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Biological Systems Engineering

An Investigation into the Chesapeake Bay Watershed Hydrologic Budget under Future Climate Change Scenarios

1/15/2015

Choung Seong, Postdoc

Venkat Sridhar (Sri), Assistant Professor

Biological Systems Engineering, Virginia Tech

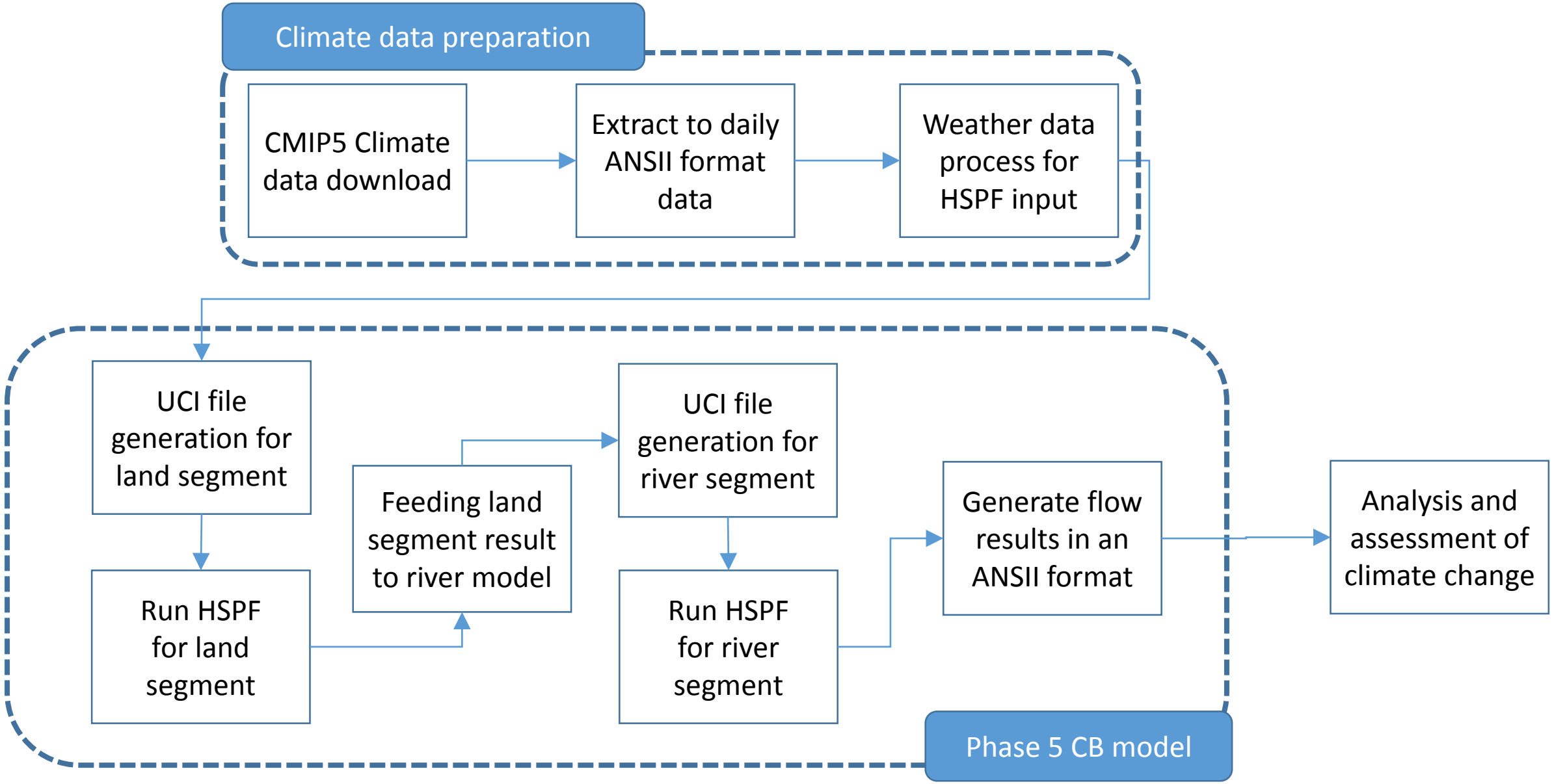
Background

- Developing a more comprehensive understanding of the possible changes in regional precipitation and related stream flow variations is essential for hydrology, water resources and water quality modeling.

Objectives

- To conduct an assessment of climate change impacts using the CB Watershed model (CBWM), and
- To provide a system dynamics framework for accessing hydrologic and water resources scenarios in a changing climate.

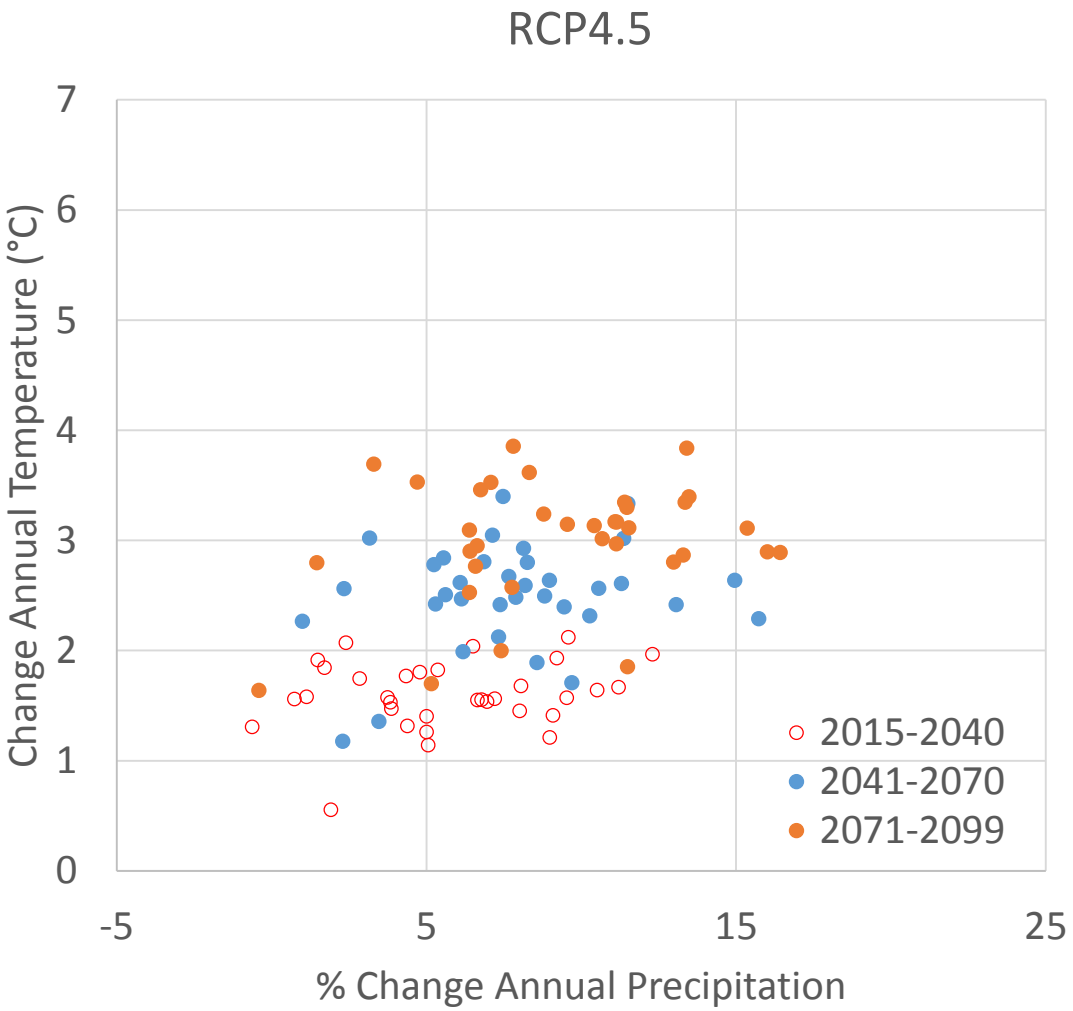
Linking Global Circulation Model derived precipitation and temperature with CBWM/HSPF

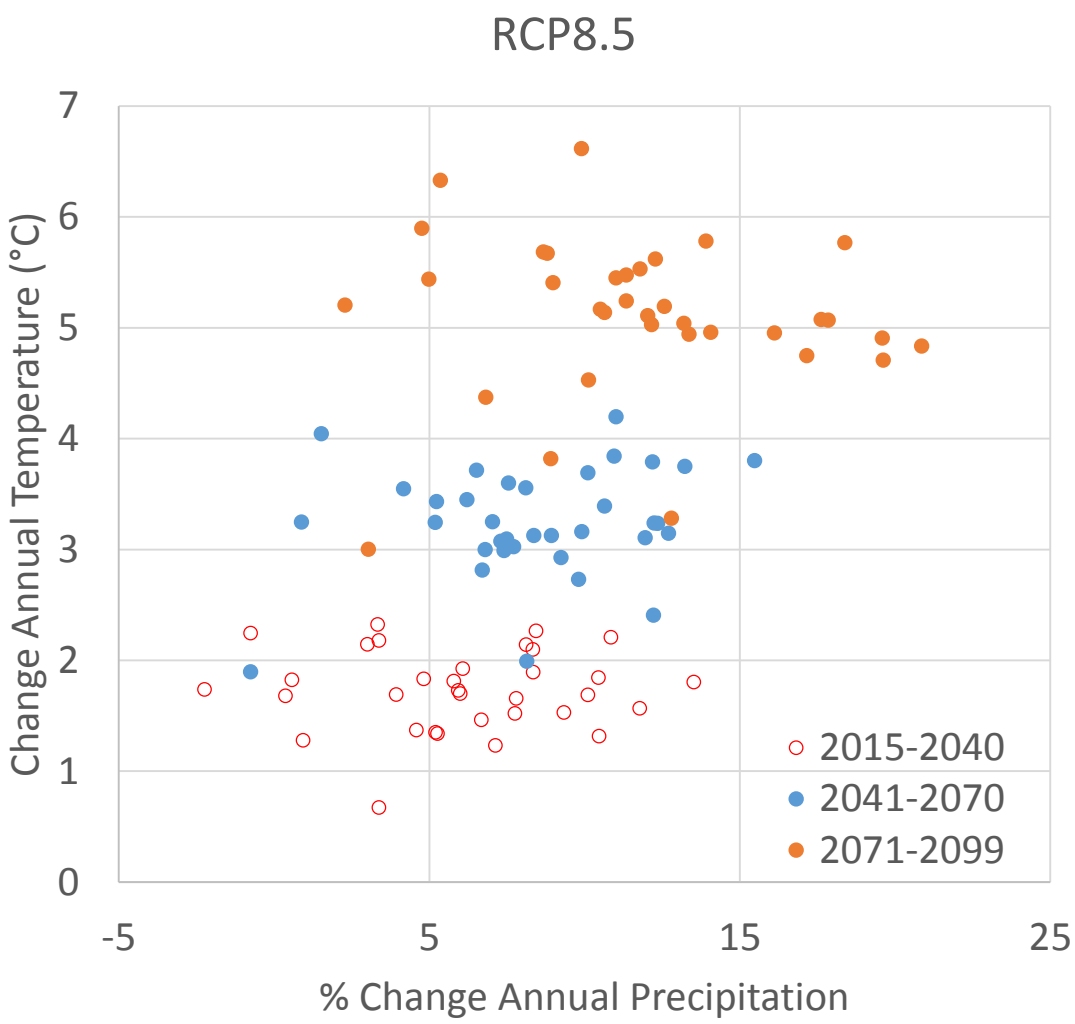


Climate Data

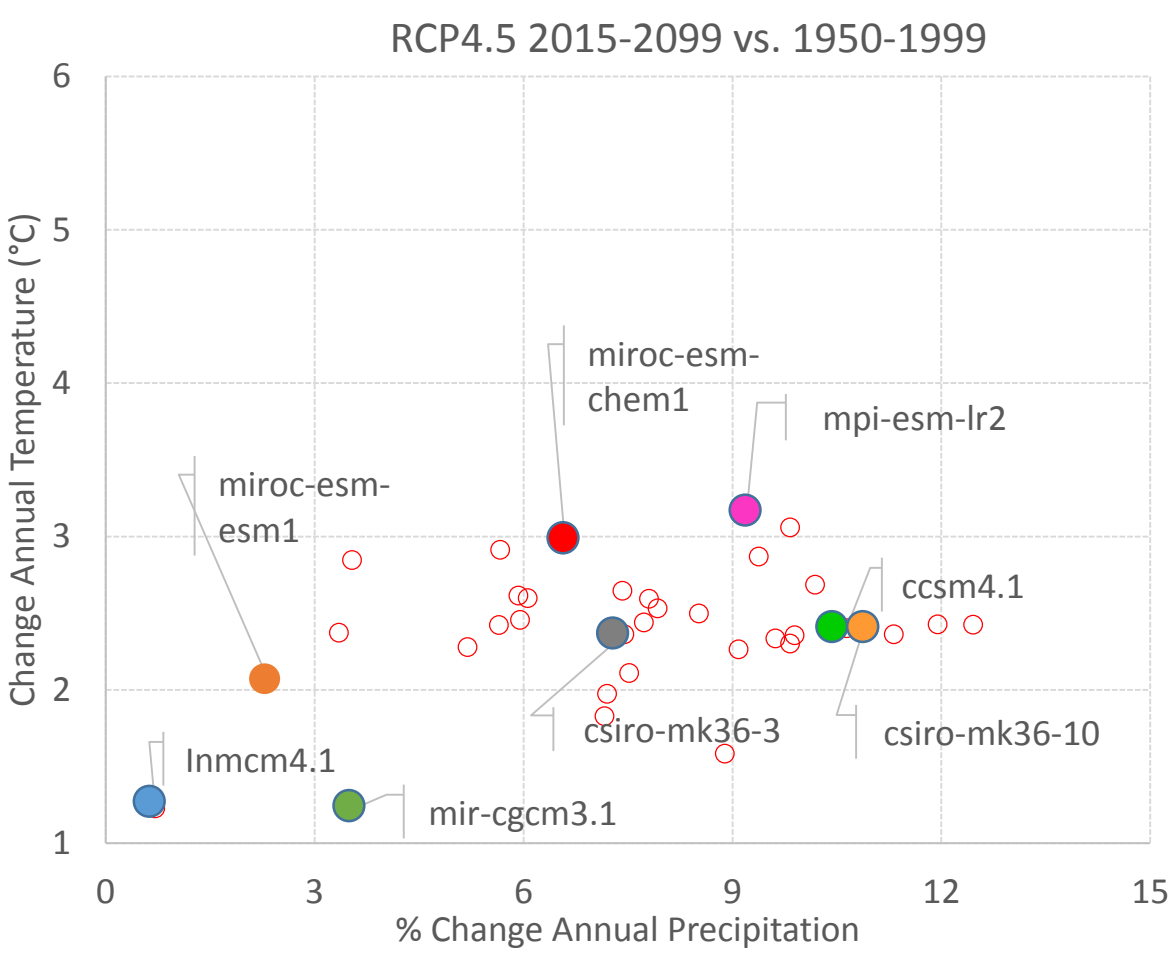
- Coupled Model Intercomparison Project Phase 5 (CMIP5) data
  - Used in the Fifth Assessment Report (AR5) by the Intergovernmental Panel on Climate Change (IPCC)
- Downscaled CMIP5 climate data
  - Bias-Correction Constructed Analogues (BCCA) from CMIP5
  - Resolution : Daily 1/8 *1/8 degree
  - Daily precipitation, max/min temperature
  - Data period: 1950 – 2099

