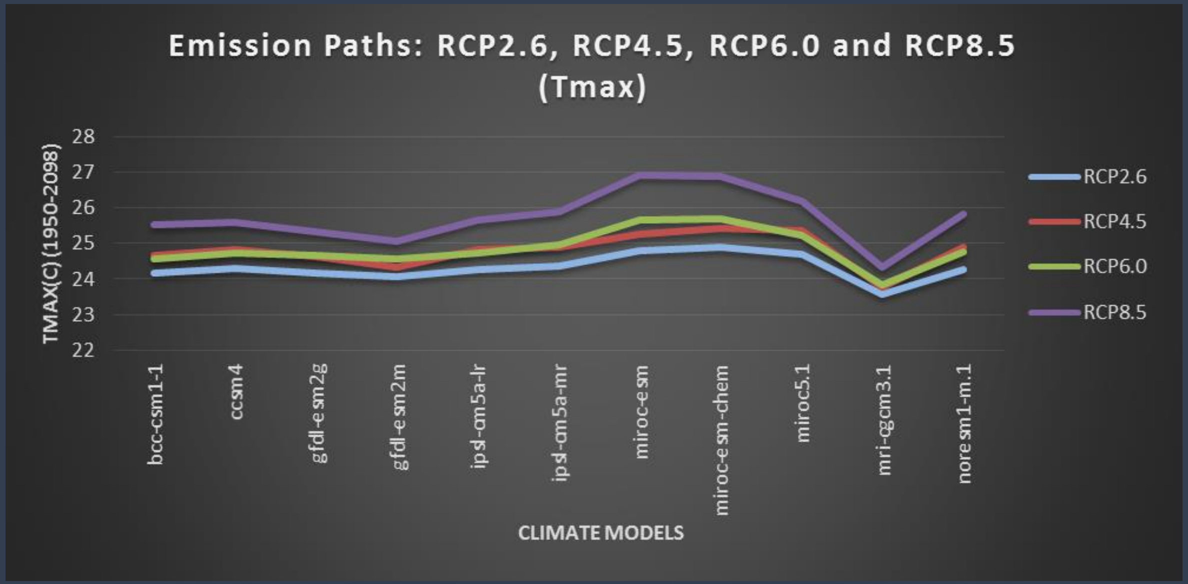
low (RCP4.5, RCP2.6)

