Chesapeake Bay Program Climate Change Modeling

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…and the whole team

MWCOG

Water Resources Technical Committee

11/9/2018

December 2017

Climate Change Loads: Nitrogen

Jurisdiction	1985 Baseline	2013 Progress	Climate Change	Growth in Load to 2025	Conowingo Load Responsibility	2013 Progress +	Phase III Planning Target
NY	18.71	15.44	0.400			15.84	10.62
PA	122.41	99.28	4.135			103.41	72.99
MD	83.56	55.89	2.194			58.09	45.39
WV	8.73	8.06	0.236			8.30	6.36
DC	6.48	1.75	0.006			1.76	2.25
DE	6.97	6.59	0.397			6.98	4.66
VA	84.29	61.53	1.722			63.25	56.37
BasinWide	331.15	248.54	9.09			257.63	198.64

*Units: millions of pounds

December 2017

Climate Change Loads: Phosphorus

Jurisdiction	1985 Baseline	2013 Progress	Climate Change	Growth in Load to 2025	Conowingo Load Responsibility	2013 Progress +	Phase III Planning Target
NY	1.198	0.710	0.014			0.724	0.491
PA	6.282	3.749	0.141			3.891	3.012
MD	7.495	3.942	0.114			4.056	3.553
WV	0.902	0.617	0.019			0.637	0.493
DC	0.090	0.062	0.001			0.063	0.120
DE	0.225	0.116	0.006			0.122	0.116
VA	14.244	6.751	0.193			6.944	6.411
BasinWide	30.44	15.95	0.489			16.436	14.20

*Units: millions of pounds

Climate Change Decision Framework

- Bay TMDL must address climate change; however, need to do so on a quantitative basis held off until 2022
  - Allows time for model upgrades to better simulate impacts
  - Allows time for Bay partner jurisdictions to figure out how they can respond
  - Likely will require substantial additional nutrient and sediment reductions
- Bay partners must include qualitative approach in Phase III WIPs; have option of starting quantitative approach early

CBP Climate Work Plan

2018

STAC Workshop

Climate Resiliency WG to investigate BMP response

Jurisdictions provide narrative in WIP3s on climate strategies

Modeling WG develop climate scenarios

2019

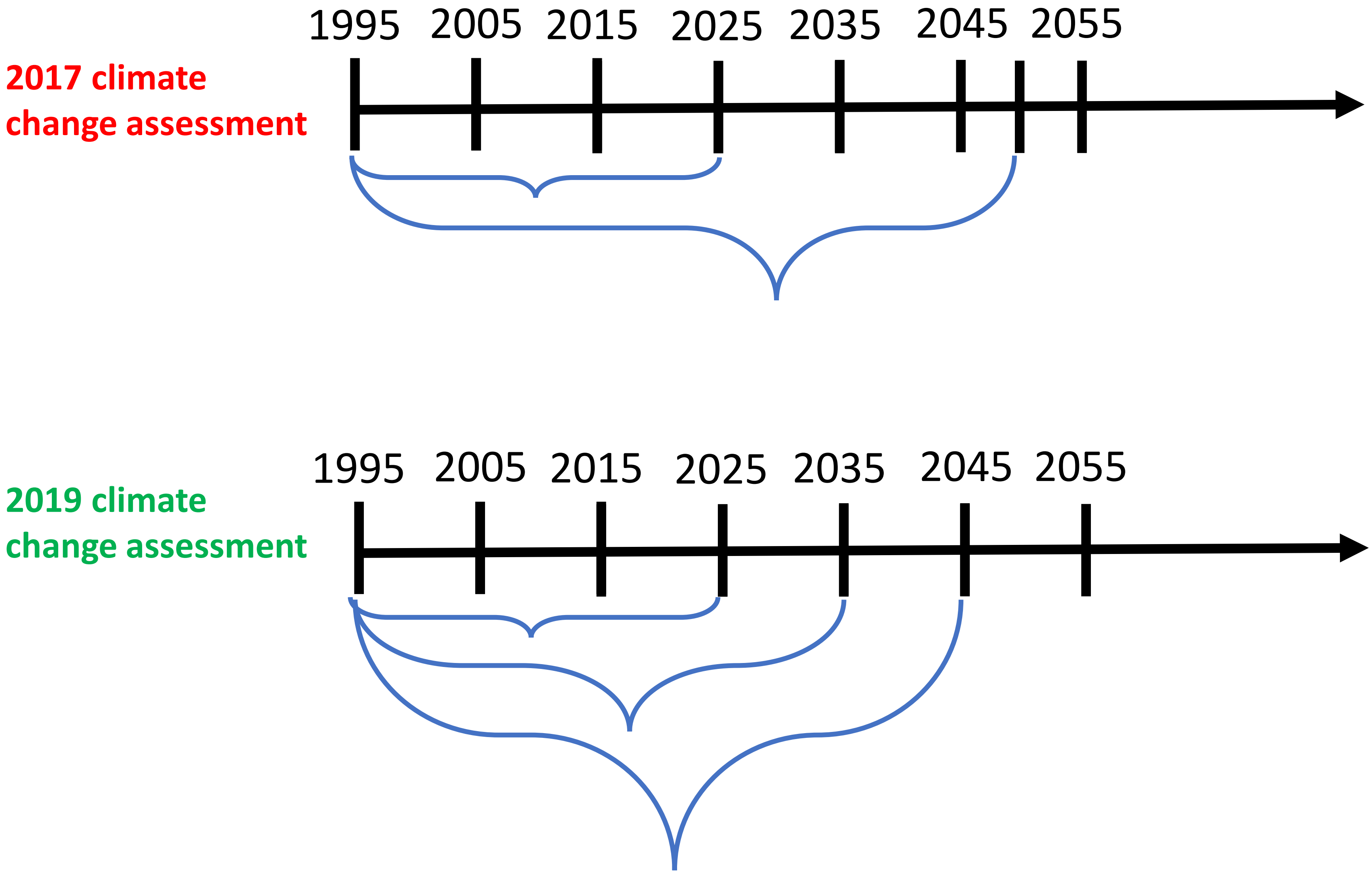
Water Quality GIT, Modeling WG, Climate Resiliency WQ direct Modeling team to develop climate change assessment for TMDL

2020

Technical Review of Models

2021

Climate change considerations will be implemented into the 2022-2023 milestones.


2017 climate change assessment
1995
2005
2015
2025
2035
2045
2055
2019 climate change assessment
1995
2005
2015
2025
2035
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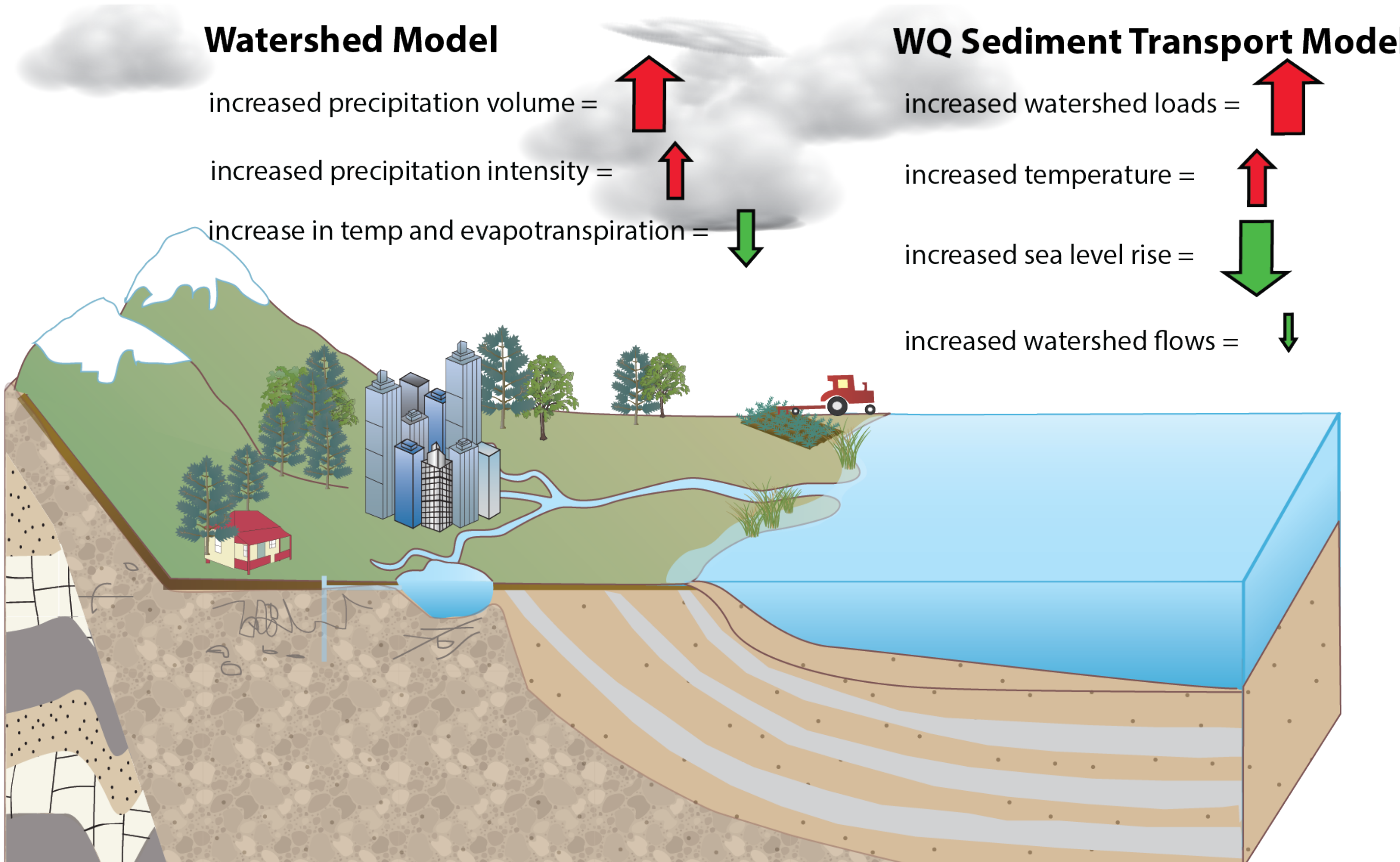
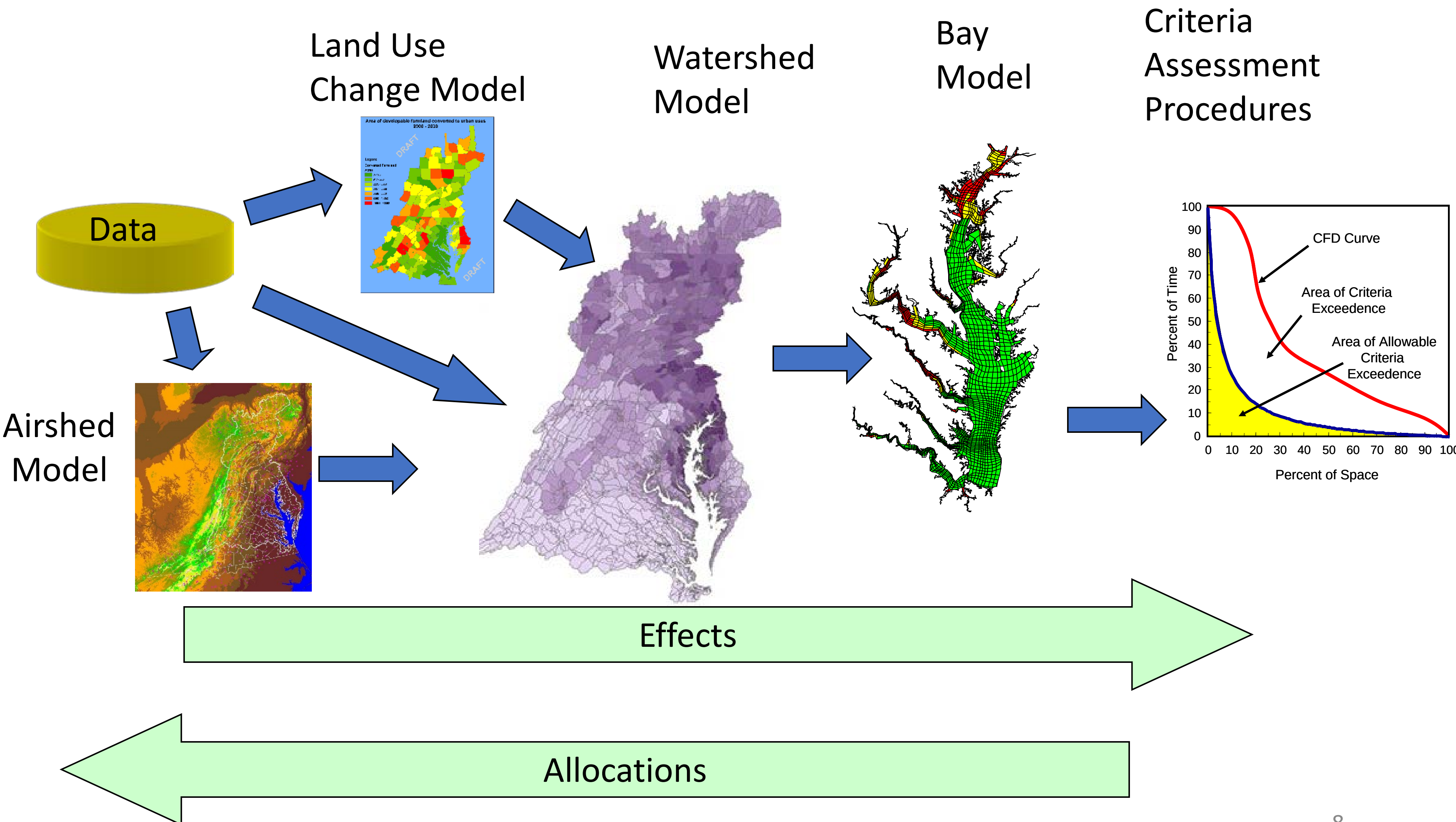
Accounting for Changing Conditions

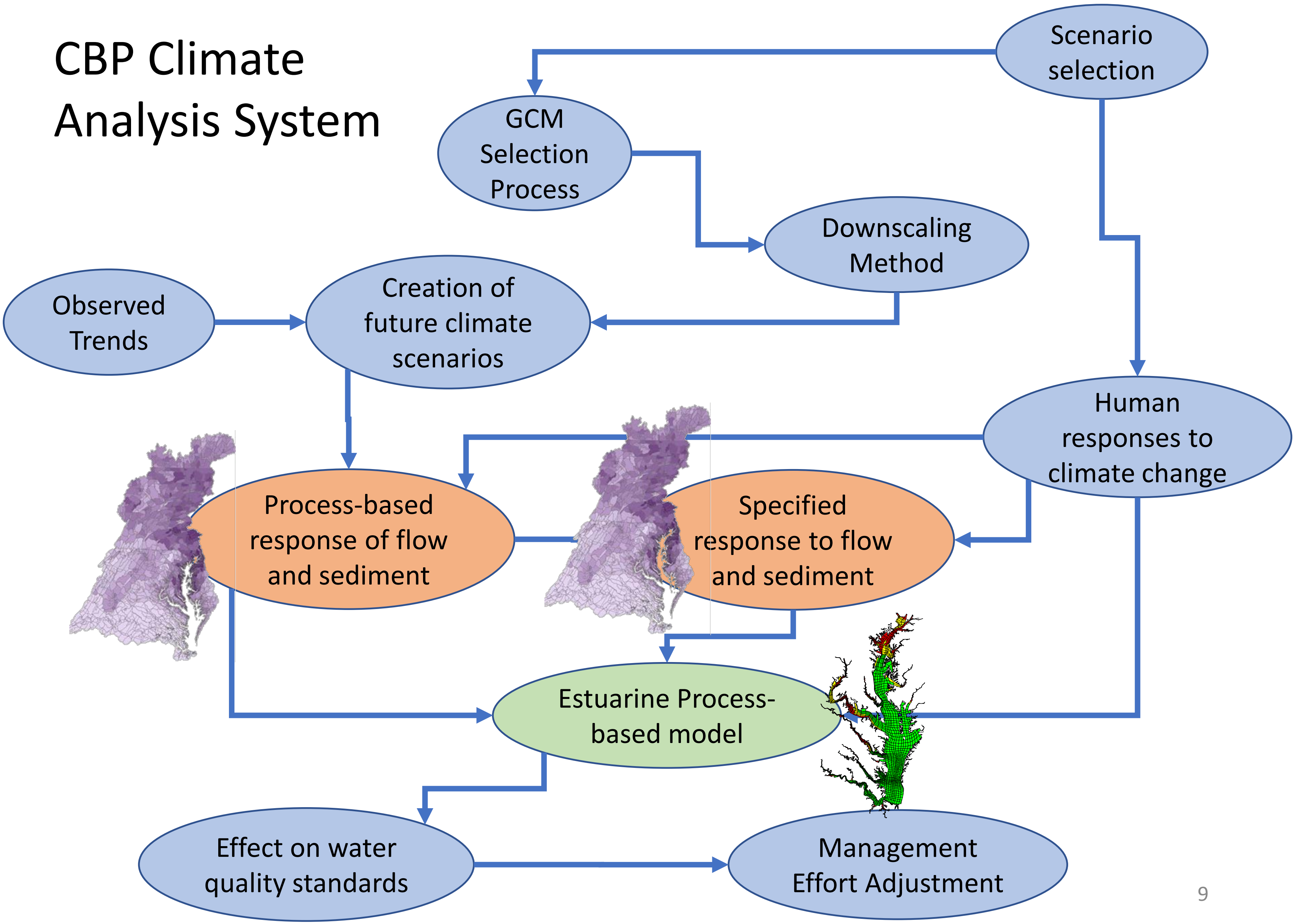
Cumulative Assessment of Bay Low Dissolved Oxygen Impacts