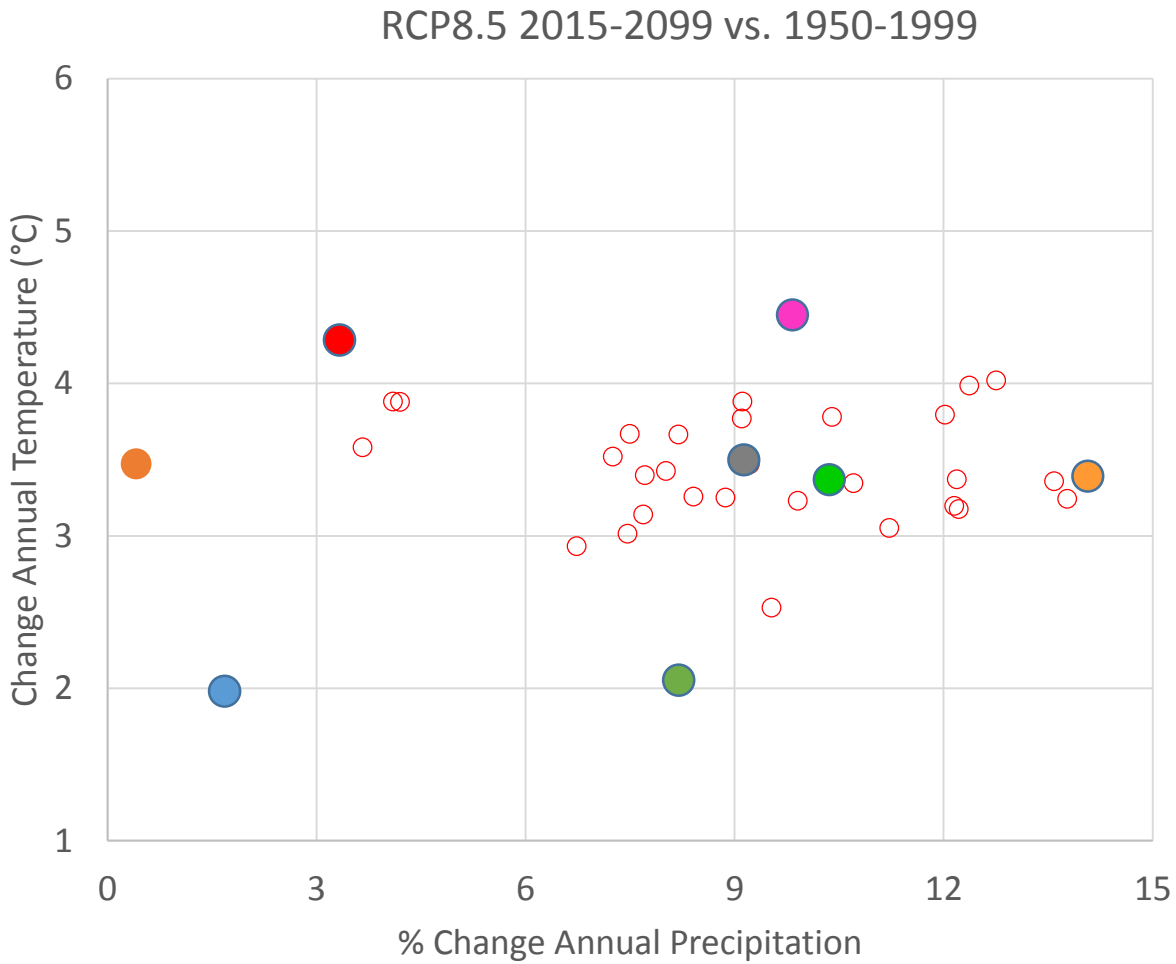
Changes in temperature vs. precipitation: A Comparison with historic data (1950 -2013) (70 scenarios in BCCA CMIP5)





Selected climate scenario for the CBWM simulation (16 scenarios)



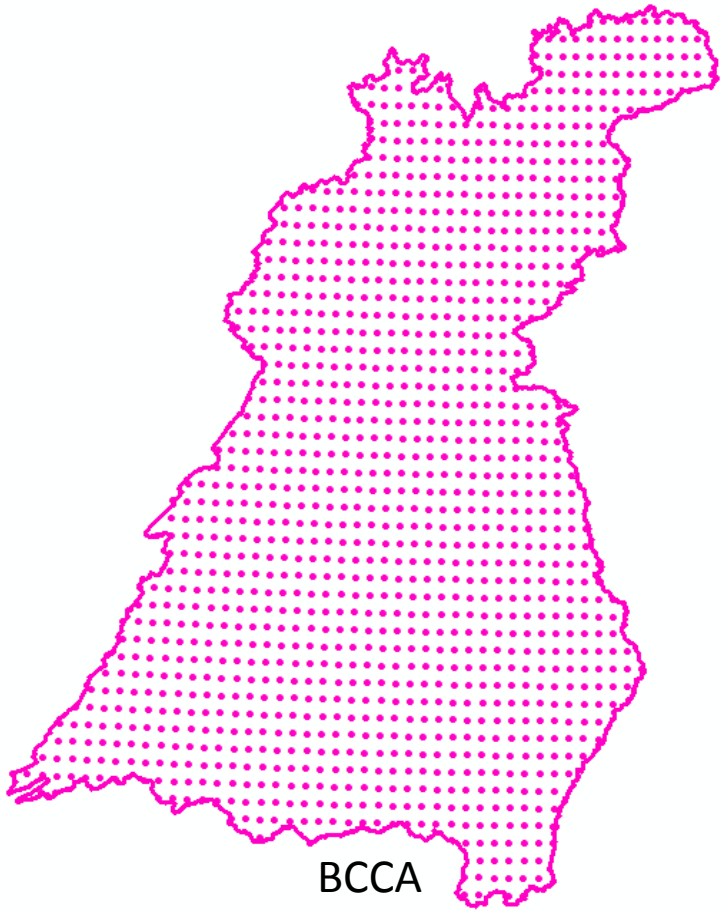


Used climate model for the CBWM simulation

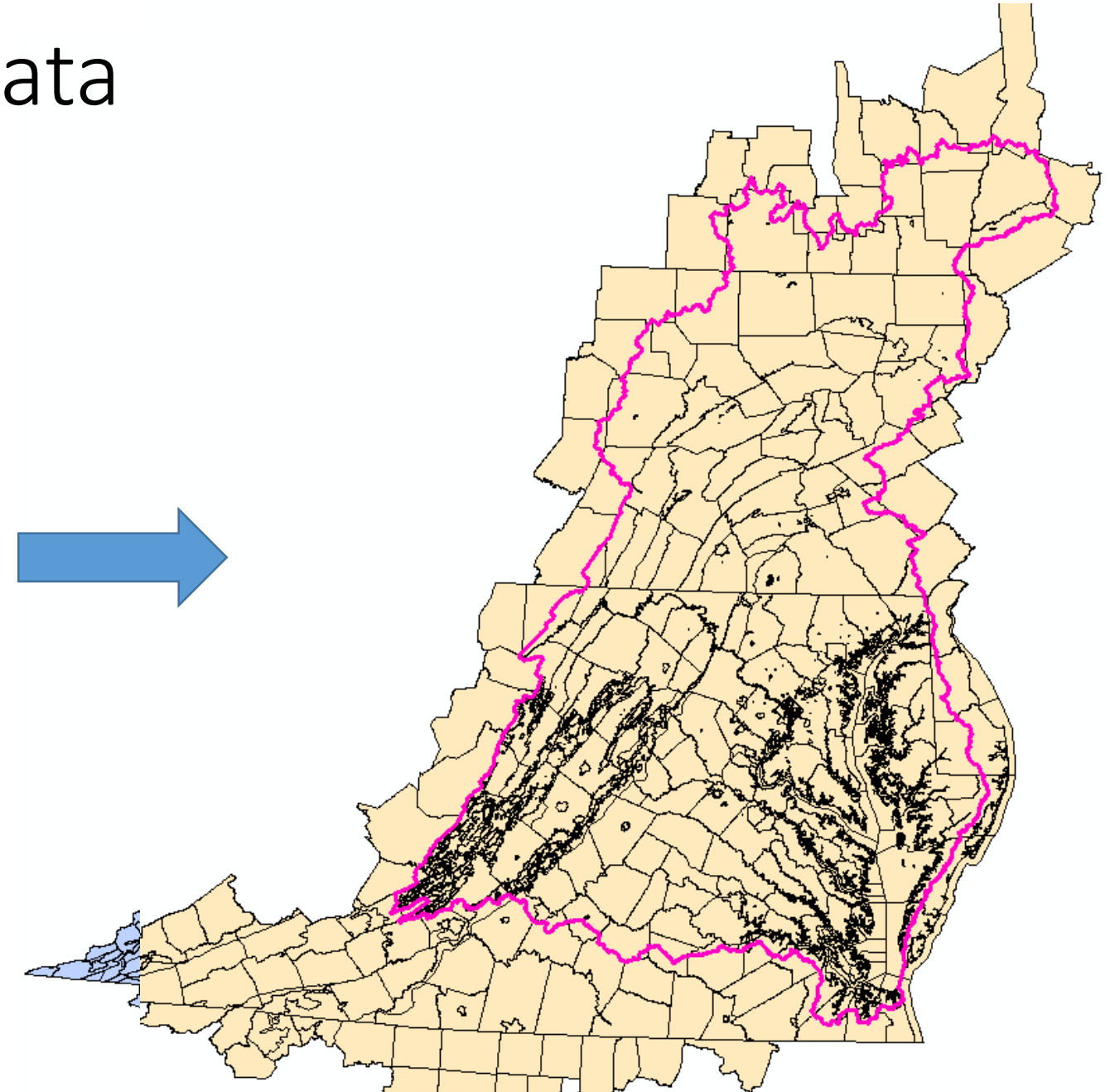
Model	Author/Source	Projected Climate
INM-CM4	Institute for Numerical Mathematics	Cool and dry
MIROC-ESM1	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	Dry
MIROC-ESM-CHEM1		Warm
MPI-ESM-LR2	Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)	Warm and wet
CCSM4.1	National Center for Atmospheric Research	Wet
CSIRO-Mk3.6.3	Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	
CSIRO-Mk3.6.10		Wet
MRI-CGCM3.1	Meteorological Research Institute	Cool and dry

Integrating Climate data

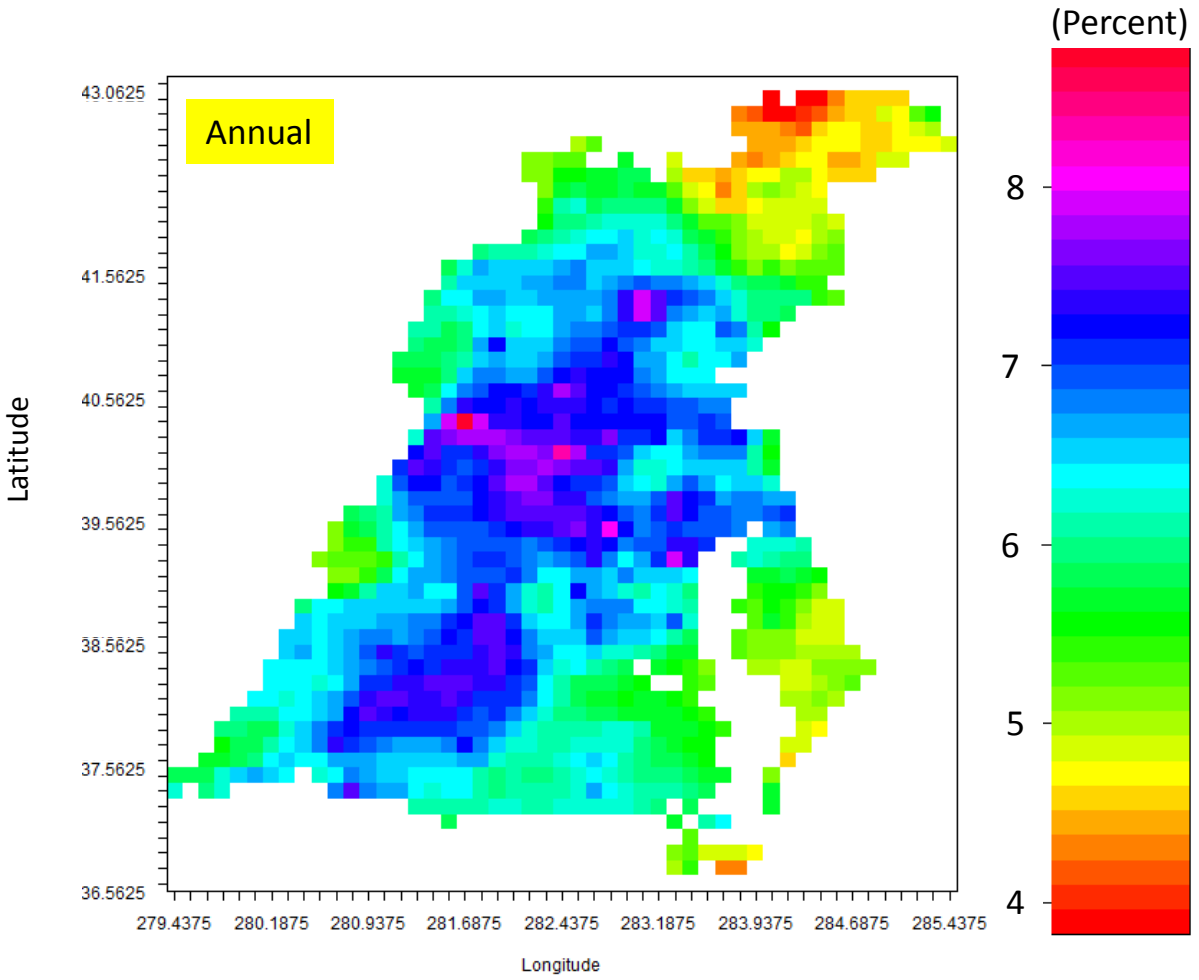
- BCCA (1/8 degree): 1244 grids



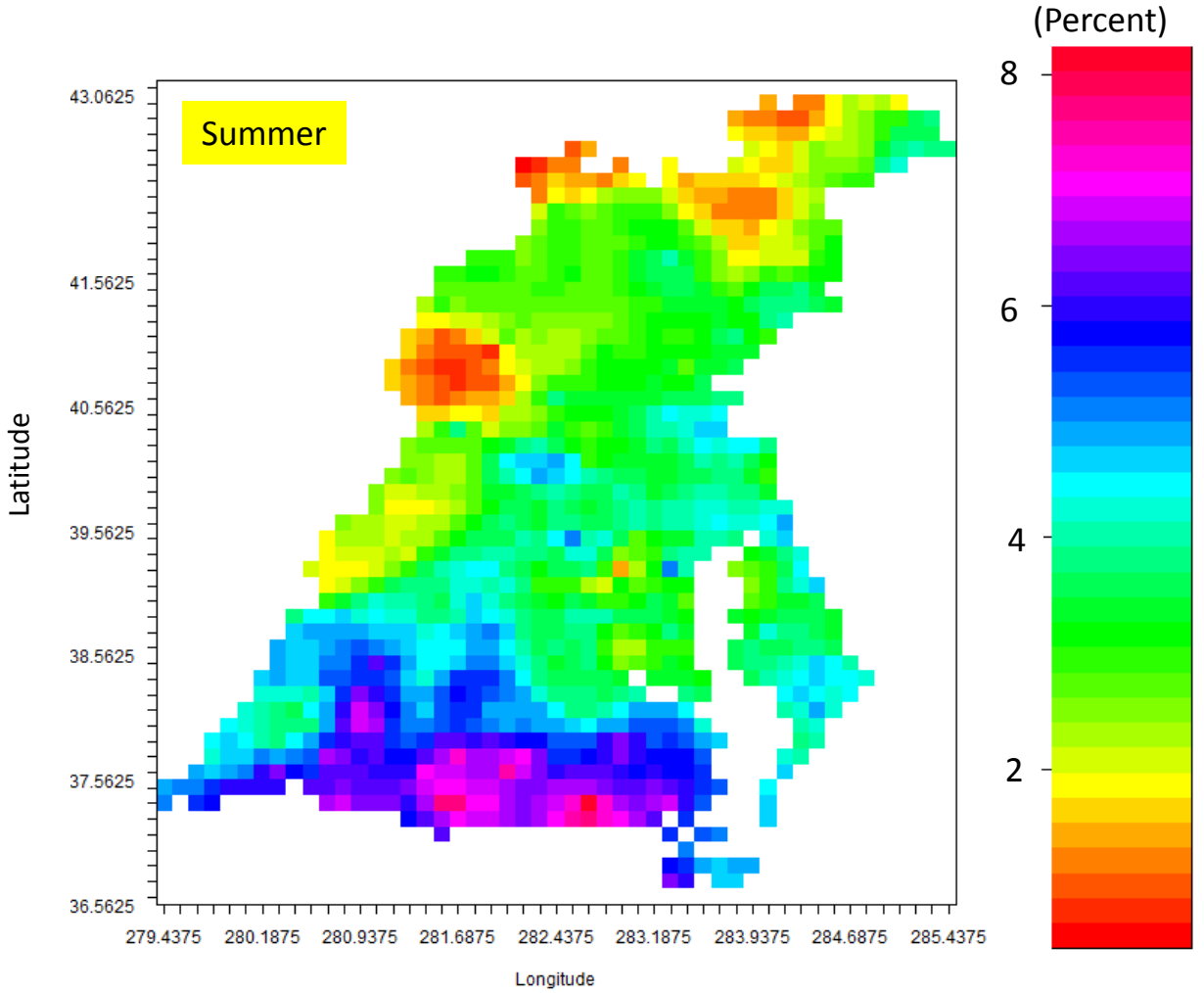
BCCA



Changes in precipitation between historic and future data

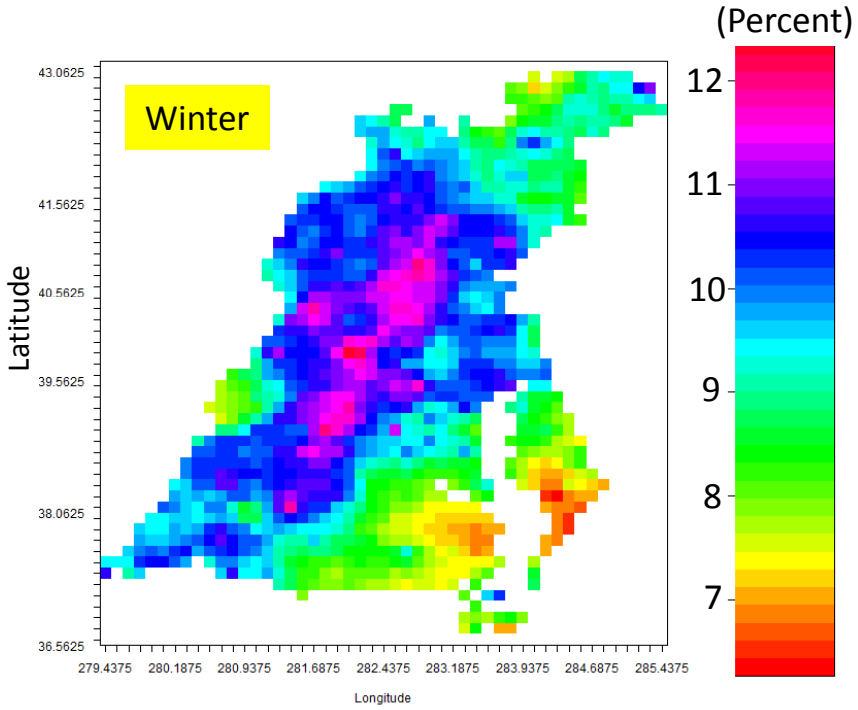


Percent differences in annual average precipitation between historic(1985-2004) and future periods