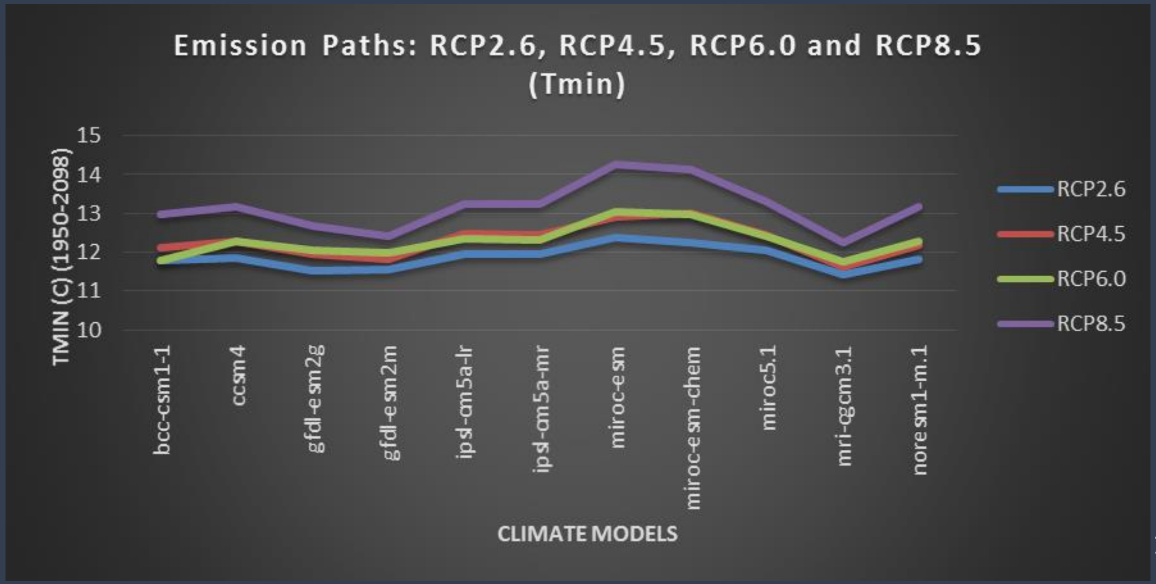
Climate Models

As a wet model: ipsl-cm5a-lr (RCP6.0)
- Highest average precipitation

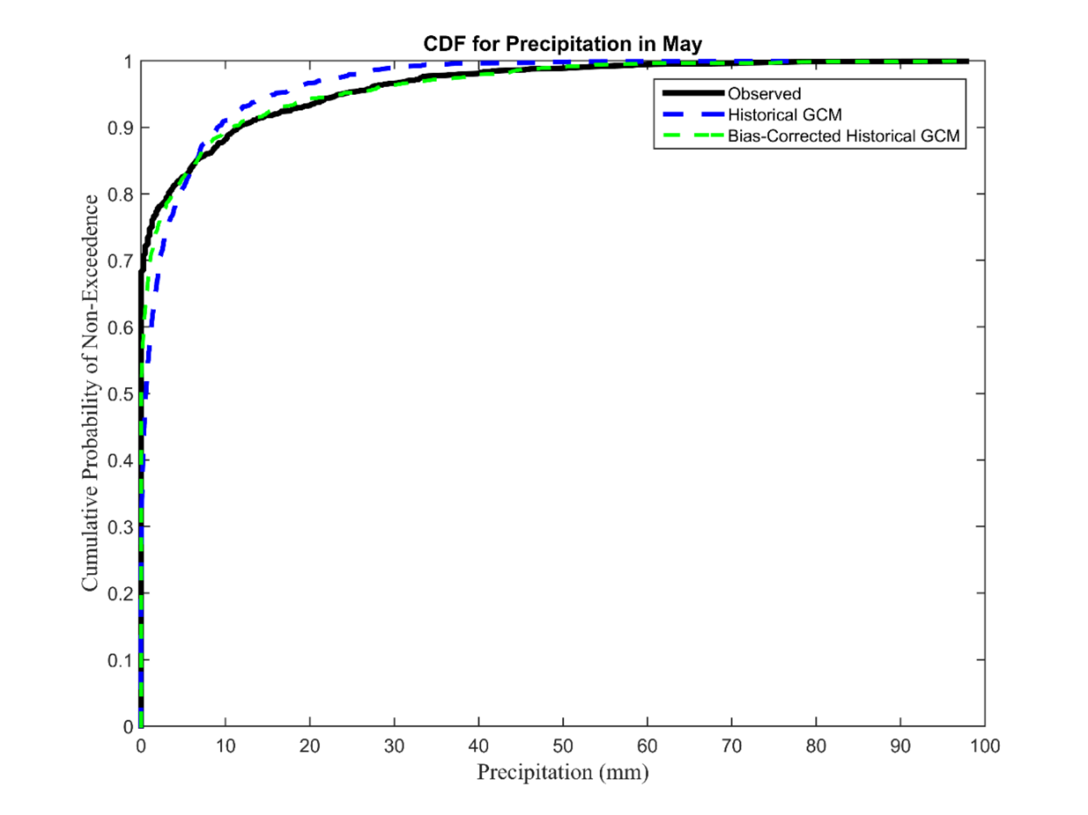
As a dry model: ipsl-cm5a-mr (RCP8.5)
-Lowest average precipitation