CBP Decision Support System



CBP Climate Analysis System



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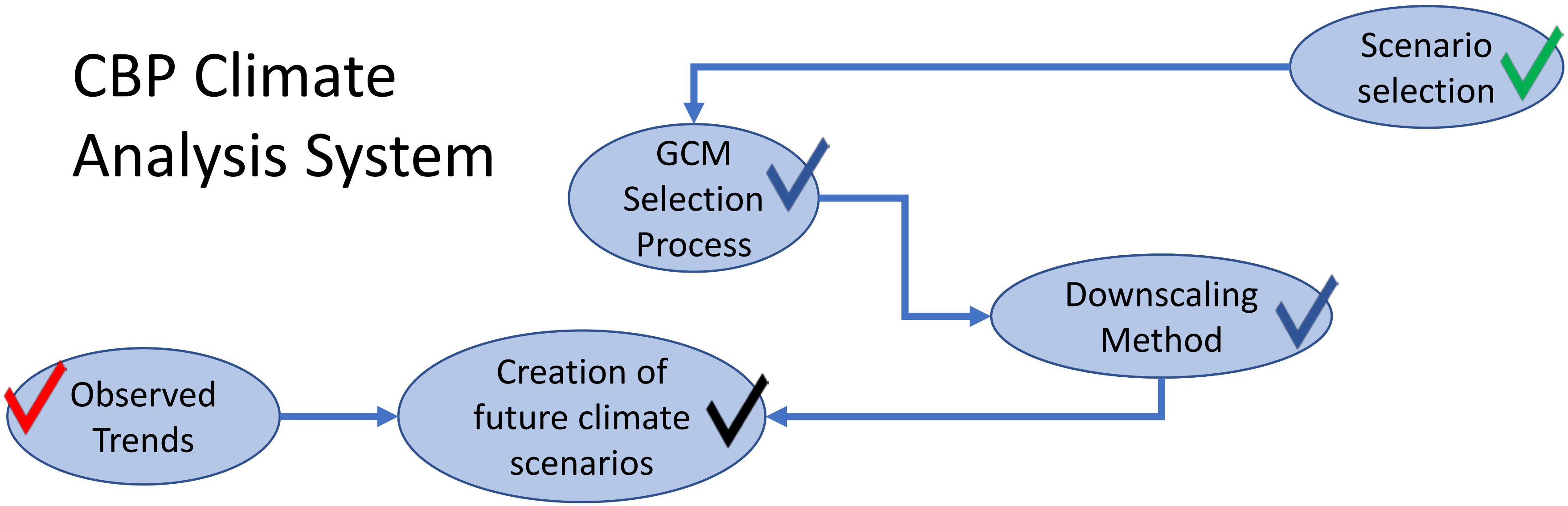

2016 STAC workshop *The Development of Climate Projections for Use in Chesapeake Bay Program Assessments* (Johnson et al. 2016).

- 2025: Use long-term observed trends for precipitation
- 2050 precipitation and all temperature: Use an ensemble of existing downscaling of CMIP5 models
- Carefully consider evapotranspiration
- Use RCP 2.6, 4.5, and 8.5

Year	Precipitation		Temperature	
	Trend	Ensemble	Trend	Ensemble
2025	**STAC/CR**	–	–	**STAC/CR**
2035	**?**	**?**	**?**	**?**
2045	**?**	**?**	**?**	**?**
2050	–	**STAC/CR**	–	**STAC/CR**

- Selections highlighted in yellow are the STAC and CBP climate resiliency workgroup recommendations and CBP approved approaches for the 2017 Climate Change assessment.
- For 2035 and 2045 the Modeling Workgroup (September 2018) recommended (a) combining the two sources using weighted means for rainfall, (b) using the ensemble for temperature.

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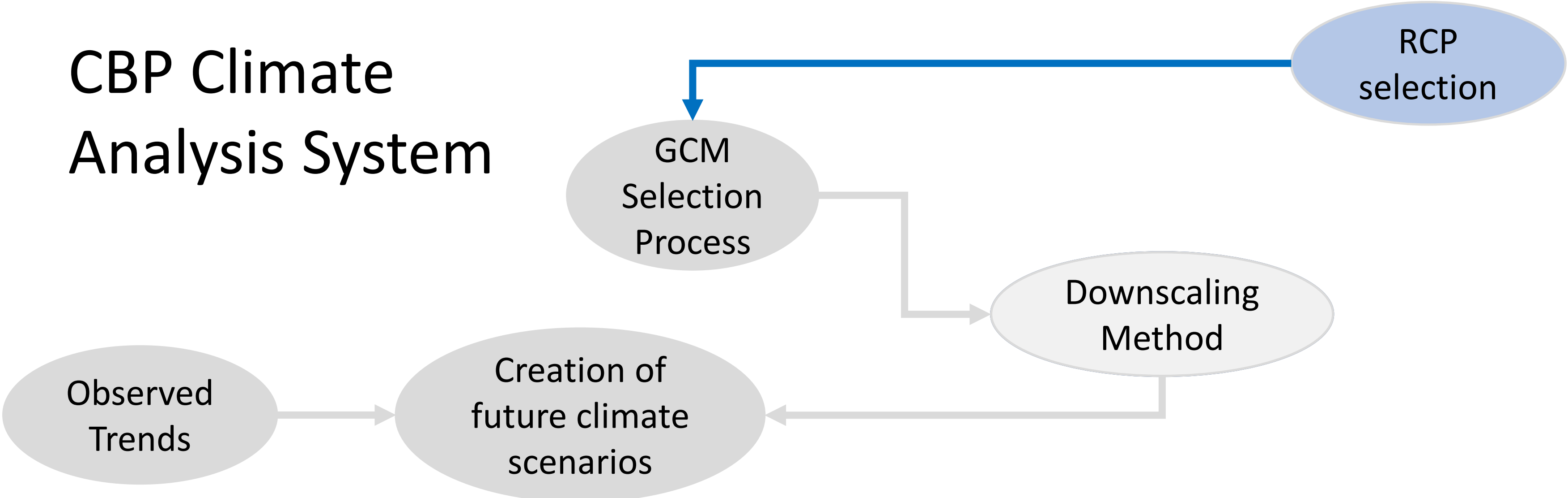
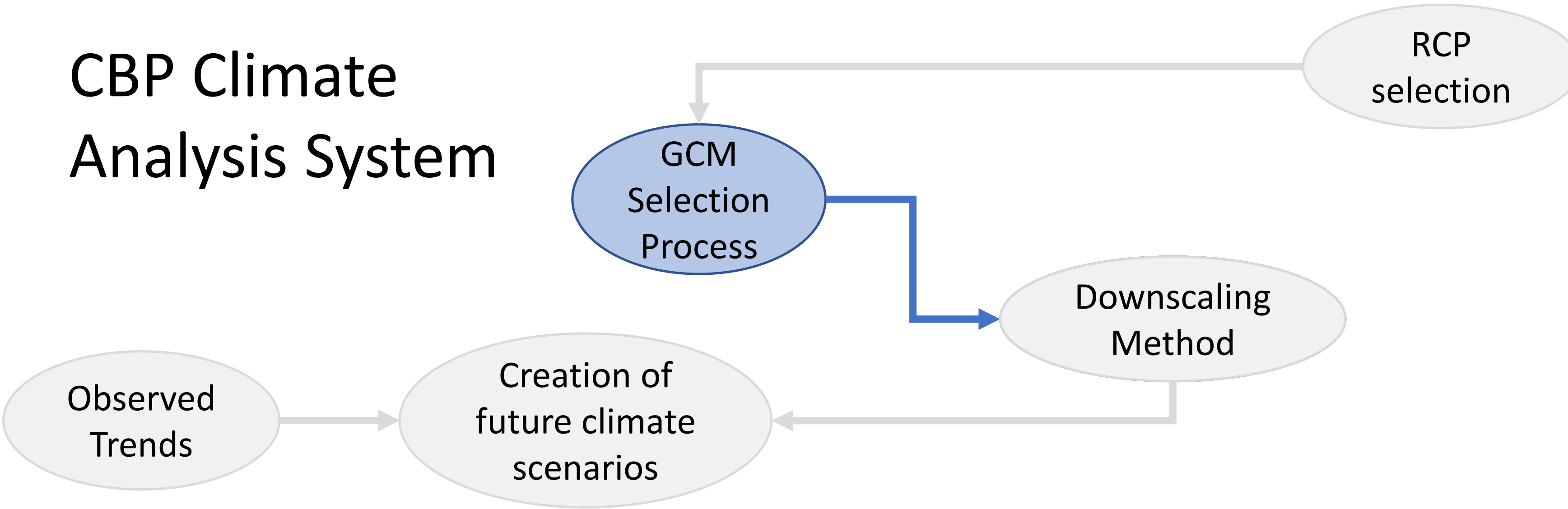
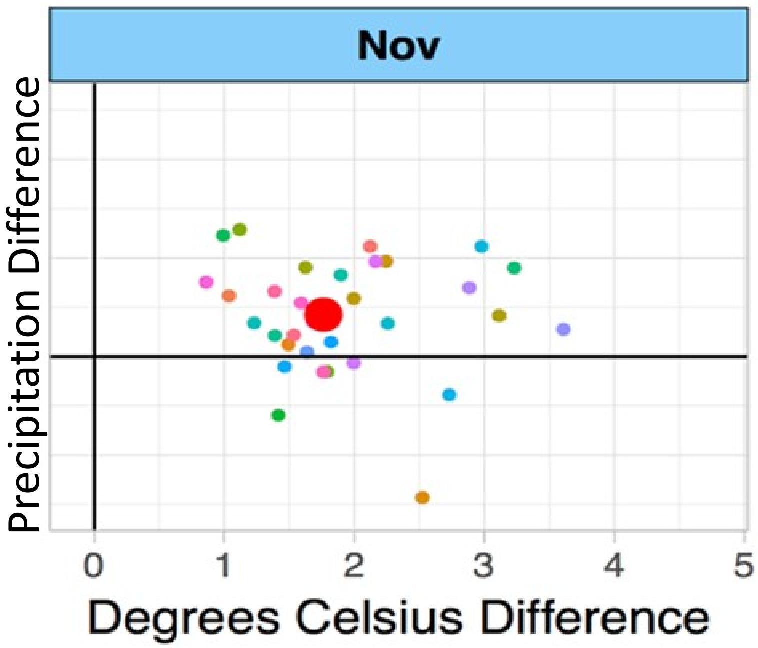


- Used RCP 4.5 for scenario run through the full modeling system and shown to PSC
- Found significant overlap with RCP 2.6 and 8.5

CBP Climate Analysis System

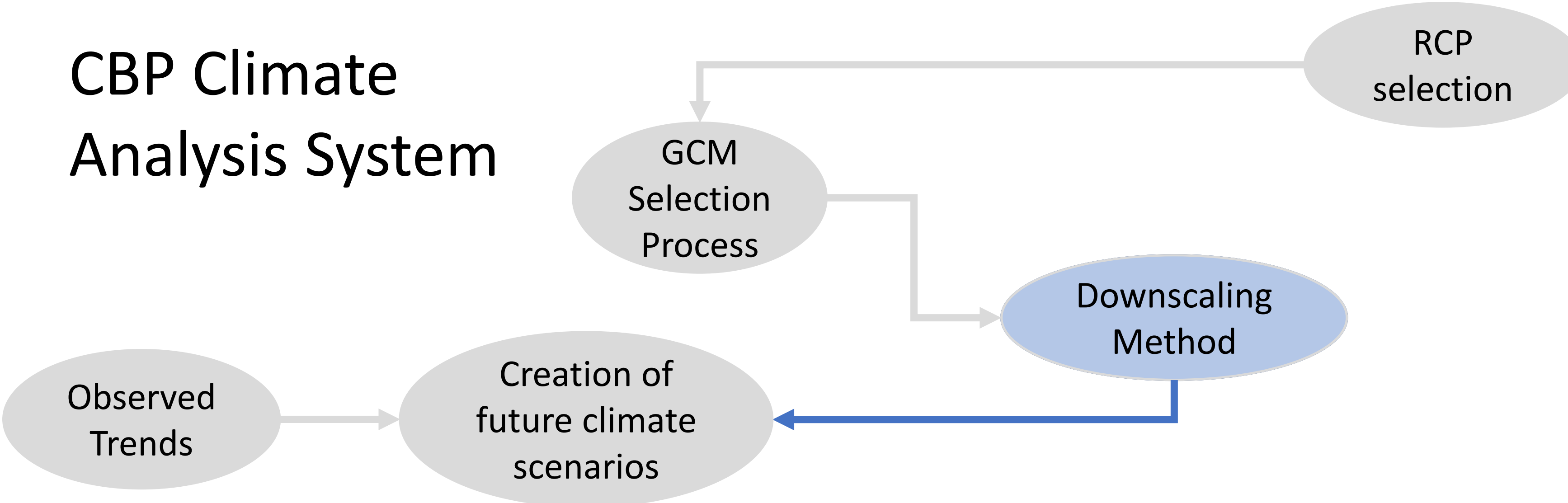




GCM selection

- Used the same group of models and model runs that were used in NOAA’s Climate Resilience Toolkit

CBP Climate Analysis System



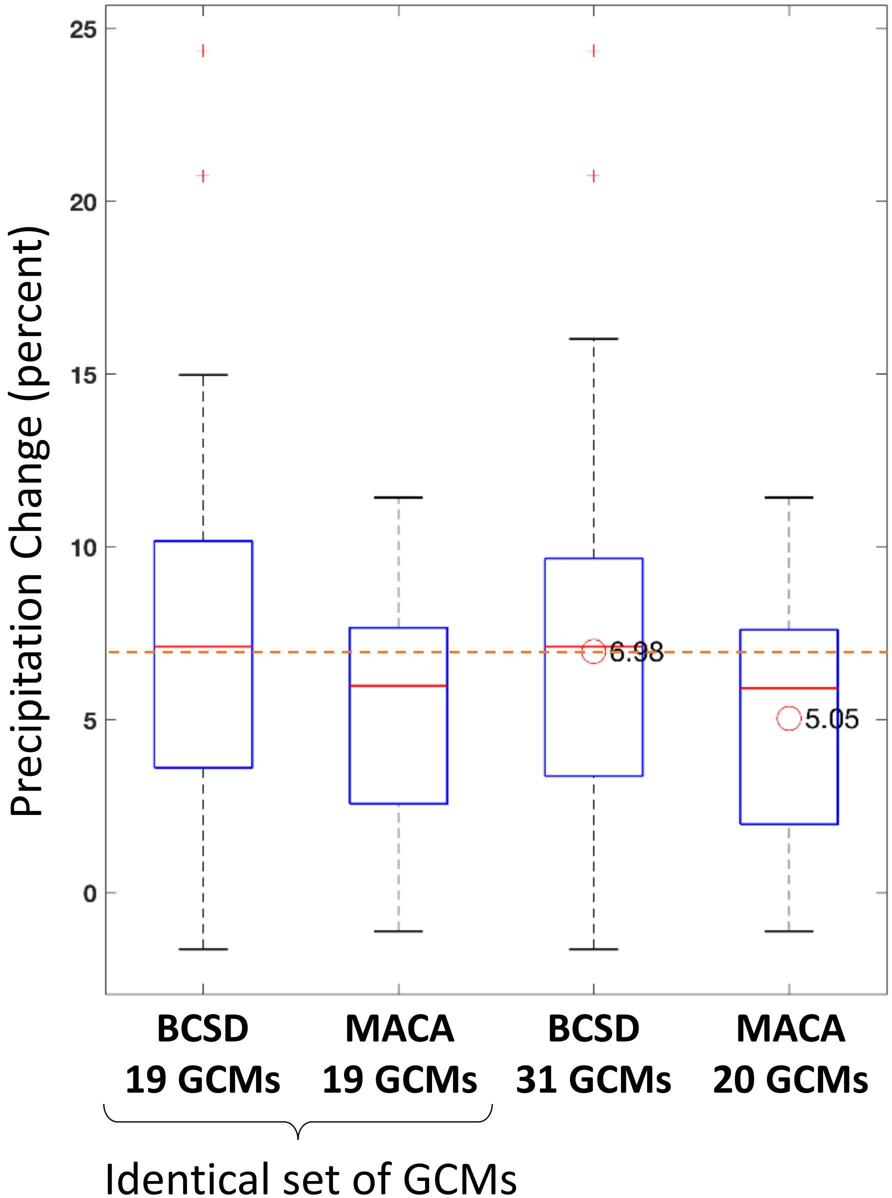
Downscaling methods:

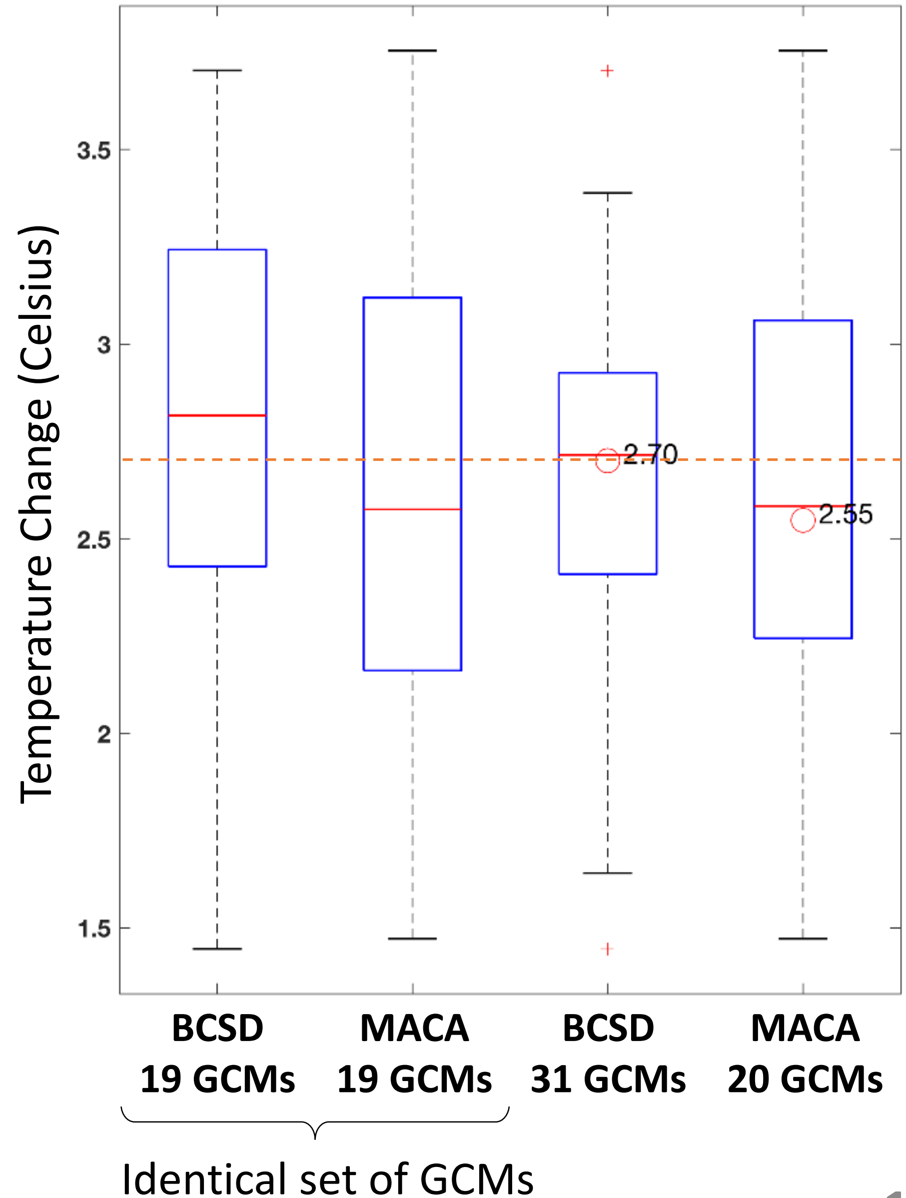
- Bias Corrected Spatial Disaggregation (BCSD) - used for runs in 2017
- Investigating Multivariate Adaptive Constructed Analogs (MACA)
- Investigating Localized Constructed Analogs (LOCA)

Literature exists to support the idea that all are reasonable approaches

Summary of BCSD & MACA delta change

RCP 8.5
2050 vs. 1995





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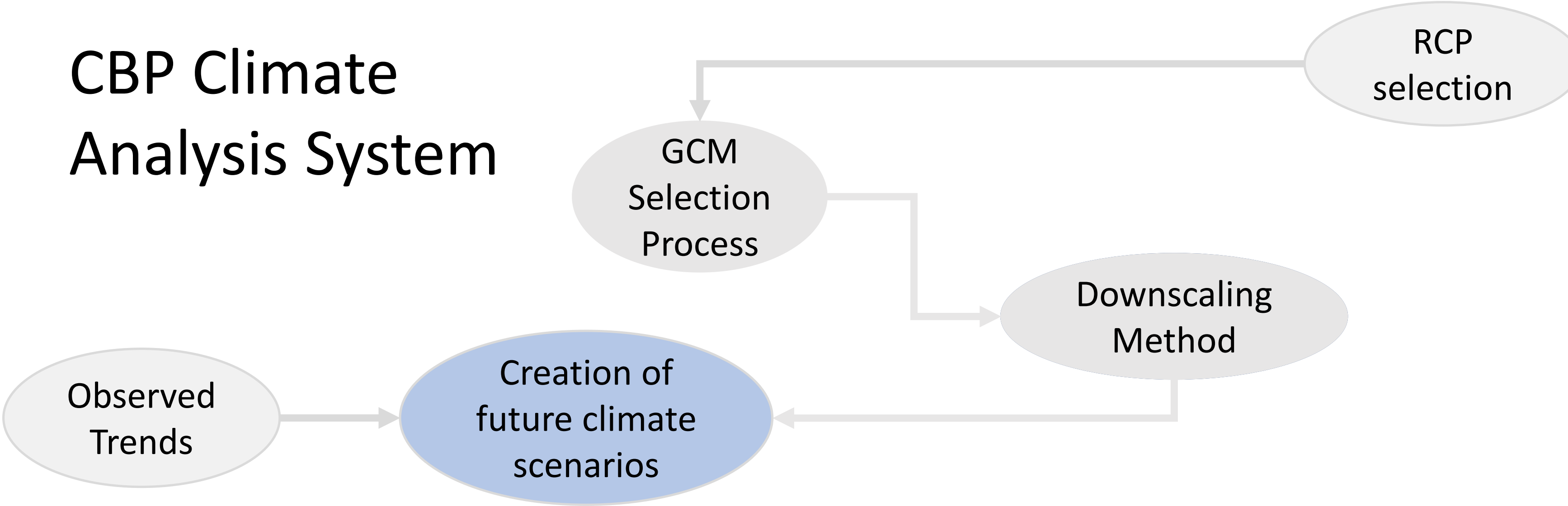
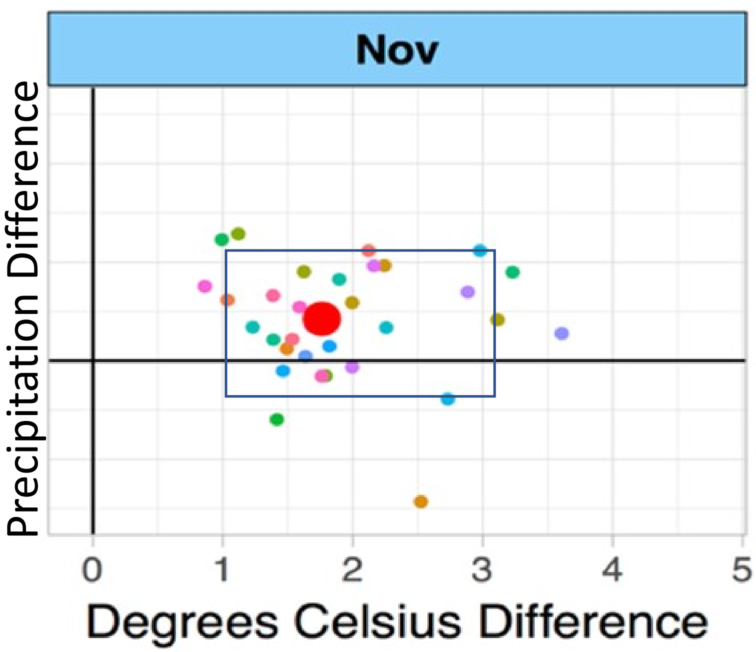
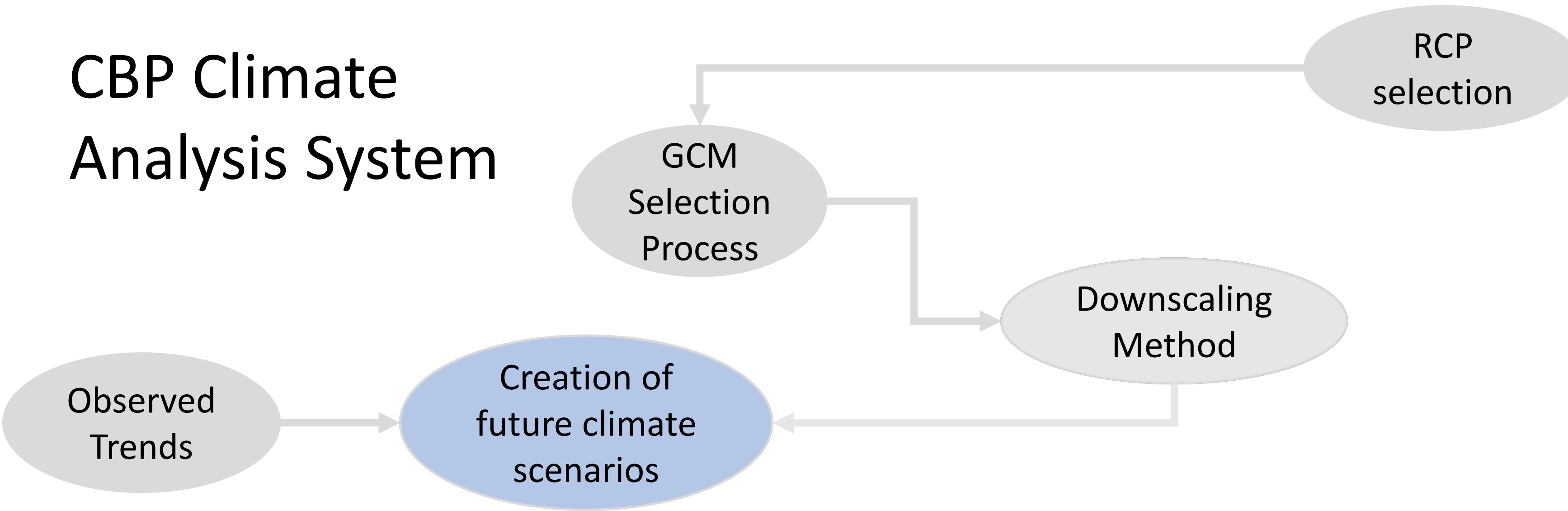




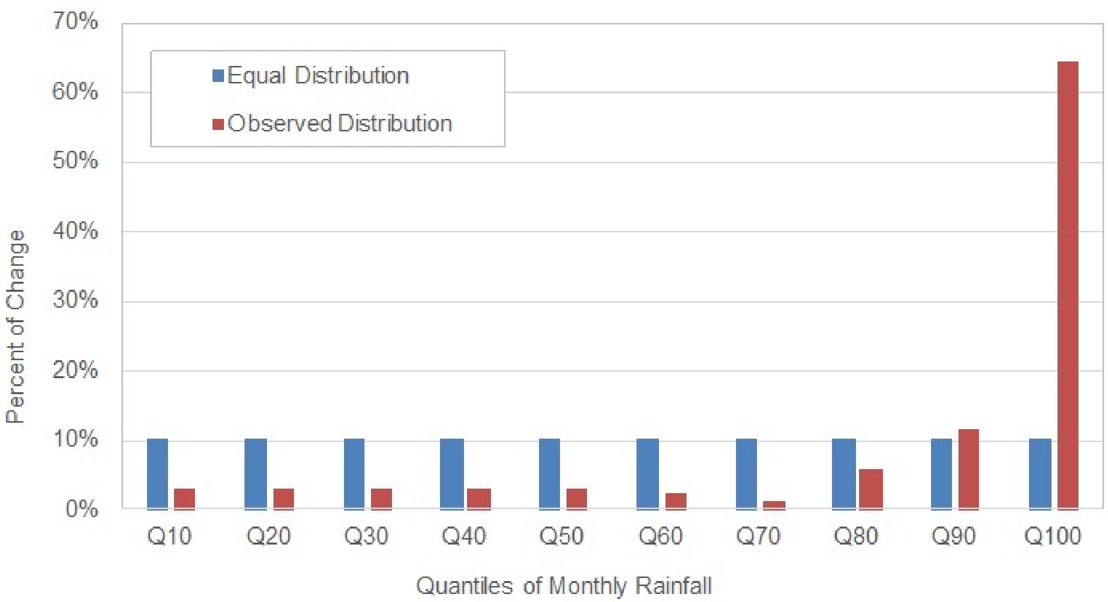
Ensemble Method

- Used the median temperature and precipitation change from the ensemble for each month for the primary run.
- Used the corners of the 90th percentile 'box' to investigate uncertainty

CBP Climate Analysis System



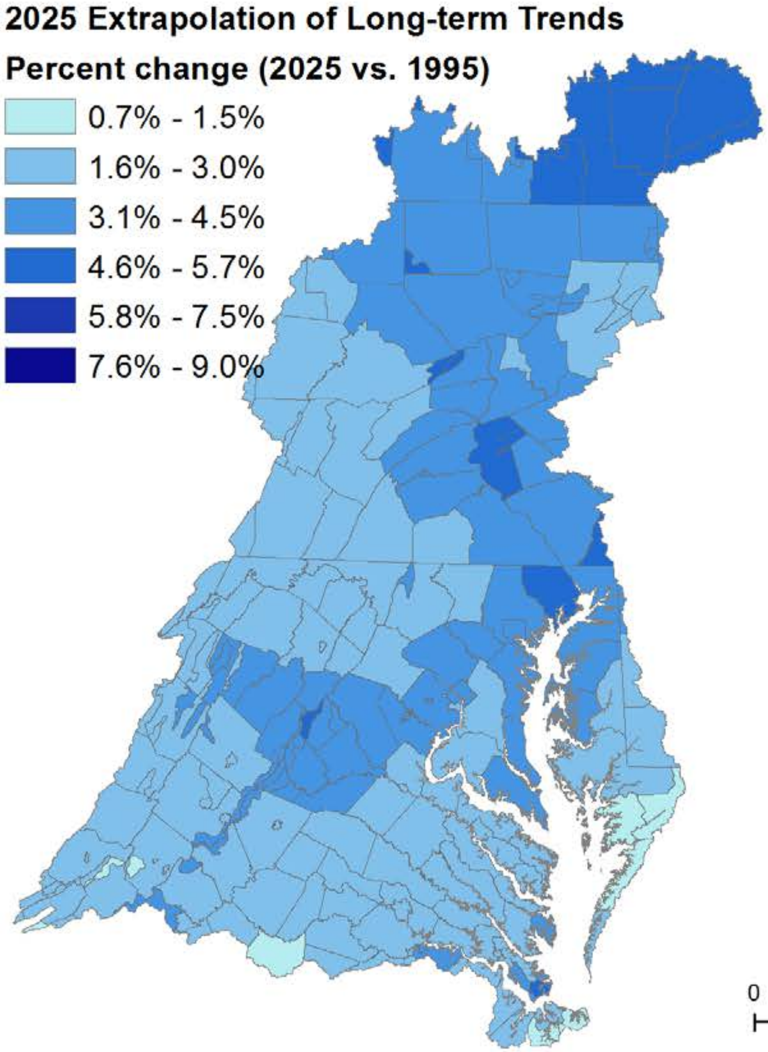
Literature shows that the increases in precipitation over the previous century have primarily occurred in the highest precipitation events.