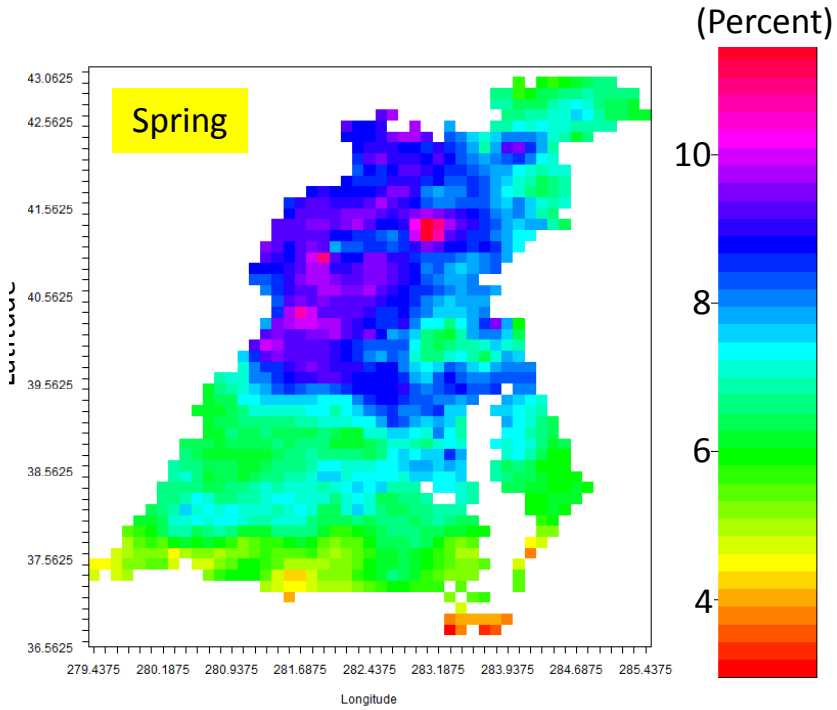


Percent differences in Summer precipitation between historic(1985-2004) and future periods

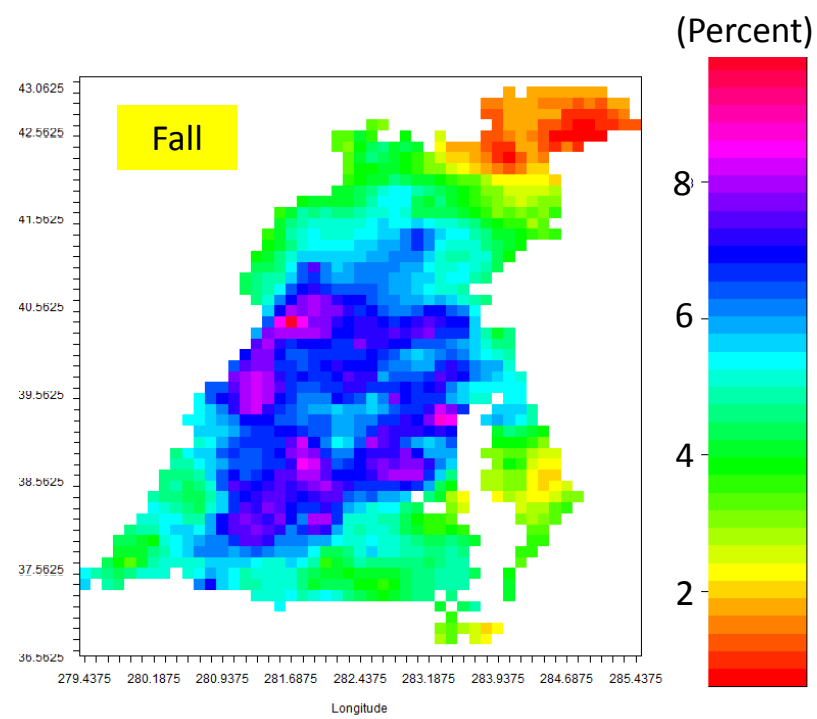
Changes in precipitation between historic and future data



Percent differences
in Winter precipitation

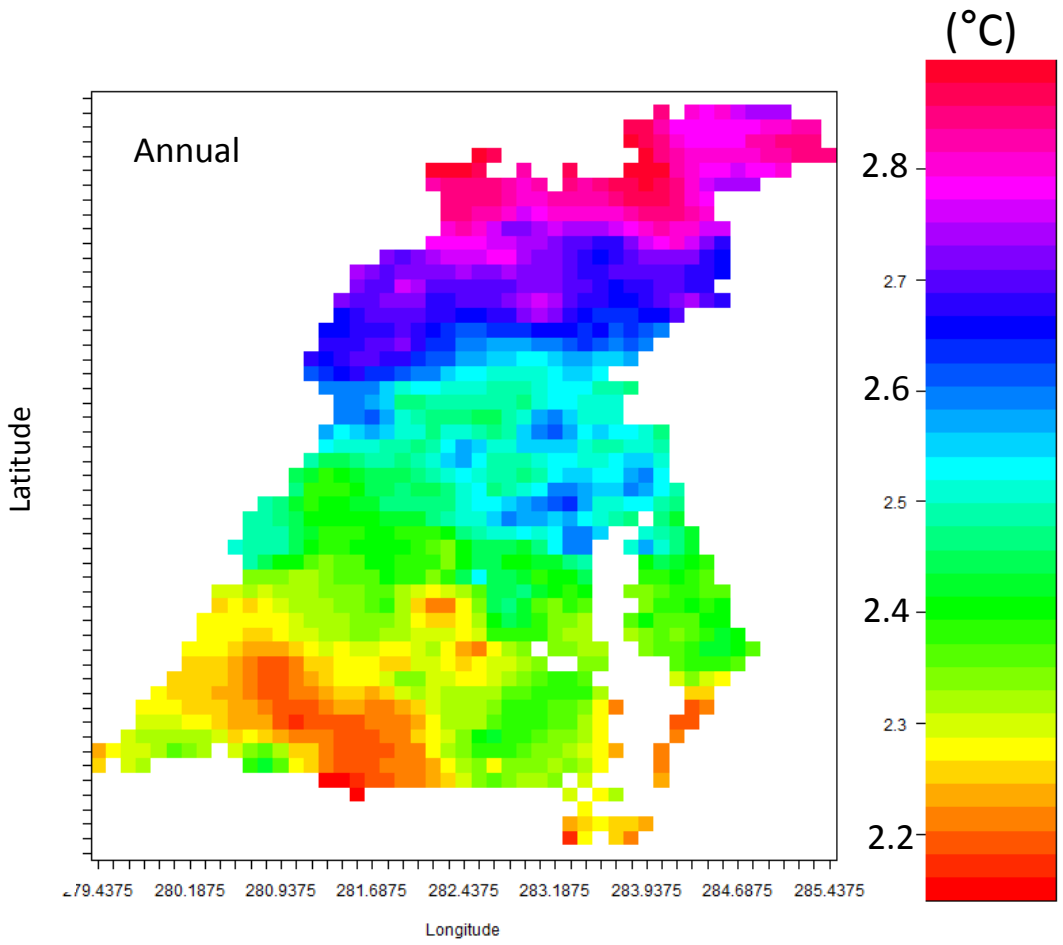


Percent differences
in Spring precipitation

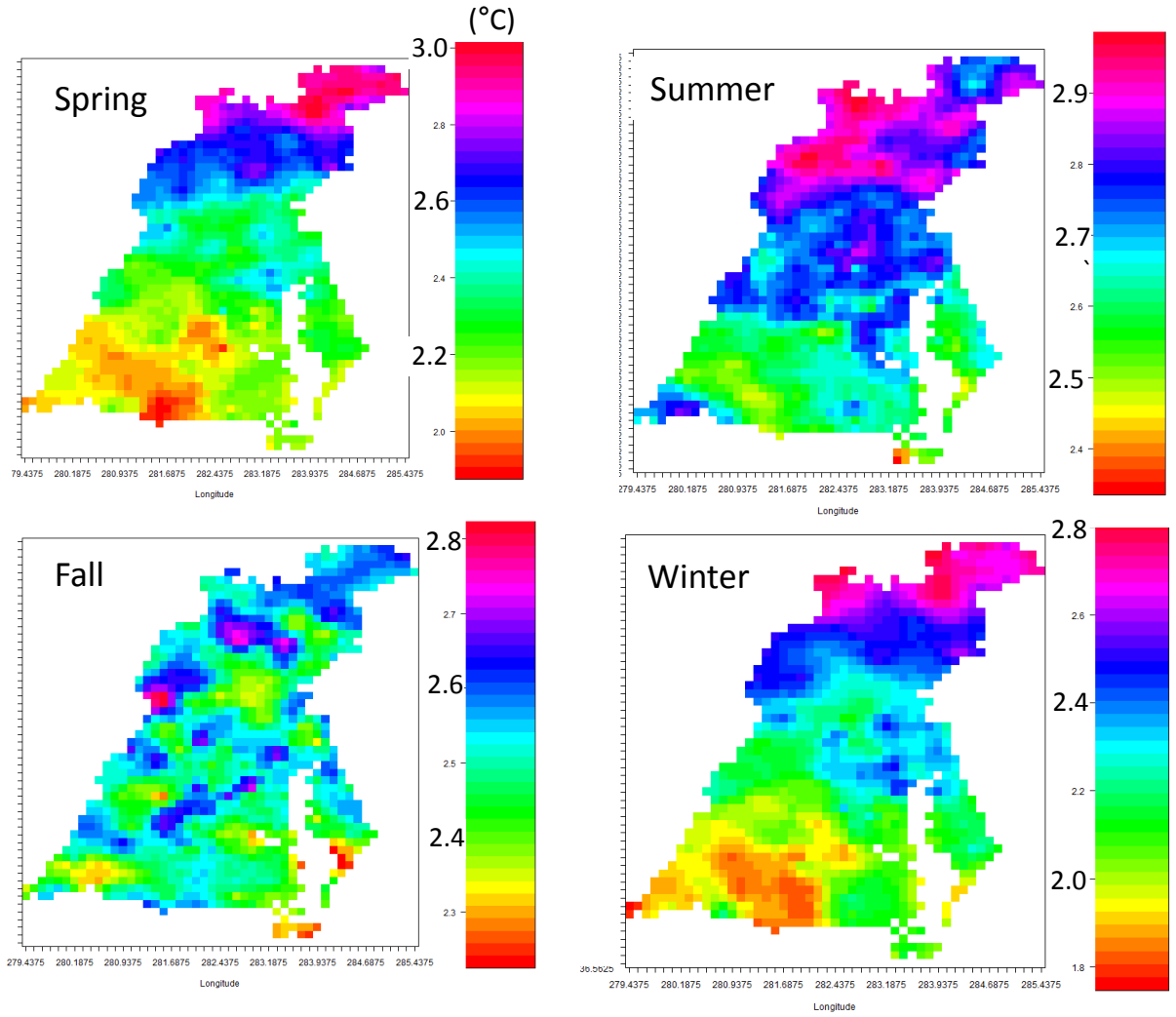


Percent differences
in Fall precipitation

Changes in temperature between historic and future data



Differences in annual average maximum temperature between historic(1985-2004) and future periods (°C)



Differences in seasonal maximum temperature between historic(1985-2004) and future periods (°C)

Stream gages for flow analysis

- Susquehanna River
- Potomac River
- Rappahannock River
- James River

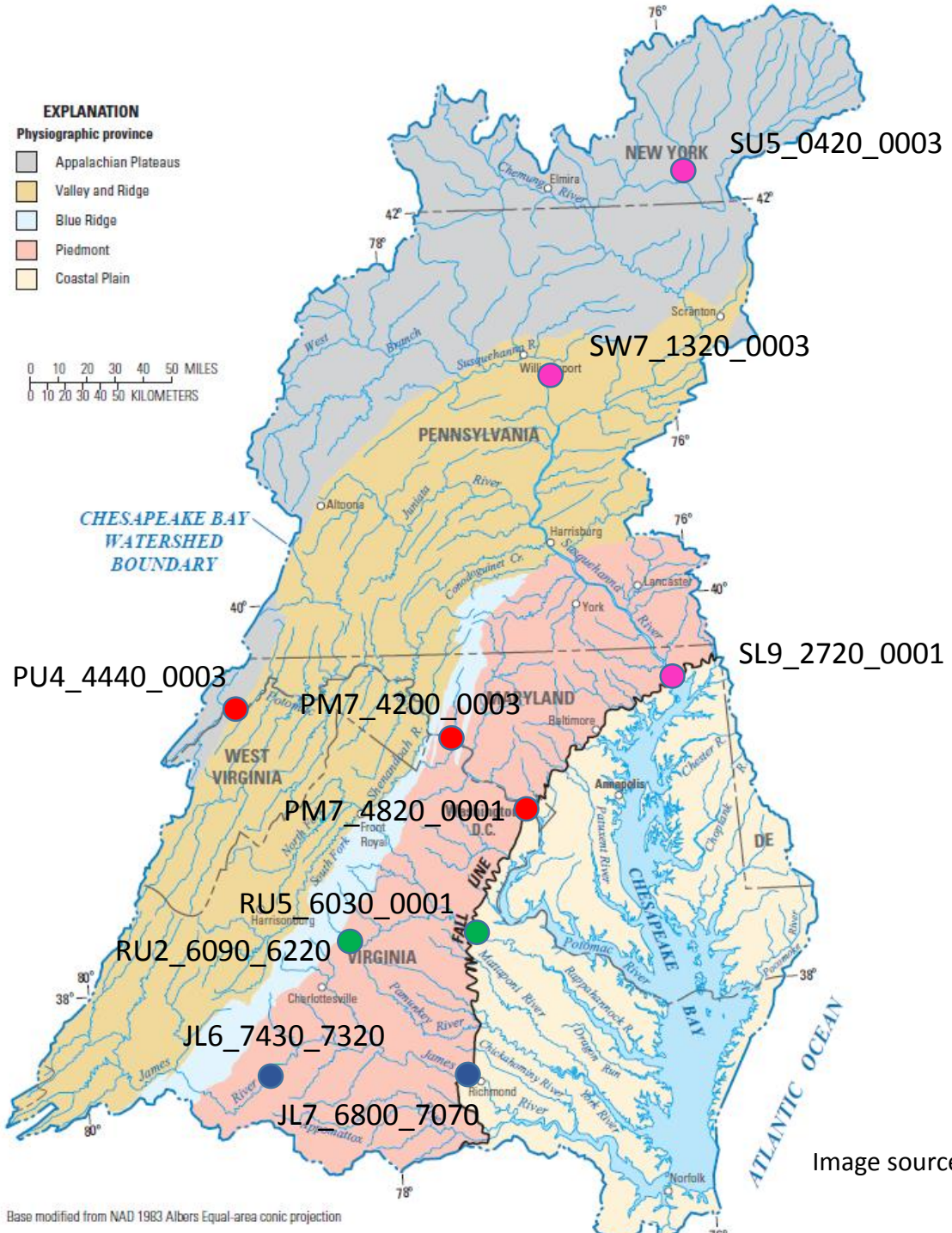
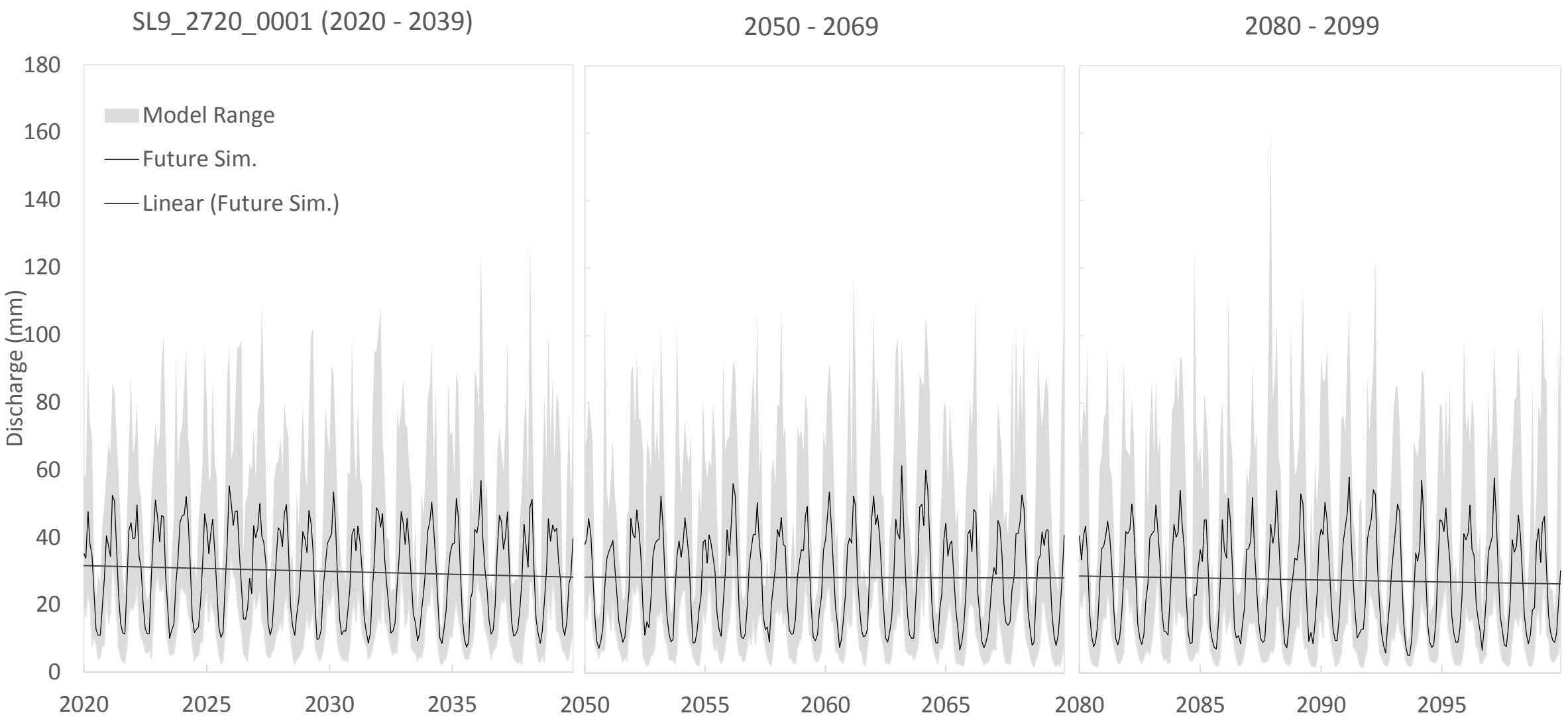