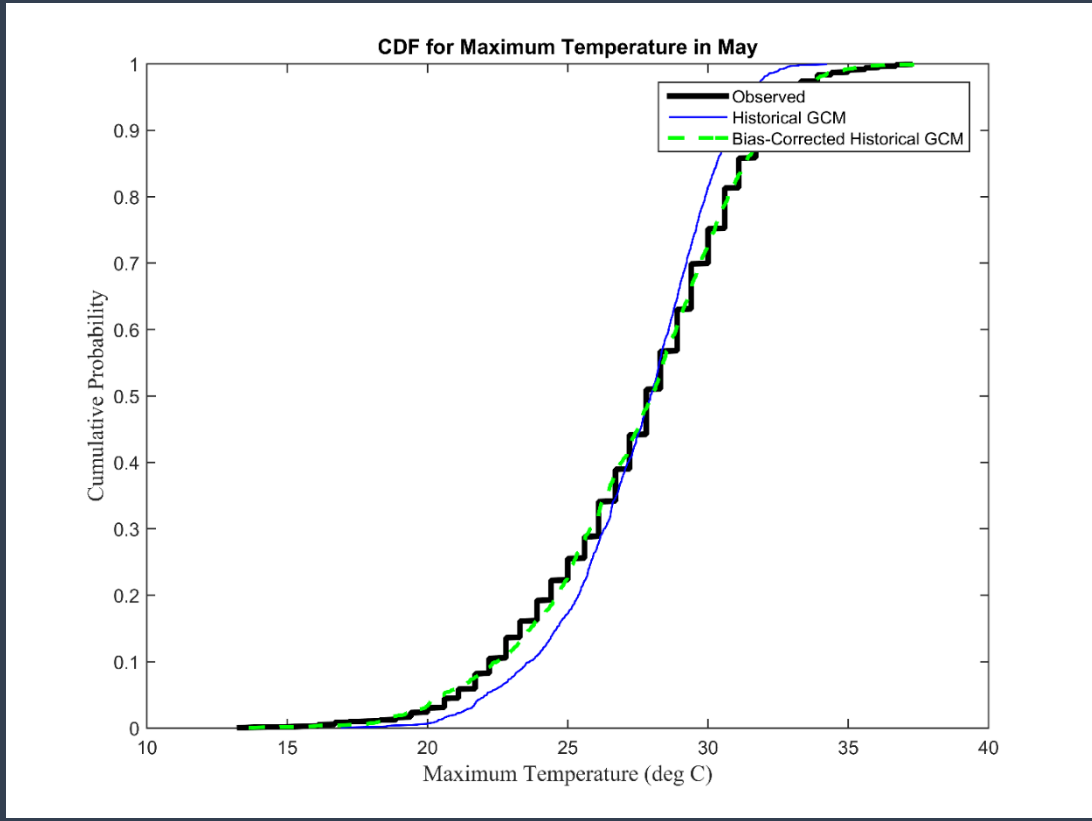




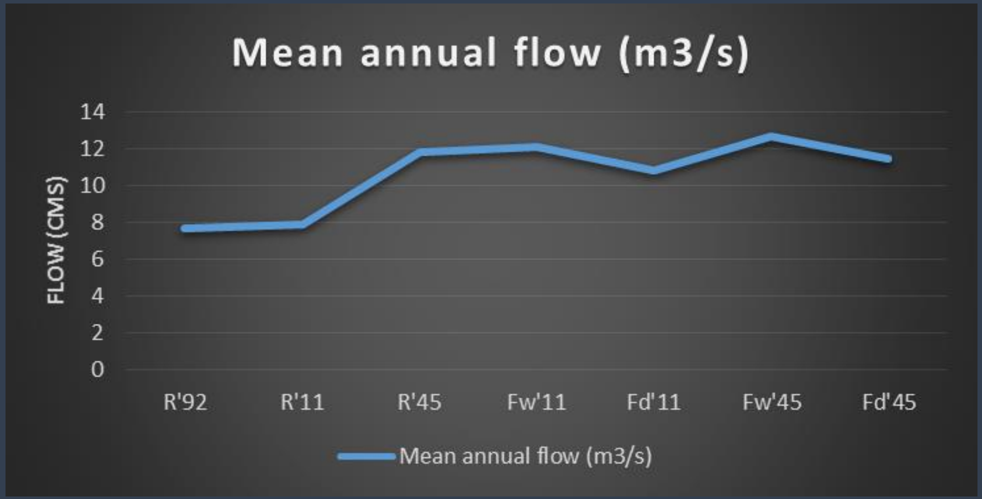


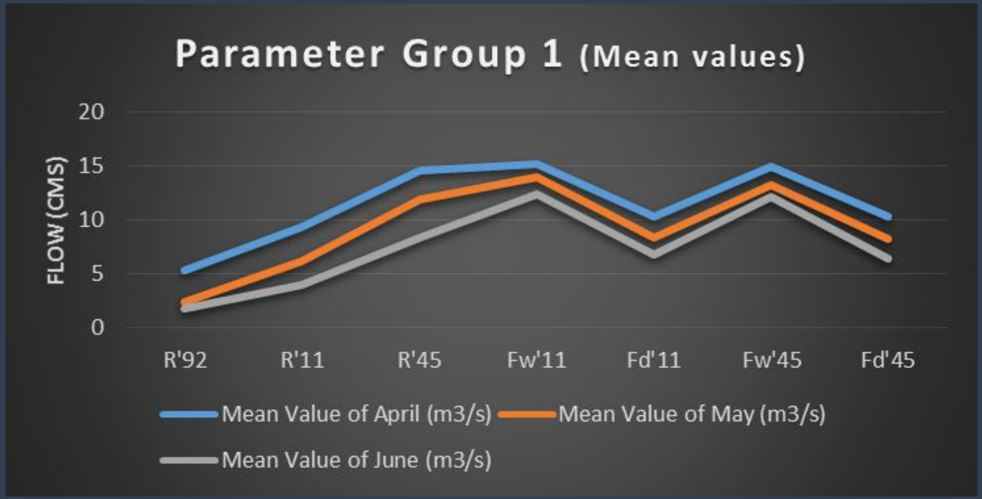