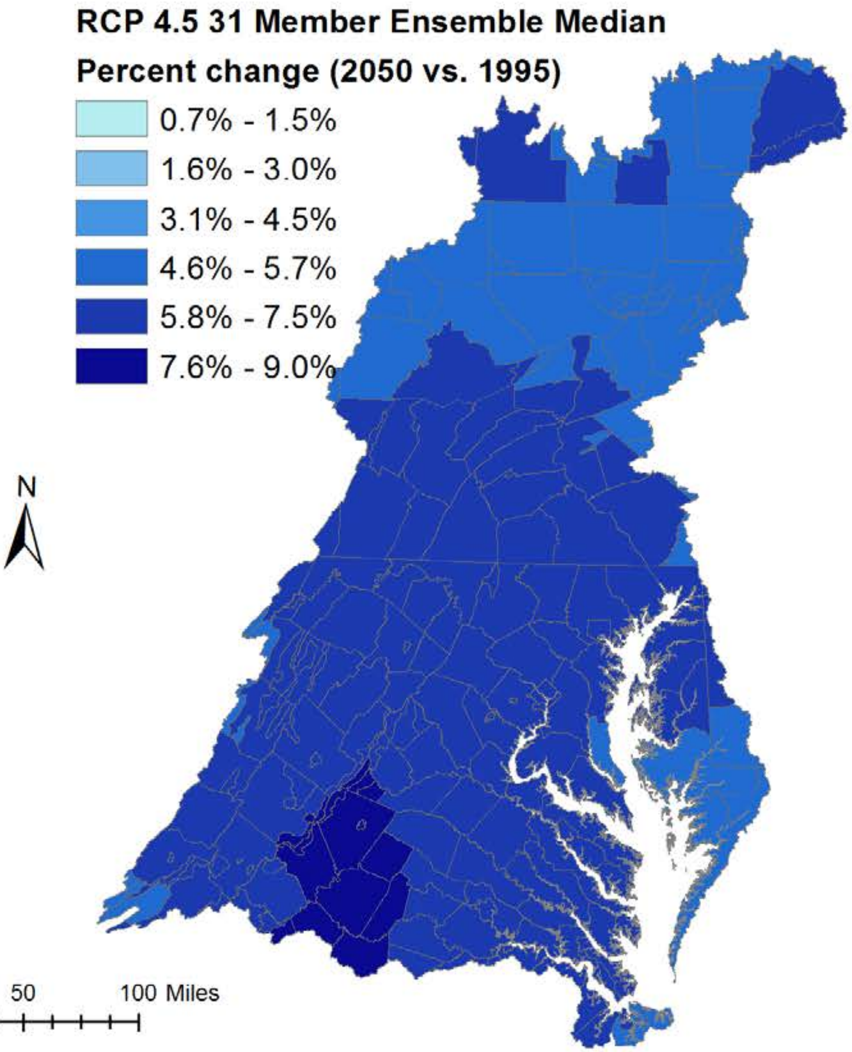
Two methods of rainfall addition

- Multiply all rainfall events by the same factor
- Multiply rainfall events within a decile by a factor such that the top decile increases a greater percentage as shown

YEAR 2025



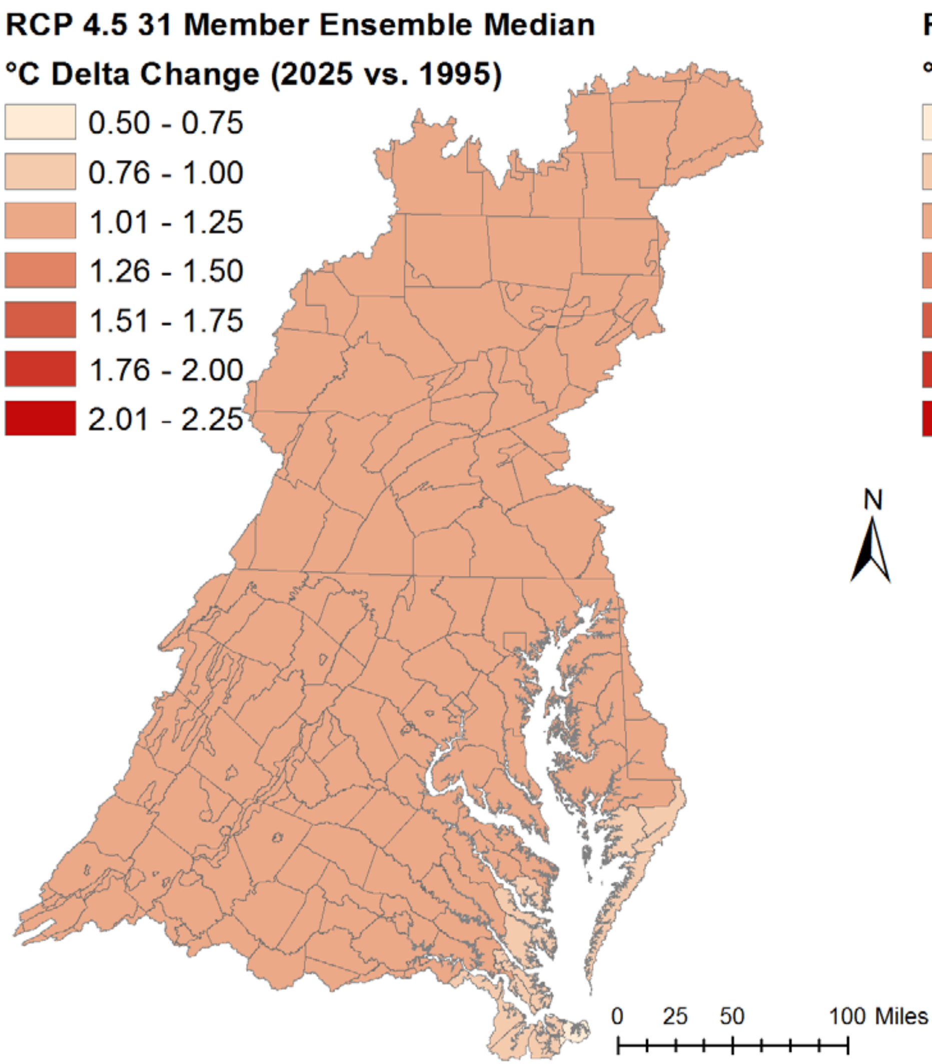
YEAR 2050



3.11% increase in average annual rainfall volume

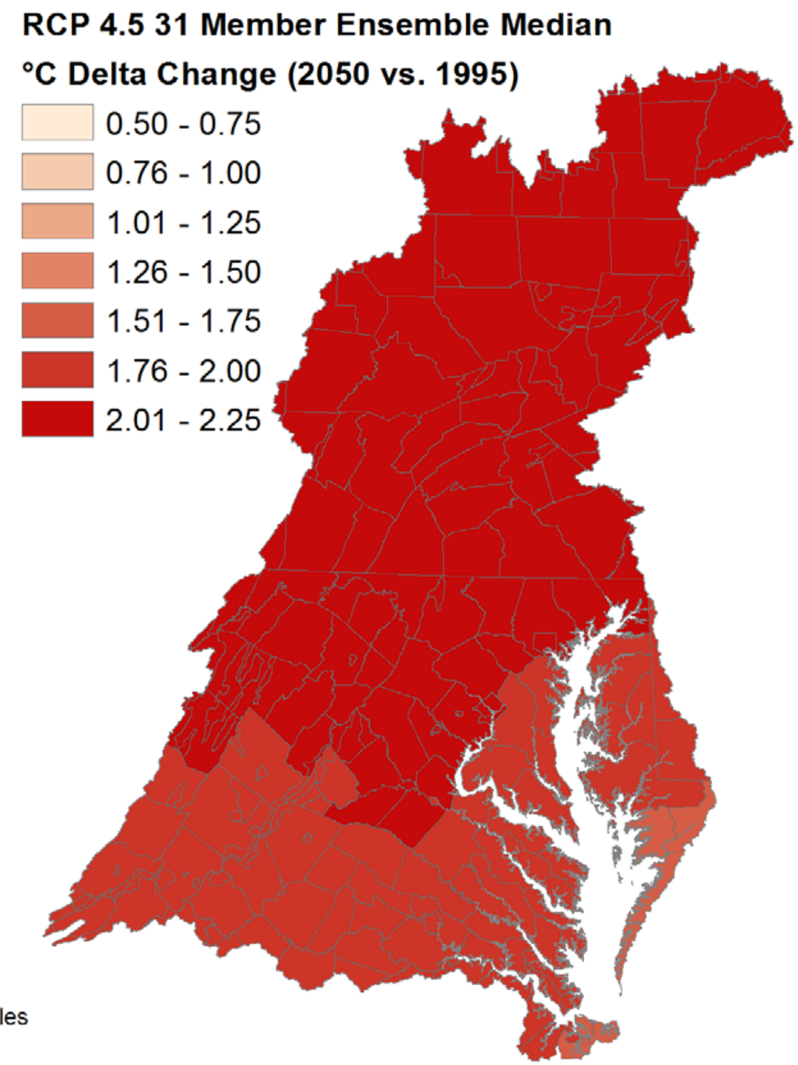
6.28% increase in average annual rainfall volume

YEAR 2025



1.12°C increase in average annual temperature

YEAR 2050



2.03°C increase in average annual temperature

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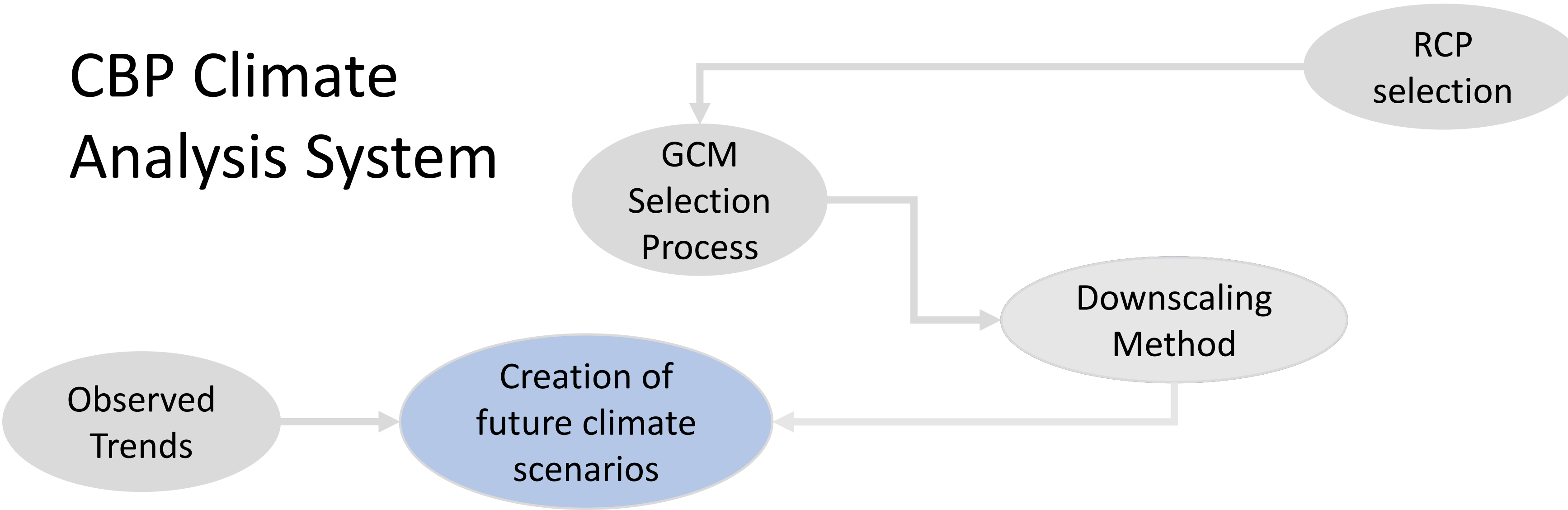

Potential Evapotranpiration

- Use Hargreaves-Samani to calculate change in PET
- Function of temperature and extraterrestrial radiation
- Apply the change in PET to the Base PET used in the Phase 6 model

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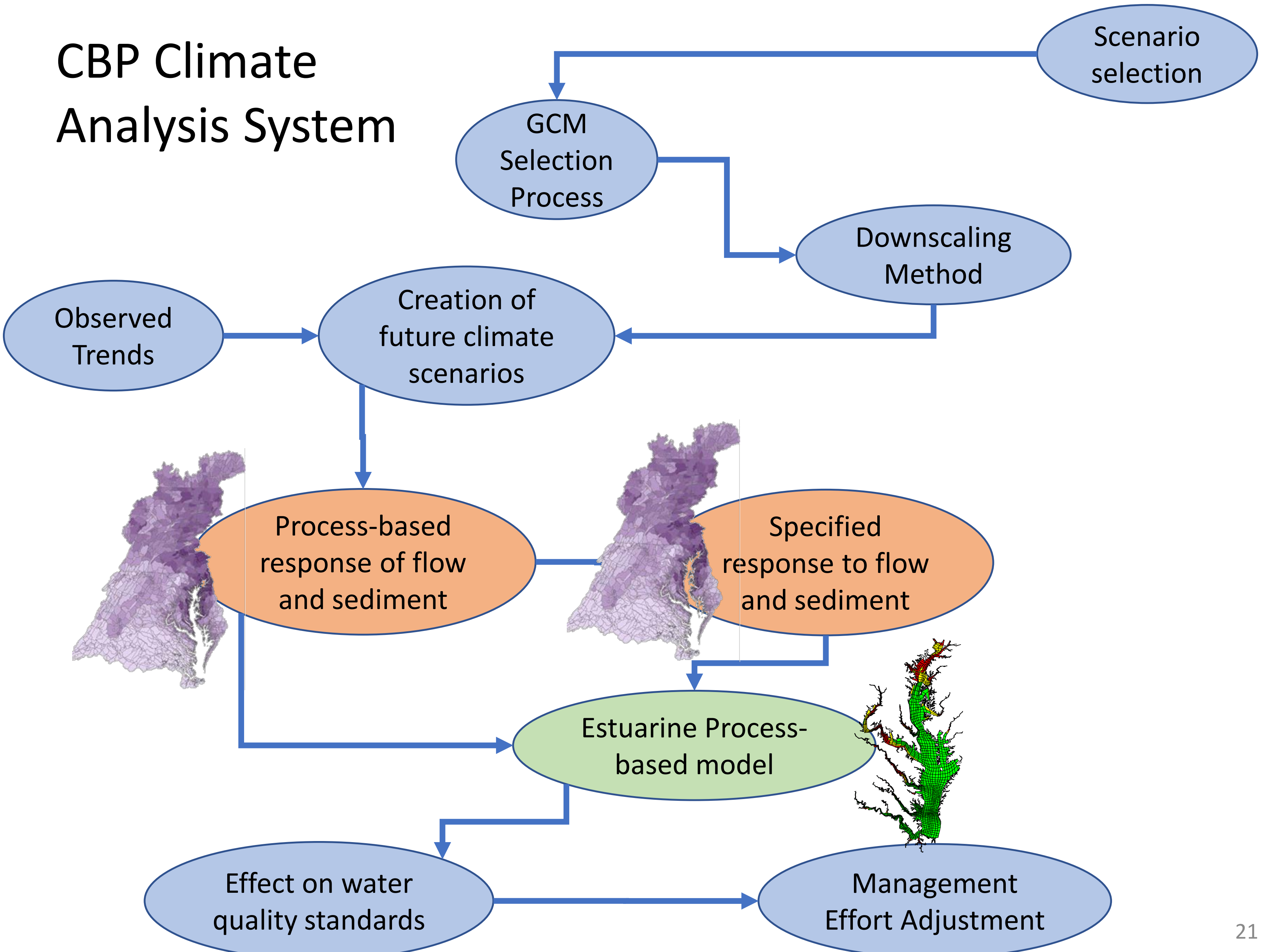

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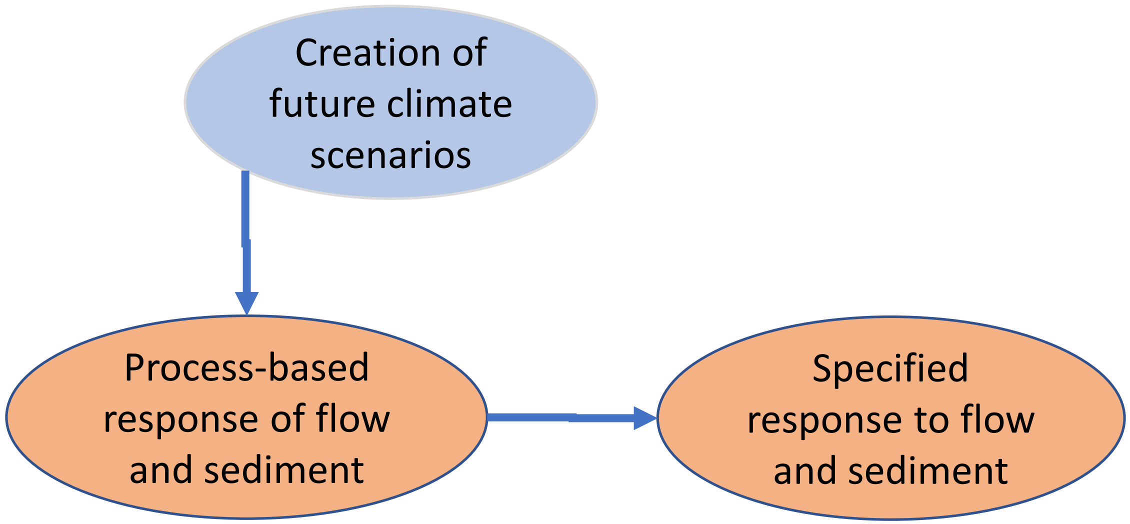

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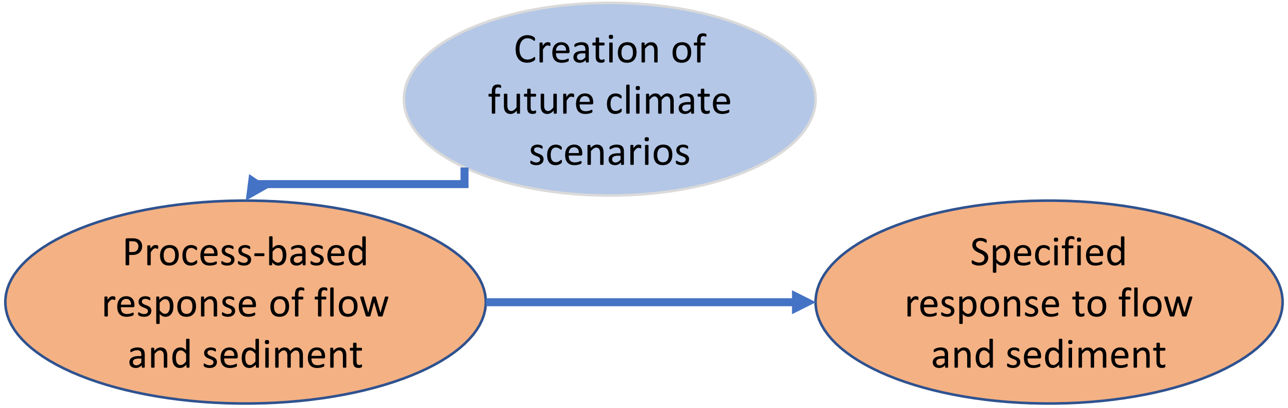