Image source: scientific investigations report 2012-5151, USGS

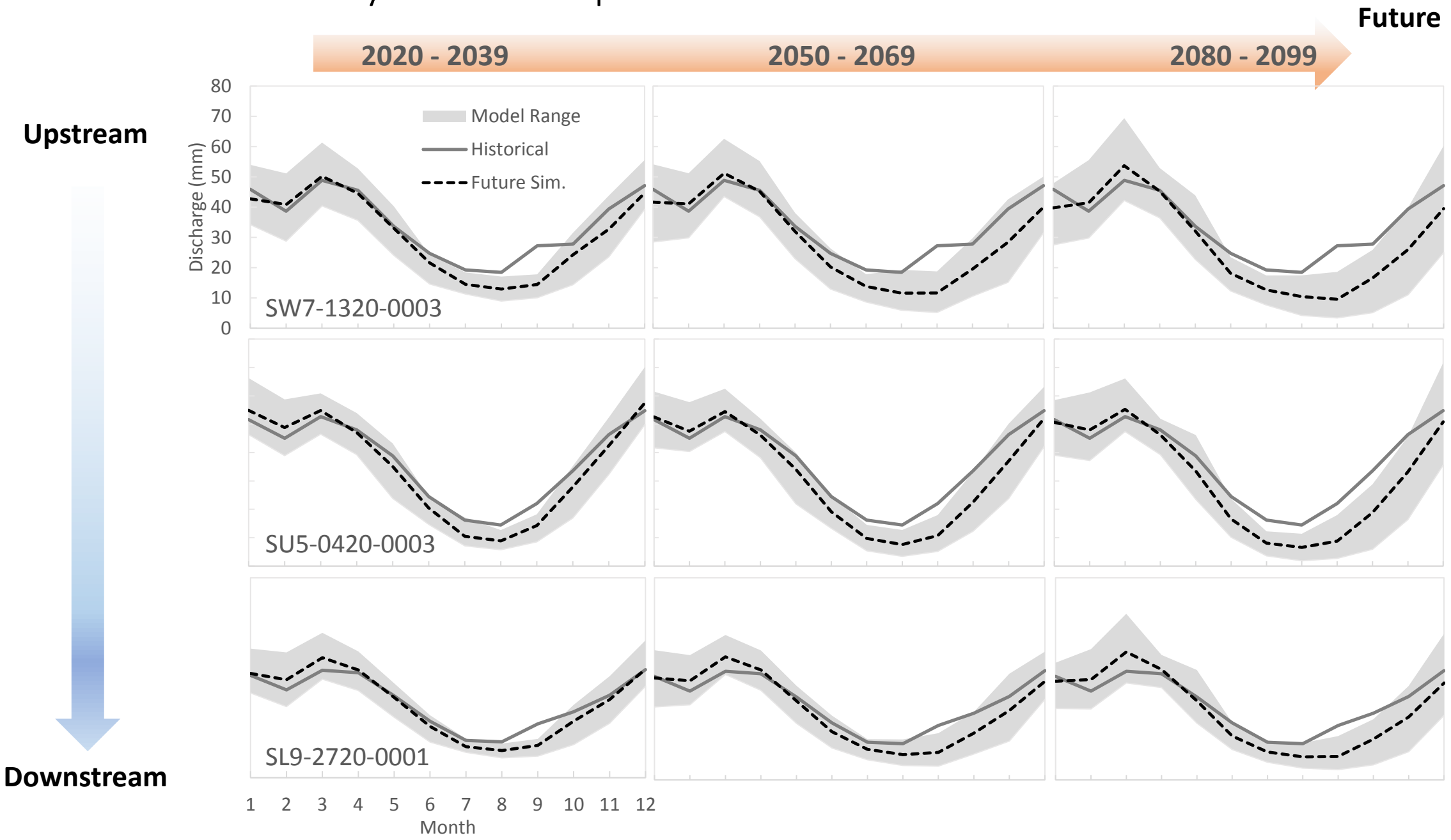
Stream gages for flow analysis

River Segment	Station ID	Station Name	Drainage Area (mi^2)
SU5_0420_0003	01512500	CHENANGO RIVER NEAR CHENANGO FORKS NY	1484.4
SW7_1320_0003	01551500	WB SUSQUEHANNA RIVER AT WILLIAMSPORT, PA	5667.1
SL9_2720_0001	01578310	SUSQUEHANNA RIVER AT CONOWINGO, MD	27069.9
PU4_4440_0003	01598500	NORTH BRANCH POTOMAC RIVER AT LUKE, MD	404.4
PM7_4200_0003	01638500	POTOMAC RIVER AT POINT OF ROCKS, MD	9659.1
PM7_4820_0001	01646500	POTOMAC RIVER NEAR WASH, DC LITTLE FALLS PUMP STA	11577.7
RU2_6090_6220	01665500	RAPIDAN RIVER NEAR RUCKERSVILLE, VA	114.6
RU5_6030_0001	01668000	RAPPAHANNOCK RIVER NEAR FREDERICKSBURG, VA	1596.3
JL6_7430_7320	02026000	JAMES RIVER AT BENT CREEK, VA	3690.5
JL7_6800_7070	02037000	JAMES RIVER AND KANAWHA CANAL NEAR RICHMOND, VA	6763.7

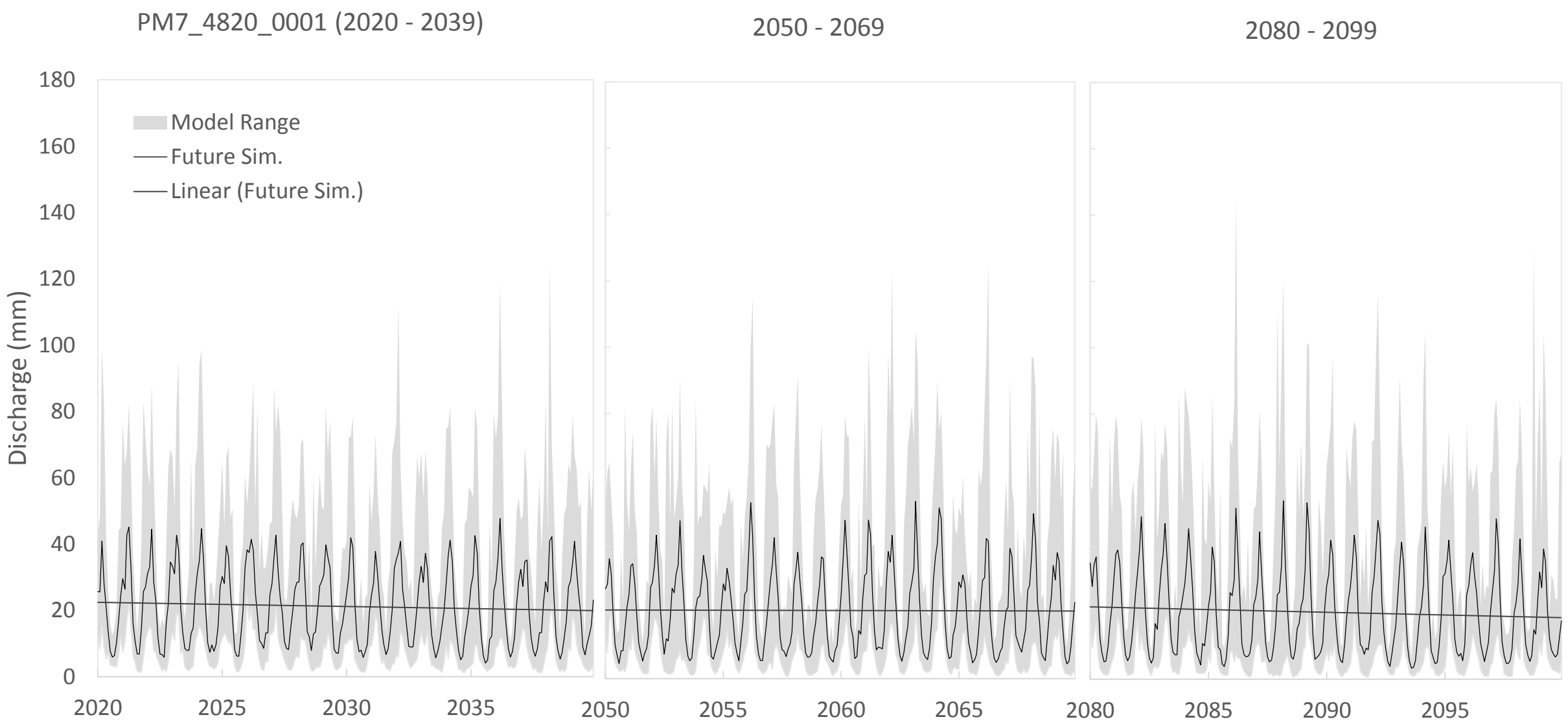
Monthly flow timeseries – Susquehanna River



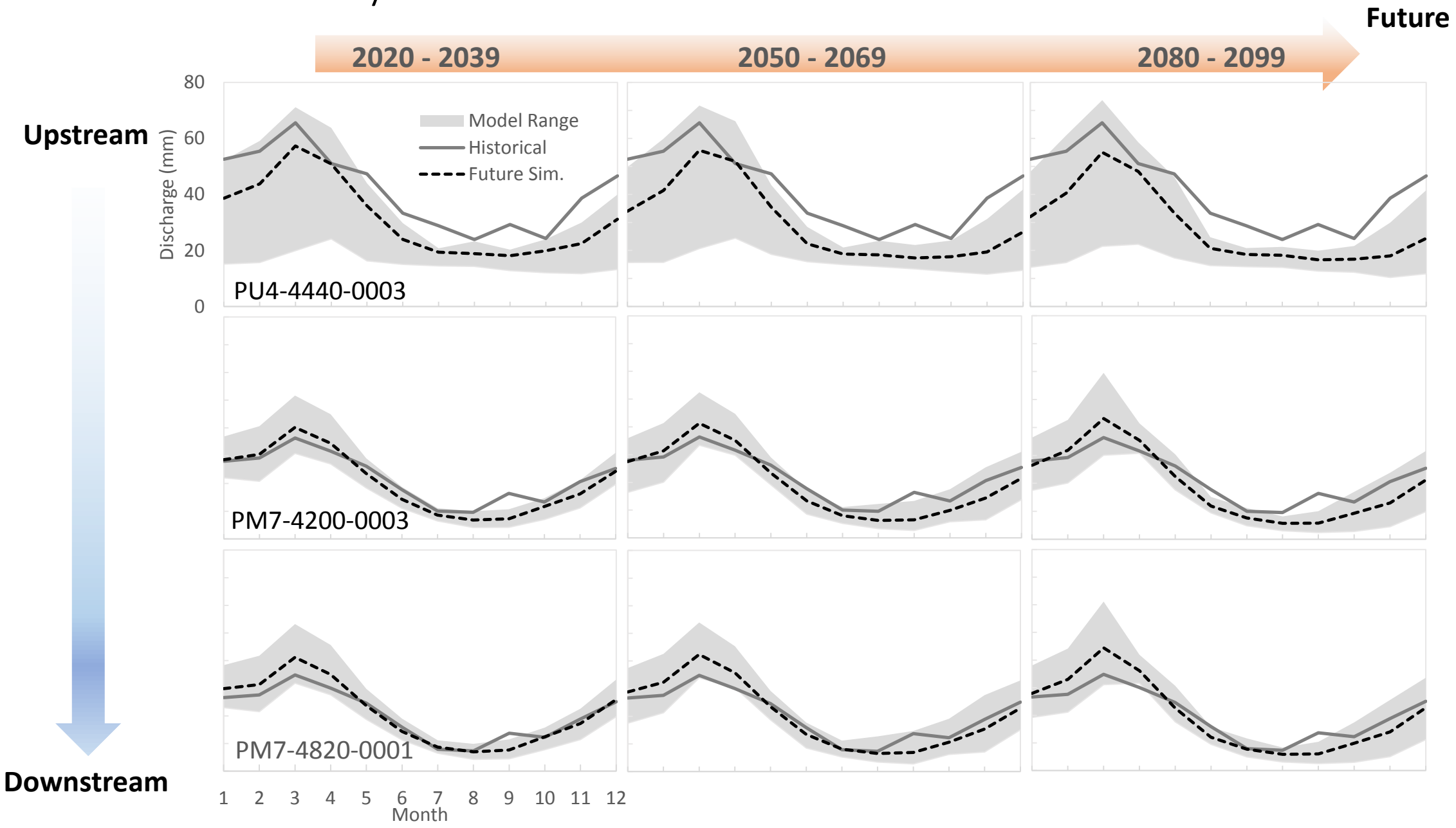
Simulated monthly flow - Susquehanna River