Bias Correction





Results





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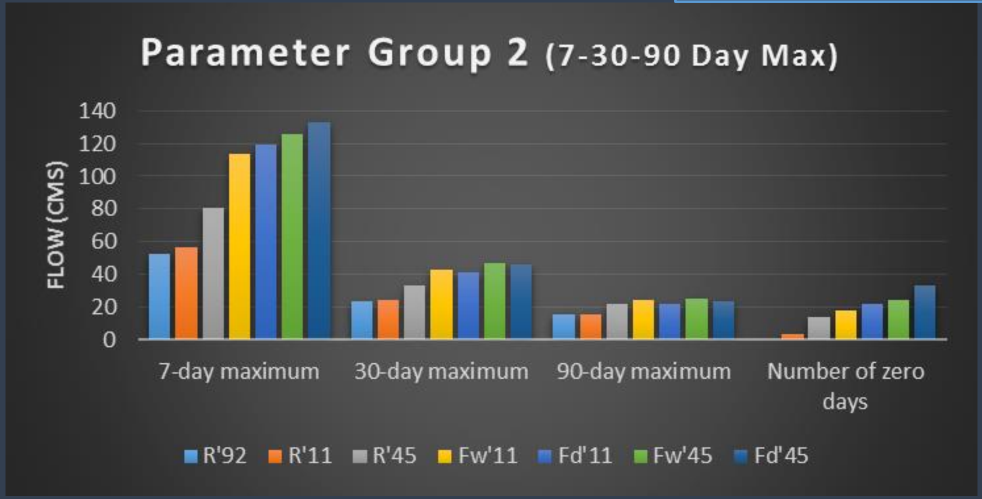