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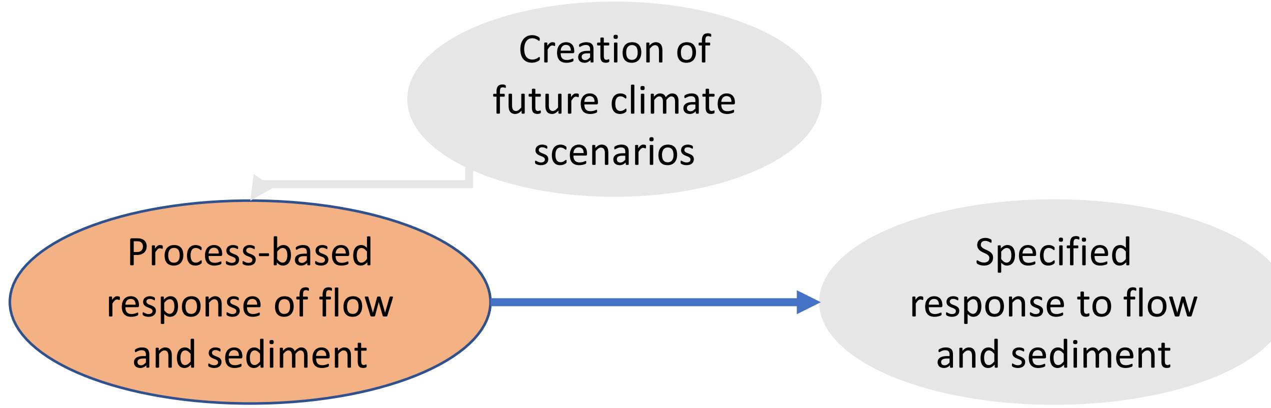
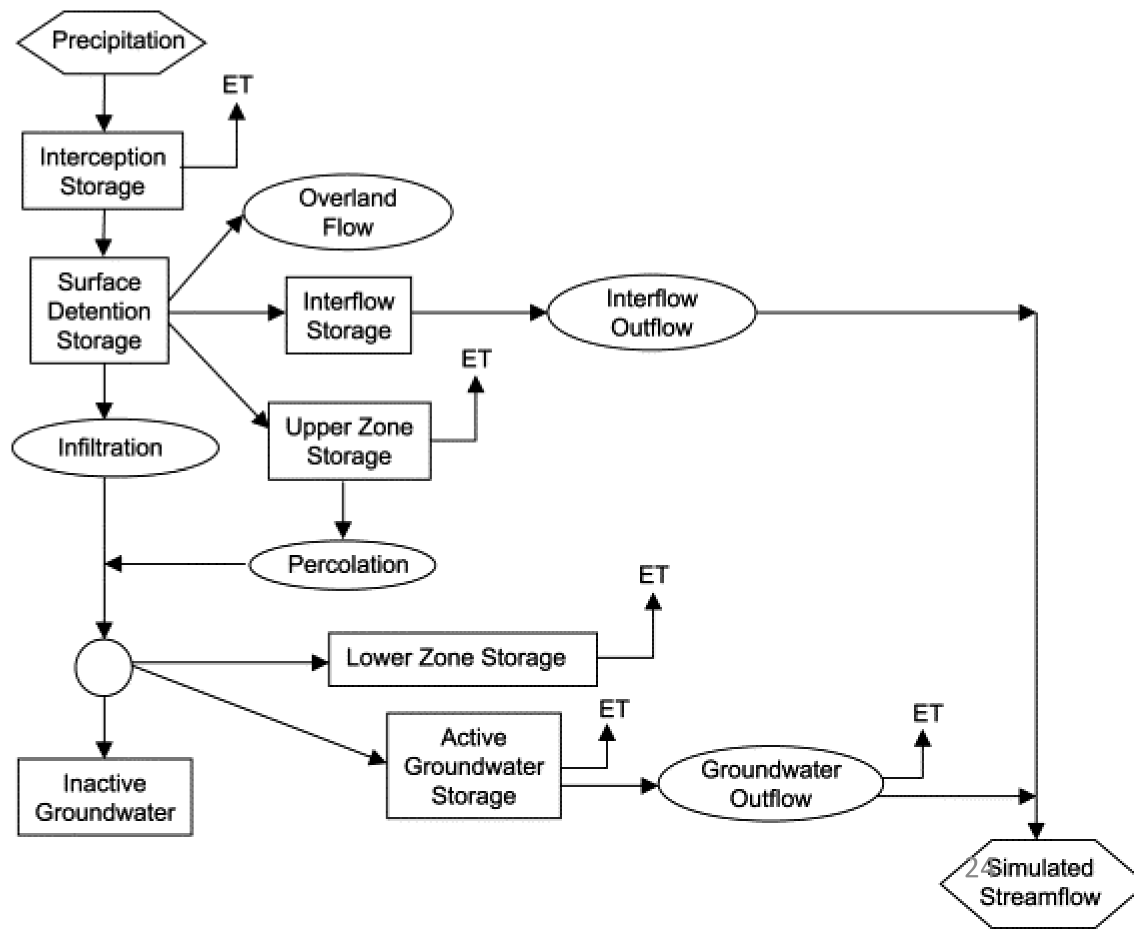


- HSPF simulation of hydrology is sensitive to:
- Precipitation
- PET
- CO2
- Temperature (snowfall and snowmelt)



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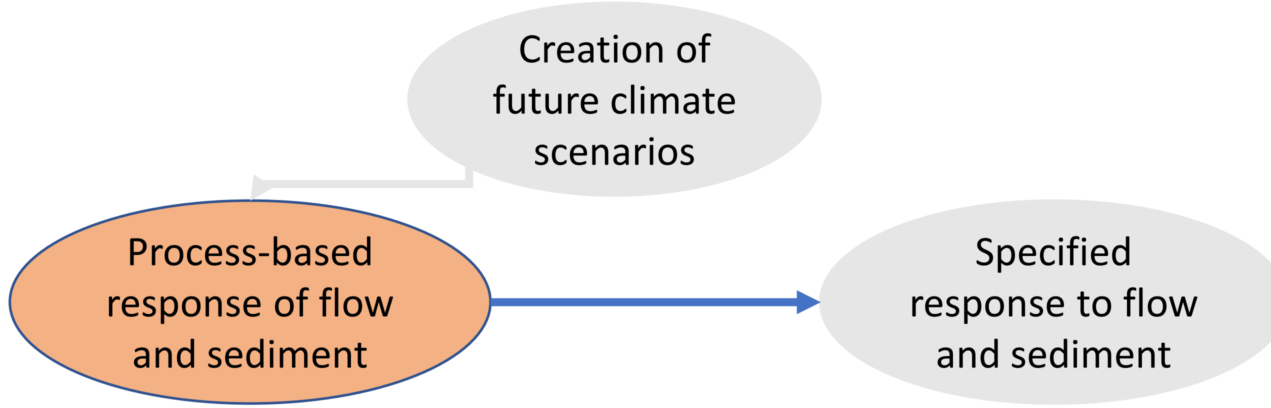
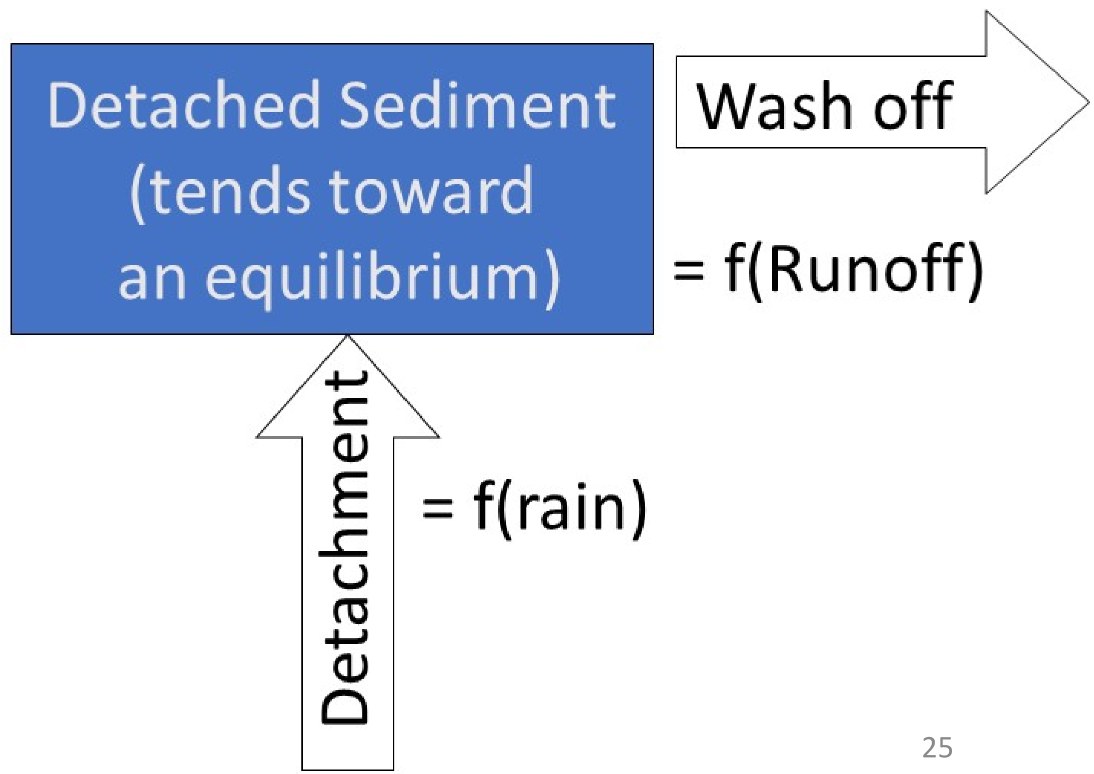
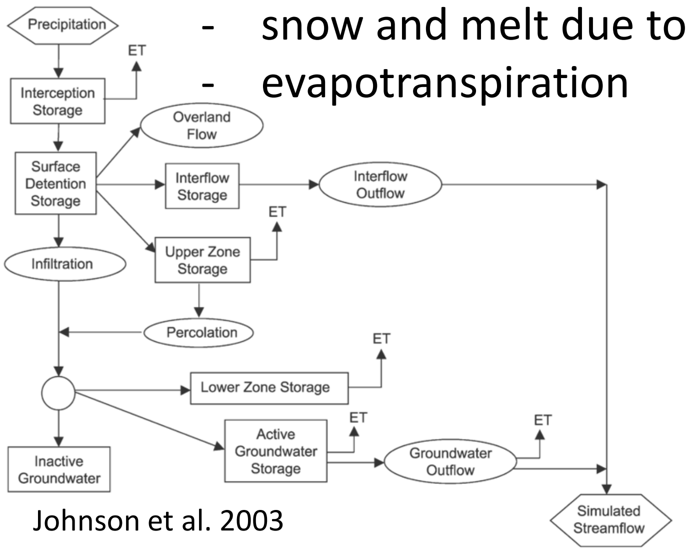


- HSPF simulation of sediment is sensitive to:
- Precipitation
- Runoff
  - PET, temperature, CO_2, precip

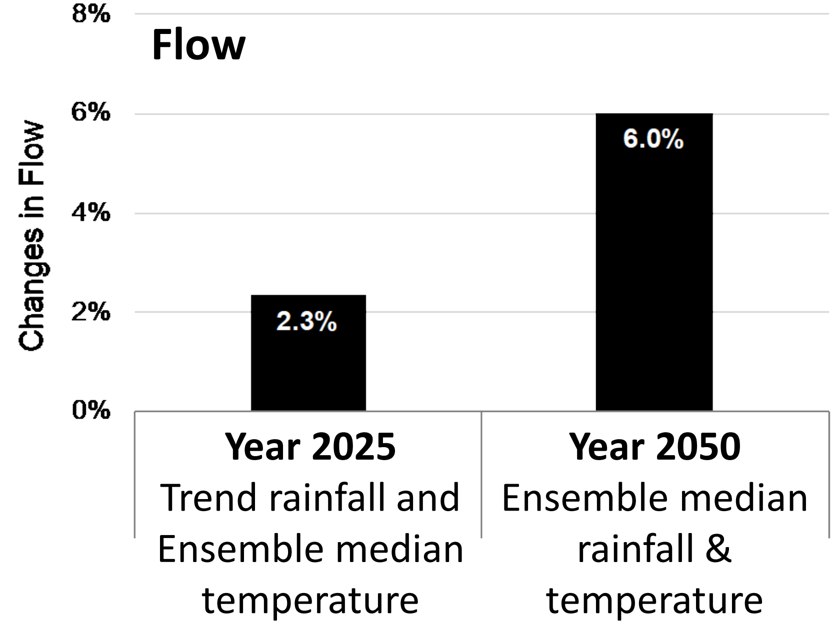


Summary of changes in delivery

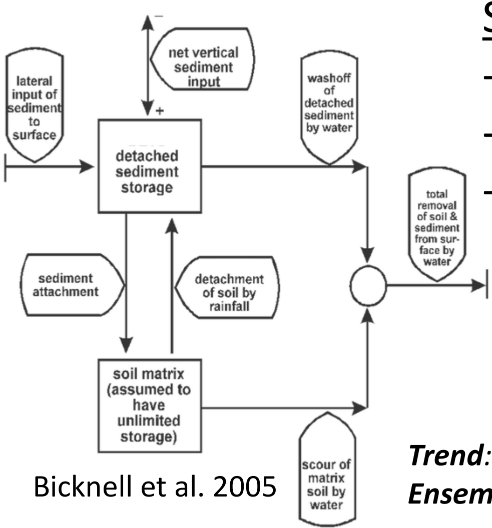
Hydrologic response:
- rainfall volume & intensity
- snow and melt due to temperature
- evapotranspiration



Johnson et al. 2003

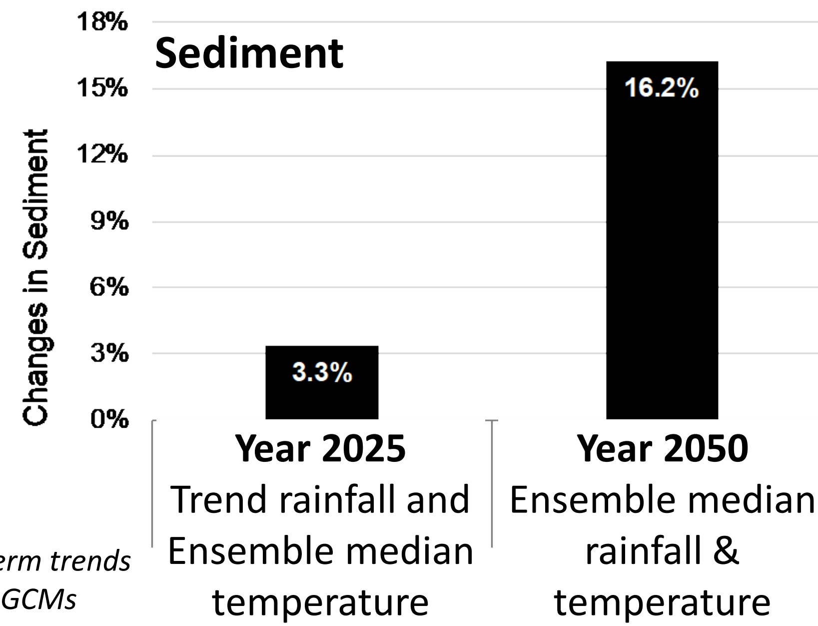


Sediment response:
- rainfall intensity
- surface runoff
- riverine scour and deposition