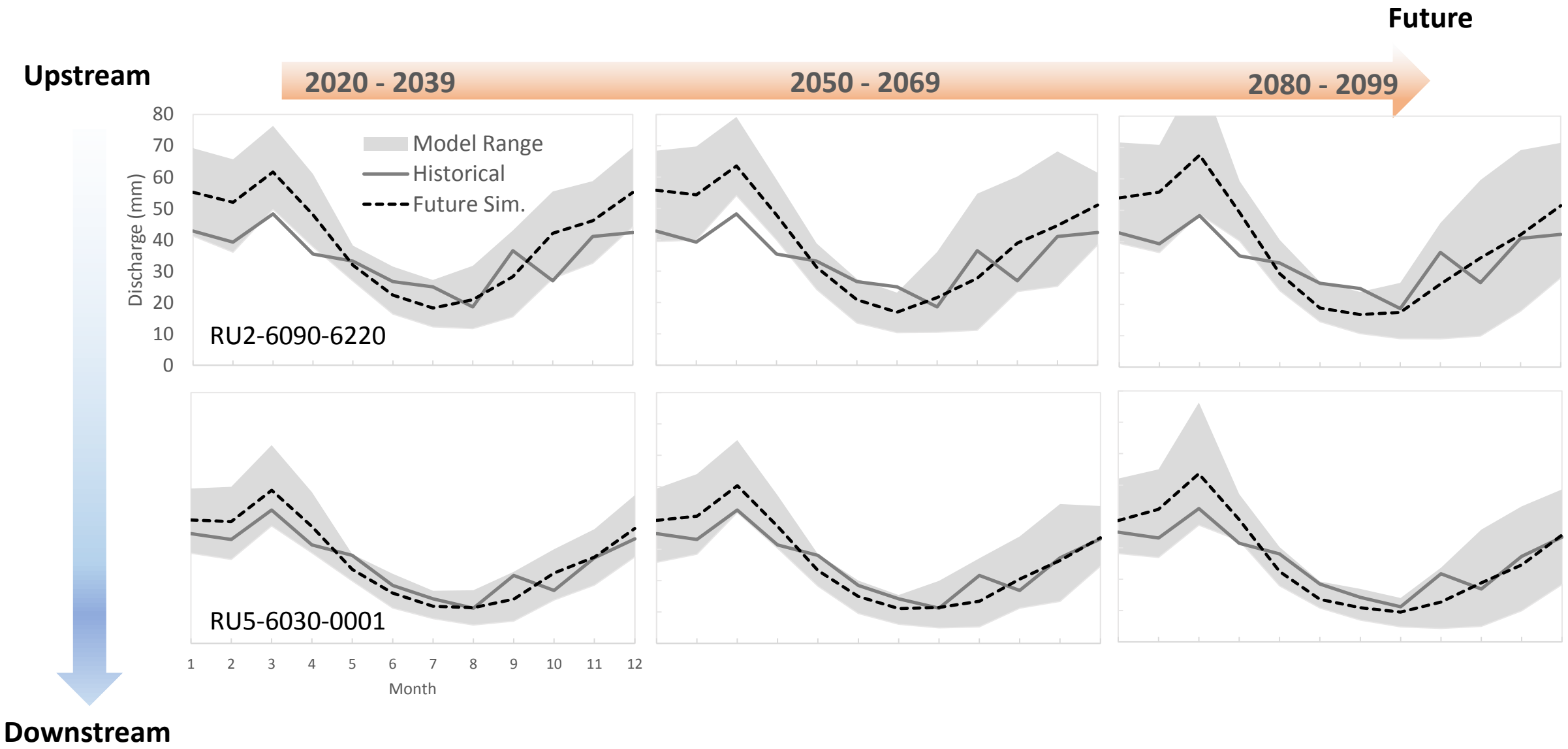
Monthly flow timeseries – Potomac River



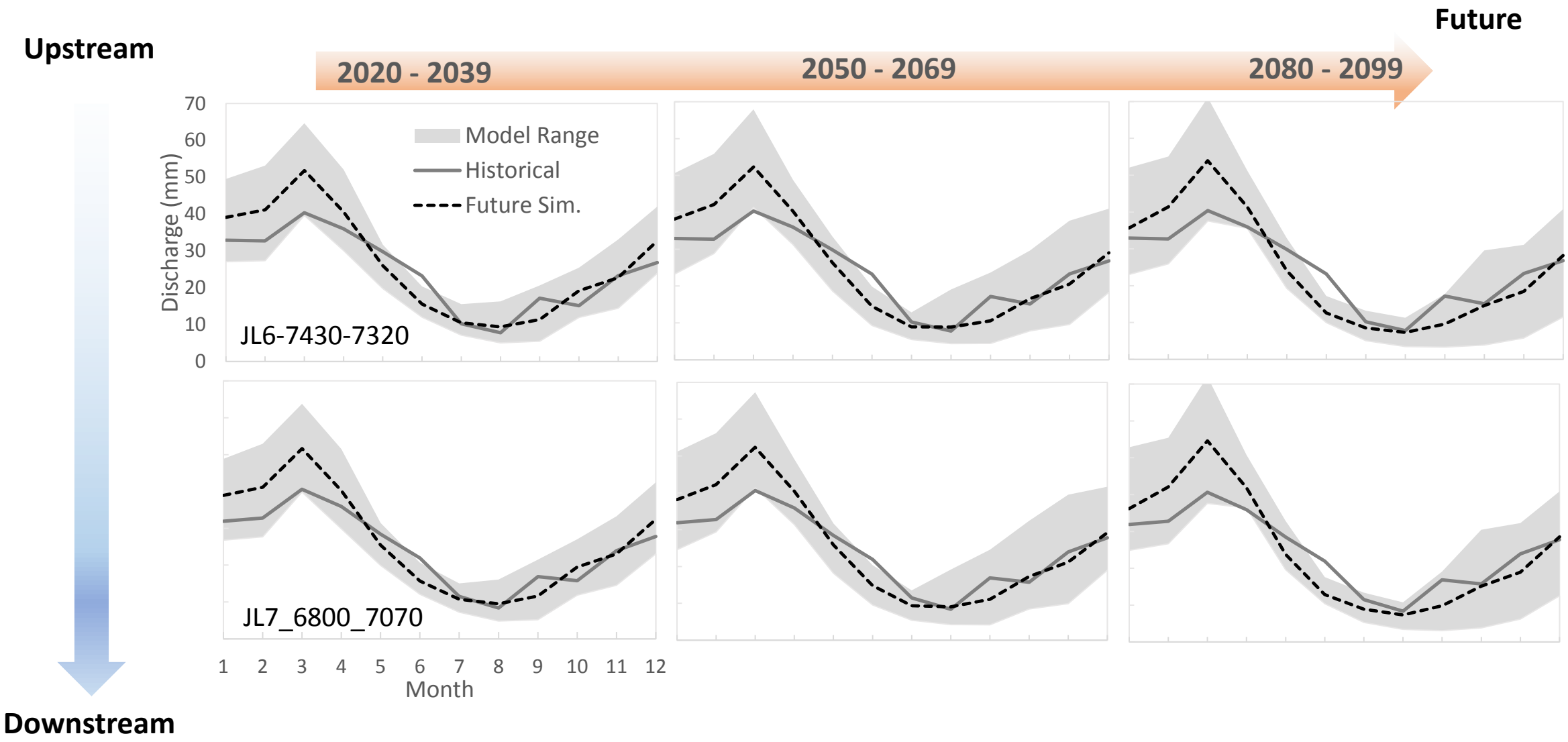
Simulated monthly flow - Potomac River



Simulated monthly flow – Rappahannock River

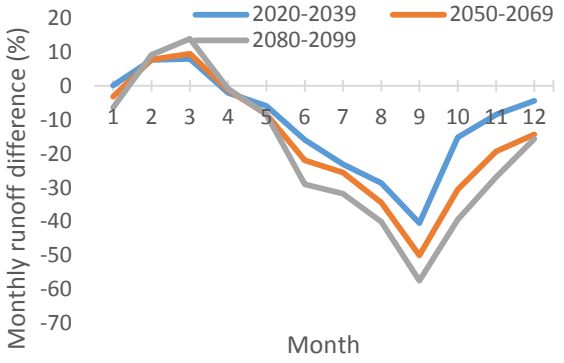


Simulated monthly flow - James River

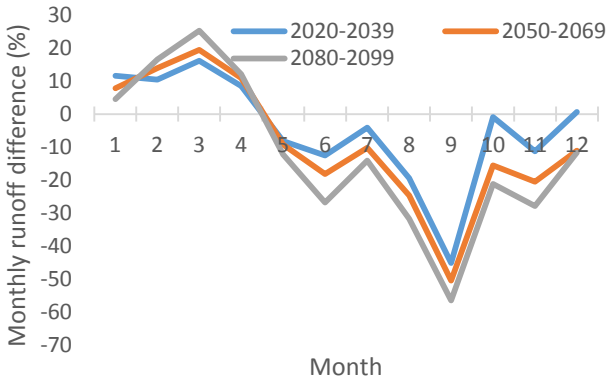


Simulated stream trends at the Fall Line

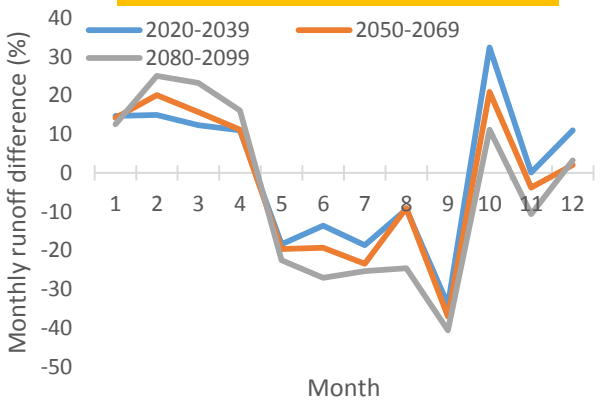
Susquehanna River



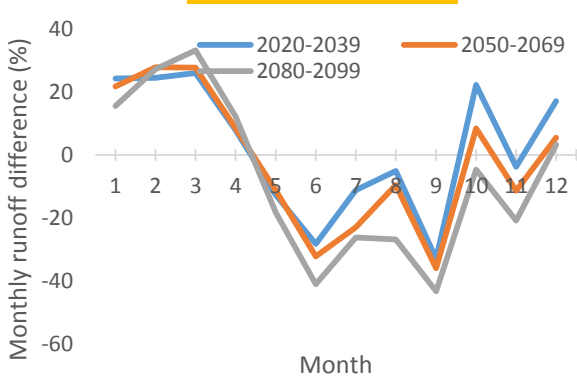
Potomac River



Rappahannock River



James River

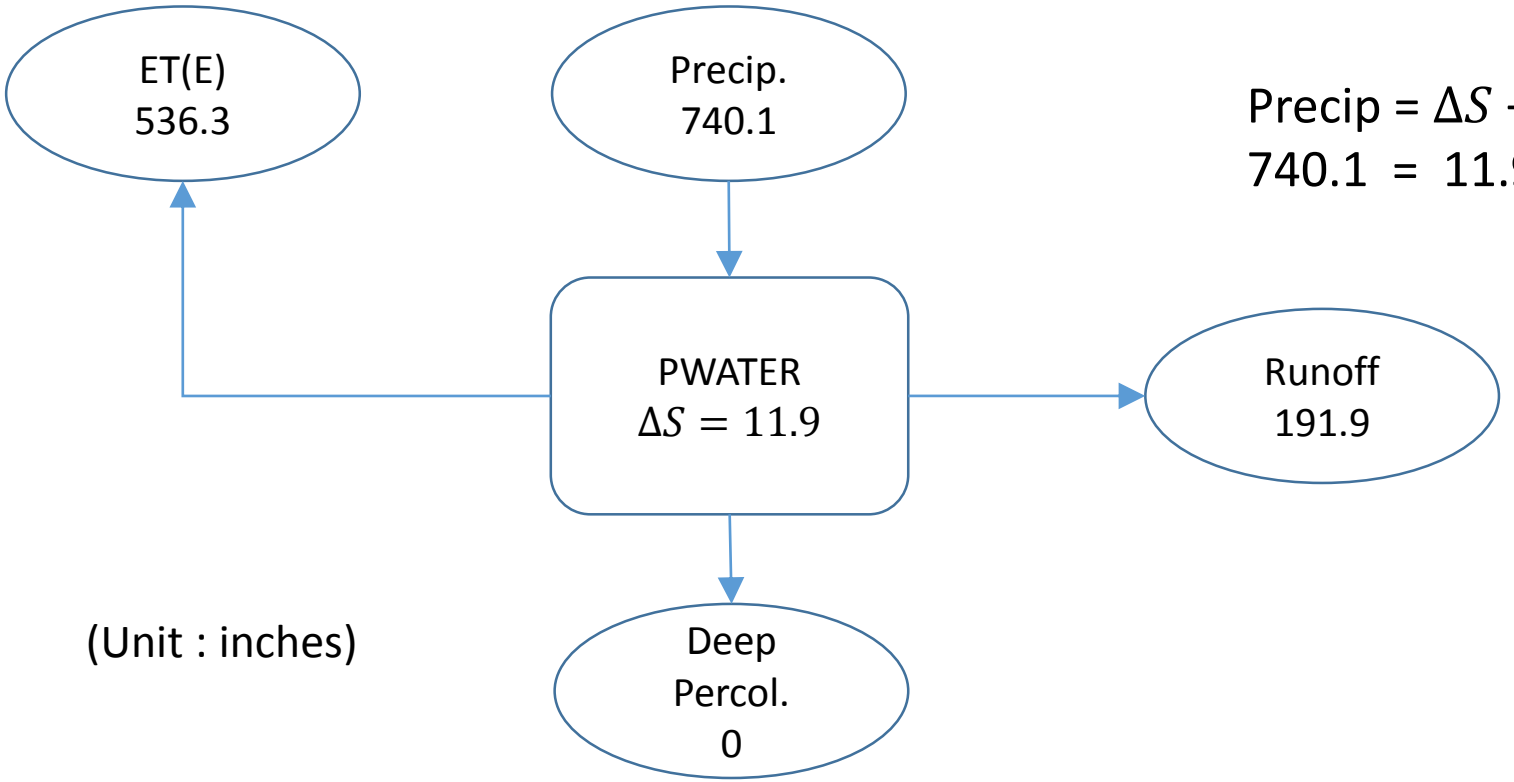


Years	Susquehanna River (SL9_2720_0001)		Potomac River (PM7_4820_0001)		Rappahannock River (RU5_6030_0001)		James River (JL7_6800_7070)	
	Mean (mm)	Diff (%)	Mean (mm)	Diff (%)	Mean (mm)	Diff (%)	Mean (mm)	Diff (%)
1985-2004	384.6	-	254.3	-	318.6	-	300.5	-
2020-2039	358.3	-6.8	254.1	0.0	327.8	2.9	319.8	6.4
2050-2069	340.1	-11.6	246.5	-3.1	322.2	1.2	310.9	3.4
2080-2099	330.6	-14.0	242.5	-4.6	319.9	0.4	300.0	-0.2

Water balance
according to snow simulation

Water balance without snow simulation

- Land segment : forest A36003
- Period : 1985-2004 (20 years)

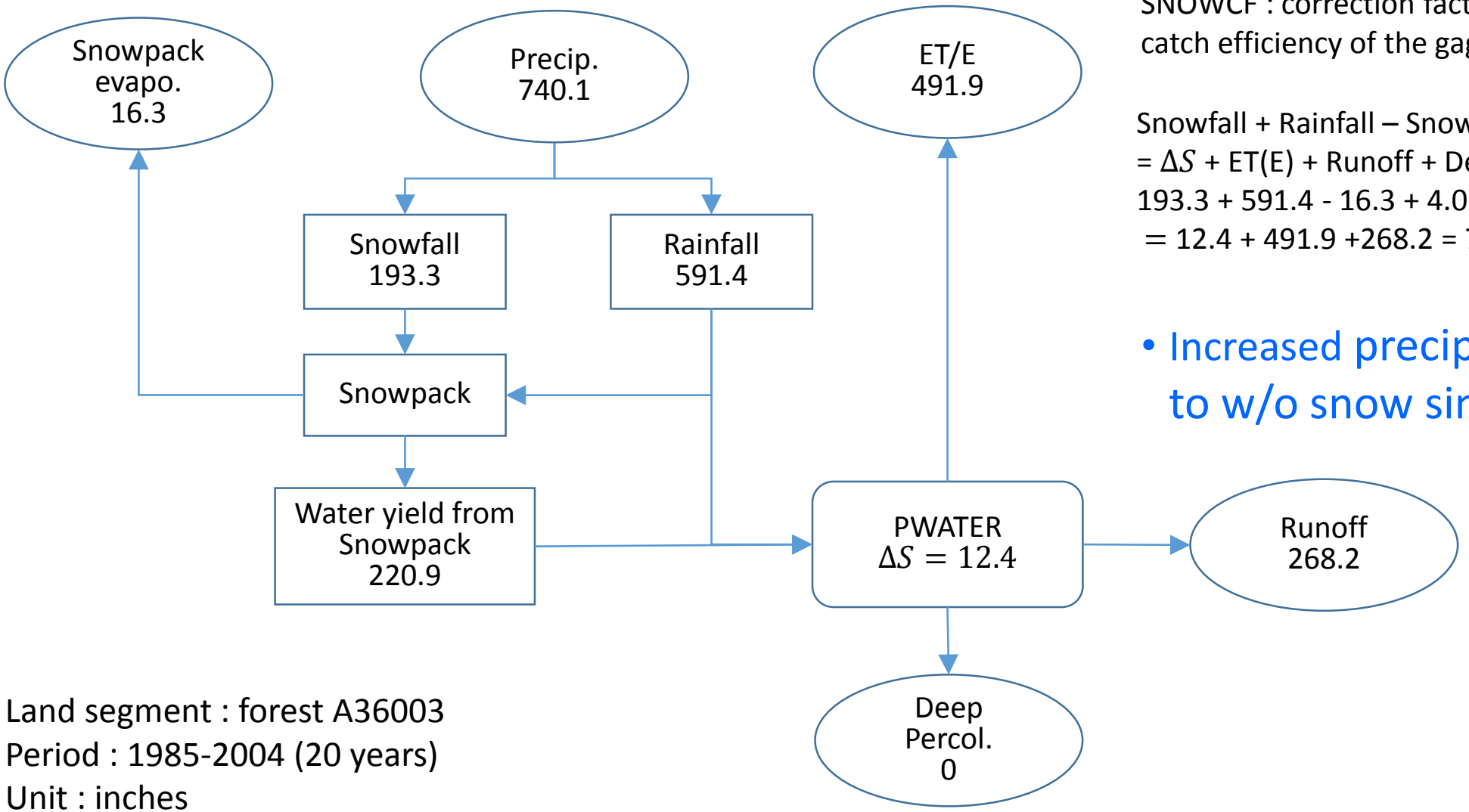


(Unit : inches)

Precip = ΔS + ET(E) + Runoff + Deep Percol.