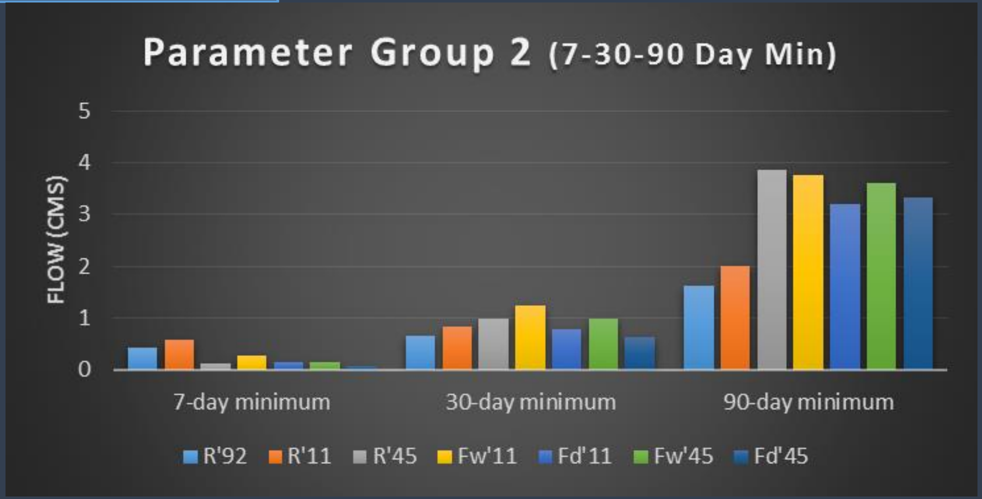

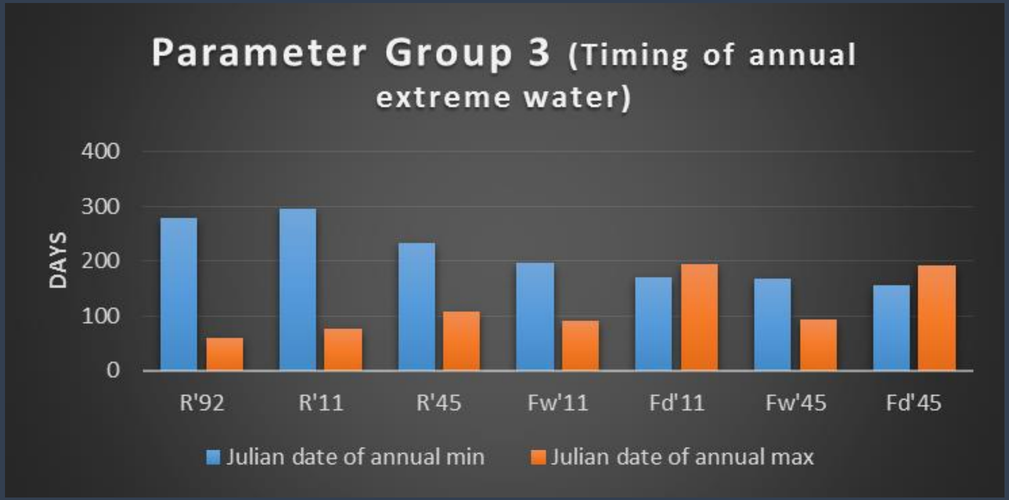

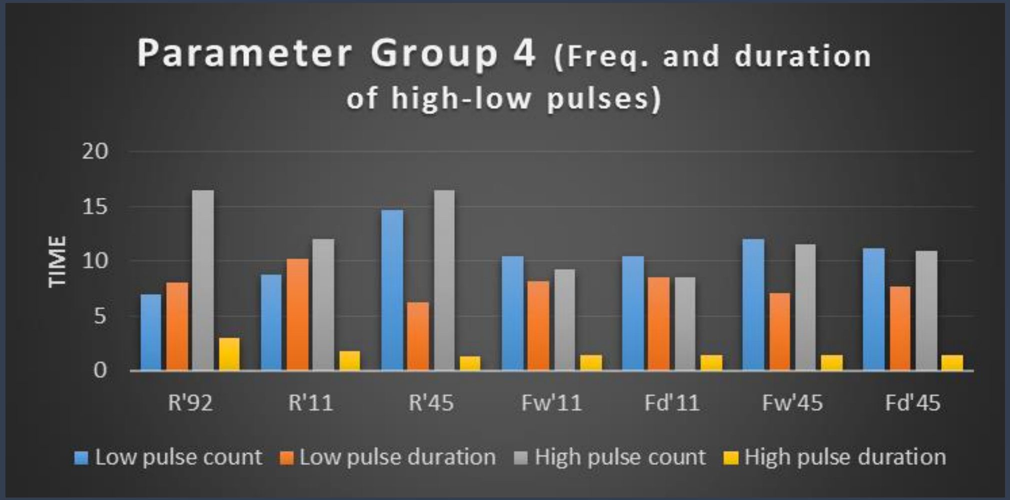

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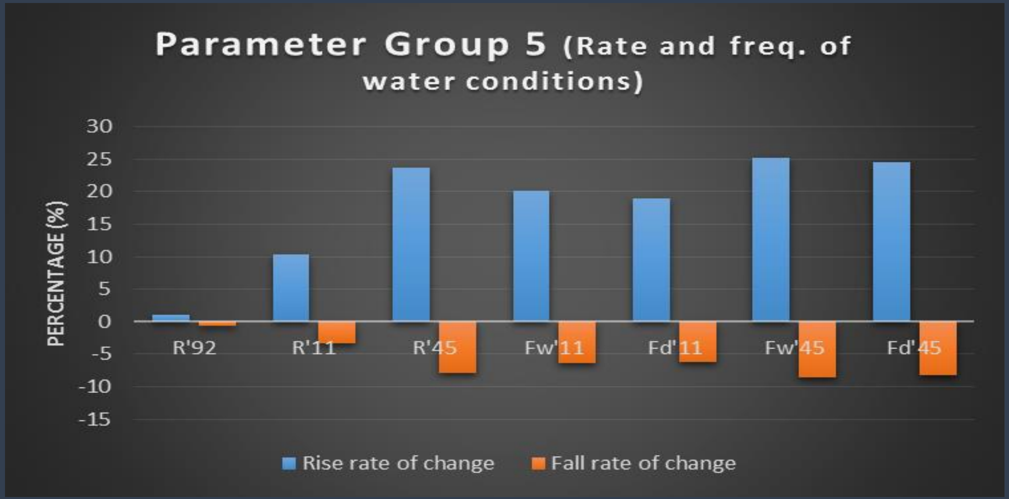

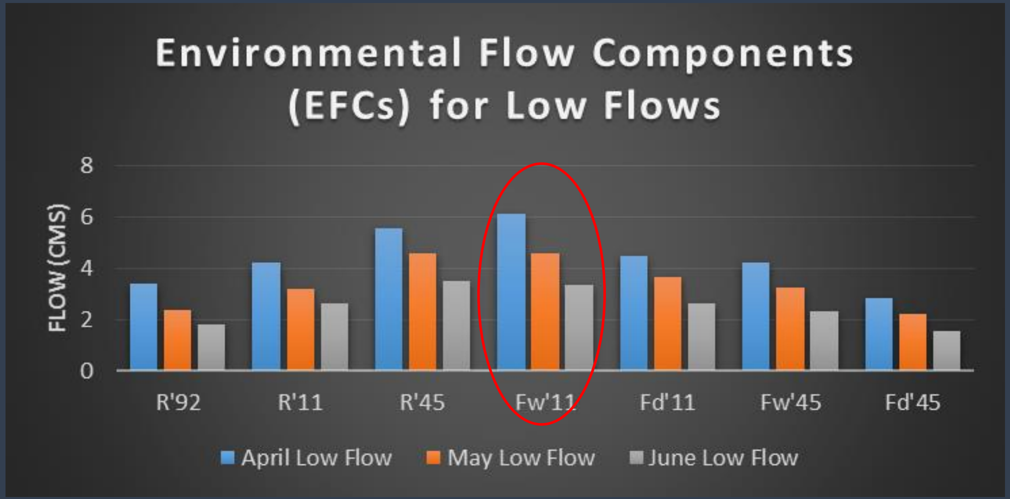

Conclusion

Ecologically Relevant Flow Metrics

- The streamflow of the upper Cahaba River has **a high probability of increasing** in the future due to LULC and Climate Change.
- The impact of **hydrological fluctuations** on the life cycle of aquatic ecosystems will not be negligible,
- The stress on the aquatic ecosystem due to extremely **low and high** flow changes will increase.

The results of this study would be helpful to researchers interested in the streamflow alterations due to LULC and Climate Change on the fish and plant ecosystems.

Acknowledgment

- Republic of Turkey Ministry of Forestry and Water Affairs, General Directorate of Combating Desertification and Erosion

Thanks for your attention!