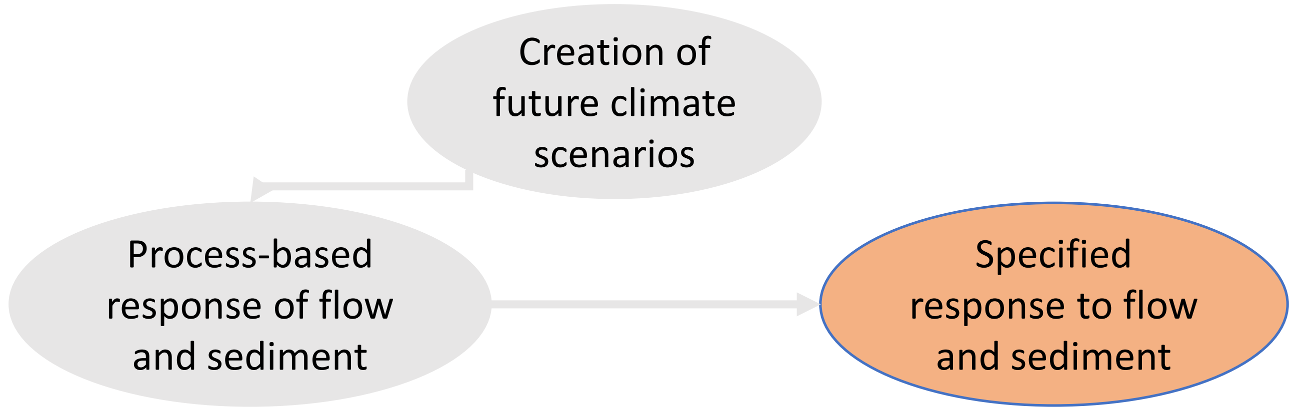


Bicknell et al. 2005

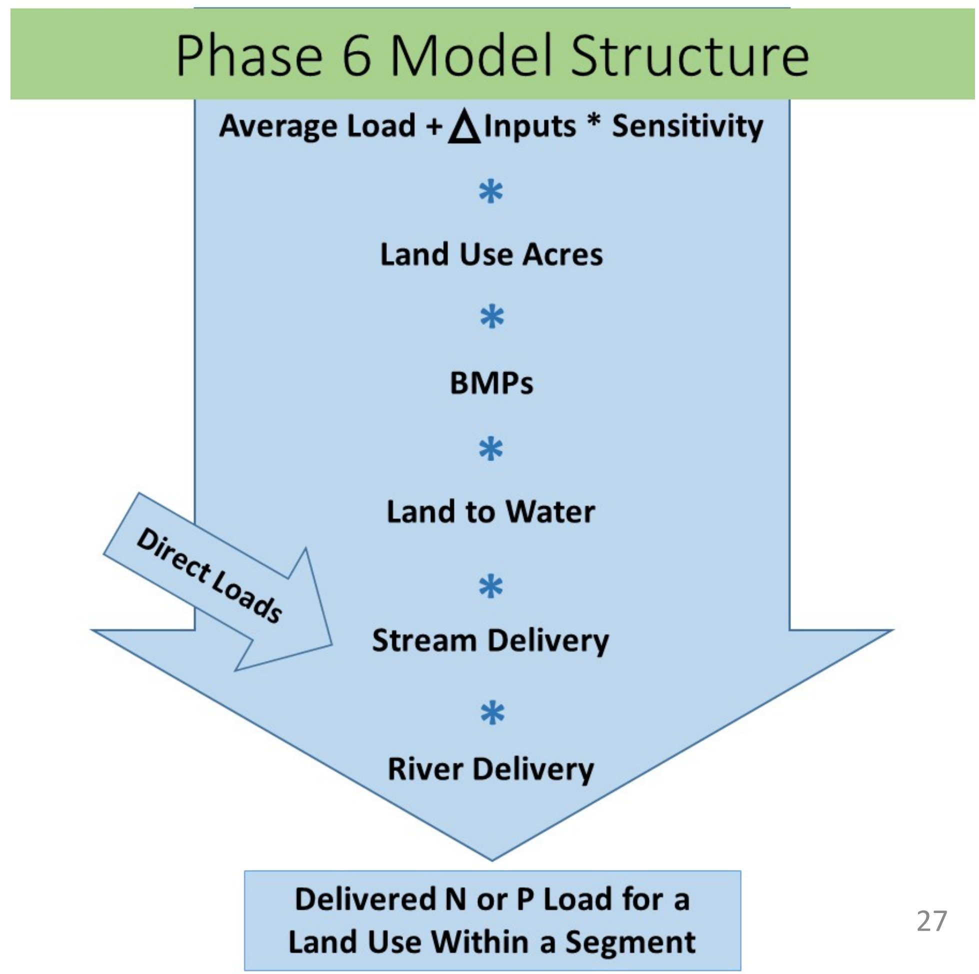
***Trend**: projection of extrapolation of long-term trends*
***Ensemble**: 31-member ensemble of RCP4.5 GCMs*



CBP Climate Analysis System



- Phase 6 model is time-averaged for N and P from the land
- Sensitivity to climate must be specified



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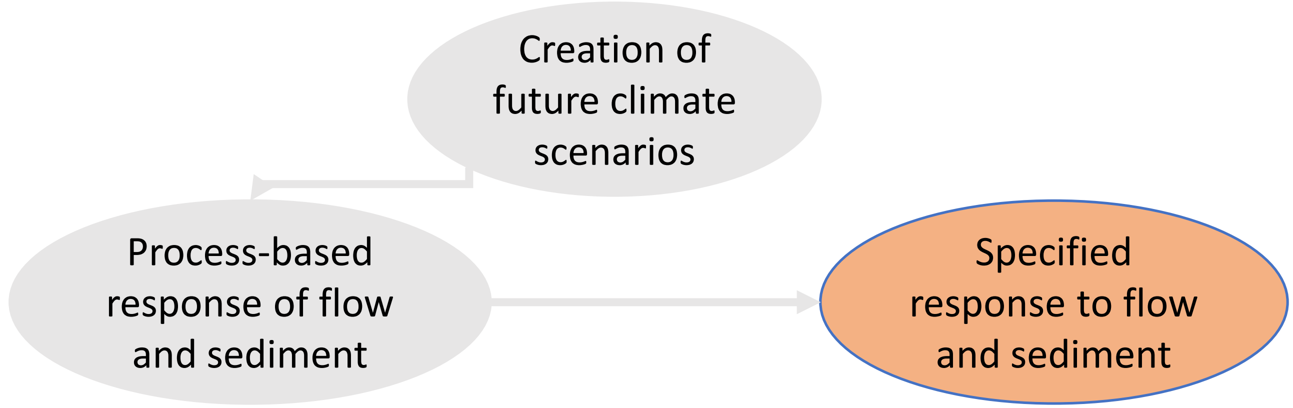
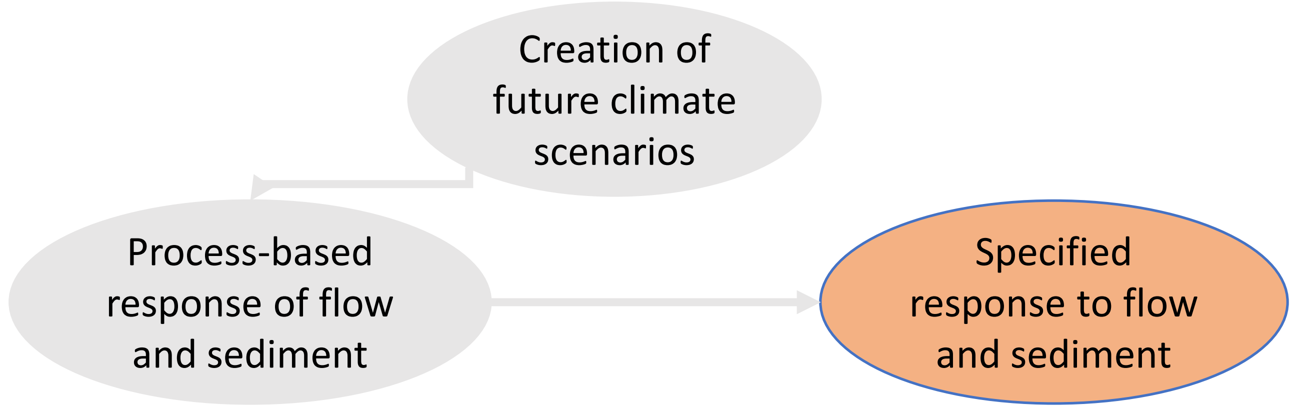


- Nitrogen Sensitivities
- Agriculture
  - Fertilizer
  - Manure
  - Atmospheric Deposition
  - Fixation
  - Crop Cover
  - Uptake

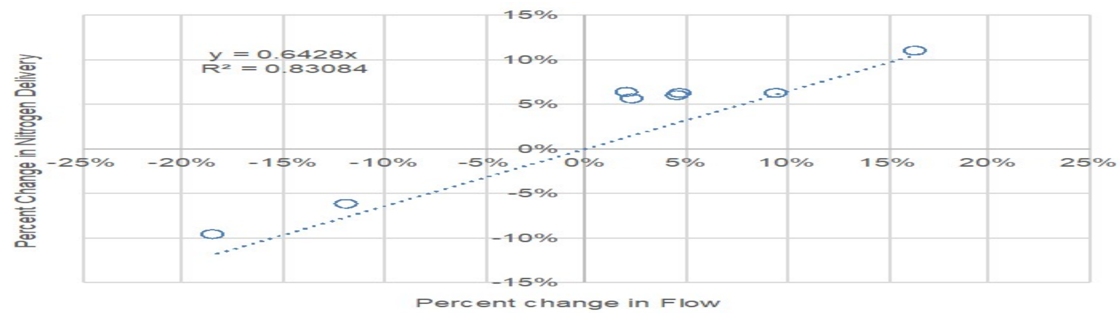
- Nitrogen Sensitivities
- Developed
  - Fertilizer
  - Atmospheric Deposition
  - Crop Cover
  - Uptake
- Natural
  - Atmospheric Deposition

- Delivery
  - Available water capacity
  - Groundwater recharge
  - Piedmont carbonate

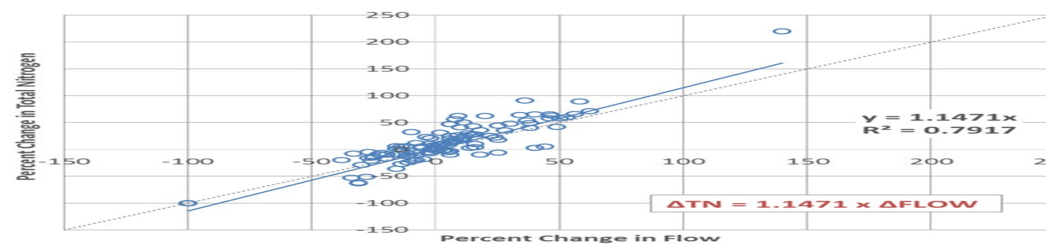
CBP Climate Analysis System



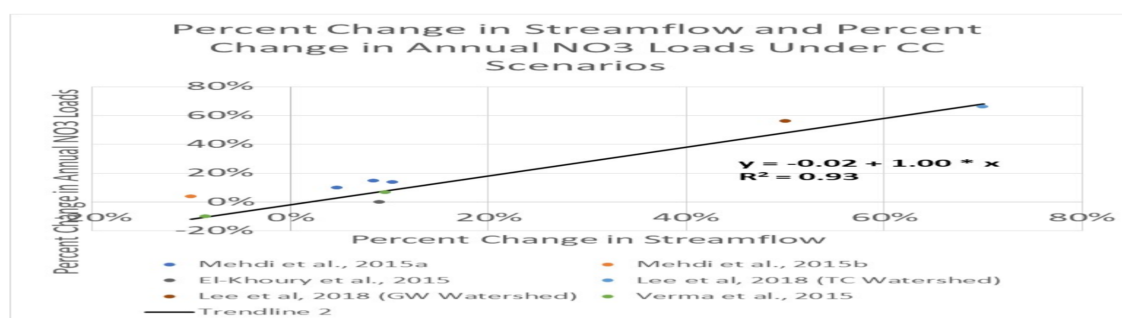
- Nitrogen assumption:
  - No changes to the concentrations
  - proportional change in load to a change in flow.



- Phase 5.3.2
  - Nitrogen change = 64% of flow change
- '20 watersheds' study
  - Nitrogen change = 115% of flow change



- CBPO literature review
  - Nitrate change = 100% of flow change



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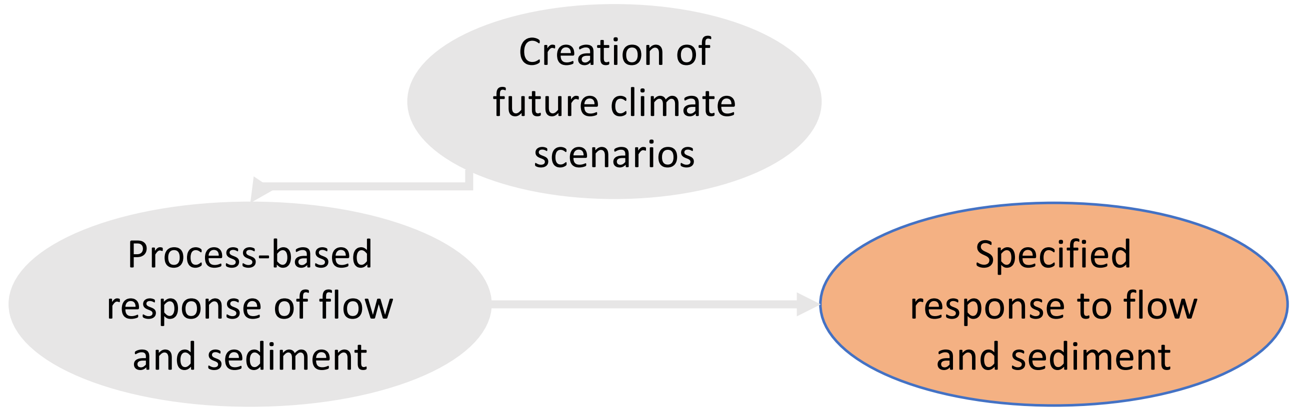
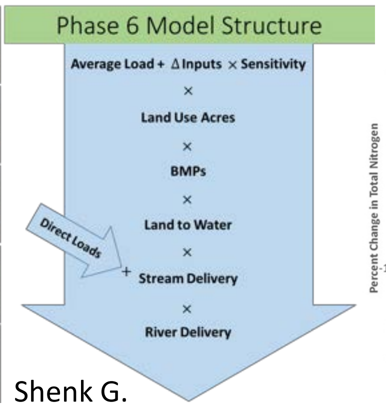


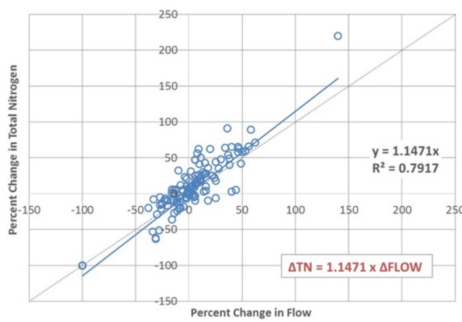
- Phosphorus Sensitivities
- Agriculture
  - Soil P
  - Applied Water Extractable P
  - Stormflow
  - Sediment Washoff
- Developed
  - Fertilizer
- Natural
  - Stormflow
  - Sediment Washoff
- Delivery
  - Well-drained soils

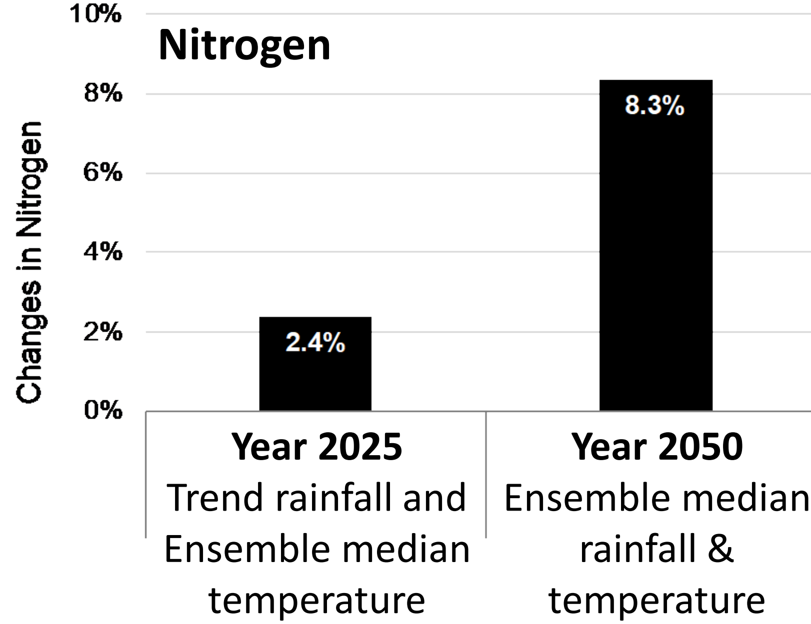
Summary of changes in delivery

<u>Nitrogen response</u>:
- sensitivity to flow
- stream bank erosion
- denitrification, organic scour

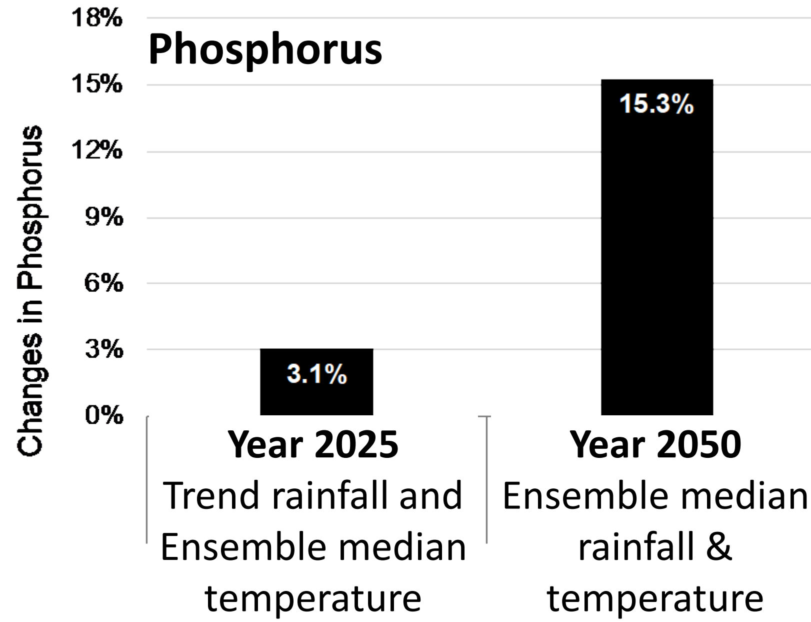


Shenk G.