740.1 = 11.9 + 536.3 + 191.9

Water balance with snow simulation



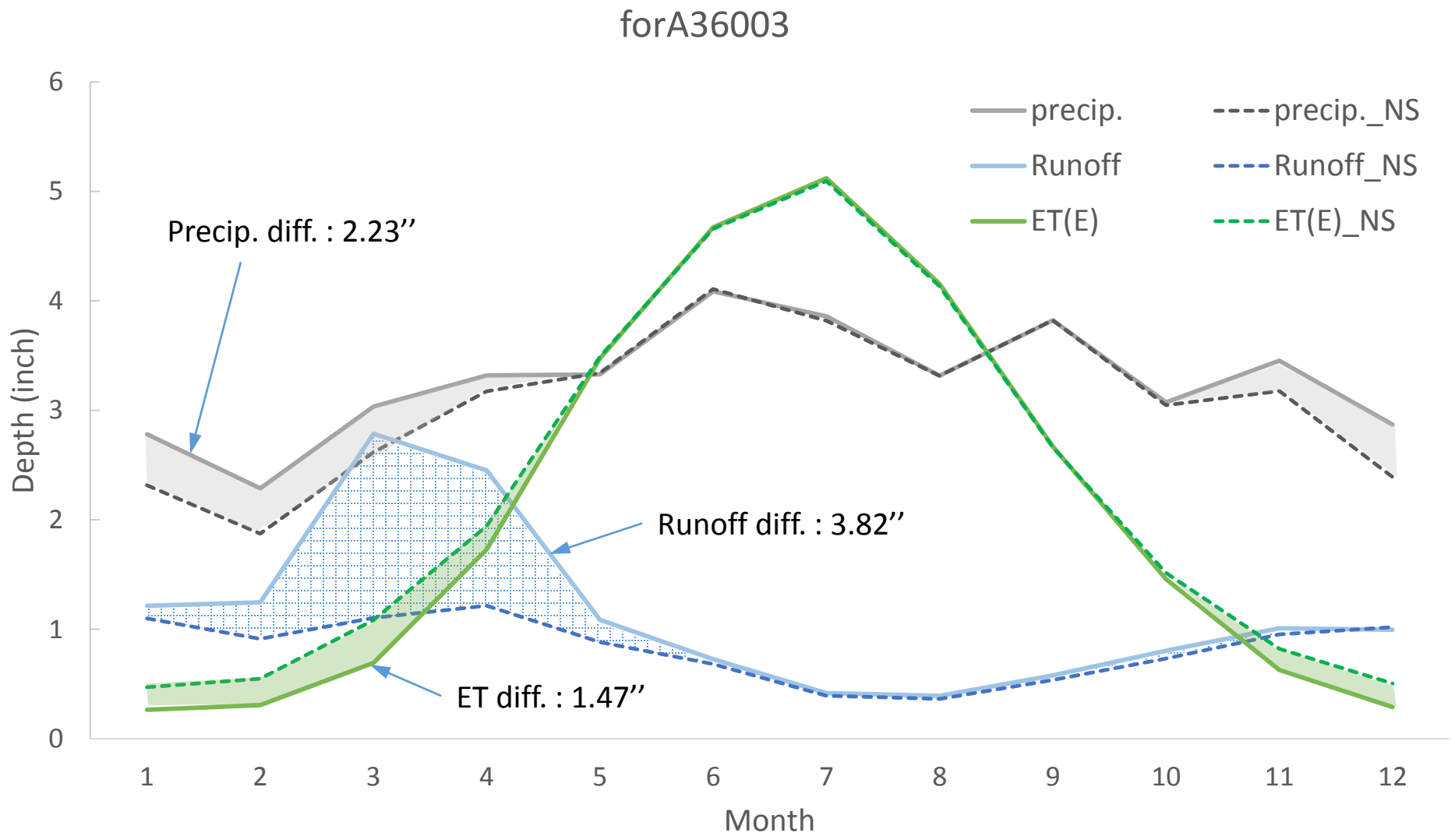
Snowfall = SNOWCF * Precip.(S)
SNOWCF : correction factor for poor catch efficiency of the gage (1.3)

Snowfall + Rainfall – Snowpack evapo. $+\Delta Ssnowp$
$= \Delta S$ + ET(E) + Runoff + Deep Percol.
193.3 + 591.4 - 16.3 + 4.0
$=$ 12.4 + 491.9 +268.2 = 772.4

- Increased precip. compared to w/o snow simulation

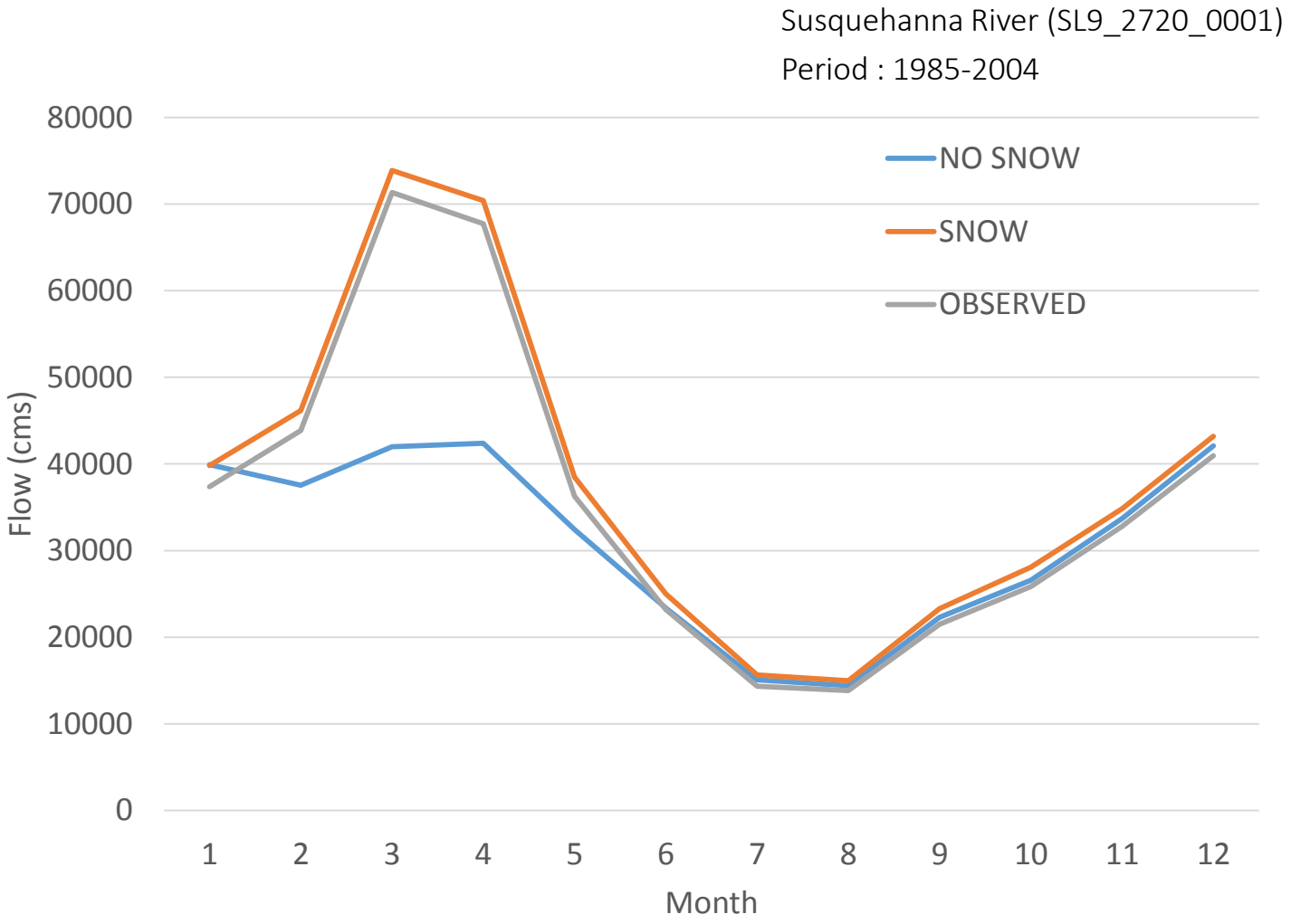
Land segment : forest A36003
Period : 1985-2004 (20 years)
Unit : inches

Monthly Runoff and ET according to snow simulation



Seasonal differences according to the snow simulation

Month	NO SNOW	SNOW	Diff(%)
1	39929	39804	0%
2	37543	46153	-19%
3	41990	73884	-43%
4	42400	70401	-40%
5	32435	38490	-16%
6	23361	25019	-7%
7	15085	15654	-4%
8	14409	14964	-4%
9	22291	23312	-4%
10	26577	28085	-5%
11	33692	34842	-3%
12	42099	43182	-3%
Total	371811	453788	**-18%**



Summary

- 5 – 15 % increase in annual precipitation on average based 8 GCMS but individual scenarios are expected to have both decreasing and increasing precipitation.
- 1 - 5 °C rise in annual temperature in the CB Watershed in the future.
- Overall less surface runoff in the future if no there is snow inclusion.
  - Especially, over 10% of less runoff is expected in Susquehanna River in 50 years but other basins show reduction in flows on annual scale .
- Seasonal runoff trends in the future
  - About 20 - 30% of less runoff from May to September, while 10 - 20% discharge increase January to March.

Further research

- Use of high resolution climate data minimizing degradation of spatial information using finer unit segment (e.g. combined river and land segments)
- Inclusion of degree-day based SNOW simulation

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Thank you

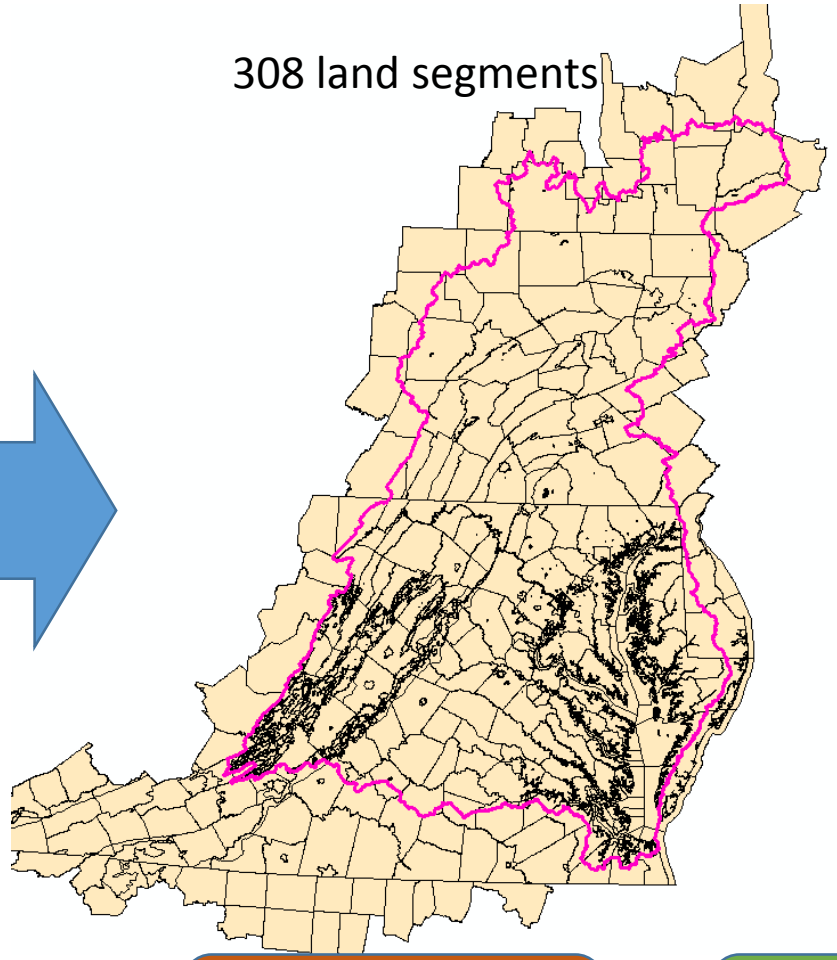
Choung Hyun Seong (chseong@vt.edu) and V. Sridhar (vsri@vt.edu)
Biological Systems Engineering

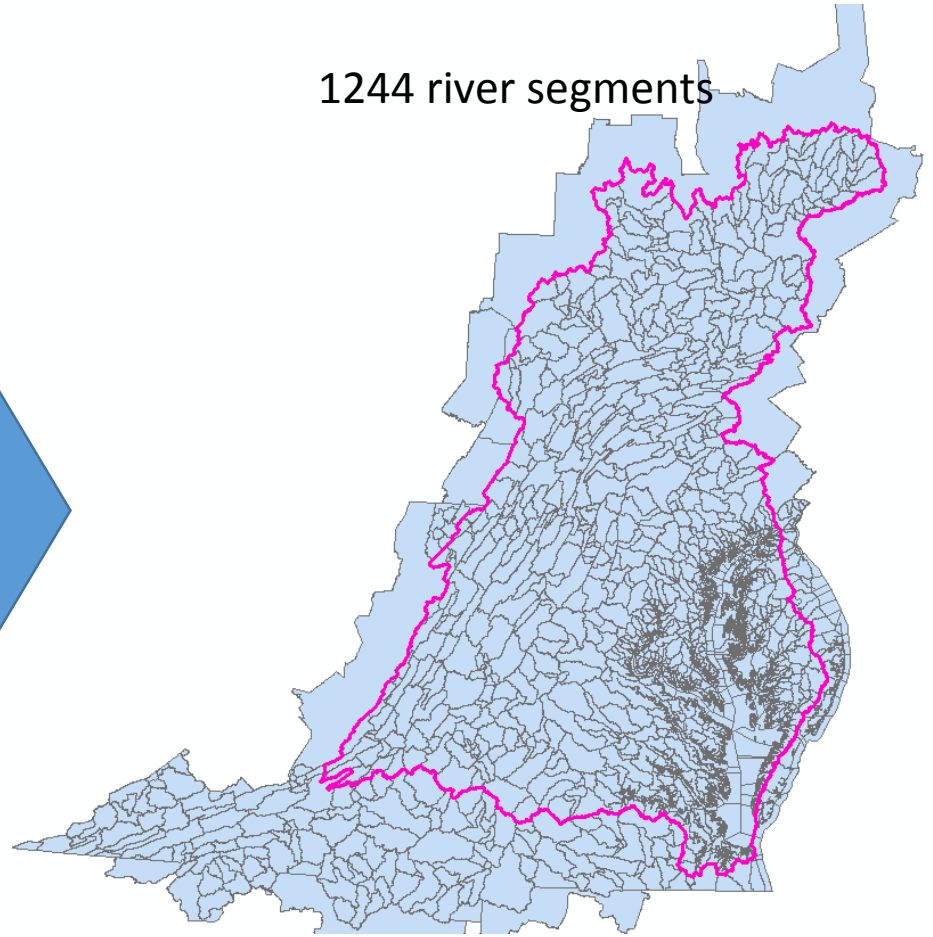
Chesapeake Bay Watershed Model (CBWM)

<u>County-based input data</u>:
- population
- land use (24)
- cropping systems
- livestock
- best management practices (BMPs)

<u>Meteorological input data</u>
- precipitation
- temperature
- solar radiation
- etc.