Image credit: www.epa.gov

Appendix A. Parameters Modified in the Calibration Process

Sensitivity	P-Value	Name	Definition	Range	SWAT Default Value	New Value
1	0.000	CANMX.hru	Maximum canopy storage	0-100	0	33
2	0.001	SOL_K.sol	Saturated hydraulic conductivity	0-2000	100.8	59
3	0.001	CN2.mgt	Initial SCS CN II Value	35-98	66	-18%
4	0.015	GW_DELAY.gw	Groundwater delay (days)	0-500	31	5.39
5	0.024	RCHRG_DP.gw	Deep aquifer percolation fraction	0-1	0.05	0.33
6	0.029	GWHT.gw	Initial groundwater height (m)	0-25	1	16
7	0.047	REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" (mm)	0-500	1	252
8	0.053	GWQMN.gw	Treshold depth of water in the shallow aquifer (mm)	0-5000	1000	370
9	0.072	GW_REVAP.gw	Groundwater "revap" coefficient	0.02-2	0.02	0.14
10	0.080	SOL_AWC.sol	Available water capacity of the soil layer	0-1	0.15	+16%
11	0.108	ALPHA_BNK.rte	Baseflow alpha factor for bank storage	0-1	0	0.73
12	0.159	SOL_BD.sol	Moist bulk density	0.9-2.5	1.45	1.63
13	0.206	ALPHA_BF.gw	Baseflow alpha factor (days)	0-1	0.048	0.22
14	0.259	SURLAG.bsn	Surface runoff lag time	0.05-24	4	12
15	0.438	ESCO.bsn	Soil evaporation compensation factor	0-1	0.095	0.71
16	0.741	EPCO.bsn	Plant uptake compensation factor	0-1	0	0.7

Appendix A. Used parameters in calibration process

Appendix B. IHA Results

	S1	S2	S3	S4	S5	S6	S7
Mean annual flow (m3/s)	7.68	7.85	11.79	12.1	10.77	12.63	11.43
Parameter Group #1							
Mean Value of April (m3/s)	5.371	9.398	14.57	15.19	10.32	15	10.26
Mean Value of May (m3/s)	2.418	6.124	11.94	13.984	8.345	13.244	8.188
Mean Value of June (m3/s)	1.765	4.008	8.343	12.4	6.733	12.18	6.437
Parameter Group #2							
7-day minimum	0.4174	0.5691	0.124	0.2701	0.154	0.1376	0.06943
30-day minimum	0.6532	0.8472	0.9883	1.246	0.7958	0.9884	0.628
90-day minimum	1.624	2.005	3.858	3.76	3.212	3.605	3.318
7-day maximum	52.34	56.48	80.66	113.6	119.2	125.9	132.9
30-day maximum	23.37	24.09	32.97	43.15	41.43	46.79	46.19
90-day maximum	15.45	15.66	21.52	24.17	21.89	25.33	23.8
Number of zero days	0	3.071	13.89	17.89	22.04	24.18	33.46
Parameter Group #3							
Julian date of annual min	279	294.3	233.1	196.8	170.6	167.6	154.7
Julian date of annual max	60	77.04	107.9	91.32	194.5	93.68	192
Parameter Group #4							
Low pulse count	7	8.786	14.64	10.46	10.5	12.07	11.14
Low pulse duration	8	10.22	6.202	8.207	8.544	7.122	7.752
High pulse count	16.5	12.04	16.5	9.25	8.571	11.57	10.89
High pulse duration	3	1.81	1.308	1.47	1.45	1.403	1.427
Parameter Group #5							
Rise rate of change	1.09	10.39	23.76	20.2	18.99	25.28	24.6
Fall rate of change	-0.591	-3.309	-7.834	-6.442	-6.126	-8.521	-8.191
Environmental Flow Components (EFC) Low Flows							
April Low Flow	3.389	4.209	5.524	6.113	4.476	4.212	2.806
May Low Flow	2.364	3.167	4.558	4.589	3.67	3.226	2.229
June Low Flow	1.788	2.615	3.476	3.341	2.628	2.322	1.534

Appendix B. IHA parameters

References

- Perrine Hame, Eboardo DALY, Tim D. Fletcher, Which baseflow metrics should be used in assessing flow regimes of urban streams?
- Indicators of Hydrologic Alteration (IHA) (https://www.conservationgateway.org)
- Coupled Model Intercomparison Project Phase 5 (CMIP5) (http://cmip-pcmdi.llnl.gov/cmip5/)
- Prism Climate Group (http://www.prism.oregonstate.edu/)
- National Land Cover Database (NLCD) (http://www.mrlc.gov/)
- USGS – Earth Resources Observation and Science (EROS) Center (http://landcover-modeling.cr.usgs.gov/projects.php)