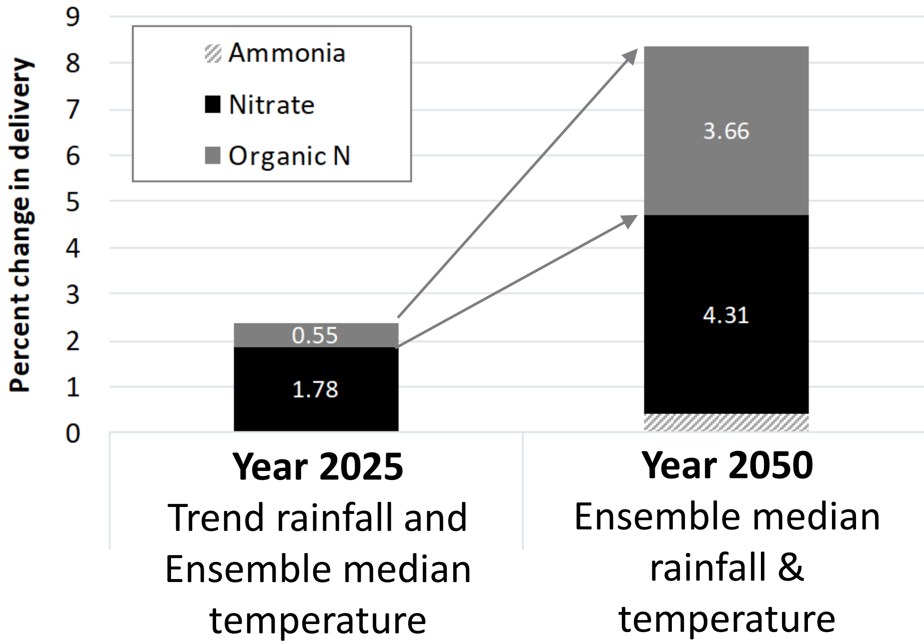
<u>Phosphorus response</u>:
- sensitivities to flow and sediment (APLE)
- stream bank erosion
- scour/deposition of inorganic and organic (HSPF)



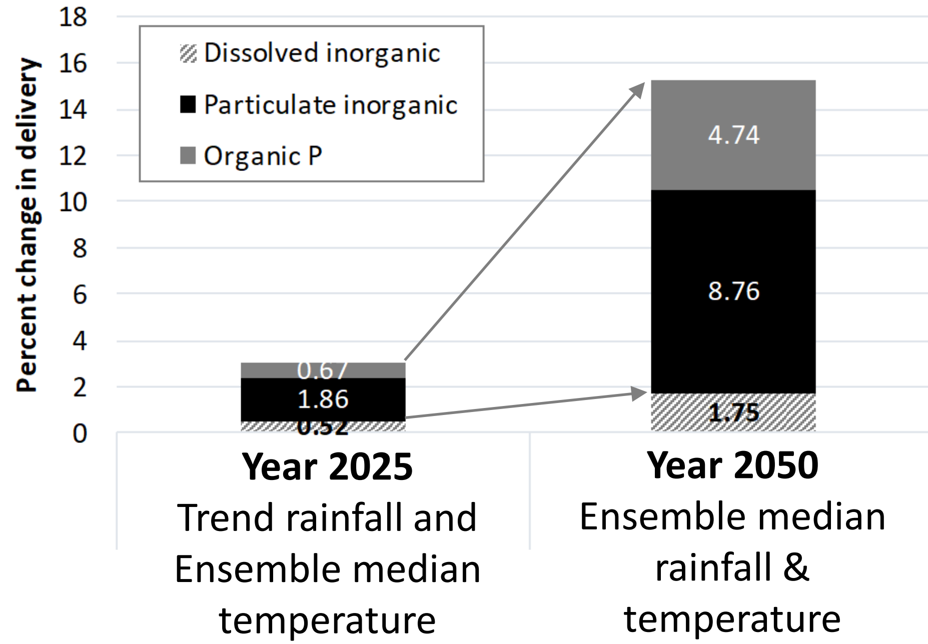
***Trend**: projection of extrapolation of long-term trends*
***Ensemble**: 31-member ensemble of RCP4.5 GCMs*

Nitrogen and phosphorus species

Simulated changes in nitrogen delivery



Simulated changes in phosphorus delivery



Arrows show relatively more increase in organic nitrogen as compared to inorganic.

Arrows show relatively more increase in particulate phosphorus as compared to dissolved inorganic phosphorus.

Trend: *projection of extrapolation of long-term trends*
Ensemble: *31-member ensemble of RCP4.5 GCMs*

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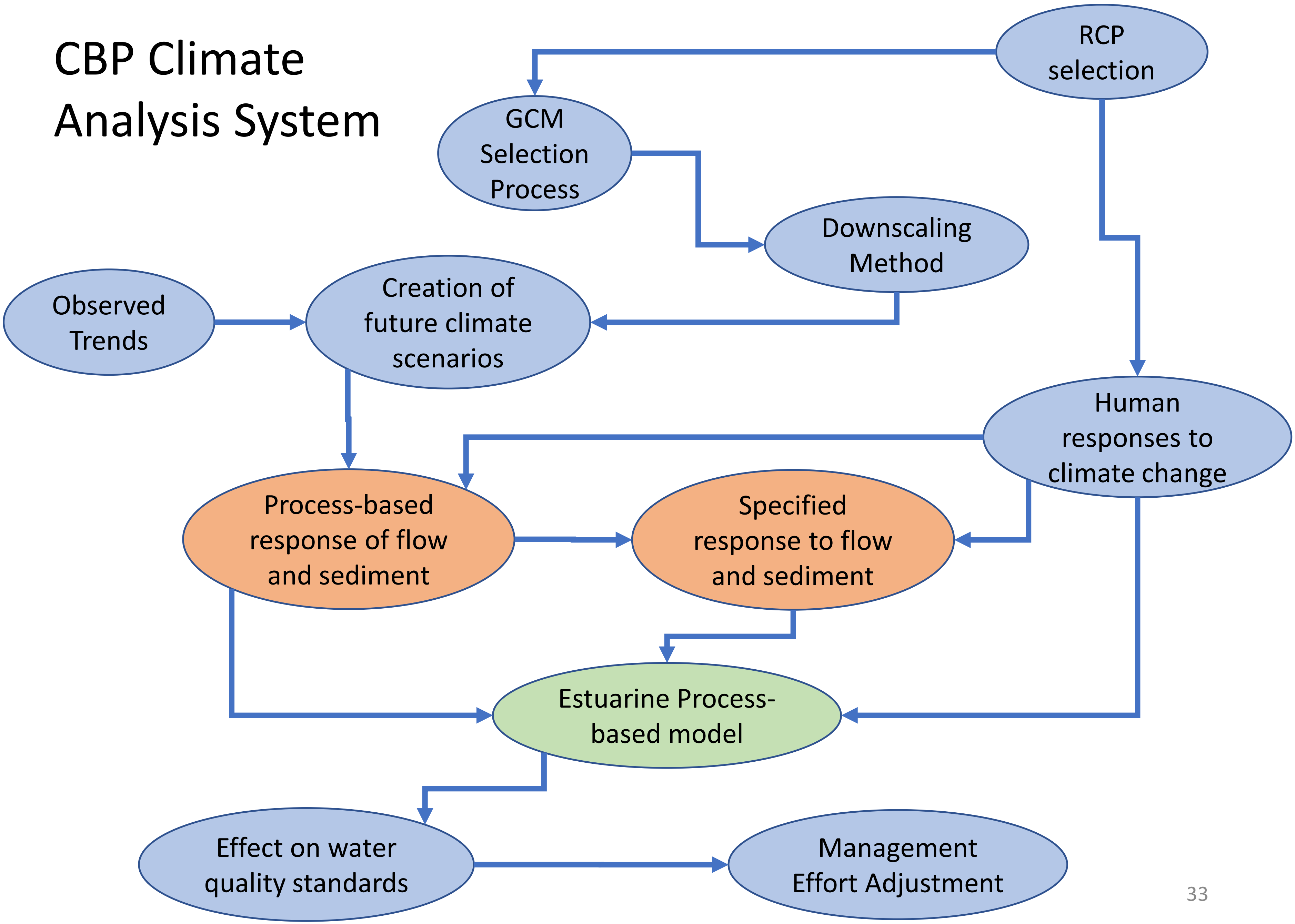

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Human responses to climate change

CBP Climate Analysis System

Human responses to climate change

- Sensitivities are built in, but need to know how they change in response to human actions

- Nitrogen Sensitivities
- Agriculture
  - Fertilizer
  - Manure
  - Atmospheric Deposition
  - Fixation
  - Crop Cover
  - Uptake

- Nitrogen Sensitivities
- Developed
  - Fertilizer
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  - Sediment Washoff
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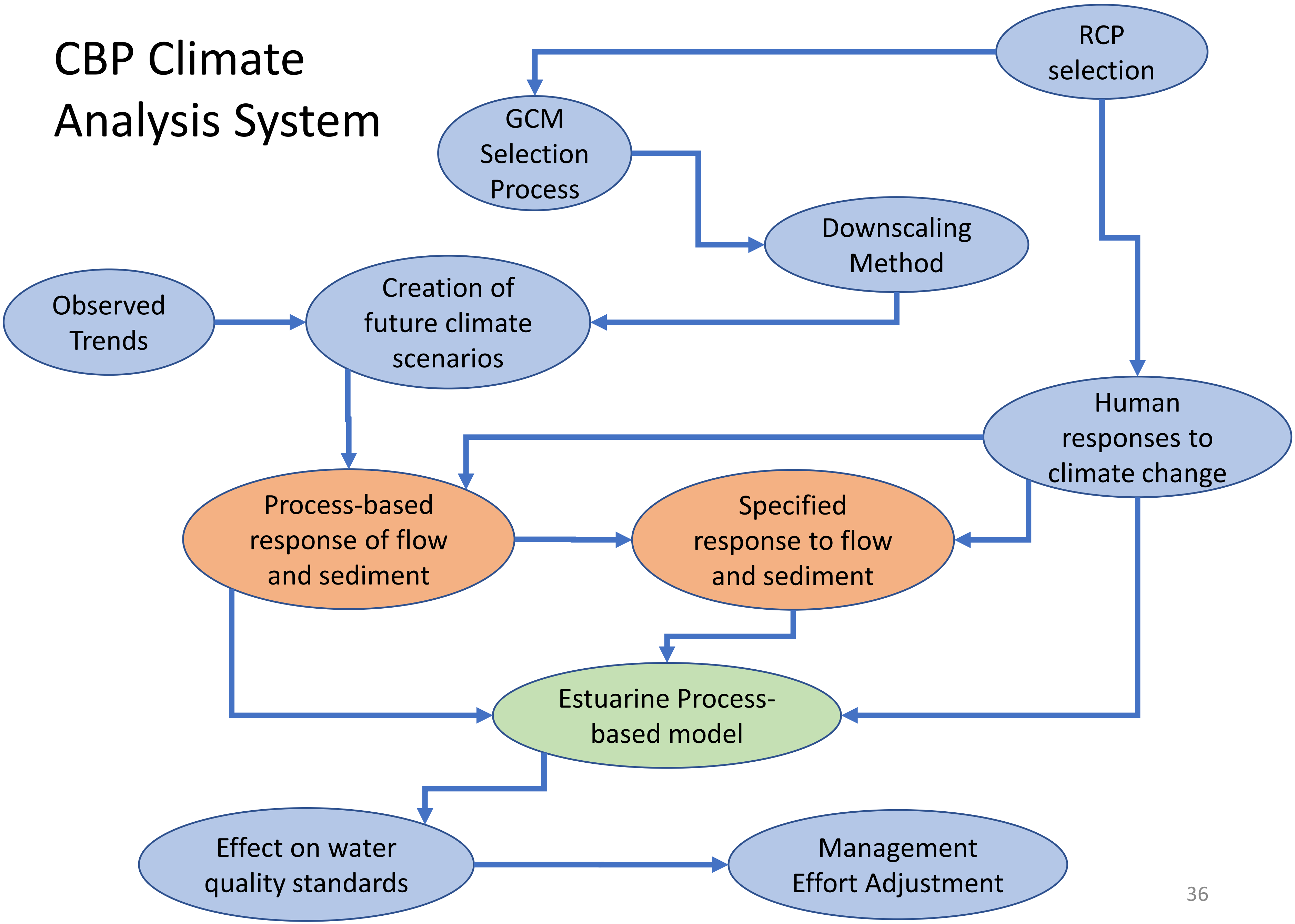
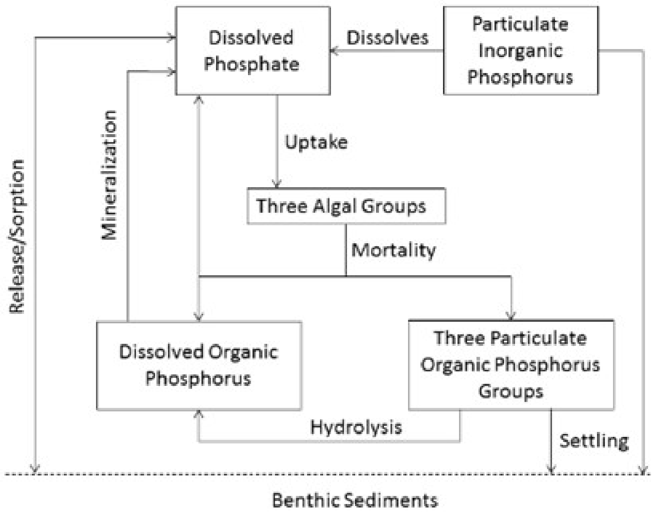
CBP Climate Analysis System



CBP Climate Analysis System

Estuarine Process-based model

Phosphorus Cycle



Carbon, nitrogen, phosphorus, sediment,
Salinity, temperature,
Algae, dissolved oxygen, Light attenuation,
Submerged aquatic vegetation, filter feeders, wetlands

MASS BALANCE EQUATIONS

$$\frac{\delta V_j \cdot C_j}{\delta t} = \sum_{k=1}^{n} Q_k \cdot C_k + \sum_{k=1}^{n} A_k \cdot D_k \cdot \frac{\delta C}{\delta x_k} + \Sigma S_j$$

https://www.chesapeakebay.net/documents/2017_WQSTM_Documentation_DRAFT_5-10-17.pdf

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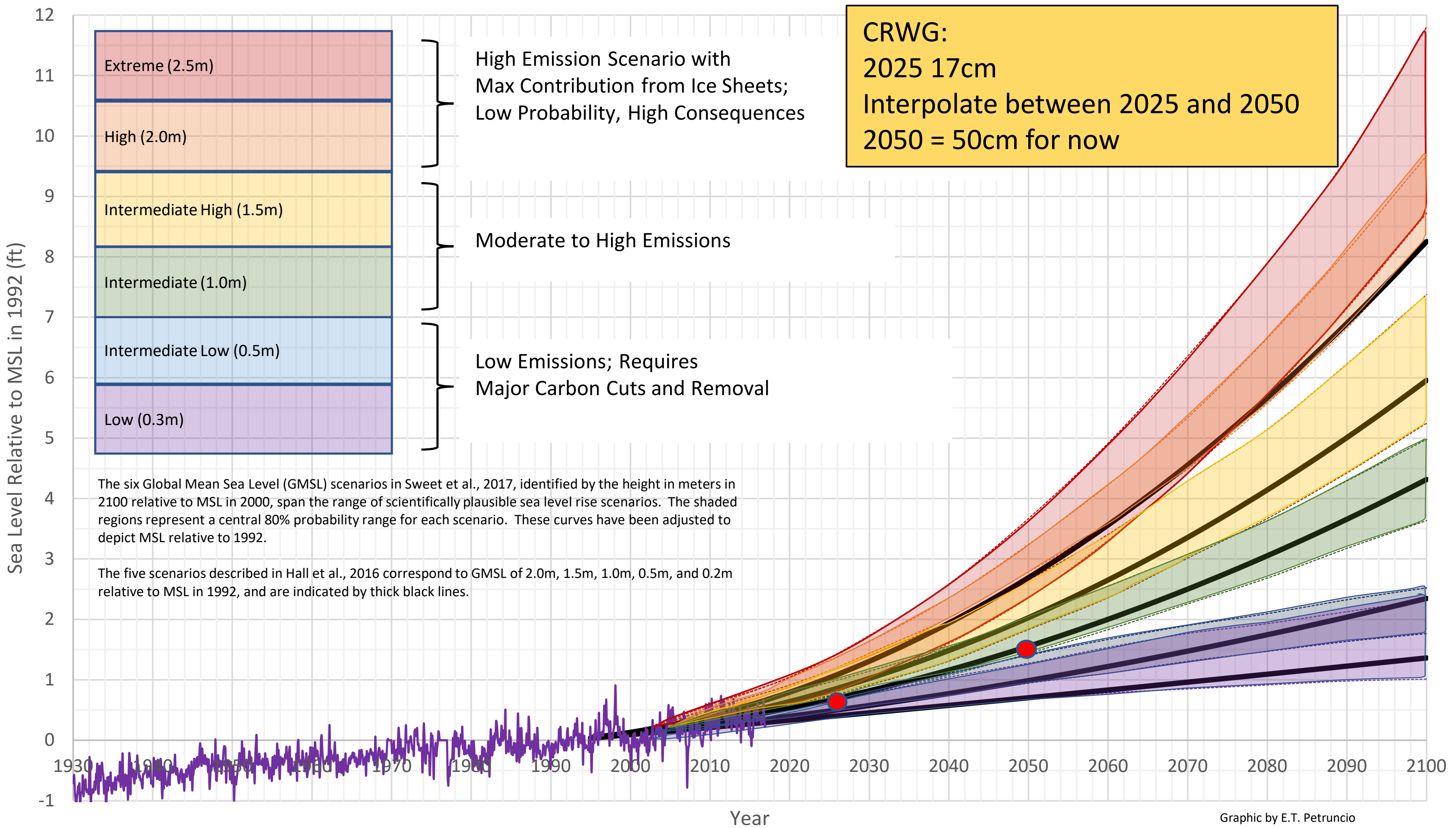
Estuarine Process-based model