<u>Topographic input data</u>
- soils
- slopes
- hydrology





Land segment simulation

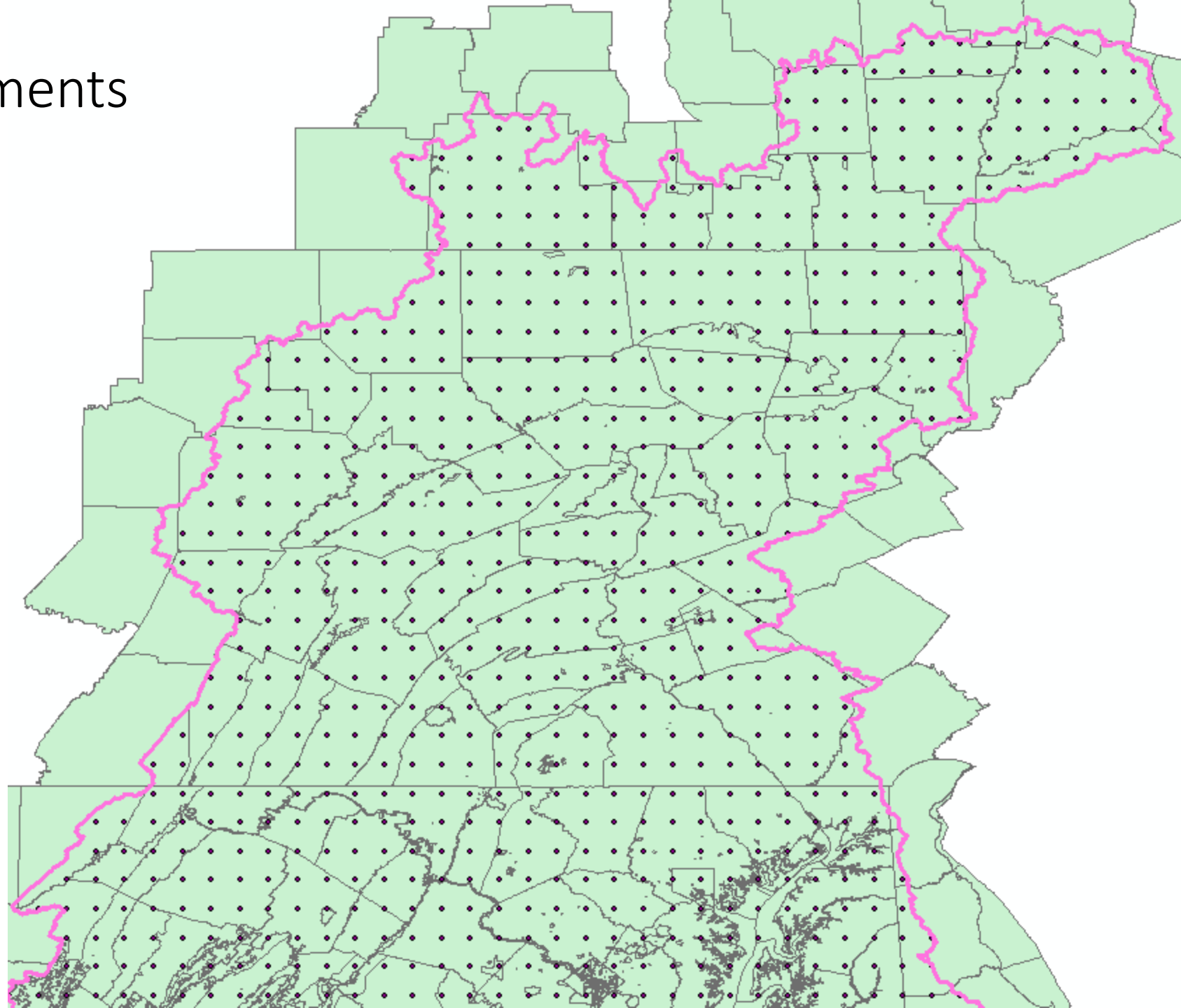
External Transfer Module (ETM)

River segment simulation

Close look at Land Segments and BCCA grids

1244 climate grid points

Averaged to 228 Land segments

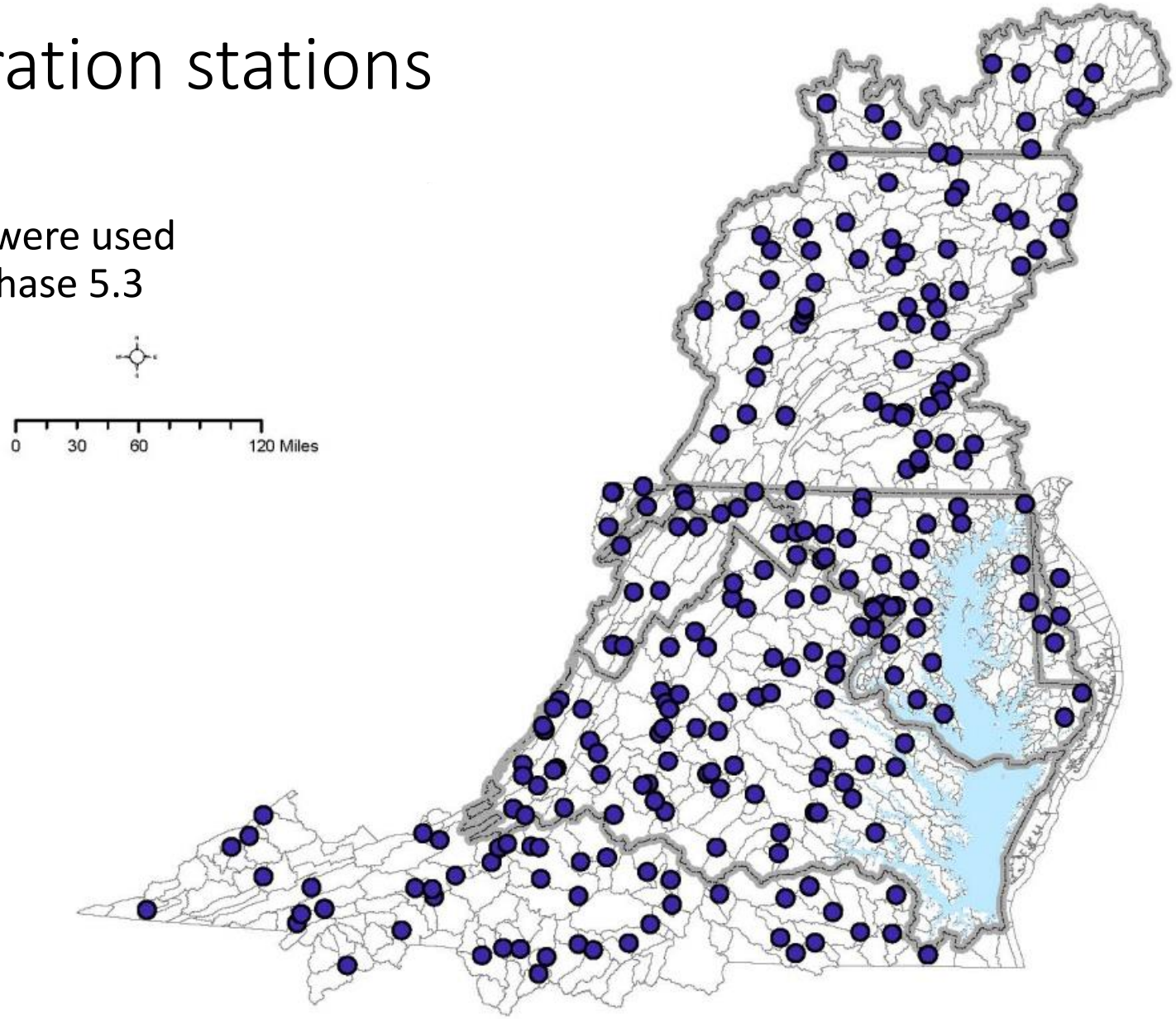


Changes in precipitation and temperature

Changes in streamflow

Hydrology calibration stations

- 287 USGS gaging stations were used for calibration of CBWM Phase 5.3



Source : Phase 5.3 community watershed model

Monthly Runoff and ET according to snow simulation

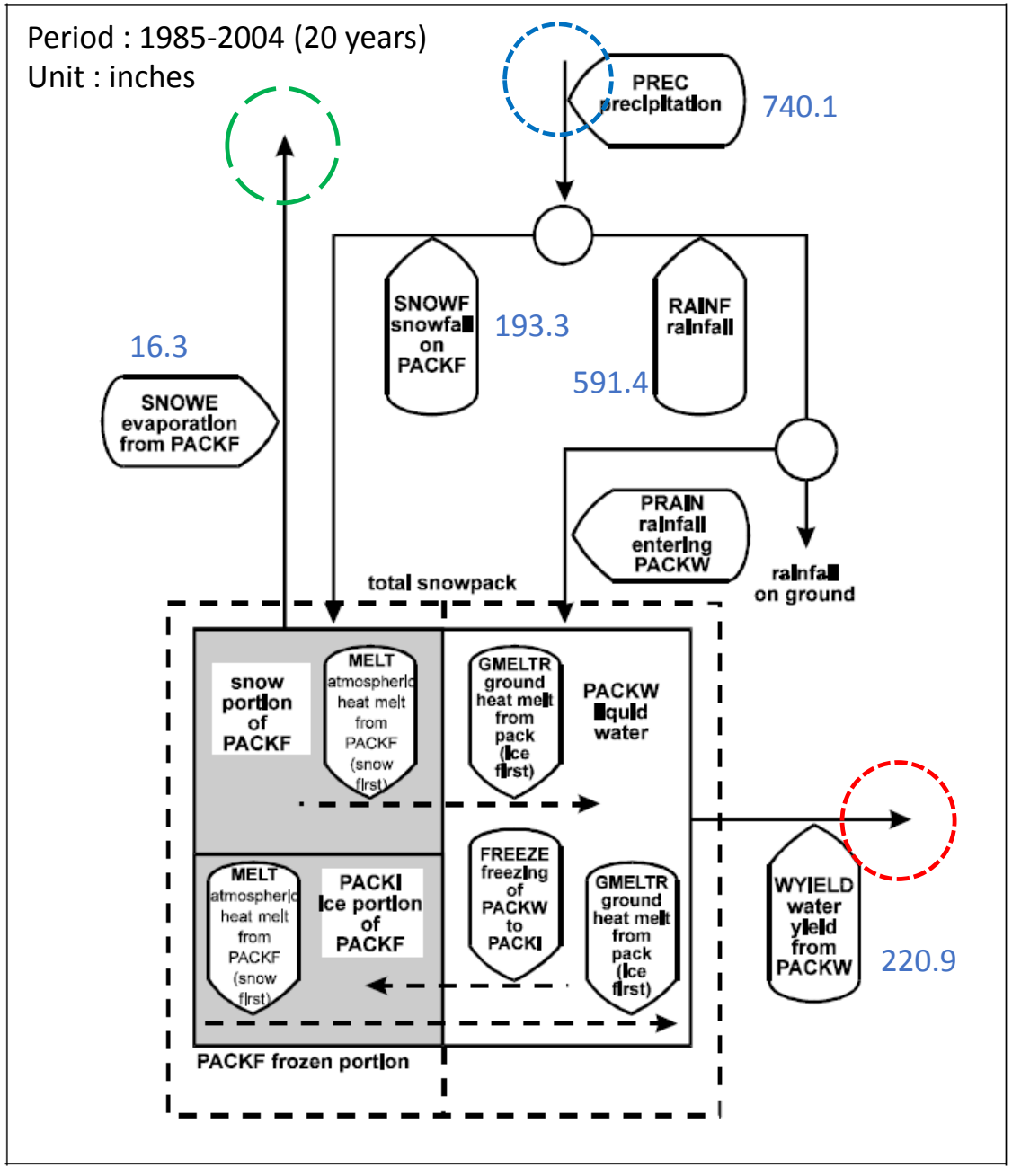
Month	With snow simulation				Without snow simulation			
	percip.	Runoff	ET(E)	Storage	percip.	Runoff	ET(E)	Storage
1	2.78	1.21	0.27	15.23	2.31	1.10	0.47	14.98
2	2.29	1.25	0.31	16.04	1.87	0.91	0.55	15.72
3	3.03	2.79	0.69	17.04	2.62	1.10	1.08	16.08
4	3.32	2.45	1.73	17.80	3.17	1.21	1.94	16.50
5	3.33	1.09	3.47	16.97	3.34	0.88	3.49	15.96
6	4.09	0.73	4.67	15.80	4.11	0.68	4.66	14.90
7	3.86	0.42	5.12	14.09	3.82	0.39	5.10	13.24
8	3.32	0.39	4.15	12.66	3.32	0.36	4.13	11.88
9	3.82	0.58	2.67	12.26	3.82	0.54	2.66	11.54
10	3.07	0.81	1.46	13.22	3.05	0.73	1.52	12.54
11	3.45	1.01	0.63	14.25	3.18	0.95	0.82	13.62
12	2.87	1.00	0.29	15.21	2.39	1.02	0.51	14.80
total	**39.23**	**13.71**	**25.46**	15.05	**37.00**	**9.89**	**26.93**	14.31

Land segment : forest A36003
Period : 1985-2004 (20 years)

(Unit : inches)

- With snow simulation
  - 6% more of annual precipitation
  - 39% more of annual runoff
  - 5% less of annual ET
- Snow simulation is required for climate change simulation

Schematics of snow module in HSPF



Precipitation

Water yield from snowpack

ET

Figure 4.2(1).2-2 Flow diagram of water movement, storages, and phase changes modeled in the SNOW section of the PERLND and IMPLND Application Modules

Schematics of PWATER module

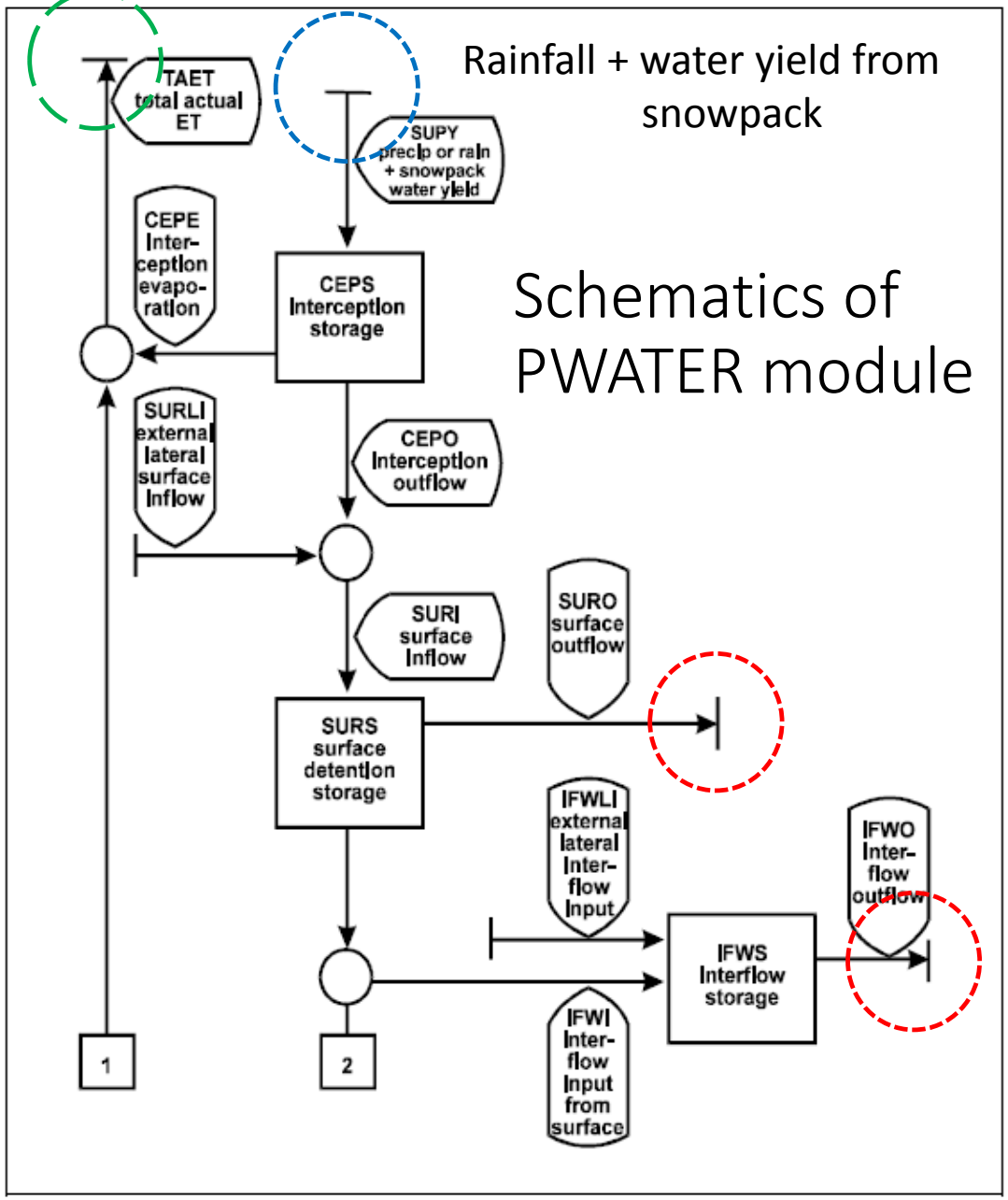


Figure 4.2(1).3-2 Flow diagram of water movement and storages modeled in the PWATER section of the PERLND Application Module

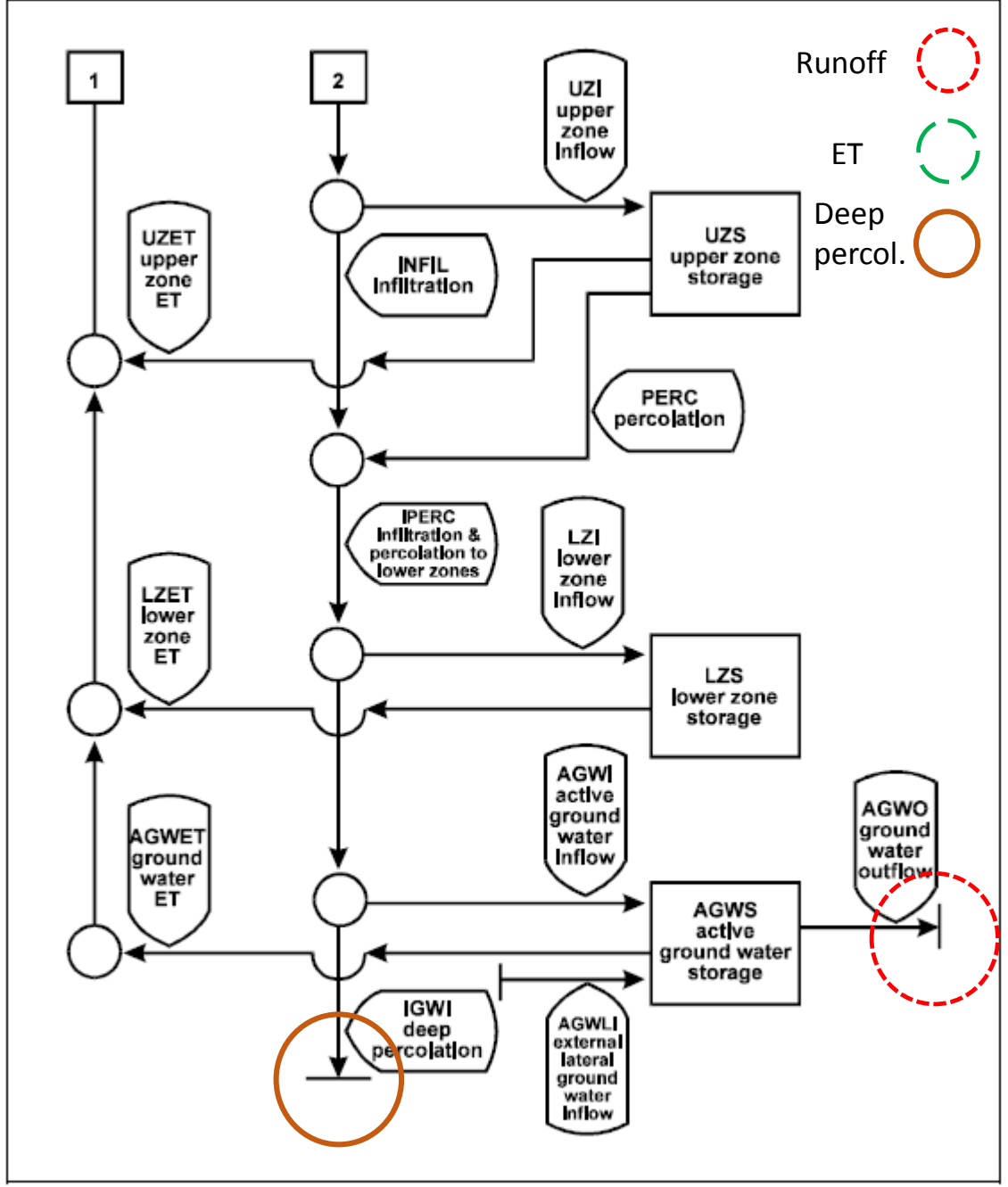
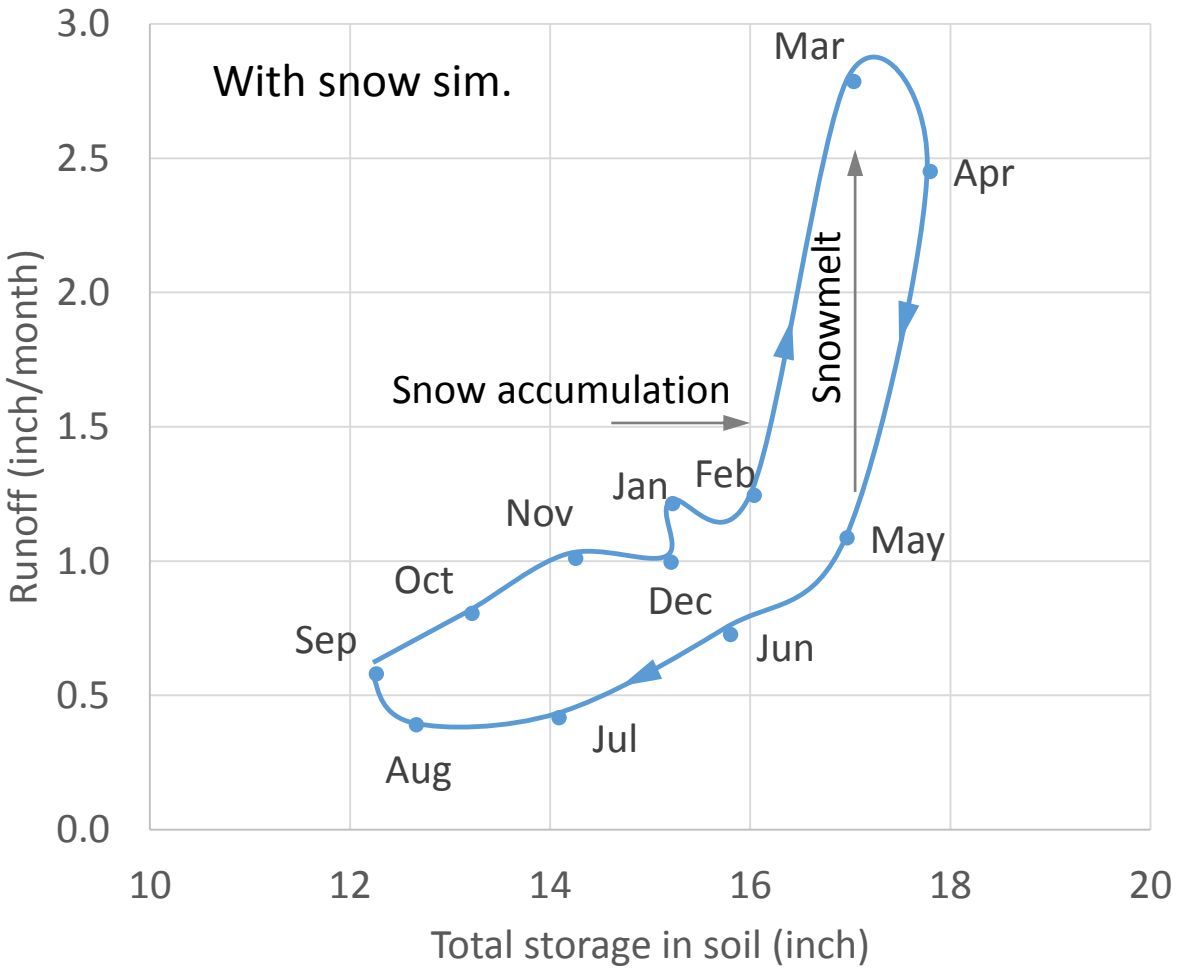
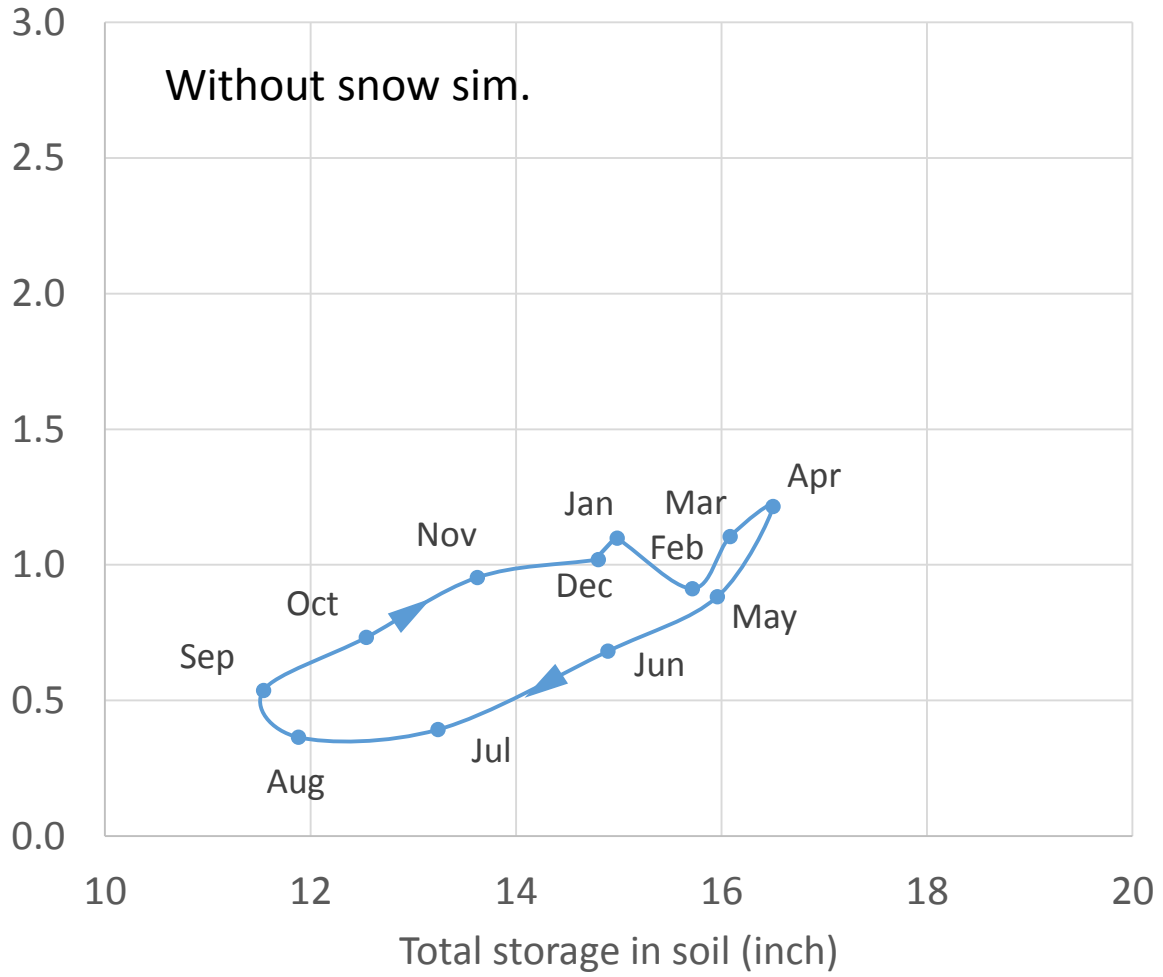


Figure 4.2(1).3-2 Flow diagram of water movement and storages modeled in the PWATER section of the PERLND Application Module (continued)

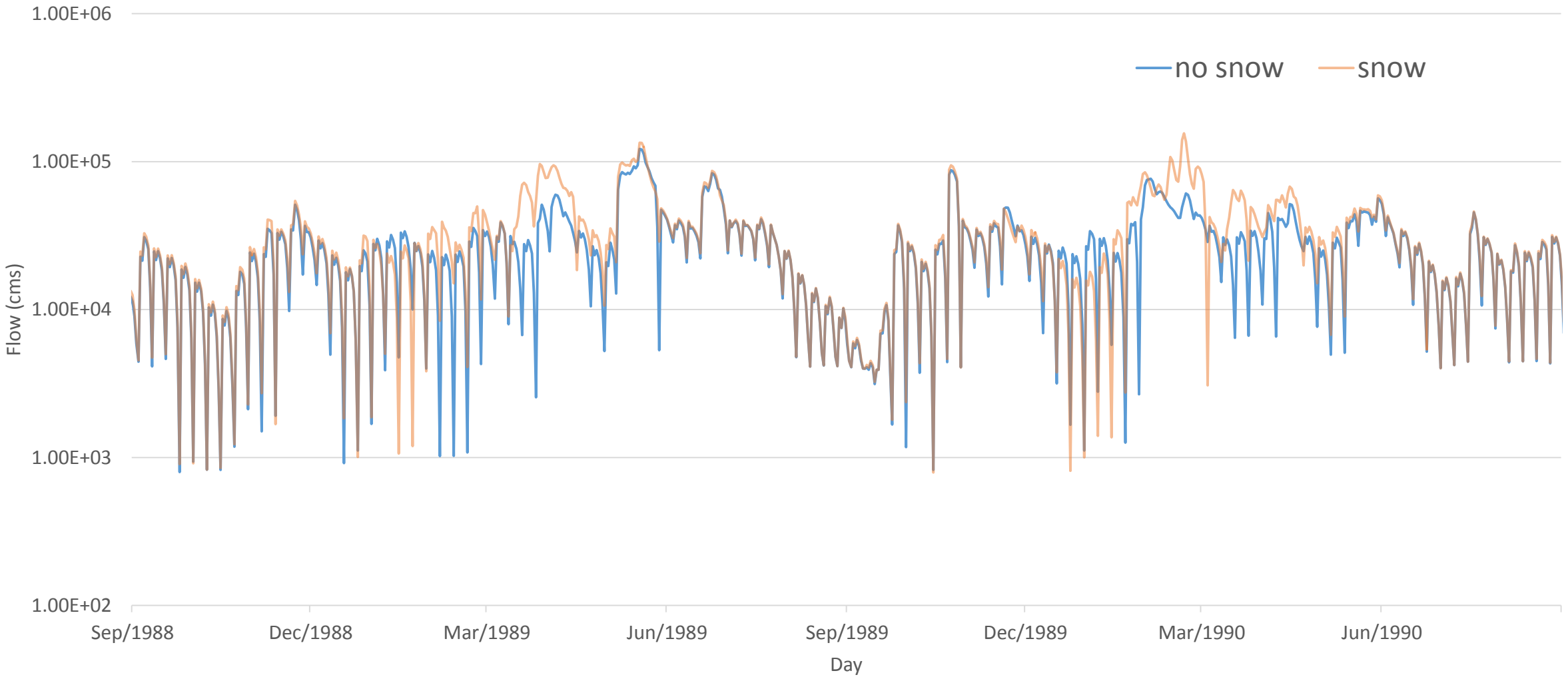
Relationship between soil storage and streamflow



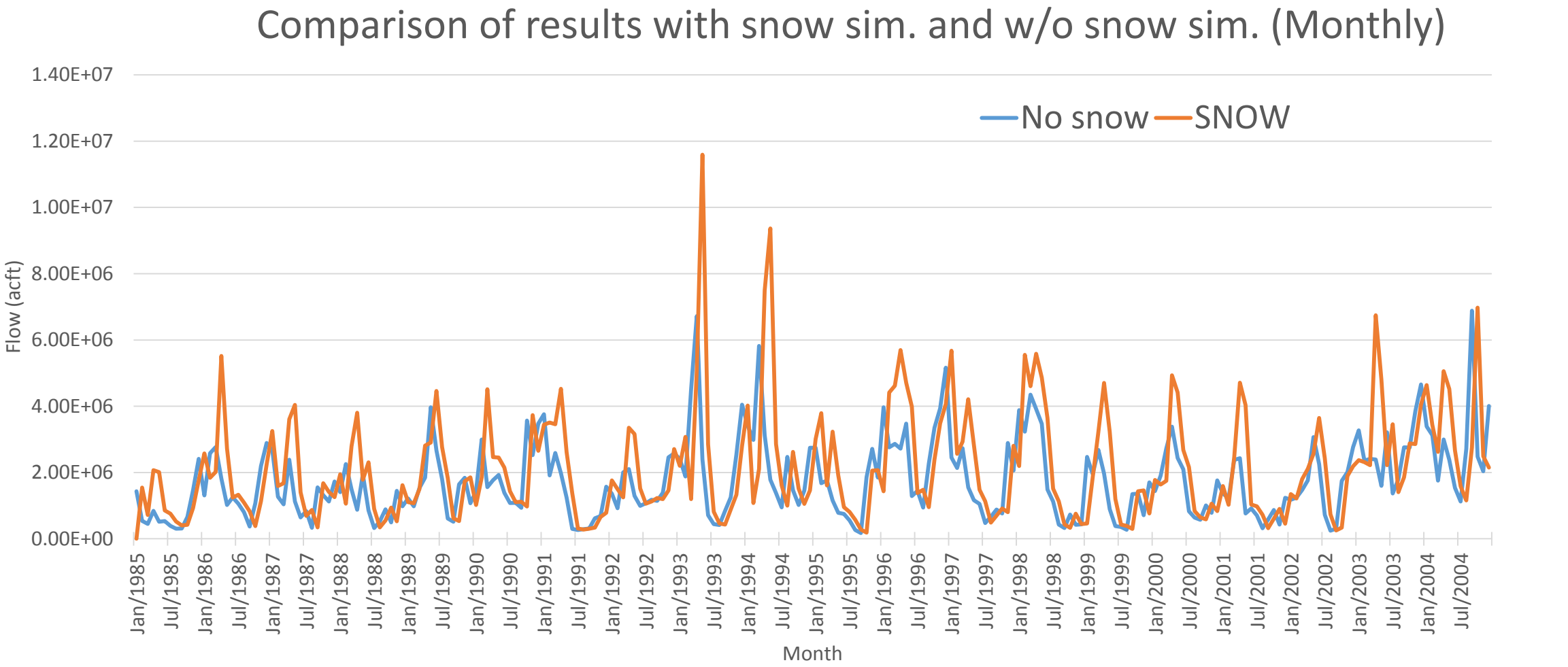


Land segment : forA36003
Period : 1985-2004 (20 years)

Comparison of daily simulation results (Sep. 1988 to Aug. 1990)



Susquehanna River (SL9_2720_0001)



Susquehanna River (SL9_2720_0001)

Period : 1985-2004