- Considerations
  - Sea level Rise
  - Surface Temperature
  - Flow, Nutrients, Sediment, Heat from the watershed
  - Ocean Boundary Condition

- Ocean temperature change is 0.9 x air temp change for now

December 2017

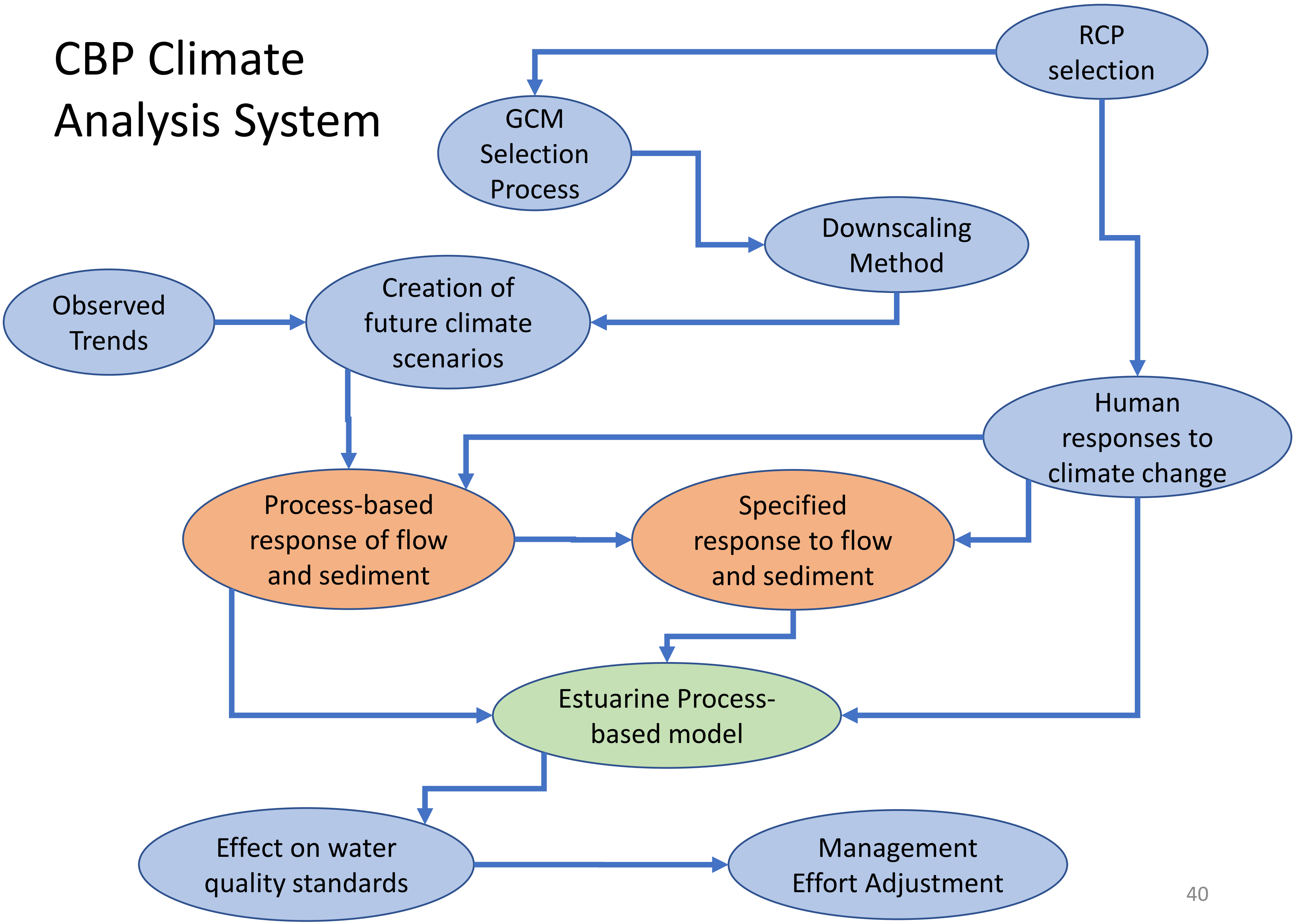
Relative Sea Level Rise



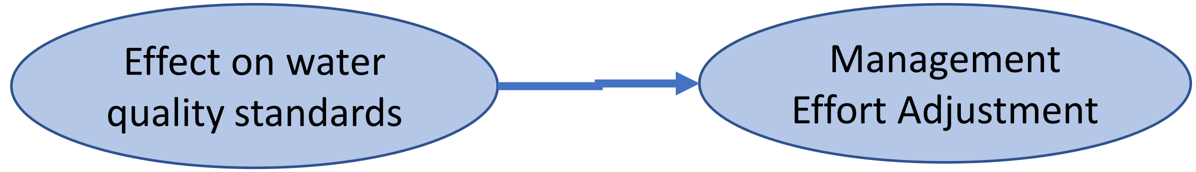
Relative Sea Level Rise Scenarios for Annapolis
with Annapolis Monthly Mean Sea Level Data for 1930-2016

Sources: Hall et al. (2016) and Sweet et al. (2017)

CBP Climate Analysis System



CBP Climate
Analysis System



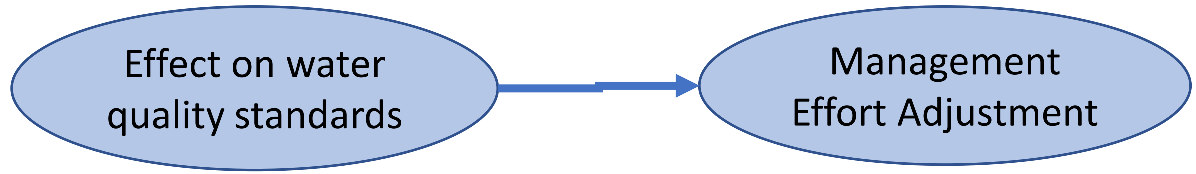
Calculate Climate Effect

December 2017 results

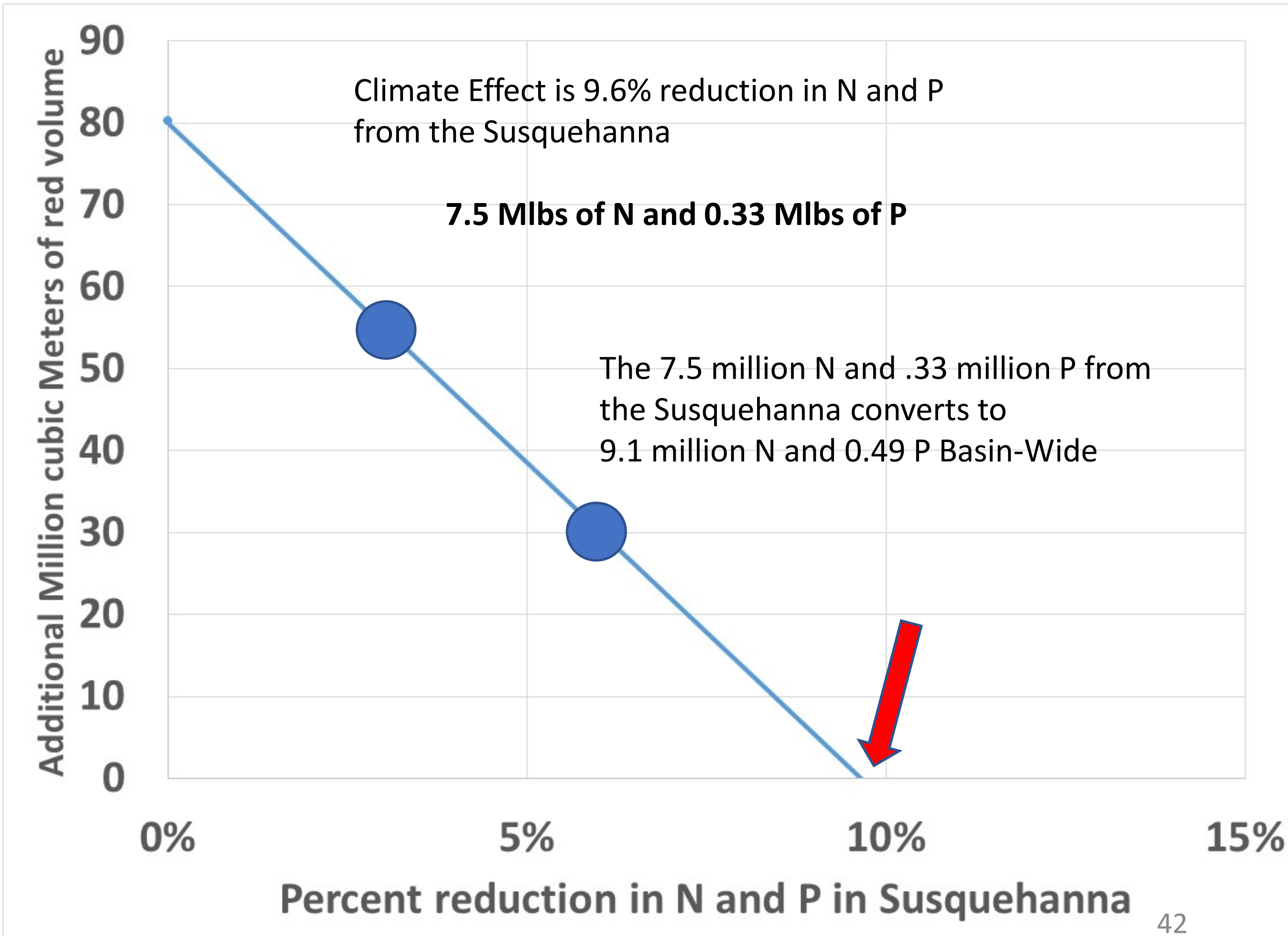
CB Seg	Designated Use	Designated Use Total Volume	Red Percent WIP + Conow	Red Volume WIP + Conow	Red Percent WIP + Conow + CC	Red Volume WIP + Conow + CC
CB3MH	DW	864	0.05%	0	0.05%	0
CB4MH	DW	2854	5.52%	158	6.50%	186
MD5MH	DW	2097	1.09%	23	1.51%	32
VA5MH	DW	1605	0.00%	0	0.00%	0
POMMH	DW	1839	0.00%	0	0.00%	0
CB3MH	DC	390	0.00%	0	0.00%	0
CB4MH	DC	2126	8.04%	171	10.09%	215
MD5MH	DC	2875	0.00%	0	0.00%	0
VA5MH	DC	1848	0.00%	0	0.00%	0
				352		432
					CC Difference	**80**

Volume Weighted means a ‘red area’ increase of 80 million cubic meters

CBP Climate Analysis System



December 2017 results



Ran Scenarios with 3% and 6% reduction in Susquehanna N and P

December 2017

Climate Change Loads: Nitrogen

Jurisdiction	1985 Baseline	2013 Progress	Climate Change	Growth in Load to 2025	Conowingo Load Responsibility	2013 Progress +	Phase III Planning Target
NY	18.71	15.44	0.400			15.84	10.62
PA	122.41	99.28	4.135			103.41	72.99
MD	83.56	55.89	2.194			58.09	45.39
WV	8.73	8.06	0.236			8.30	6.36
DC	6.48	1.75	0.006			1.76	2.25
DE	6.97	6.59	0.397			6.98	4.66
VA	84.29	61.53	1.722			63.25	56.37
BasinWide	331.15	248.54	9.09			257.63	198.64

*Units: millions of pounds

December 2017

Climate Change Loads: Phosphorus

Jurisdiction	1985 Baseline	2013 Progress	Climate Change	Growth in Load to 2025	Conowingo Load Responsibility	2013 Progress +	Phase III Planning Target
NY	1.198	0.710	0.014			0.724	0.491
PA	6.282	3.749	0.141			3.891	3.012
MD	7.495	3.942	0.114			4.056	3.553
WV	0.902	0.617	0.019			0.637	0.493
DC	0.090	0.062	0.001			0.063	0.120
DE	0.225	0.116	0.006			0.122	0.116
VA	14.244	6.751	0.193			6.944	6.411
BasinWide	30.44	15.95	0.489			16.436	14.20

*Units: millions of pounds

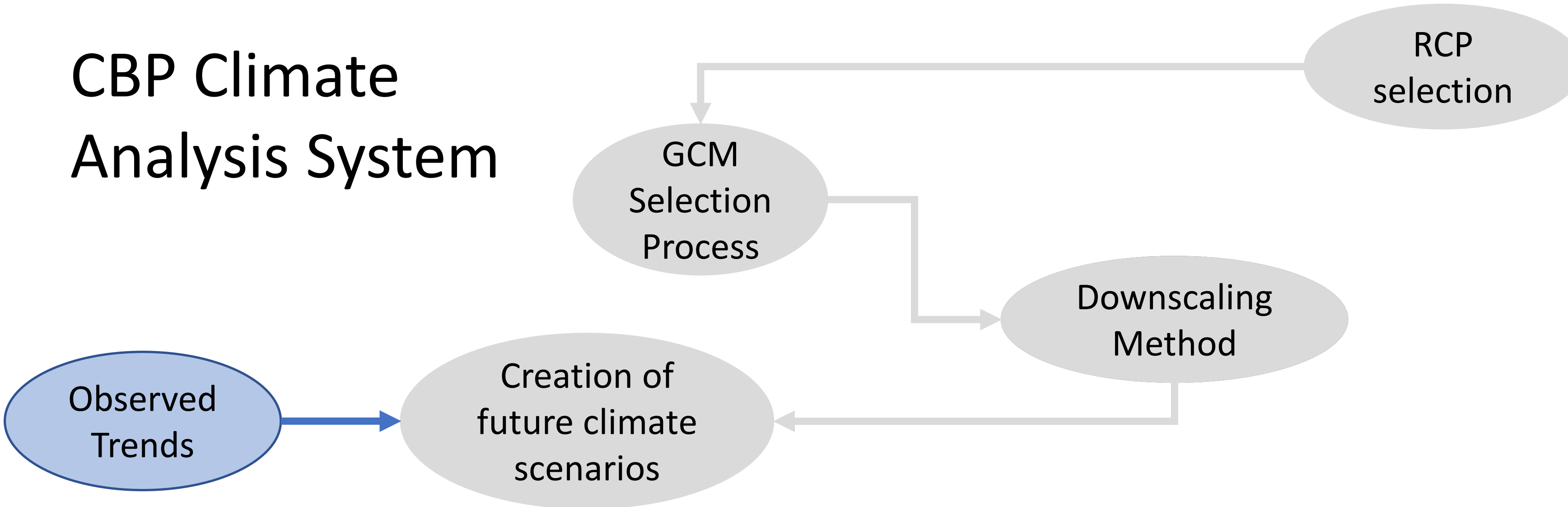
Climate Change Decision Framework

- Bay TMDL must address climate change; however, need to do so on a quantitative basis held off until 2022
  - Allows time for model upgrades to better simulate impacts
  - Allows time for Bay partner jurisdictions to figure out how they can respond
  - Likely will require substantial additional nutrient and sediment reductions
- Bay partners must include qualitative approach in Phase III WIPs; have option of starting quantitative approach early

CBP Climate Work Plan

2018	2019	2020	2021
STAC Workshop Climate Resiliency WG to investigate BMP response Jurisdictions provide narrative in WIP3s on climate strategies Modeling WG develop climate scenarios	Water Quality GIT, Modeling WG, Climate Resiliency WQ direct Modeling team to develop climate change assessment for TMDL	Technical Review of Models	Climate change considerations will be implemented into the 2022-2023 milestones.

CBP Climate Analysis System



Observed Precipitation Trends

- 1927-2014 PRISM precipitation data
- Aggregated to annual values of a county
- Ordinary least squares regression to determine slope
- 30 years of slope applied to each month of 1991-2000 rainfall data